

# Hierarchical Mine Planning for a Semi-Mobile In-Pit Crushing and Conveying System Using Discrete-Event Simulation

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## Abstract

Semi-Mobile In-Pit Crushing and Conveying system is becoming more commonly used in open pit operations worldwide. The system allows the continuous transport of ore and waste from the pit to their respective destinations by moving the crushing process near or into the pit with the use of semi-mobile crushers and replacing the majority of the hauling cycle with conveyors. Mine planning for such a system involves different levels of decision-making depending on the time horizon under consideration. The primary objective of this study is to develop a discrete-event simulation model to link long-term predictive mine plans with short-term production schedules in the presence of uncertainty. This research presents a methodology that assesses the interaction and impact of operational delays and uncertainties on the mine plan based on decisions of extraction, conveying, processing, stockpiling, blending, and destination. This was done by considering operational delays and uncertainties and comparing the long-term strategic plan with the short-term tactical plan. The effects of operational delays and uncertainties influencing all components of the production system are evaluated. Arena Simulation Software was used to design, develop, and evaluate a discrete event simulation model representing the life of mine for a bauxite deposit.

**Keywords:** Semi-Mobile In-Pit Crushing and Conveying system, discrete-event simulation, open-pit mining, production scheduling, strategic and tactical planning

## 1 Introduction

Globally, mining has been developing in a competitive environment that has led companies to seek new strategies that guarantee operational effectiveness. This motivates the redesign of organizational and productive structures, to achieve satisfactory levels of competitiveness and higher production. Real world uncertainties need to be integrated into strategic and tactical mine plans to ensure minimum production variations as required by the dynamics of the mining operation.

The mine needs to do a detailed cost-benefit analysis of different crushing and transportation options. With some operating scenarios favored by the reduction of equipment prices with shorter delivery times, it may seem attractive to switch from traditional solutions to more innovative ones. Nevertheless, decisions are put on hold waiting to see what happens to mineral prices before committing to an investment (Toepf, 2017).

In response to these needs, new methodologies and tools are continuously being investigated to experiment with alternatives regarding decisions that need to be made in the presence of uncertainty. Some existing mine production models incorporate several variables in operations and do not consider uncertainty (Upadhyay and Askari-Nasab, 2018). However, because of the complexity of the operating environments in the mining sector, it is required to include uncertainties and to consider methodologies such as the simulation of systems that can model probability functions where a priori information is not known, to generate useful and easily understood information for production supervisors and mine managers.

Even though simulation has been a very useful tool for planning and decision-making in production systems (Hira, 2010), problems have arisen in the mining sector with implementing simulation

models in relation to the investment of time and cost in the maintenance of the models created, and the difficulty in the adequate interpretation of the results produced by the computer systems specialized in simulation. Following the above, this research aims to assess the interaction and impact of production uncertainties on the mine plan based on decisions from a model of discrete event simulation. Details on mining operations in relation to extraction, conveying, processing, stockpiling, blending and destination can be incorporated into the strategic and tactical mine planning process. By including additional features in the simulation model, it can provide realistic and practical short-term tactical plan (Upadhyay and Askari-Nasab, 2018).

IPCC is an alternative for the continuous transport of materials (ore and waste) from the mine. There are three main types of IPCC systems: Fixed, Semi-Mobile, and Fully Mobile (Ben-Awuah and Seyed Hosseini, 2017; Mohammadi *et al.*, 2011).

- a) Fixed IPCC systems are designed to reduce transportation distances to the waste landfill (or ore plant) and are near the limit of the pit. This system requires a fleet of trucks to transport the material to the crusher unit. After the material has been crushed, it is fed into a conveying network which delivers it to a spreader (waste) or a stacker (ore) (Nehring *et al.*, 2018). Fixed IPCC is designed to be at the same location during the life of the mine. It is not expected to be relocated until about 15 years. The system is usually set in a concrete structure (Sandvik Mining and Construction, 2007; Osanloo & Paricheh, 2019).
- b) Semi-mobile IPCC systems are suitable for harder rocks, higher capacities up to 10,000 tpd, located near the mining face, and installed on a steel structure. Trucks transport material to the crusher. The system moves between the levels progressively as the mine advances. The crusher can be relocated every 2-5 years close to the main production area when the haulage distance increase (Mohammadi *et al.*, 2011; Nehring *et al.*, 2018; Osanloo & Paricheh, 2019).
- c) Fully mobile IPCC systems consist of a mobile crusher mounted on tracks associated with a shovel. It is limited to softer rock with production rates of about 5,000 tpd (Mohammadi *et al.*, 2011). The loading equipment feeds directly into the crusher, thus

eliminating the truck fleet. From the mobile crusher to the destination, the material is transported by a set of conveyors (Sandvik Mining and Construction, 2007). Trucks can still be used during each sinking phase of a mine, however the transport distance is usually limited (Dean *et al.*, 2015).

One relevant aspect to consider when comparing haulage systems is cost reduction. From the three types of systems presented, the semi-mobile was selected for the functional convenience of type of rock to handle and capacity, while taking advantage of keeping it near a working frontline for a considerable time in a working area, from one to ten years (Topf, 2017). IPCC is considered a low operating cost alternative due to its continuous operation, however, it requires a high capital cost and has less flexibility (Londoño *et al.*, 2014). The semi-mobile IPCC (SM-IPCC) system was compared to the traditional loading and hauling system, being able to reduce the cost of material transportation by about 60% (Ben-Awuah and Seyed Hosseini, 2017). The SM-IPCC combines the advantages of the truck system and a Fully mobile IPCC, however, it is important to consider that the location of the crusher is at an adequate distance from the mining face for at least one year before it is relocated (AkbarpourShirazi *et al.*, 2014).

The IPCC system is very susceptible to production uncertainties, therefore special care must be taken to establish a control system, with the ability to anticipate changes that may compromise mine planning and operations. That is why geology, mine planning, and supervision of operations must be very well aligned and integrated with the requirements of the IPCC system (Carter, 2015).

In this sense, the main objective of this study is to develop, evaluate, and validate a discrete event simulation model that integrates long and short-term open pit production scheduling. The simulation model aims to connect the gap between a long-term deterministic annual strategic schedule and a short-term operational plan. The simulation model takes into account relevant constraints and major operational uncertainties during mining and processing. The mining system is based on a semi-mobile IPCC system (SM-IPCC) for a bauxite mining operation.

## 2 Conceptual Plan and Method

## 2.1 Mine Plan and Design

The proposed simulation model arises in response to the need to connect long-term predictive mine plans with short-term production schedules in the presence of uncertainty. A topography file and a block model were provided for pit limit optimization and production scheduling using Whittle software (GEOVIA Whittle, 2019). GEMS software (GEOVIA Gems, 2019) was used to design the optimum pit shell and mine layout consistent with the SM-IPCC system of mining (Ben-Awuah and Seyed Hosseini, 2017). This simulation will evaluate alternative courses of action based on the hypothesis of decision making under conditions of uncertainty.

The total tonnage for production scheduling can be seen in Table 1. The designed final pit shell has 3.0 billion total tonnes to be mined out of which 1.6 billion tonnes is ore. The production tonnages are further defined in Table 1 by pushbacks, which can be put into perspective with the pushback design layout in Figure 1. The economic parameters used for the mine optimization process are shown in Table 2 (Minkah, 2014).

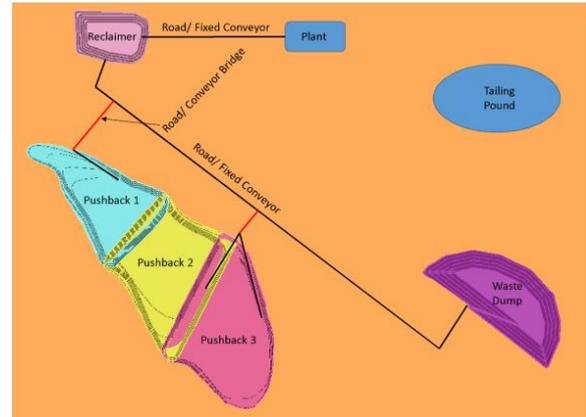
**Table 1 Summary of Material Tonnages** (Ben-Awuah and Seyed Hosseini, 2017)

Description	Total tonnage (Mt)	Ore tonnage (Mt)
Whittle optimum pit shell	2,763	1,610
Designed pit shell	3,003	1,566
Pushback 1	822	402
Pushback 2	1,260	587
Pushback 3	921	577

**Table 2 Economic parameters** (Minkah, 2014)

Description	Value
Reference mining cost	\$3.16 /tonne
Reference processing cost	\$9.6 /tonne
Selling price	\$0.76 /% mass
Discount rate	10 %

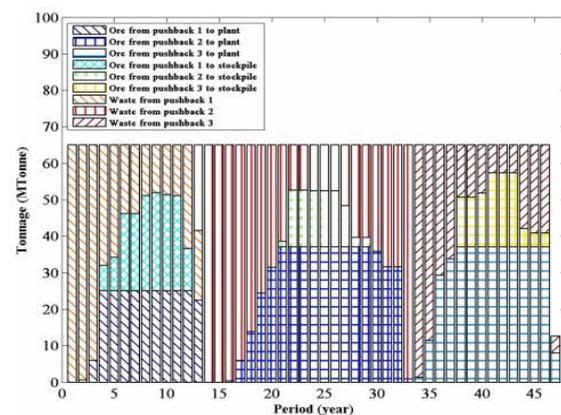
The conceptual design layout for the SM-IPCC system mining operation showing pushbacks, waste dump, conveyors, reclaimer, processing plant, and tailings pond as shown in Figure 1 is used as the design basis for the simulation.



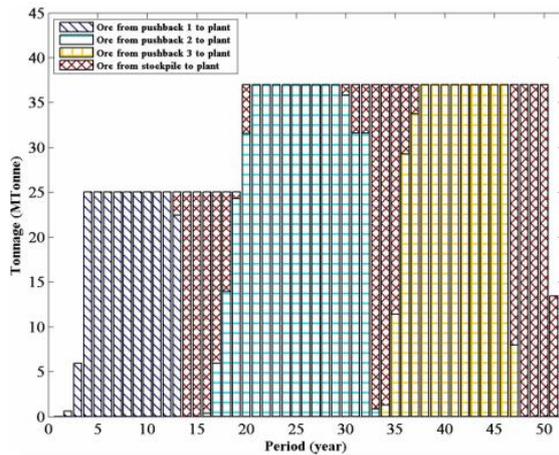
**Figure 1 Conceptual layout of the SM-IPCC system mining operation showing pushbacks, waste dump, conveyors, reclaimer, processing plant and tailings pond** (Ben-Awuah and Seyed Hosseini, 2017)

After production scheduling optimization with Whittle software, Figure 2 represents the mining activity in each pushback and Figure 3 illustrates the processing plant material schedule. The production parameters used in the mine optimization exercise and some resulting operational observations are as follows:

- Mining rate is 65 Mtpa.
- Mining life ends in Period 47.
- Processing rate is 25 Mtpa from Years 1 to 19; and 37 Mtpa from Year 20 onwards.
- Processing ends in Period 51.
- Stockpiling is required during pushback mining to facilitate stockpile reclamation to the processing plant during pushback transitioning.
- Ore processing continues for additional 4 years beyond the end of pit mining activities.



**Figure 2 Mining activity in each pushback** (Ben-Awuah and Seyed Hosseini, 2017)



**Figure 3 Processing plant material schedule (Ben-Auwah and Seyed Hosseini, 2017)**

## 2.2 Experimental Design

The experimental design for the discrete event simulation of the SM-IPCC system includes:

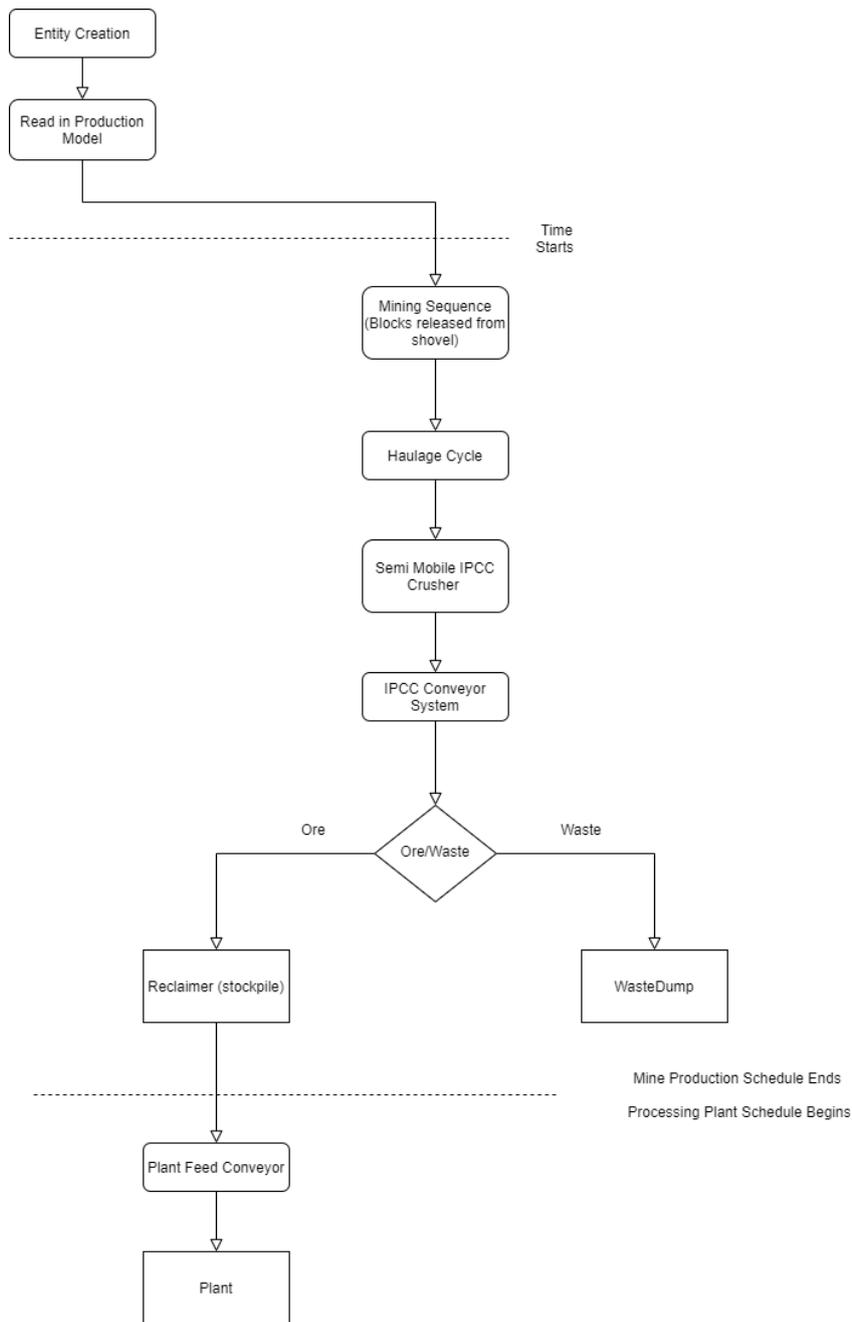
- i) Case 1: This is the base case simulation model. This simulation model duplicates deterministic mining activities for each pushback and processing plant material schedule using Arena software (Rockwell Automation, 2020). This serves as a validation process for the simulation model to ensure the SM-IPCC system is functioning as designed and all input material tonnages reconcile with output material tonnages. This case will produce similar figures to Figure 2 and Figure 3.

- ii) Case 2: This simulation models builds on Case 1 by adding operational delays to the SM-IPCC system. This enables evaluation of the effect of operational delays on the processing plant feed.

- iii) Case 3: This simulation model builds on Case 2 by introducing operational uncertainties using statistical distributions to represent stochastic production parameters. This enables evaluation of the effect of operational uncertainties on the processing plant feed.

Figure 4 illustrates the basic flow chart representing the movement of entities entering and leaving the simulation system. Each entity represents a block of material with location, tonnage and grade in the production schedule.

The daily amount of mined material extracted on a First-In-First-Out (FIFO) basis at the production rate goes to the crusher feed. It is then transported, and a decision is made between ore and waste. Waste is sent to the waste dump and ore is sent to the stockpile. The proposed layout uses a stockpile reclaimer system to feed the plant. It is assumed that a large stockpile of ore is accumulated on top of an apron feeder which transfers material to the plant feed conveyor. Due to the stockpiling and reclaiming approach proposed, stockpile management is organized using the First-In-First-Out (FIFO) modeling method.



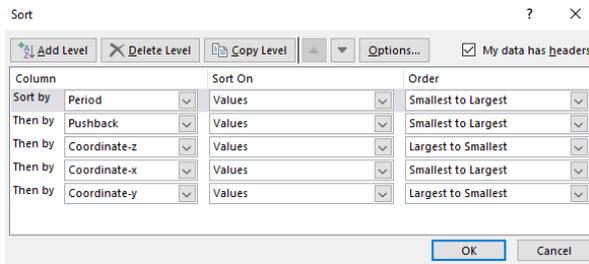
**Figure 4 Simulation flowchart representing the movement of material through the SM-IPCC mining system**

The long-term production schedule consists of 92,365 rows of mining blocks data, which is read into the SM-IPCC simulation model one row at a time when the entities enter the system. The Whittle production schedule data has the following 10 columns for each mining block:

1. BlockID
2. Coordinate-X
3. Coordinate-Y
4. Coordinate-Z

5. Rocktype
6. Tonnage
7. Period
8. Pushback
9. Al<sub>2</sub>O<sub>3</sub> Grade
10. SiO<sub>2</sub> Grade

Figure 5 shows the production schedule file sorted in the order; Period, Pushback and Coordinates via Excel spreadsheet custom sort.

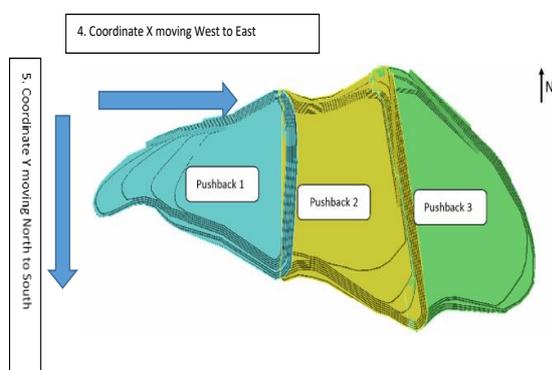


**Figure 5 Custom sort of Whittle production schedule file**

This means that the mining blocks will enter into the SM-IPCC simulation model in the following order:

1. Period – Ascending order (Years 1 - 47)
2. Pushback – Ascending order (1 - 3)
3. Coordinate Z – Descending order (these are bench levels, starting from the top and moving down)
4. Coordinate X – Ascending order (moving West to East)
5. Coordinate Y – Descending order (moving North to South)

This mining precedence ensures that mining block extraction generally proceeds with Period 1 in Pushback 1 starting from Bench 1 moving from West to East and North to South (Figure 6). This means that every bench will be mined sequentially from the North-West corner to the South-East corner of a pushback. This system of extraction ensures each pushback gets mined to completion before another starts, from the point closest to the plant to the furthest.



**Figure 6 Mining sequence showing direction of mining blocks extraction**

While the mining blocks data are read into the SM-IPCC simulation model, each entity get assigned attributes to enable tracking of the mining blocks as

they go through the simulation model. The attribute datasets assigned are:

- a) BlockID
- b) Coordinate-Z
- c) Rocktype
- d) Tonnage
- e) Period
- f) Pushback
- g) Al<sub>2</sub>O<sub>3</sub> Grade
- h) SiO<sub>2</sub> Grade

Specifically, every mining block that travels through the SM-IPCC system carries eight local attributes of data from the production schedule that is unique to the block. This data is used to manage the material flow and compile summary statistics of the mining blocks attributes.

### 2.3 Verification of the SM-IPCC Simulation Model - Periods 13 and 33

As part of the simulation model verification process, many different variations of the implementation parameters were tested before completing the final model. In total, over a hundred simulations were executed. With the input file having 92,365 mining blocks to read-in, running the simulation model for the entire mine life was time consuming. Periods 13 and 33 from the production schedule file were used as input data throughout the simulation design and modelling process as these two periods combined have blocks from all 3 pushbacks and contained both ore and waste. With this truncated production schedule file, test runs for the completed SM-IPCC simulation model were conducted in less than 2 hours compared to approximately 14 hours required to run the production schedule for the entire mine life. Once modelling for all paths and processes have been tested, Case 1 was implemented to verify the base case simulation experiment.

### 2.4 Cases to Evaluate

The completed SM-IPCC simulation model was used to evaluate 3 cases as outlined in Section 2.2. The mine optimization and simulation parameters used in the implementation scenarios are as follows:

#### 2.4.1 Case 1 – Full Production Schedule

- a. The mining rates for the haulage cycle, semi-mobile crusher, and IPCC conveyor system

were set at 65 Mtpa as defined in the deterministic mine optimization process in Whittle. This was implemented in the simulation model as 7420 t/h, which equates to 65 Mtpa (all time units are set to hours).

- b. The plant feed conveyor was set at 25 Mtpa for Years 1-19 and 37 Mtpa for Years 20 onwards. This was implemented as 2854 t/h and 4224 t/h respectively.

#### 2.4.2 Case 2 - Full Production Schedule with Operational Delays

In this implementation, operational delays are implemented as deterministic parameters using mean values.

- a. Similar mining rates for all paths and processes as implemented in Case 1.
- b. 168 hrs (7 days) delay was added for relocation of semi-mobile crusher after every 2nd bench.
- c. 336 hrs (14 days) delay for crusher and conveyor system relocation between pushbacks.
- d. 1 hr delay in crusher operation when switching rock types. This also ensures the crusher and conveyors run empty before switching rock types.
- e. Annual processing plant shutdown delay was set to 504 hrs (21 days).

#### 2.4.3 Case 3 - Full Production Schedule with Operational Delays and Uncertainties

In this implementation, operational delays are implemented as stochastic parameters using statistical distributions.

- a. Crusher relocation every 2nd bench was set to Uniform distribution (156 hrs, 180 hrs), representing mean +/- 12 hrs.
- b. Pushback delays was set to Uniform distribution (312 hrs, 360 hrs), representing mean +/- 24 hrs
- c. Crusher rock type switching delay was set at Normal distribution (1 hr, 0.1 hr), representing a mean with standard deviation of 10%.
- d. Haulage cycle rate was set to Triangular distribution (6678 t/h, 7420 t/h, 8162 t/h), representing mean +/- 10%.
- e. Crushing rate was set to Normal distribution (7420 t/h, 371 t/h), representing mean with standard deviation of 5%.
- f. IPCC Conveyor system rate was set to Normal distribution (7420 t/h, 371 t/h),

representing mean with standard deviation of 5%.

- g. Processing plant feed rate for Years 1-19 was set at Normal distribution (2854 t/h, 143 t/h) and for Years 20 onwards was set at Normal distribution (4224 t/h, 212 t/h); representing mean with standard deviations of 5%.
- h. Annual processing plant shutdown delay was set to Triangular distribution (428.4 hrs, 504 hrs, 579.6 hrs) representing mean +/- 15%.

### 3 Results and Discussion

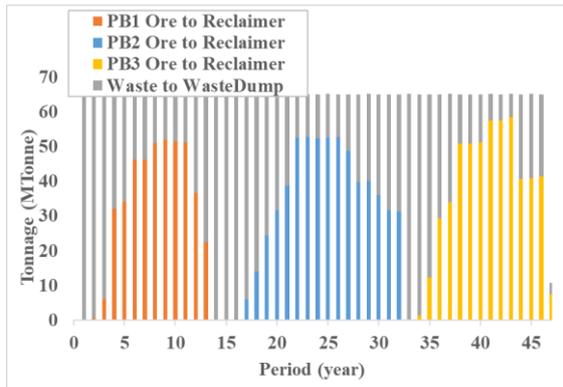
Comparison of the implementation scenarios was done based on the resulting production schedules, cashflows, NPVs and mine life. The simulation experiments implemented provides a workflow for linking long-term strategic plans with short-term tactical plans. The results for the three cases were analyzed to show the impact of operational delays and uncertainties on the mine plan.

#### 3.1 Case 1: Full Production Schedule

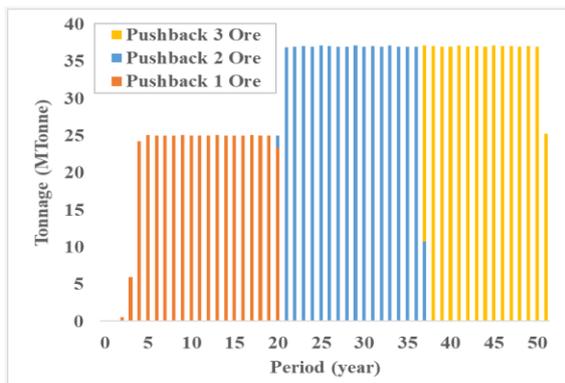
Figure 7 shows the mining production schedule and Figure 8 presents the plant feed production schedule. According to the results, the following information can be deduced:

- Simulation ended on September 6, 2070.
- Pit mining duration of 47 and ore processing duration of 51
- Total ore tonnes to plant is 1.566 billion tonnes.
- Total rock tonnes are 3.003 billion tonnes.

These statistics are consistent with the Whittle production schedule results which serve as the focus for the Case 1 experiment. With a start date of January 1st, 2020, the life of mine (LOM) is 51 years including 4 years of stockpile processing after pit ore extraction ended in Year 47. All the material tonnages are accounted for at the appropriate destinations.



**Figure 7 Mining production schedule (Case 1 - Full Production Model)**



**Figure 8 Plant feed production schedule (Case 1 - Full Production Schedule)**

Furthermore, Figure 7 and Figure 8 are both close match to Figure 2 and Figure 3, which was the goal of this case. The mining production schedule is almost identical, while the processing schedule has a few small discrepancies. This was mainly due to two factors. The first being the method in which the blocks are mined in the simulation model. By mining each pushback in an x, y, z pattern, we are not targeting the ore on each bench first as Whittle would have using Milawa Balance. This is causing small shortfalls in Years 2 – 4 (2%) of the processing schedule. The second factor can be seen at the top of all the schedule bars in Figure 7 and Figure 8. The mining and processing rates are not perfectly uniform across the graphs. It would be near impossible to achieve an exact mining rate of 65 Mtpa or processing rates of 25 and 37 Mtpa. This is because the simulation is extracting blocks from the production schedule as entities. The system only acknowledges the tonnage of each block reaching their destinations once all the tonnage for the block has been processed. It would not account for a partial block that is in process at the turn of a period.

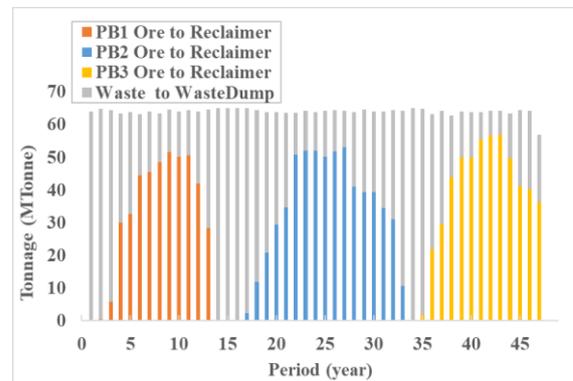
Overall, the results of the base case (Case 1) are exactly as expected, and the SM-IPCC simulation model is now ready to incorporate delays and uncertainties.

### 3.2 Case 2: Full Production Schedule with Operational Delays

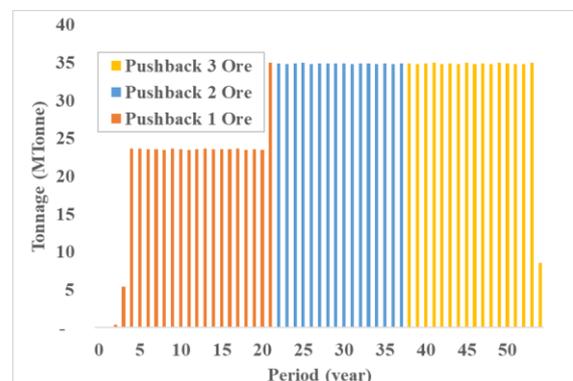
Mining production schedule for Case 2 is shown in Figure 9. Figure 10 depicts the scheduling for the processing plant in the same case.

Again, the following conclusions can be deduced from the results:

- Simulation ended on February 27, 2073.
- Pit mining duration of 47 and ore processing duration of 54.
- Total ore tonnes to plant is 1.566 billion tonnes.
- Total rock tonnes are 3.003 billion tonnes.



**Figure 9 Mining production schedule (Case 2 - Full Production Model with Operational Delays)**



**Figure 10 Plant feed production schedule (Case 2 - Full Production Model with Operational Delays)**

From the results, all the materials are once again accounted for and have reached their proper output destinations. The projected mine life has been

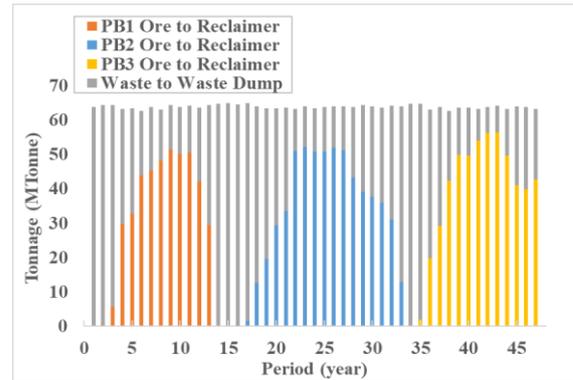
extended by about 9 months for pit mining and 2.25 years for plant processing. This was due to the operational delays causing shortfalls in the annual mining production rate. This was of course the anticipated impact of this case on the mine's time horizon. In the design basis scenario (Case 1), near perfect mining and processing rates are realized, while the new simulation scenario (Case 2) shows how operational delays affects the LOM. It also clearly demonstrates more realistic mining and processing schedules as the practical production rates usually differ year to year when compared to the targeted production rates, which are theoretically achieved every year in strategic mine planning.

From Figure 9 and Figure 10, there are shortfalls in almost all years in the mining production schedule while the processing schedule do not show shortfalls. With these impacts to the schedules, it provides the opportunity to identify potential operational challenges and come up with strategies to manage these shortfalls throughout the LOM. Strategies to consider include increasing mining capacity temporarily through owner or contractors and reducing operational delays through efficiency. The corresponding processing throughput will increase until the SM-IPCC simulation becomes processing limited in these years. These additional investigations will not be implemented at this time.

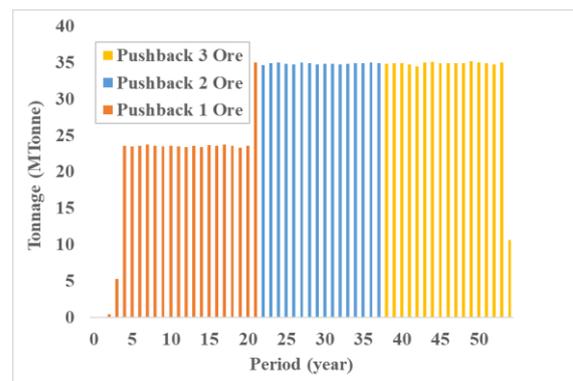
### 3.3 Case 3: Full Production Schedule with Operational Delays and Uncertainties

Mining production schedule for Case 3 is shown in Figure 11. Figure 12 illustrates plant feed production schedule for the same case. The following conclusions can be gathered from this case:

- Simulation ended on Mar 20, 2073
- Pit mining duration of 48 and ore processing duration of 54.
- Total ore tonnes to plant is 1.566 billion tonnes
- Total rock tonnes are 3.003 billion tonnes



**Figure 11 Mining production schedule (Case 3 – Full Production Model with Operational Delays and Uncertainties)**



**Figure 12 Plant feed production schedule (Case 3 – Full Production Model with Operational Delays and Uncertainties)**

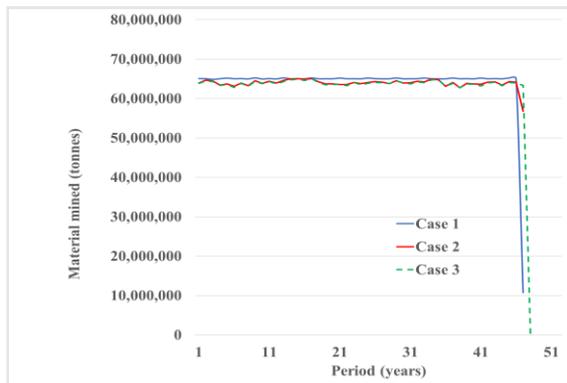
From the results, all the materials are accounted for and have reached their proper output destinations. By introducing uncertainties through statistical distributions, the LOM is once again extended by additional 10 months for pit mining and 2.6 years for plant processing. This case further introduces more practicality into the SM-IPCC simulation model as real-life operational delays are usually uncertain and changes over the years. With the impacts of operational delays and uncertainties on the schedules, it provides the opportunity to identify potential operational challenges and come up with strategies to manage these shortfalls throughout the LOM.

### 3.4 Comparison: Case 1, Case 2 and Case 3

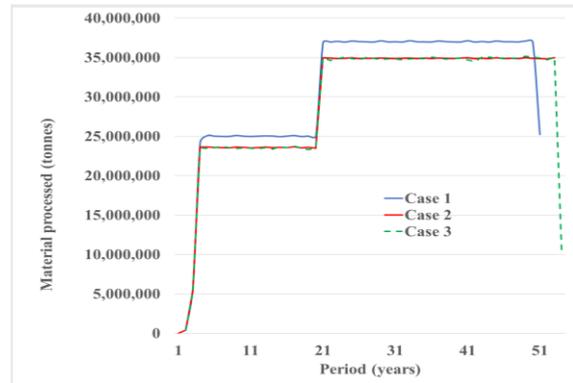
The SM-IPCC simulation model results were compiled and evaluated using Excel spreadsheets and charts.

Figure 13, Figure 14, and Figure 15 show the simulation results for rock tonnes mined, ore

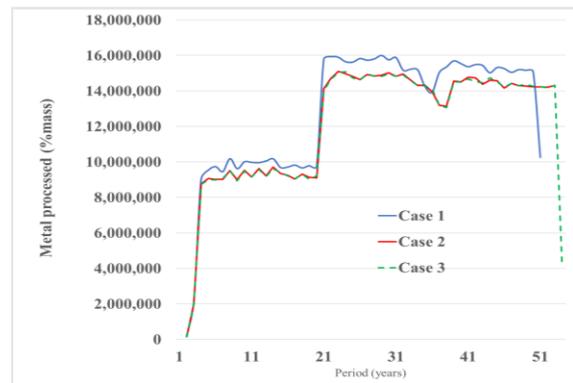
tonnes processed, and metal content produced respectively over the life of mine in the three cases. The amount of material mined after the simulation is presented in Figure 13, where it is possible to contrast the behavior in the cases. Case 1 is an ideal behavior where the whole production is uniform. However, in the other cases, it is observed how they are affected by delays and uncertainty. Figure 14 presents the variations in annual ore tonnes processed for the three cases. There is an average difference of 1.4 Mt between Periods 4 - 19 and 2.1 Mt for Periods 21 - 50 between Case 1, Case 2, and Case 3. This is caused by the delay and uncertainty which extends the life of mine. The metal content of the ore expressed in %mass is shown in Figure 15. The gap from Period 22 results from similar variations in ore tonnes processed.



**Figure 13 Rock tonnes mined**



**Figure 14 Ore tonnes processed**



**Figure 15 Metal content**

With the quantities presented in the respective Figures, the NPV was calculated for each case, considering the value of the metal processed as output, and the rock tonnes mined and ore tonnes processed as inputs with operational costs.

The summary of economic results is shown in Table 3. With operational delays and uncertainties, the total end-of-mine life NPV with a 10% discount rate is \$ 2,021 million for Case 3 compared to \$ 2,028 million for Case 2 and \$ 2,233 million for Case 1. A reduction in NPV of 9.2% is observed comparing Case 2 to Case 1, and 9.5% comparing Case 3 to Case 1.

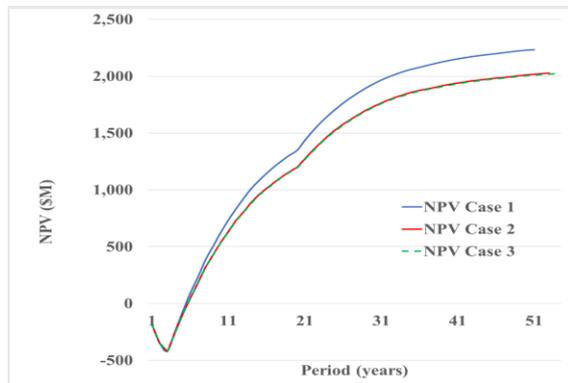
**Table 3 NPV results by case**

Case	Description	NPV (\$M)	LOM		Comparison (% reduction)
			Mining (Years)	Processing (Years)	
1	Full production schedule	2233	47	51	-
2	Full production schedule with operational delays	2028	47	54	9.2
3	Full production schedule with operational delays and uncertainties	2021	48	54	9.5

Figure 16 shows the annual cumulative progression of the NPV values of the different cases during the

mine life. The behavior of the net present value curves is similar in shape. Cases 2 and 3 are less profitable in comparison with Case 1, as a result of operational delays and uncertainty. From Period 8,

it is observed the accumulated NPV for Case 2 and Case 3 begins to deviate from Case 1, resulting from lower metal content.



**Figure 16 Annual cumulative progression of the NPV by case over time**

## 4 Conclusions

This research has developed, verified, and validated a discrete-event simulation model to link long term and short term mine planning for a semi-mobile in-pit crushing and conveying system using Arena simulation software. The implementation of real options in mine planning considers the fact that most mining operational parameters are stochastic rather than deterministic. This allows the real options methodology to incorporate uncertain operational parameters in project evaluation, increasing the reliability of the expected results.

The most important variables considered in this study were those related to operational uncertainties because they have a great impact on production. The most influential uncertainties are those related to the conveyor system, crusher, haulage, loading, processing plant, and their interaction in the system.

Current mine planning methods consider stochastic input variables as deterministic parameters, generating inconsistent mine plans, and a gap between short- and long-term predictive models. Therefore, models used for mine planning must be able to analyze operational variabilities and incorporate changes in these variables during evaluation.

A case study for a Bauxite deposit was performed using a simulation model for a SM-IPCC mining system. Three mining operation cases were evaluated. Case 1 replicated the mine plan generated by Whittle in Arena software; Case 2 added operational delays to Case 1; and Case 3 added operational uncertainties to Case 2. The impact of operational delays and uncertainties on the mine plan is investigated using a discrete-event simulation model for the three cases. The LOM for Case 1 was 51 years compared to Case 2 and Case 3 which was 54 years. Comparing Case 1 to Cases 2 and 3, there is 9.2% and 9.5% reductions in NPV respectively.

## References

- AkbarpourShirazi, M., Adibee, N., Osanloo, M., Rahmanpour, M. (2014), "An Approach to Locate an in Pit Crusher in Open Pit Mines", *International Journal of Engineering*, Vol. 27, No. 9, pp. 1475-1484.
- Carter, R. A. (2015), "Precise Planning is Paramount for IPCC Success", *Engineering and Mining Journal*, Vol. 216, No. 7, pp. 42.
- Dean, M., Knights, P., Kizil, M. S., & Nehring, M. (2015), "Selection and planning of fully mobile in-pit crusher and conveyor systems for deep open pit metalliferous applications", *Future Mining, AusIMM, The University of New South Wales, Australia*, pp. 146.
- E. Ben-Awuah. and N. Seyed Hosseini (2017), "An economic evaluation of a primary haulage system for a bauxite mine: load and haul versus in-pit crushing and conveying", in *MOL Report Eight 2017*, pp. 202-1 - 202-14.
- GEOVIA GEMS (2019), Strategic mine planning software. Ver. 6.8.3, Vancouver.
- GEOVIA Whittle (2019), Strategic mine planning software. Ver. 4.7.3, Vancouver.
- Hira, D. S. (2008), *System simulation*. S Chand & Co Ltd, 2<sup>nd</sup> edition, pp. 248.
- Hillier, F. S. and Lieberman, G. J. (2001), *Introduction to operation research*, 7<sup>th</sup> edition. McGraw-Hill. pp. 1140.
- Londoño, J. G., Knights, P. F., & Kizil, M. S. (2014), "Modelling of In-Pit Crusher Conveyor alternatives", *Mining Technology*, Vol. 122, No. 4, pp. 193-199.
- Minkah, E. A. (2014), "Determination of optimized Inchiniso pit, Ghana Bauxite Company Limited", *Unpublished MSc Thesis*, University of Mines and Technology, Tarkwa, 86 pp.

Mohammadi, M., Hashemi, S. and Moosakazemi, F. (2011), "Review of in-pit crushing and conveying (IPCC) system and its case study in Copper Industry". *Proceedings of the 11th IMHC Beltcon 2011*, Scatman N (ed), Pittsburgh, pp 67–86.

Nehring, M., Knights, P., Kizil, M., & Hay, E. (2018), "A comparison of strategic mine planning approaches for in-pit crushing and conveying, and truck/shovel systems", *International Journal of Mining Science and Technology*, Vol. 28, No. 2, pp. 205-214.

Osanloo, M., & Paricheh, M. (2019), "In-pit crushing and conveying technology in open-pit mining operations: A literature review and research agenda", *International Journal of Mining, Reclamation and Environment*, Vol. 34, No. 6, pp. 430-457.

Rockwell Automation. (2020), Arena Simulation Software, <https://www.arenasimulation.com/>

Sandvik Mining and Construction. (2007). "Bulk Materials Handling", <https://mining.test.ibp.sandvik.com/en/products/equipment/bulk-materials-handling>, Accessed: July 18, 2020.

Topf, A. (2017) "In-pit crushing and conveying systems changing the way ore is moved", Mining.com, <http://www.mining.com/in-pit-crushing-systems-changing-the-way-ore-is-moved/>, Accessed: July 20, 2020).

Upadhyay, S. P. and Askari-Nasab, H. (2018), "Simulation and optimization approach for uncertainty-based short-term planning in open-pit mines", *International Journal of Mining Science and Technology*, Vol, 28, No. 2, pp 153–166.

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