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MOL

Mining Optimization Laboratory

2018 Mining Optimization Laboratory Technical Seminar
University of Alberta & Laurentian University
9th Annual Meeting

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Wednesday, September 19, 2018
University of Alberta, Edmonton, Alberta, Canada
Attend in Person or as a Remote Audience by Web Conferencing

8:00 – 8:20 AM	**Web Conference Login / Breakfast**
	Session 01 – Underground / Block Cave Production Scheduling Optimization
8:30 – 8:55 AM	01 - Draw rate optimization in block-cave production scheduling – ***Y. Pourrahimian***
8:55 – 9:20 AM	02 - Production scheduling optimization in block-cave mining with material flow – ***F. Khodayari***
9:20 – 9:45 AM	03 - New Afton block caving operation ***(Webinar)***
9:45 – 10:15 AM	**Coffee Break**
	Session 02 – Simulation Modeling of Mining and Processing Systems
10:15 – 10:40 AM	04 - An investigation into dispatch optimizers using truck-shovel simulation **– *A. Moradi Afrapoli***
10:40 – 11:05 AM	05 - IAMGOLD's Westwood and Cote Gold projects
11:05 – 11:30 AM	06 - A conceptual design and simulation of an in-pit crushing and conveying system – ***E. Ben-Awuah***
11:30 – 11:55 AM	07 - NSERC Collaborative Research & Development Grant Info ***(Webinar)***
12:00 – 1:30 PM	**Lunch – Faculty Club**
	Session 03 – Surface Mine Planning Optimization and Tailings Management
1:30 – 1:55 PM	08 - Long-term open-pit production planning with stockpiling – ***M. Tabesh***
1:55 – 2:20 PM	09 - A new mining fleet management system linking operations to short-term plan – ***S. Upadhyay***
2:20 – 2:45 PM	10 - A risk-based mine planning model for oil sands production scheduling – ***A. Maremi***
2:45 – 3:10 PM	11 - Incorporating stockpiling and cut-off grade into oil sands production planning – ***E. Ben-Awuah***
3:10 – 3:30 PM	**Coffee Break**
	Session 04 – Early Stage Research
3:30 – 3:55 PM	12 - A review of models and algorithms for strategic mining options optimization – ***B. O. Afum***
3:55 – 4:20 PM	13 - A hybrid algorithm for stope boundary optimization – ***V. Nikbin***
4:20 – 4:45 PM	14 - Improved oil sands production planning through statistical analysis and simulation – ***E. Cervantes***
5:00 – 6:00 PM	**Reception – Faculty Club**

8:30 – 9:45 AM	**Session 01 – Underground / Block Cave Production Scheduling Optimization**
8:30 –8:55 AM	1 – Draw rate optimization in block-cave production scheduling using mathematical programming *Farshad Nezhadshahmohammad, Firouz Khodayari, and Yashar Pourrahimian*

Among the underground mining methods available, caving methods are favored because of their low cost and high production rates. Block-caving operations offer a much smaller environmental footprint compared to equivalent open pit operations due to the much smaller volume of waste to be moved and handled. In general draw control is fundamental to success or failure of any block cave operation. Establishing relationships among draw columns to consider depletion rates of other draw columns is complex but essential to provide a reasonable solution for real block caving mines. This paper presents a mixed-integer linear programming (MILP) model to optimize the extraction sequence of drawpoints over multiple time horizons of block cave mines with respect to the draw control systems. A mathematical draw rate strategy is formulated in this paper to guarantee exact solutions. Draw control management provides optimal operating strategies while meeting practical, technical and environmental constraints. Furthermore, dilution and caving are improved indirectly, because the method considers the draw rate strategy according to geotechnical properties of the rock mass. Surface displacements are controlled by using the draw rate in all drawpoints during the life of the mine. Application and verification of the presented model for production scheduling based on the draw control system are presented using a case study.

8:55 – 9:20 AM	2 – Production scheduling optimization in block-cave mining with consideration of material flow *Firouz Khodayari and Yashar Pourrahimian*

Most of the today's open pit mines have to dig deeper compared to the past which means higher stripping ratios, higher rates of waste removals, and as a result, a bigger footprint to be taken care of throughout the mine closure. Underground mining with lower rates of waste movement and smaller environmental footprints can be considered as good alternatives; block caving can be one of the best options because of its high rates of production (comparable to open pit mining) and the low operating cost (less blasting is required; the gravity does the job). By drawing a rock from excavation level in the lower part of the mine, a gap is created, lack of support for the overlying rock mass and the gravity will cause the rock to fracture and cave, then the fragmented ore is extracted within the drawpoints. Some drilling and blasting operations might be needed, depend on the hardness of the rock. The production schedule for such operations can be a complex problem: from which part of the layout the mining should be started? In which direction the mining should be continued? How much ore should be extracted from each drawpoint in each timeline? How the flow of material impacts the extracted tonnages and grades? How can we manage the flow of material? An optimum production schedule can remarkably change the profitability of the project. The flow of material during the life of mine has not been properly captured in the current mathematical optimization models. The main goal is to maximize the net present value of the project while taking into account the technical and operational limitations and the flow of material which include the vertical and horizontal movements among the draw columns. The flow of material during the extraction is captured by considering the adjacent draw columns which could be a source for the horizontal movements through each of the drawpoints. A probability is defined based on the distance of adjacent draw columns from their adjacent drawpoints which determine their impact on each drawpoint's tonnage and grade. This function is taken into account in the production scheduling optimization. Finally, the net present value of the project is maximized during the life of mine while both the material flow and limitations are considered. Such a production schedule can increase the overall profitability of the mining project; reduce the dilution and probability of unexpected events which can happen during a block cave mining operations.

9:20 – 9:45 AM	3 – New Afton block caving operation *Webinar*

The New Afton copper-gold mine is located approximately 350 kilometers northeast of Vancouver in the south-central interior of British Columbia. The property is only 10 kilometers from the regional hub of Kamloops and is easily accessible by paved road. The New Afton Mine occupies the site of the historic Afton Mine, a previous operation of Teck Resources Limited ("Teck"), and includes an open pit, underground workings, historic support facilities, a new concentrator and recently constructed tailings facility. The New Afton deposit extends to the southwest from immediately beneath the Afton Mine open pit. New Afton began production in June 2012 and began commercial production ahead of schedule in July 2012. The underground operation is expected to produce, on average, 85,000 ounces of gold and 75 million pounds of copper per year over a 12-year mine life.

9:45 – 10:15 AM	Coffee Break

10:15 – 12:00 AM	**Session 02 – Simulation Modeling of Mining and Processing Systems**
10:15 – 10:40 AM	4 – An investigation into dispatch optimizers using truck-shovel simulation and a new multi-objective truck dispatching technique *Ali Moradi Afrapoli, Mohammad Tabesh, and Hooman Askari-Nasab*

Over the past five decades several models have been developed to make the decision of assigning active trucks to the right shovels. Most of the algorithms try to make decisions in a way that optimize a specific objective and ignore others. This paper introduces a new multi-objective truck-dispatching model that assigns trucks based on optimizing multiple objectives at the same time, including the goals and production requirements from the upper stages. Moreover, we have developed a simulation model to test the proposed model against the Modular Dispatch logic presented in White and Olson (1986). We have developed the simulation model in Rockwell Arena and incorporated CPLEX to solve the dispatching models while running the simulation model. However, incorporating complicated decision-making tools in the simulation model causes a drastic increase in the simulation run time. Therefore, to deal with the high time consumption problem of the model, herein, we developed a heuristic dispatching subsystem mimicking the Modular Dispatch logic and compared the key performance indicators and run times for the three techniques.

10:40 – 11:05 AM	5 – IAMGOLD's Westwood and Cote Gold projects

The Westwood Project is located on the Doyon property, 2.5 kilometers east of the former Doyon Gold Mine in the Bousquet Township, approximately 40 kilometers east of Rouyn-Noranda and 80 kilometers west of Val d'Or in southwestern Québec, Canada. This area is approximately 420km northeast of Montreal. The Westwood Project covers 1,925 hectares and consists of 120 titles, one mining lease, one surface lease and three tailings leases.

11:05 – 11:30 AM	6 – A conceptual design and simulation of an in-pit crushing and conveying system for a Bauxite mine *Eugene Ben-Awuah and Navid Seyed Hosseini*

The choice of a primary haulage system in mine planning remains a complex problem. Load and haul is normally utilized for material handling in open pit operations. In-pit crushing and conveying (IPCC) is a system that is not typically considered as a primary method of transportation in today's mining world. Using an IPCC system has many advantages including cost savings, safety and environmental impacts which make IPCC an attractive material handling option. Depending on design parameters, IPCC can achieve full or partial replacement of trucks for material transportation within and out of a mine. In order to use an IPCC system, the pit design must be optimized for conveyor systems with straight and elongated walls as large amount of time is needed to set-up and dismantle the system to relocate conveyors to other benches. The objective of this research is to design and simulate the configuration of a semi-mobile IPCC system for a Bauxite mine. The simulation model will evaluate production parameters and their impact on the mine plan including; shovel-crusher operations, conveyor systems operations, haul road networks, processing plant operations, ex-pit stockpiling and in-pit backfilling.

11:30 – 11:55 AM	7 – NSERC Collaborative Research & Development Grant Information *Webinar*

A review of NSERC collaborative research programs and their benefits to the sponsors.

12:00 – 1:30 PM	Lunch
1:30 – 3:10 PM	**Session 03 – Surface Mine Planning Optimization and Tailings Management**
1:30 – 1:55 PM	8 – Long-term open-pit production planning with stockpiling *Mohammad Tabesh and Hooman Askari-Nasab*

Long-term open-pit production planning is a complicated process that includes deciding on the order of extraction of blocks and their destinations in order to satisfy various technical constraints. Moreover, stockpiles can be considered to as buffers of material for future use or sources of high or low-grade ore for controlling blending requirements. In this paper, we present a mathematical formulation that uses aggregated units for making mining, processing and stockpiling decisions while respecting various mining and processing constraints. First, we propose a non-linear model that estimates stockpile grade and controls the head grade of material sent to the processing plants. Next, we use the idea of piecewise linearization to modify the model

to be able to solve it with mixed integer linear programming solvers. Afterwards, we show how our model compares against other linear stockpiling models in the literature. Finally, the model is tested on a small dataset to evaluate the performance of the model and show the errors introduced by linearization.

1:55 – 2:20 PM	9 – A new multi-objective multi-stage mining fleet management system linking dynamic operation to short-term plan *Ali Moradi Afrapoli, S. Upadhyay, and Hooman Askari-Nasab*

By starting current millennium, fluctuation in the market price of mineral products has encouraged mining companies to cut down their operating costs. One useful way of reducing operating costs in mining operations is to make optimal operational decisions. A decision maker system can be implemented to make required optimal operational decisions. Mining fleet management systems are systems responsible for semi-dynamic and dynamic decisions to be made in a mining operation. Since 50 years ago several types of mining fleet management system have been developed by different researchers. However, none of the proposed systems considers effects of the short-term plan on dynamic truck assignment. Herein, we proposed a multi-objective multi-stage mining fleet management system that deals with the aforementioned shortcoming of the currently available systems. The developed system, in its so called upper stage, links semi-dynamic operational decision-making process to the short-term production plan by simultaneously assigning shovels to mining faces and allocating trucks to the shovels implementing its first multi-objective decision-making model. Then in its second stage, in a real-time dynamic decision-making process, it decides on the next destination of trucks asking for new assignment by optimizing its second multi-objective decision-making model. The developed fleet management system had been verified using an Iron ore case study and the results are presented in this paper.

2:20 – 2:45 PM	10 – A risk-based mine planning model for oil sands production scheduling and waste management with stockpiling *Ahlam Maremi and Eugene Ben-Awuah*

Oil sands mine management requires achieving multiple goals with the available limited resources and lease area. Public opinion and government policy makers continually put pressure on the waste management practices and the environmental footprints of oil sands mining companies. An effective and efficient waste disposal planning system, together with a long-term mine plan are required to ensure profitability and sustainability of the mining operation. In this paper, a mixed integer linear goal programming (MILGP) framework is developed to determine the production schedule simultaneously with dyke construction schedule. In-pit dykes are constructed in the mined-out area simultaneously with the advancement of the pit phase mining. To minimize the risk from geological uncertainty, Kriging estimates with a variance penalty scheme are used for mine planning. The topmost layer of the overburden, known as Muskeg are stockpiled to be used for land reclamation. The lower part of the overburden is used for dyke construction in addition to the interburden and tailings coarse sands dyke materials. A limited duration stockpiling strategy is incorporated for the ore material that exceeds the processing capacity in each period. A robust constraint for managing tonnage fluctuations is introduced. The model is implemented and verified on an oil sands dataset.

2:45 – 3:10 PM	11 – Incorporating stockpiling and cut-off grade optimization into oil sands production and dyke material planning using goal programming *Navid Seyed Hosseini and Eugene Ben-Awuah*

In achieving maximum benefit in oil sands mining, the time and sequence of removing ore, dyke material and waste from the final pit limit is essential to the long-term production schedule. In-pit waste management strategy requires the simultaneous construction of dyke with the advancement of mining operations. This paper seeks to determine: 1) the time and sequence for removal of ore, dyke material and waste to maximize Net Present Value (NPV); 2) the quantity of dyke material required for dyke construction to minimize construction costs; and 3) the impacts of stockpiling and stockpile reclamation with limited time duration. An Integrated Cut-Off Grade Optimization (ICOGO) model was used to generate an optimum cut-off grade policy and a schedule for mining ore and waste, as well as overburden, interburden and tailings coarse sand dyke material for long-term production planning. Subsequently, a Mixed Integer Linear Goal Programming (MILGP) model was developed to generate a detailed production schedule for removal of ore, waste and dyke materials from the final pit limit. The MILGP model uses the cut-off grade profile and schedule generated by the cut-off grade optimization model as guide to define the grade constraints and production goals required by the MILGP model. The developed models feature stockpiling with limited duration for long-term production scheduling. The models were applied to an oil sands case study to maximize the (NPV) of the operations. In comparison, whereas the ICOGO model solved the optimization problem faster, the MILGP model results provide detailed mining-cut extraction sequencing for mining.

3:10 – 3:30 PM	Coffee Break
3:30 – 4:40 PM	**Session 04 – Early Stage Research**
3:30 – 3:55 PM	12 – A review of models and algorithms for strategic mining options optimization *Bright Oppong Afum and Eugene Ben-Awuah*

In major mining projects, deviations from optimal mine plans will result in significant financial losses, future financial liabilities, delayed reclamation and resource sterilization. It is important that the strategic mine plan makes optimum use of available resources and provide continuous quality ore to drive sustainable mining and profitability. This requires the development of a well-integrated strategy of mining options for open pit and/or underground mining and their interactions. However, current tools and methodologies used in the mining industry are not adequate in dealing with the complexity of subjecting a deposit to rigorous mining options optimization with a measure of optimality. Development of new technologies, quantification of uncertainty and optimization in strategic mine planning plays an important role in reducing financial risk and environmental footprints, and promoting sustainable development through improved resource governance and total mine reconciliation. This research reviews available models and algorithms that evaluates and strategically optimizes various mining options. Extensive literature review and gap analysis matrix are used to identify the associated limitations and opportunities for improvement on the existing models and algorithms.

3:55 – 4:20 PM	13 – A hybrid algorithm for stope boundary optimization *Vahid Nikbin, Majid Ataee-Pour, and Yashar Pourrahimian*

Determination of stope boundaries is one of the significant steps after the underground mining method selection. Obviously, it should be an optimal plan. However, a comprehensive algorithm has not been presented for it, till now. Most of them are heuristic and we cannot confide to their solutions. Other algorithms which are rigorous have numerous simplifications that limit their practical domains. In this paper, we present a hybrid algorithm by combining both famous Branch and Bound (B&B) and a new Dynamic Programming (DP) algorithm. Our criteria for prune week branches are the same to the traditional B&B algorithm. Corresponding value to each branch is determined by a new proposed DP algorithm. Indeed, we use this DP algorithm to solve some of the sub-problems within the initial our main problem. Finally, by comparing results of this hybrid algorithm with other works, we prove its abilities in the determination of optimal stope boundaries.

4:20 – 4:45 PM	14 – An improved approach to optimal production planning and equipment selection in open pit mines in the Athabasca oil sands through statistical analysis and simulation *Eduardo Cervantes and Hooman Askari-Nasab*

This study investigated the current method used by a major mining company for predicting the long-range productivity of their open pit extraction operations in the Alberta oil sands, and presents an improved method which lowers operational risk and uncertainty by being significantly more accurate. The traditional technique employed by the company was determined to be, to some extent, an oversimplification of a rather complex system. This procedure consisted in generating a single line of best fit based on a single year's worth of historical production data. The key metric used to measure productivity is TPGOH (tonnes of material per gross operating hour). This line of best fit was then used to plan production and the equipment requirements for the LOM (life-of-mine) range. It was evident that this approach resulted in highly variable and therefore unreliable results. Initially, in order to reduce the variance in the results, this study proceeded to conduct extensive historical data analysis and data classification. This early effort saw the organizing of the (previously uncategorized) data, as well as the addition of more historical records, which resulted in considerably better predictions than the original approach where the data was taken in bulk without much filtering. The next step in this study involved a major change in direction regarding the method for prediction. Originally, the abscissa was the haul distance and the ordinate contained the average TPGOH, but then the concept of EFH (Equivalent Flat Haul) was introduced as a replacement in the x-axis as a controlling parameter. Additionally, a digital model of the mine's road network was generated, along with accurate distances and correct gradients. Velocity reports from GPS data in the equipment were analyzed in order to determine actual velocities of different kinds of equipment in flat sections of road and other scenarios. Code was developed in order to convert the digital road network into usable data which was subsequently used to estimate travel times from specific shovel sources to dump destinations, in accordance with the mine plan. The new approach incorporates simulation at each step to provide much more accurate predictions for long-range production planning and, in turn, equipment selection forecasting. Producing accurate LOM production planning and optimized equipment usage yield substantial added value to the operation, and these translate to reduced risk and uncertainty.