Environmental Modelling & Software 51 (2014) 45–58

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Integration of reclamation and tailings management in oil sands surface mine planning

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ARTICLE INFO

Article history:
Received 30 January 2013
Received in revised form
25 September 2013
Accepted 27 September 2013
Available online 18 October 2013

Keywords:
Reclamation planning
Tailings management
Mine planning
Oil sands
Open-pit mining
Integer programming
Strategic planning

ABSTRACT

The processing of oil sands generates large volumes of slurry, known as tailings, that is impounded in tailings ponds. Oil sands operators are committed to develop reclamation plans to ensure that the mine site is restored to a natural or economically usable landscape. Since most of the material that is needed for capping of the tailings pond is produced in mining operation, it is reasonable to include material requirement for reclamation as part of mine planning. In this paper, an integrated long-term mine planning model is proposed that includes tailings capacity and reclamation material requirements. A mixed integer linear programming (MILP) model is developed to test the performance of the proposed model. The MILP model is coded in Matlab®. It is verified by carrying out a case study on an actual oil sands dataset, and has resulted in an integer solution within a 2% gap to the optimality. The resulted production schedule meets the capacity constraint of the tailings facility and guarantees the production of the required reclamation material.

1. Introduction

It is well understood that extraction of minerals triggers a number of environmental issues. In the case of oil sands surface mining, the most important environmental impacts arise from tailings ponds. Tailings is a mixture of sand, fine material, and remaining bitumen in water, produced at the end points of a hot water purification process that captures the bitumen from oil sands. The leaking of toxic tailings into the aquifers, landing of birds on the tailings ponds and the loss in the vegetation of the mine site and tailings ponds are just examples of the environmental concerns in oil sands mining. Different lists of environmental impacts and their significance for mining projects are addressed in the literature. Singh (2008) reviews some general environmental issues involved in mining projects, such as land use, socio-economic impacts, impacts on water quality and impacts on the site ecology. Woynillowicz and Severson-Baker (2009) and Rodriguez (2007) list the environmental issues for open-pit mining and in-situ operations for oil sands production. The impacts are classified in three categories of water-related, land-related, and air-quality-related.

In treatment of tailings-related problems, the first difficulty is the dewatering of tailings slurry and to reclaim the tailings pond into a trafficable landscape. The next problem is to provide the required material for capping. Most of the material that will be used in later periods for reclamation is produced either in mining operation, or in oil sands processing. The net present value (NPV) is well introduced to measure the economic value of production over the mine-life. Knowing that any displacement of material for reclamation increases the overall costs, it is essential to consider reclamation material requirement as part of the mine planning model to avoid unnecessary expenses. In addition, the volume of total tailings produced and the contents of the tailings slurry are important, due to the limited facilities for storage of tailings. Therefore, material requirement for reclamation and the capacity of tailings facility must be integrated in the long-term mine planning model.

Mine planning includes a variety of techniques that are used to find the best order of extraction from a mine with respect to constraints involved in mining and processing of the extracted material. Different time horizons can be defined for any mining problem.

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http://dx.doi.org/10.1016/j.envsoft.2013.09.026

In long-term mine planning, the focus is on strategic decisions that influence the problem over the mine-life, such as the capacity of mining and processing facilities, the required capacity of tailings facility, and material requirements for mine site reclamation. This research is built on the basis of two concepts of mine planning optimization, and environmental impacts involved in oil sands production.

1.1. Long-term open pit mine production schedule

Real instances of mine planning mathematical formulation include a large number of decision variables, associated with 3–10 million blocks and 15-40 time periods. Due to the large number of decision variables, real mine planning problems are intractable under current exact solution methods. Numerous commercial software and heuristic methods are developed for the problem. However, there is no guarantee for the optimality of a heuristic solution. Some techniques, such as using larger mining units to generate a more practical production schedule (1969; Tabesh and Askari-Nasab, 2011), will reduce the problem size and make it possible to solve the problem with exact mathematical programming methods.

The earliest well known deterministic optimization model for open pit mine planning is proposed by Johnson (1969), offering to solve the model with Dantzig–Wolf decomposition technique. The proposed model is a comprehensive mathematical model by considering dynamic cut-off grade and multiple destinations. However, it is not computationally tractable for large-scale problems. Since then, much work has been done to overcome the dimensionality problem.

Boland et al. (2009) develop an iterative aggregation and disaggregation method. The authors use larger aggregated mining units to solve the mining problem, then use blocks for processing. They disaggregate the mining units iteratively and refine them with respect to processing, up to the point that the refined aggregates produce the same optimal solution for the linear programming relaxation of the mixed integer programming. Two approaches are proposed by Bley et al. (2010) to improve the CPU time by reducing the size of the MILP model, which are modeling the problem as a knapsack problem to eliminate some decision variables, and adding inequalities through modeling the problem as the cutting plane with conflict between two or multiple blocks. Cullenbine et al. (2011) propose a sliding time window heuristic model to find an approximate optimal solution for the integer programming model of block extraction. Their proposed heuristic defines and solves an approximation model recursively through the following steps: (1) variable reduction for early time periods, (2) defining an exact sub-model over a window of middle periods, and (3) defining a relaxed sub-model over the later time periods. Topal and Ramazan (2012) present a strategic mine planning model using network flow model. The authors apply the model on a real case over a 50-year mine-life time. The case includes a mining district with more than 100 mining pits and 13 processing plants in Western Australia.

1.2. Environmental impacts of oil sands production

The concept of sustainable mining is developed to include environmental aspects of mineral production in mine planning and design. Considering of environmental issues may influence mining problems in two different – but related – areas: mine design and mine planning. Mine design includes a group of techniques that determine the overall configuration of the mine at the end of mine life, such as the optimal pit limits. An “environmental cost” is usually defined to include the environmental impacts in mine design (Rodriguez, 2007). On the other hand, the goal of mine planning is to optimize the mine production plan. An optimized mine plan maximizes the NPV over the mine-life, subject to a number of constraints, including precedence between mining blocks, mining and processing capacities and average head grade requirements for the processing plant. Tailings issues can be considered in mine planning. Extracting and processing of each block generates a specific volume of tailings. Mine planning may include tailings management by defining proper decision variables and coefficients to control the volume of generated tailings from extraction of each block.

In the literature, two groups of methods have been used to include environmental considerations in mine projects: qualitative and quantitative methods. Qualitative approaches are based on various reports that monitor the environmental concerns in mining projects. Quantitative approaches tend to quantify the impacts and include them in mine planning and mine design numerically.

A review of qualitative works, including environmental management and communication tools in the mining industry, is presented by Sinding (1999). The author discusses the specifications of environmental management tools, such as environmental management systems, environmental impact assessment, life cycle assessment and environmental accounting. Different phases in any typical mining production are reviewed and the proper tools for each phase are suggested. Manteiga and Sunyer (2000) introduce a simplified three-step methodology for environmental evaluation assessment, including the establishment of an assessment framework, assessment of the environmental situation, and the environmental assessment. The authors define indicators to measure the final results of each step.

Quantitative methods are the second class of methods, by considering the social and environmental impacts either in mine design or mine planning. Rodriguez (2007) develops a heuristic algorithm and defines a new term as the “environmental cost” (EC) to be added to other mining and processing costs. The EC covers a variety of environmental costs related to drilling and blasting, pit excavation, waste rock dumping, tailings disposal, and decommissioning. The revised economic block value (EBV) is used to find the pit limit for the open pit mine design problem in an iterative algorithm.

Odell (2004) uses the sustainability primer methodology that is based on multi-criteria analysis (MCA). MCA consists of a number of distinct approaches, but all with the same basis of defining different scenarios and assess each one through a number of explicit criteria. Assessment of scenarios is typically done in MCA tables. However, the MCA approach is a good choice if the time and financial resources are available, sufficient supporting data is accessible, the project team is expert in analyzing tables, and the decision options are determined. The author applies MCA methodology to an open pit copper mine in Peru.

Fuzzy logic is the other tool that is used to measure descriptive values. Many environmental impacts are described qualitatively. Moreover, in many cases it is necessary to have the judgment of an expert to assess quantitative indicators. Expert judgment changes the quantitative nature of an indicator to qualitative. Fuzzy logic, membership functions, and fuzzy sets are strong tools in transforming the fuzzy nature of environmental variables to crisp values. Shepard (2005) discusses the implementation of fuzzy logic in the quantification of environmental impact assessment. The author reviews the traditional approach of environmental impact assessment and introduces fuzzy logic as successful approach in quantification of environmental impacts.

In most of the current literature, the focus is on qualitative approaches rather than quantitative ones. The scope of current quantitative approaches involves mine design, not mine planning. Although current mine planning models are relatively