ABSTRACT

The transition from open-pit to underground mining is one of the most important strategic decisions in the life cycle of a mining project, largely affecting the economic feasibility, the recovery of resources, the safety of operations, and environmental sustainability. The conventional methods used to calculate the transition depth mainly use economic indicators like Net Present Value (NPV) and stripping ratio, which does not put in consideration the overall environment and social implication of the mining activity. This study fills this gap by creating a comprehensive, sustainability-integrated framework for optimizing the depth of transition from open-pit to underground mining.

The thesis presents a novel approach which combines economic optimization, carbon emission accounting, and multi-criteria sustainability assessment in unified decision-making framework. Carbon Penalty Adjusted Net Present Value (CNPV) model is created to internalize the carbon emissions in economic analysis, such that mine planning fits the global goals of decarbonization. Sensitivity analysis of carbon emission is conducted in order to realize how the change in emission can affect the value of the project and depth of transition. Simultaneously, an Analytic Hierarchy Process (AHP)-based model is formulated to estimate qualitative and semi-quantitative Environmental, Social, and Governance (ESG) indicators, resulting in a Composite Sustainability Index (CSI). The CSI is then converted to an economic penalty, which allow the CSI to be readily integrated with the financial optimization models.

These sustainability elements are integrated into a Mixed-Integer Linear Programming (MILP) that is developed to maximize the overall project value and, at the same time, to find out the optimal transition depth. A nested shell decomposition strategy is adopted to solve computational issues of MILP solver related to large-scale block models. This strategy makes the MILP model scalable and can be applied to real-world deposits. The suggested framework is validated through a case study application to a real copper mine in India where several sustainability scenarios are compared.

Carbon emission sensitivity analysis conducted in the study suggests that transition depth is decreased with the increment of carbon emission. It indicates open-pit operations are more sensitive to carbon emission than underground mining. It also appears that an increase of 20 percent carbon emission leads to a 1.8 percent decrease in CNPV of open-pit operations and a decrease by 0.63 percent in underground operations. In the case study

application, it has been observed that when sustainability aspects are incorporated in OP-UG planning, the transition depth and project valuation has changed considerably. For example, the transition depth has changed to 300 m with carbon penalty, 375 m with CSI penalty, and 275 m with the combined adjustment from 425 m under traditional approach (economic consideration alone). The traditional NPV of rupees 7,355 billion get reduced by 11.38 percent in the combined adjustment scenario, however, the addition of sustainability gains increases the total value of the project by 4.12 percent.

The study contributes to the advancement of sustainable mine planning by offering a well-constructed, quantitative and interdisciplinary approach of transition optimization. The formulated framework assists the decision-makers to obtain economically competitive, environment friendly as well as socially acceptable mining practices in the context of growing regulatory and sustainability challenges.