

Simulation Applications at PT Freeport Indonesia's DOZ / ESZ Block Cave Mine

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Abstract

A block cave mine is a complex system with numerous factors and interdependent sub-systems affecting its production capability. Although computer simulation is not a new production and optimization analysis technique in block cave mining, few simulation studies have considered detailed geotechnical and draw control considerations in addition to equipment capacity and availability constraints. This paper presents the application of these and other constraints in a simulation study of PT Freeport Indonesia (PTFI)'s Deep Ore Zone (DOZ) / Ertsberg Stockwork Zone (ESZ) block cave mine. It also illustrates the necessity of undertaking a simulation model to accurately estimate the mine's performance and highlight the potential pitfalls using deterministic models in evaluating the productive potential of block cave mines.

1 Introduction

PTFI's DOZ / ESZ block cave mine, located in the province of West Papua, Indonesia has been in production since year 2000. The mine initially started out as a 25,000 tonnes per day (tpd) operation, using mechanised block cave mining methods. Since then, various opportunities have been identified and studies were undertaken to increase ore production to 35,000 tpd; 50,000 tpd; and most recently, 80,000 tpd.

With the planned increases in production, additional load is placed on the existing ore handling systems and mine infrastructure. In order to validate the ore handling system's capability and to analyse the effect of geotechnical data in new mining areas, PTFI decided to include a simulation study as part of the overall 80,000 tpd DOZ / ESZ feasibility study. The simulation model provides a check of the design capacities and draw rate and identifies any potential bottlenecks in the production system.

2 Systems Thinking

Simulation is fundamentally an application of the "systems approach" or "systems thinking." Nearly all of the tools of operations management (with the exception of simulation) have been developed to address detailed complexity and provide little assistance to deal with dynamic complexity. Dynamic complexity arises when cause and effect are distant in time and location and when many consequences of actions are unintended. Systems thinking provides us with a language to understand, analyze, and communicate situations that involve dynamic complexity. A system is typically defined as a collection of parts that interact with each other to function as a whole. In order to model the DOZ / ESZ production system in detail, the following sub-systems were identified.

- Extraction Level
 - Drawpoints
 - Daily Draw Rate
 - Fragmentation / Geotechnical Data
 - LHD Operations

- Secondary Breakage Equipment
 - Medium and Low Reach Drill Rigs
 - Non-Explosive Boulder Breaking Drills
 - Stationary Rock Breakers, Mounted on each Grizzly
- Orepasses
- Chute Feeders
- Haulage Level
 - Haul Trucks
 - Conveyors
- Primary Crushing Systems
- Conveying to Surface

Each of these sub-systems, or elements, is interdependent. In other words, any delay or interference (e.g., maintenance, out-of-ore condition) of a single element will have an effect on another element, unless a sufficient buffer exists between the elements. Each element has a mechanical availability, determined by both planned and unplanned maintenance; an element's average throughput through the system is a function of its availability, utilization, and capacity.

3 Objective

The simulation model simulates and evaluates the ore handling system of the proposed 80,000 tpd DOZ / ESZ block caving operation. PTFI decided to analyze year 2006 (for model validation), and years 2010, 2012, and 2014 (since the production plan is to produce the planned maximum tonnage in these years).

The model was constructed using the Arena simulation software and was utilized for evaluating changes in ore handling productivity. Such changes may be the result of ore handling and process equipment capacities, the number of available drawpoints, ore fragmentation, and mine operating procedures.

Preparation of the ore handling simulation was accomplished by completing the following actions.

- Acquiring an understanding of the production, secondary breaking, and material handling arrangements proposed for the mine.
- Conceptualizing and developing accurate graphic and mathematical models of the ore handling system.
- Preparing Arena simulation code necessary to depict the model graphics and mathematics in computer-executable code.
- Defining input and output requirements of the model.
- Verifying that the Arena code accurately portrays the model.
- Validating that the model accurately represents the proposed operations.

3.1 System Description

Figure 1 illustrates the DOZ, DOZ West, and ESZ mining areas. Included in this figure are colour designations between Skarn and Diorite rock types. This distinction was used as a basis for identifying differences in rock fragmentation characteristics. The layout is an offset herringbone arrangement of the Extraction Level for DOZ / ESZ and contains 1,324 drawpoints and 55 orepasses, including 39 panels.

The planned layout provides a maximum of 25 drawpoints in a panel drift section being served by one LHD. The model includes special procedures for loading wet muck with a remote LHD. PTFI identified drawpoints that are currently classified as "wet" and are expected to contain wet muck. The wet drawpoint classifications change dynamically for each year that the model is run. Wet drawpoints, as well as the adjacent two drawpoints, are mucked using remote LHDs. Remote LHDs are assumed to have the same operating parameters as a manual LHD, except loading duration is assumed to be twice that of manual LHD

loading, significantly reducing its production potential. Each orepass is equipped with a grizzly to prevent entry of oversize rocks. Stationary rock breakers are installed at each grizzly to reduce oversize.

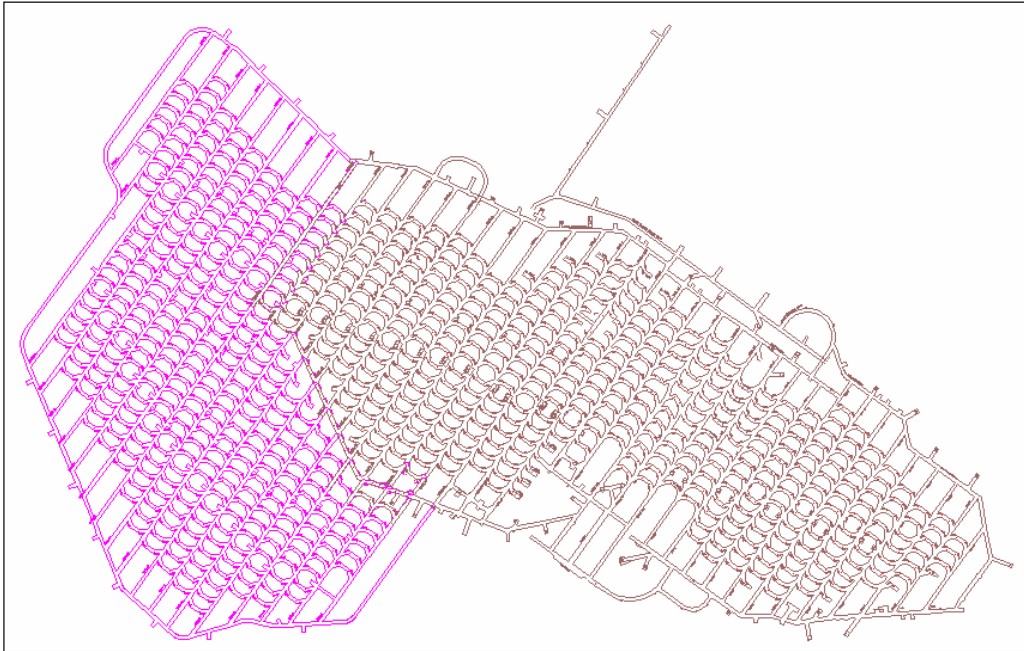


Figure 1 Mining Footprint

Drawpoint availability is a key consideration in accurately modelling a block cave mine operation. In this regard, it is noted that the Call & Nicholas, Inc. (CNI) memorandum titled, *DOZ – ESZ 80k expansion – Revised Fragmentation by Year*, dated September 2006, was utilized to develop drawpoint hang-up criteria.

To establish drawpoint availability, the three most common causes of drawpoint downtime are typically defined as high, medium, and low hang-ups; maintenance; and drawpoint oversize. Such hang-ups are typically relieved by a conventional drill and charging apparatus (Commando). Drawpoint oversize is defined as rocks in the muck pile too large for the LHD loading in the drawpoint to handle. Generally, this oversize ranges from 2 m³ to 10 m³. It is assumed that crews will be allowed to enter unoccupied drawpoints in a drawpoint panel where an LHD is loading, in order to drill and blast oversize rocks using Commandos.

Low hang-ups and drawpoint oversize will require drilling and blasting in the drawpoint before it becomes available for production. These conditions are addressed in the simulation study by probability distributions, which are defined for the tonnage drawn from a drawpoint before it hangs up, and are directly used as input to the simulation model. CNI updated the fragmentation data and hang-up frequency by rock type (Table 1). The drawpoint oversize was calculated from the CNI fragmentation curves.

Table 1 Hang-Up Frequency by Rock Type by Year (Tonnes between Events)

Rock Type	Year	High Hang-Ups *	Medium Hang-Ups	Low Hang-Ups	Drawpoint Oversize
Skarn	2006	149,700	1,000	1,514	162
Skarn	2010	165,400	1,100	1,499	198
Skarn	2012	169,100	1,200	1,499	247
Skarn	2014	172,500	1,300	1,496	267
Diorites	2006	N/A	N/A	N/A	N/A
Diorites	2010	59,100	700	775	65
Diorites	2012	115,900	1,000	897	65
Diorites	2014	155,300	1,200	996	70

* High hang-ups were not considered in the simulation model due to low frequency.

Oversize can be drilled, charged, and blasted within the operating shift. However, low and medium hang-ups will be drilled when the LHD surrenders the panel and will only be blasted between shifts. The model allows for three conventional blasting periods per day, occurring during shift changes.

Further secondary breaking is performed on the grizzly by stationary rock breakers. Each grizzly is assumed to have a finite capacity of oversize rocks, and if the maximum capacity is reached, the simulation model will prevent an LHD from dumping.

Secondary blasting and breaking size distribution analysis provides a breakdown of the successive secondary drilling and blasting of low hang-ups, blasting / breaking drawpoint oversize, and rock breaking required to move the daily production from the drawpoints to the truck haulage system. Using the CNI fragmentation curves that PTFI provided, size distribution curves were prepared for each mining year in the Skarns and Diorites. The table for Skarns in 2006 is presented in Table 2. Figure 2 presents the results of the secondary blasting and breaking size distribution estimates graphically for the Skarns in years 2006. These curves depict the stepping down in size of the daily production through each of the sizing procedures.

Assumptions were made to distribute treated material after each sizing process (Table 2). The average aspect ratio of a typical block was provided by CNI at 2.46 for the Skarn and 2.76 for the Diorite. For the purposes of breaking blocks on the grizzly, it was assumed that 25% of the material dumped on the grizzly would pass due to effective dumping by the LHD operator, since the criteria for passing on the grizzly was based on the long-side of the block rather than the short-side. This is a factor agreed to by PTFI prior to completing this analysis.

Table 2 2006 Average Skarn Sizing Distribution

Aspect Ratio =		2.46							
Particle distributions averaged over entire column height.									
Volume	m ³	0.0009	0.165	1.000	2.000	10.000	45.500	165.000	316.000
Short Side	m	0.071	0.406	0.741	0.933	1.596	2.645	4.063	5.046
Longest Side	m	0.175	1.000	1.822	2.296	3.926	6.506	9.995	12.412
Avg. % Passing		42.5	66.3	78.8	83.2	92.8	98.5	100.0	100.0
		Criteria							
Summary of Table		(Side-m)	Volume - m³	% Passing					
Passing Crusher		0.203	0.001	42.47					
Passing Grizzly		1.000	0.165	66.31					
Passing Oversize		2.296	2.000	83.16					
Passing Low Hangup		3.926	10.000	92.81					
Passing Medium Hangup		6.506	45.500	98.49					
Passing High Hangup		9.995	165.000	100.00					

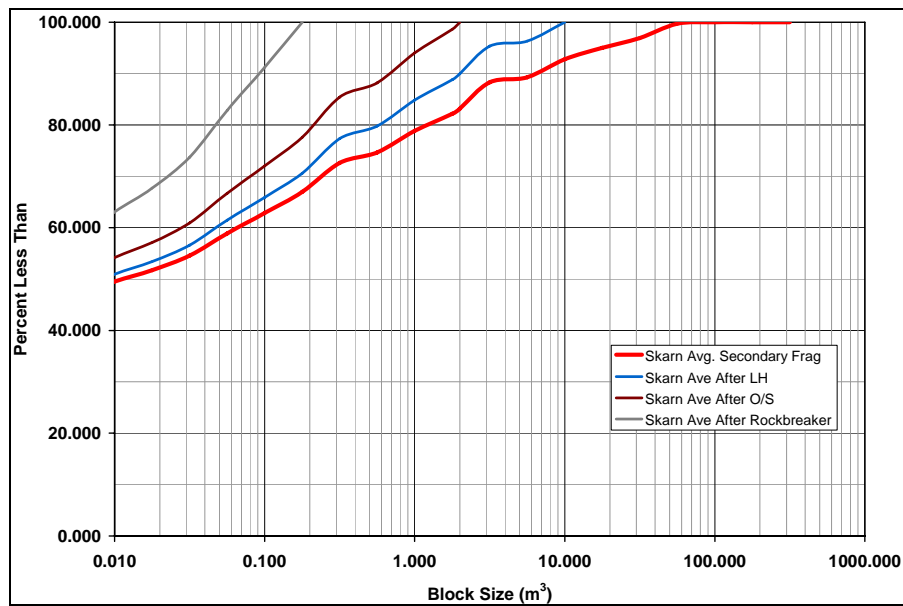


Figure 2 2006 Skarn Secondary Fragmentation Estimates – Average

Orepasses are connected to the Haulage Level from the Extraction Level. Trucks are loaded by chutes on the Haulage Level (Figure 3) and are then dispatched from the crusher dumps to orepass locations along the DOZ / ESZ Haulage Drifts. Priority is given to orepasses with the highest tonnage in order to minimize LHD dumping delays on the Extraction Level. Trucks are only dispatched to orepasses that contain at least a full truckload; therefore, trucks will always be loaded to capacity.

A second gyratory crusher was incorporated into the ore flow design to provide additional crushing capacity and flexibility in the overall material handling system. The additional overall crushing capacity mitigates the coarser fragmentation expected from the Diorites later in the mine life. After Crusher No. 2 is commissioned in 2007, when one crusher or the other is unavailable or underutilized, provisions have been made to direct haulage trucks to the other crusher through a haulage loop connection drift driven between Crusher No. 1 and Crusher No. 2. From the haulage truck layout, it is assumed that three dump positions are available at Crusher No. 1 and two at Crusher No. 2. As soon as a truck is finished dumping, it moves to the back of the dump, allowing following trucks access to the dumps.

Ore is dumped directly from haulage trucks into a 500-tonne capacity bin above Crusher Nos. 1 and 2, which are both assumed to have a maximum throughput rating of approximately 2,500 tonnes per hour.

Crusher, conveyor, and feeder availability are incorporated into the simulation model, and operating parameters are altered by use of the input sheets. The conveyor availabilities were based on actual data collected over the past five years, which were averaged for the model's input.

Crushed ore is loaded onto a set of transfer conveyors, which conveys it to surface stockpiles. The ore flow system is illustrated schematically in Figure 4.

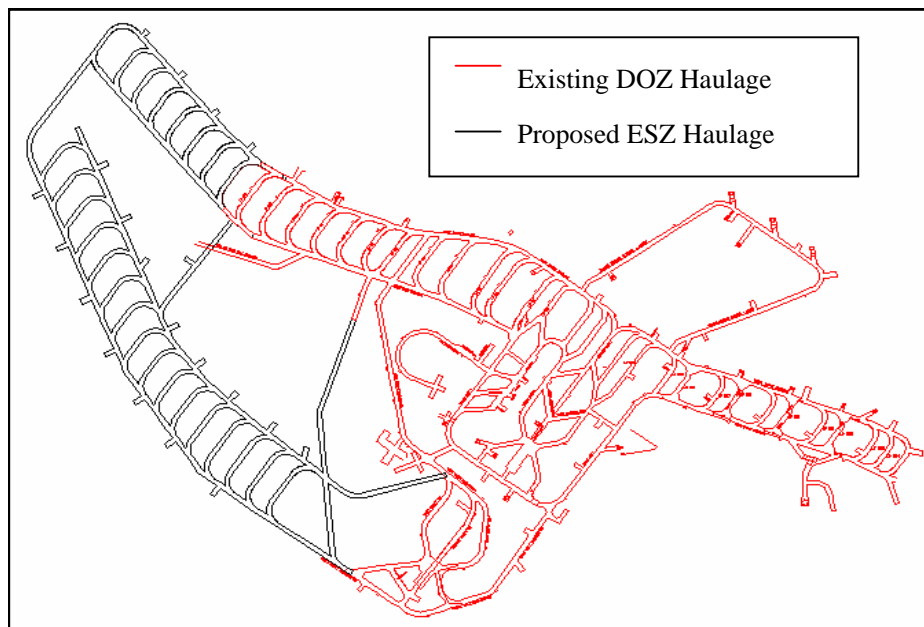


Figure 3 Haulage Level Layout

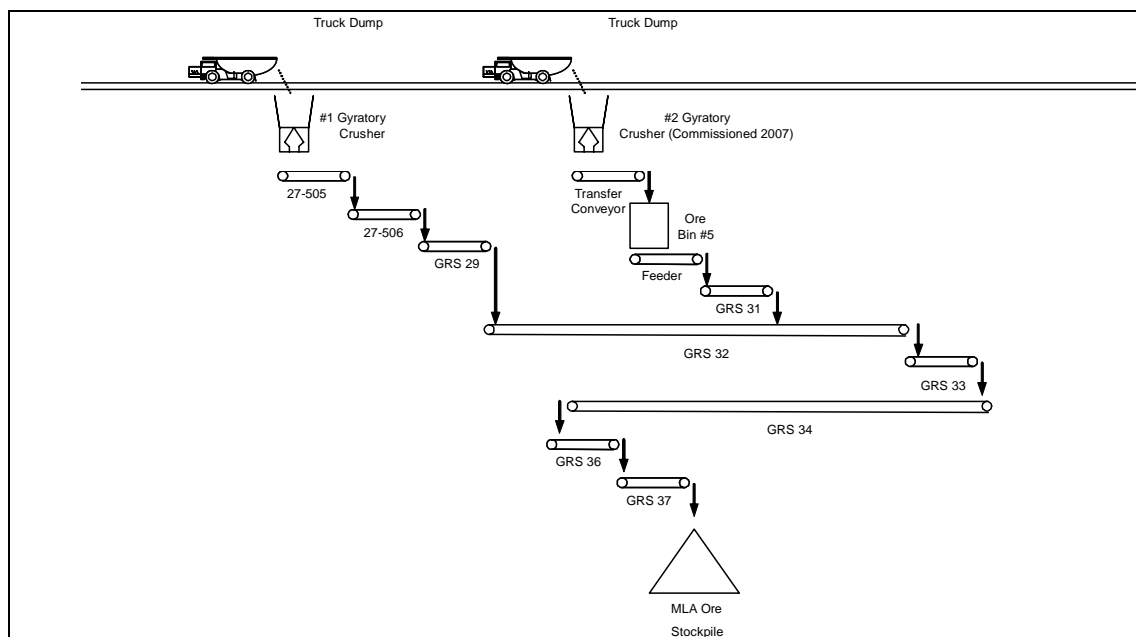


Figure 4 Ore Flow System Diagram

The simulation model includes a two-dimensional colour animation of all drawpoint drifts (Figure 5). The animation was used in the model verification process and includes the following features.

- LHD movement along panel drifts, loading, dumping
- Dynamic drawpoint status display (e.g., Available [Dry or Wet], Low Hang-Up Incurred, Medium Hang-Up Incurred, Draw Limit Reached, Brow Maintenance, Roadway Maintenance)
- Drill rig operating in drawpoint
- Orepass levels

- Truck haulage, loading, dumping
- Material handling system schematic, including status display (e.g., Operating, Scheduled Maintenance, Unscheduled Maintenance [unplanned failures])

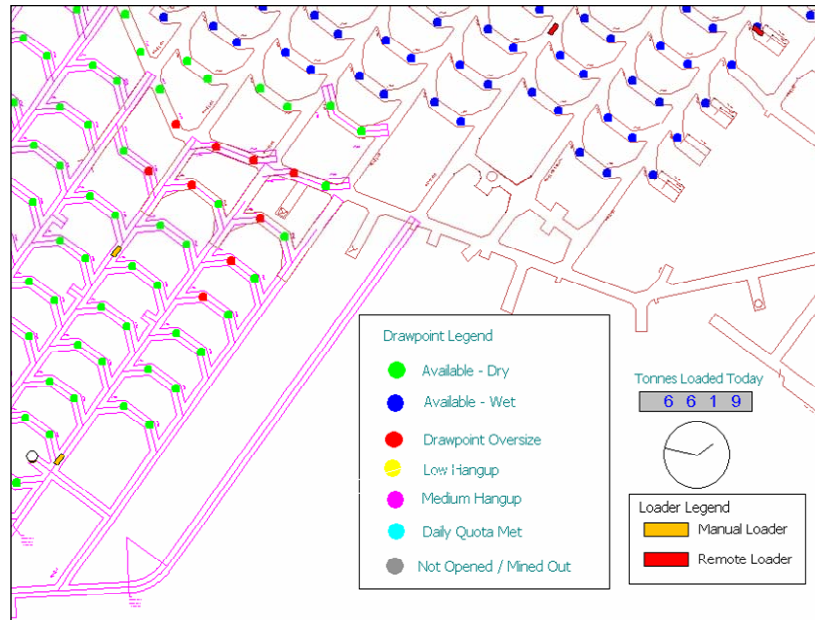


Figure 5 Arena Animation Example

3.2 Simulation Results

Table 3 summarizes the total (including spare units) primary production units required for years 2006, 2010, 2012, and 2014. Table 4 shows the average number of drawpoints in each status at the end of shift.

Table 3 Total Primary Production Summary

Description	Unit	2006	2010	2012	2014
Required – Manual Loader	tpd	30,839	19,571	41,829	58,580
Sim Result – Average – Manual Loader	tpd	30,845	19,569	41,775	58,459
Required – Remote Loader	tpd	11,932	57,329	35,669	21,073
Sim Result – Average – Remote Loader	tpd	11,925	56,912	35,621	20,196
Total Required	tpd	42,771	76,900	77,498	79,654
Simulation Result	tpd	42,767	76,481	77,390	78,640
Production Difference	t	-4	-419	-109	-1,014
1. LHDs					
Number of Manual LHDs	ea	10	6	11	18
Number of Remote LHDs	ea	6	17	11	7
Total Number of LHDs	ea	16	23	22	25
Extraction Level LHD Utilization	%	65	81	84	87
Average Tonnes per LHD per day		2,673	3,325	3,518	3,146
2. Trucks					

Description	Unit	2006	2010	2012	2014
Tonnes per Truck per Day	t	3,888	3,824	3,869	3,932
Number of Trucks	ea	11	20	20	20
Truck Utilization	%	90.2	95.7	93.5	96.9
3. Orepass Stations					
Average Rock Breaker Utilization	%	25.7	35.9	42.6	57.4
Production Loss Due to Blocked Grizzly	%	0.7	1.7	5.4	11.3
4. Secondary Breaking and Drilling					
Number of Medium Hang-Up Drills	ea	2	2	2	2
Number of Commandos	ea	5	10	14	18
Medium Hang-Up Drill Utilization	%	39.0	74.5	69.9	61.7
Commando Drill Utilization	%	62.6	70.5	76.6	63.8
5. Crushing					
Crusher No. 1 Utilization	%	52.9	58.9	47.7	32.5
Crusher No. 2 Utilization	%	0.0	37.1	50.1	67.5

Table 4 End-of-Shift Drawpoint Status Summary

Description	Unit	Year			
		2006	2010	2012	2014
Available – Dry	ea	161	145	276	296
Available – Wet	ea	52	211	151	83
Drawpoint Oversize	ea	15	31	41	14
Low Hang-Up	ea	5	15	14	14
Medium Hang-up	ea	7	35	20	21
Draw Limit	ea	117	129	124	98

4 Pitfalls of Deterministic Models

It can be argued that the results in this paper could have been calculated using deterministic methods instead of a simulation model. The most common deterministic (static) method employed when calculating equipment requirements in mining is the spreadsheet. The limitation of the spreadsheet is not so much the inclusion of the element of variance (based on statistical distributions) to model process times etc., as this can be incorporated with commercial software packages such as @RISK; rather, the limitation is the element of time that cannot be incorporated sufficiently into spreadsheets. This leads to invalid assumptions when systems are analyzed using deterministic models. To illustrate this, a typical LHD cycle is analysed below.

An efficient and productive LHD is probably the most important factor for a block cave mine to achieve its target tonnage. Table 5 describes a typical LHD operating cycle. The “Deterministic Model” column describes whether the component of the cycle can be accurately quantified with a deterministic (spreadsheet) model, and the “Simulation Model” column shows whether it can be quantified using a simulation model.

Table 5 LHD Cycle quantification possibilities

Description	Deterministic Model	Simulation Model	Variance in Duration
Load Time	Yes	Yes	Yes
Travel Full	Yes	Yes	Yes
Wait to Dump – Congestion	No	Yes	Yes
Wait to Dump – Grizzly Blocked	No	Yes	Yes
Wait to Dump – Orepass Full / Hung-up	No	Yes	Yes
Dump Time	Yes	Yes	Yes
Travel Empty	Yes	Yes	Yes
Wait for Ore – No Drawpoints Available for Loading	No	Yes	Yes
Relocation travel time	No	Yes	Yes
Maintenance / Failure Downtime	Yes	Yes	Yes
Travel time, Shift Breaks, Pre-Shift Inspection	Yes	Yes	Yes

Simulation results from the DOZ / ESZ study reveal the following typical LHD cycle (Figure 6).

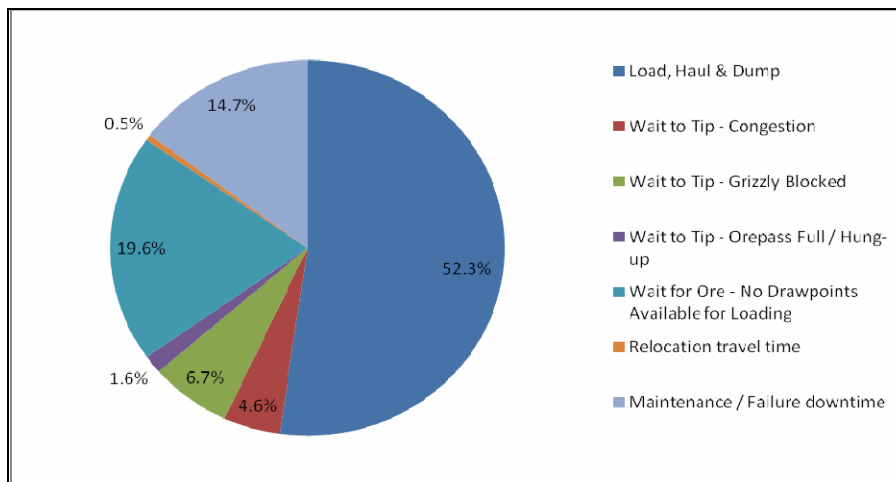


Figure 6 Typical LHD Cycle Summary

Derived from Table 5 and Figure 6, the stochastic components of a typical LHD cycle is a total of 33.0% (4.6% + 6.7% + 1.6% + 19.6% + 0.5%). This equates to over 2 hours of a LHD’s cycle per shift with 6.5 hours of effective operating time. In other words, it can be concluded that in this case, there is a 33% chance of over / under estimating the LHD fleet if a static (deterministic) calculation is used. The same reasoning can be followed for all mobile equipment in the mine’s fleet.

5 Study Conclusions

The results presented herein represent the optimized fleet of equipment for each year of production that was assessed. The criterion to be met was the planned sustainable daily production rate.

The results for years 2010, 2012, and 2014 indicate that production could fall short by 0.5%, 0.1%, and 1.3%, respectively. The reasons for the shortfall are mainly due to noncompliant drawing of panels.

The noncompliance could be caused by various factors, including, but not limited to, the following.

- Excessive number of active drawpoints in the panel (too many for an LHD to load). In a few instances, there are up to 19 drawpoints in a panel drift, all being classified as “wet,” which cannot be productively serviced by a single LHD.
- Cumulative draw tonnage of panel is too high for an LHD capability. High frequency of drawpoint oversize (especially Diorite drawpoints) reducing drawpoint availability.
- Long tram distances to orepass location.
- High percentage of blockage at each grizzly (year 2014). The coarser material expected increases time necessary to break rocks at the grizzly and decreases LHD efficiency.

The objective of this model is not to optimize the production schedule; rather, to identify panels that are predicted to fall short of the planned draw rate. Plans could be implemented to counteract panel noncompliance, including a revised draw rate schedule, drawpoint development schedule, and additional rock breaking (grizzly) capacity or other more drastic measures (e.g., layout changes).

The 2006 PC-BC plan was used to validate the model, and the results compared to actual site data. The DOZ / ESZ 80,000 tpd team confirmed that results were on par with current equipment fleets and data measured on site. The simulation result for the production quantity was within 0.01% of the actual data.

In 2010, the fragmentation and resulting frequency of hang-ups and drawpoint oversize worsens as the percentage of production in Diorite increases to 45%. This is also apparent in the percentage of LHD production time lost to blockage at each grizzly, increasing from 0.7% to 1.7%.

In 2012, mining in Diorite increases to 74.5%. This increases the frequency of hang-ups and drawpoint oversize, such that the number of drill rigs required to treat drawpoint oversize increases from 10 units to 14 units. The percentage of LHD production time lost to blockage at each grizzly increases from 1.7% to 5.4%.

In 2014, mining in Diorite increases to 90%. Again, this increases the frequency of hang-ups and drawpoint oversize, such that the number of drill rigs required to treat drawpoint oversize increase from 14 units to 18 units. Due to the large volume of coarser Diorite, the percentage of LHD production time lost to blockage at each grizzly increases significantly from 5.4% to 11.3%. Associated with this is very high rock breaker utilization in 2014. The model shows average rock breaker utilization at the orepasses in ESZ Panels 01, 02, and 03 of 99% (of effective operating time).

The crushers and ore handling systems indicate adequate capacity to handle target production in all of the years under study in this paper. The maximum utilization of Crusher No. 1 is 59% (2010), and Crusher No. 2 is 65% (2014).

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