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Introduction to the *Interfaces* Special Issue on Operations Research in Mining

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This special issue in mining presents surveys and applications. Specifically, in the former category, the issue contains a tutorial on open-pit mine-scheduling models, a literature review on equipment selection, and a combination of a tutorial and literature review on ventilation systems in underground mining. In the latter category, the issue contains applications on open-pit mine scheduling, underground mine design, underground mine production scheduling, and logistics and mining.

Keywords: introduction; mining applications; tutorials; summary; special issue.

Relatively few articles offer advancements in methodology or state-of-the-art reviews in mine planning, and the academic literature includes few documented examples of successful operations research applications of mining. However, with advancements in hardware and software and through interdisciplinary work between mining engineers and industrial engineers, the mining industry is increasingly using operations research in its decision-making processes. Newman et al. (2010) provide a literature review detailing surveys, methodologies, applications, and case studies at the time of the writing.

This special issue focuses on some applications and surveys that have appeared since Newman et al. (2010). We begin this issue with three articles on literature reviews and tutorials: (1) a tutorial on ways to increase the tractability of open-pit mine scheduling models, (2) a literature review on equipment selection for open-pit mining, and (3) a combined literature review and tutorial on ventilation systems in underground mining. We then include four successful applications concerning (1) open-pit mine scheduling, (2) underground mine design, (3) underground mine production scheduling, and (4) logistics and mining.

We begin with a tutorial by Lambert et al. who address the constrained ultimate pit limit problem, an integer program that produces a production schedule

regarding which blocks to extract and when to extract them, given constraints on precedence and resources, such as extraction and processing capacities. This tutorial suggests methods to improve the problem's tractability; these methods, which can be applied to the monolith (i.e., undecomposed) problem, include (1) variable definition, (2) preprocessing, (3) algorithmic choice, and (4) the provision of an initial feasible solution. This paper should interest any mining practitioner, and any operations researcher who desires a basic introduction to precedence-constrained knapsack problem structure.

Burt and Caccetta review equipment selection for open-pit mining; equipment selection involves choosing an appropriate fleet of trucks and loaders to satisfy material movement requirements of the mine. Important considerations include the ability of the chosen fleet to meet demand, the compatibility of existing equipment with newly purchased equipment, and productivity balancing across the fleet. In this paper, the authors outline modeling and solution approaches for equipment selection problems and point to future research directions to improve both the modeling and solution outcomes for practical applications of this problem. This paper should interest mining practitioners involved in equipment procurement and operations researchers studying similarly structured problems.

In the final methodological and (or) review paper in this issue, Acuña et al. present a review of primary mine ventilation systems, an essential component of all underground mines. Large mine networks can be complex, often comprising hundreds of interconnected roadways and ventilated by fans and regulators positioned around the network. Minimizing the power costs of these systems is a challenging nonlinear mathematical program. This paper presents mathematical formulations and a review of the solution methods to determine the minimum fan-power cost design of primary mine ventilation systems. This paper should interest any mining or ventilation practitioner, and any operations researcher who desires an introduction to the formulation of and solution methods to primary mine ventilation network models.

We then present four successful applications. Smith and Wicks maximize medium- to long-term copper production for a mining complex composed of multiple deposits and open pits subject to constraints on shovel capacity and placement, global shovel fleet capacity, and working space-related shovel capacities. The formulation also accounts for sequencing, stockpiling, ore blending, and concentrator capacity. The authors apply rolling time horizon heuristics to their mixed-integer program, resulting in solutions that demonstrate the effectiveness of their model applied to large-scale multipit operations. The resulting life-of-complex mine plans support medium-term planning in active operations.

Grossman et al. develop two software tools, PUNO and DOT, for optimally designing the tunnel system (or access) layout in an underground mine. These tools, based on principles of geometry, have been applied to ore deposits at the Prominent Hill mine in South Australia and the Leeville gold mine in Nevada, and generate designs more quickly and at least as cost efficiently as the designs prepared by mining engineers. In addition, the authors' tool

reveals new options through which the engineers' original designs could be improved.

O'Sullivan and Newman maximize life-of-mine metal production, subject to constraints on maximum monthly extraction and backfilling quantities, maximum and minimum monthly metal production, and sequencing between extraction and backfilling operations at the Lisheen lead-zinc mine in south central Ireland. The authors solve their integer programming model with a heuristic to produce a schedule that adds value to the mining operation by (1) shifting metal production forward in the schedule, (2) reducing waste mining and backfilling delays, (3) avoiding expensive mill-halting drops in ore production, and (4) enabling smoother workforce management. This work provides examples of the way in which nonobvious solutions can help improve operations and how the improvements in hardware and software enable the determination of such solutions.

Finally, Garcia-Flores et al. present a supply chain problem in mining—that of medium-term rail scheduling for Rio Tinto Iron Ore in Western Australia. The authors formulate a nonlinear program that considers complex blending of ore types, network capacity, train numbers, and contractual obligations, and solve it using successive linear programming. The model consistently produces plans with a higher iron ore throughput than the manual approach previously used; it reduces the time planners spend determining schedules (e.g., from five hours to less than one hour). The model also increases the amount of material transported to the ports by one million tonnes in a typical planning horizon; this represents an increase in sales of over \$100 million.

Reference

- Newman A, Rubio E, Caro R, Weintraub A, Eurek K (2010) A review of operations research in mine planning. *Interfaces* 40(3):222–245.