Sustainable development, digitalization, mineral value chains, and new paradigm shifts

The sustainable development of the Earth's mineral resources ensures the continuous supply of the raw materials and metals upon which we rely. It is a critical global problem, particularly given the growth of emerging economies and increasing environmental concerns. Digitalization and related advances have facilitated important technological progress and the emergence of several paradigm shifts in the mining industry.

One of these shifts is based on the concept of a mining complex or mineral value chain, introduced to reflect an integrated engineering system. This integrated system manages the quality-quantity and extraction of materials from a group of mines, followed by the treatment of the materials through different interconnected processing facilities to generate saleable products for delivery to customers and/or the spot market. Given its integrated nature, a mining complex is optimized simultaneously in a single mathematical model, integrating all its components to capitalize on their synergies, facilitate multi-source data integration, as well as account for and manage technical risks.

Most technical aspects of a mining complex/mineral value chain are substantially affected by uncertainties (stochasticity) stemming from multiple sources. These range from the materials available in the ground to the operational performance of a mining complex, including the ability to adapt to endogenous and exogenous changes. The effects of uncertainty are compounded by multi-level decision-making. This includes decisions about which materials to extract and when, how to stockpile and/or blend materials, use available processing streams, handle waste, manage capital investments, sequence rehabilitation, and how to transport the various products.

Critical sources of uncertainty in this integrated system include the quality and quantity of materials produced from the mines (material supply uncertainty) and the metal's spot market price (demand uncertainty). With new technological developments, it is possible to quantify and account for these uncertainties, as well as to assimilate new information collected as a mining complex operates, including data from various sensors. This new information needs to be evaluated and used to update models, forecasts, and further support complex, multi-level decision-making.

To date, new geostatistical simulation frameworks and smart(er) simultaneous stochastic optimization approaches allow us to perform the strategic planning of industrial mining complexes under uncertainty at a new scale of intricacy, not imagined a decade ago. As always, new challenges and opportunities emerge, thus it is hoped that the development of new paradigms will extend to stochastic 'self-learning' mining complexes. Self-learning will capitalize from developments in artificial intelligence, enabling engineering production systems to learn from operations and respond to new, real-time incoming production information collected by a wide range of online sensors, already available in industrial mining complexes.

New digital technologies and related R&D will continue to create technological step-changes and paradigm shifts to advance the performance of mineral value chains and support the sustainable and responsible development of mineral resources – all new, advanced and exciting developments for both the mining industry and academia.

R. Dimitrakopoulos