Application of dynamic simulation for the Gahcho Kué project

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Application of dynamic simulation conducted for the Gahcho Kué Project is discussed. A detailed dynamic simulation model was constructed from the rock face to the sorthouse product to assist in the detail engineering of the project. Mining in different pits was modelled including simulations of the ROM ore supply and rehandling systems to quantify the ore delivery to the primary crusher. The plant model was broken down to discrete capital equipment items and various feed types and mass balances were tested to ensure that the production target is met. To assist the project team with optimal equipment selection, different crushers were simulated. Overall, the dynamic simulation helped minimize the project risks and improve confidence.

INTRODUCTION

Gahcho Kué diamond mine is located at Kennady Lake, 280 km northeast of Yellowknife and has a mine life of approximately eleven years. It treats 3.0 Mt/a of ROM ore and is scheduled to produce on average 4.5 million carats annually over its mine life. Open pit mining on the three kimberlitic pipes takes place using truck and shovel.

When the mine was still in the engineering phase, it was important to evaluate various risks associated with selection of equipment, integration of the mining and processing operations and verification of design capacity, to name a few. Dynamic simulation was then chosen as a tool to integrate different mine components and audit the design so that the project engineers can test 'what-if' scenarios and confirm design decisions.

Dynamic simulation has been applied for various industries including mining since 1961, when the first ever specialist simulation software programme known as GPSS (still being used) was released by IBM (Ståhl, Ingolf 2001 and Sturgul, 1997a). Since then the range of software tools has expanded dramatically, with 55 packages included in the latest simulation software survey conducted biannually by the Institute for Operations Research and Management Science (Anon., 2015). It is, however, worth noting that many software vendors split the functionality and supply application-specific simulation programmes (such as assembly or business process re-engineering). General information on the most popular simulation software used in the mining and related industries can be found in a paper by Sturgul, (1997b).

Simulation has been traditionally used for manufacturing (perceived to be the root industry of simulation), services, transport, logistics and distribution, telecommunications and other typical 'discrete' industries with mining being relatively small area of dynamic simulation application. For example, in the OR/MS simulation software survey [Anon., 2015] only seven vendors quoted mining as an application area. At the same time mining presents a significant potential for the application of dynamic simulation due to the very nature of its business, as shown by Gentry and O'Neil (1984) to be:

- Capital-Intensive
- Long Life Cycle (Up To 30 Years)
- High risk.

Simulation is a powerful tool to analyse operations over extended time horizons which can reduce mining risks, thus generating rewards exceeding those, for example, in the manufacturing or service industries, where costs and inherent risks are generally lower.

Although mining in the past used to be slow in recognition of simulation, lately there has been a visible growth of simulation studies done for the mining clients. A good indicator is Application of Computers in Mining (APCOM), an annual conference where simulation presentations have gained a substantial footprint. In 1996 the first (and to the authors' knowledge the only) specialist internet symposium on mine simulation was jointly organized by the departments of Mining Engineering at the University of Idaho (USA) and the National Technical University of Athens (Greece). A great deal of simulation software testing work has been done by a group of experts (Runciman, Vagenas, and Baiden, 1999) at the Laurentian University Mining Automation Laboratory (LUMAL) in Sudbury, Ontario, Canada, who tested several different simulation software tools for mining applications.

While the absolute majority of simulation software can handle discrete events, there are some which are capable of modelling both discrete and continuous processes, the latter being indispensable for processes in liquid (or quasi-liquid) form such as the ones applied in the diamond plants. Witness™ is an example of such simulation software which has both discrete and continuous modelling capabilities, and this software was used for the Gahcho Kué mine simulations. Discrete and continuous simulations of the bulk conveying systems were analysed in detail by Lebedev, (1998, 2008). Examples of other applications of Witness™ simulation software for the mines are given by Lebedev and Staples (1998, 2001).

It is important to note that the work described in this paper was completed in the feasibility study and has not been yet benchmarked against the real mine performance.

The model was built with the Witness™ simulation software for general (as opposed to specialist) applications yet offering a full range of functions required for this specific operating environment. Sufficient information on the software, product brochures, case studies and white papers can be found at the developer's website at www.lanner.com.

All simulation experiments were executed to cover a full year of real-time operation (365 calendar days or 8760 hours, equivalent to 525 600 minutes). The simulation time unit was set to 1.0 minute.

To authors' knowledge, this is the first published simulation work covering the entire process from rock face to glove box. For better visibility, the simulation model animation screenshot was split into the three figures attached at the end of this paper. Figure 1 shows the mining component and primary crushing. Secondary crushing, milling and DMS appear in Figure 2, while the recovery plant is shown in Figure 3.

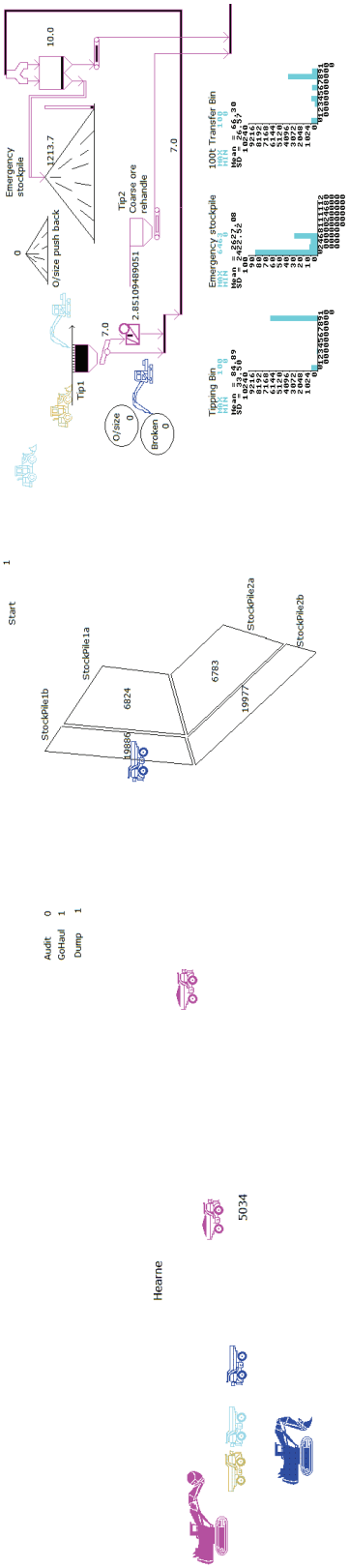


Figure 1. Animation screenshot of mining and primary crushing

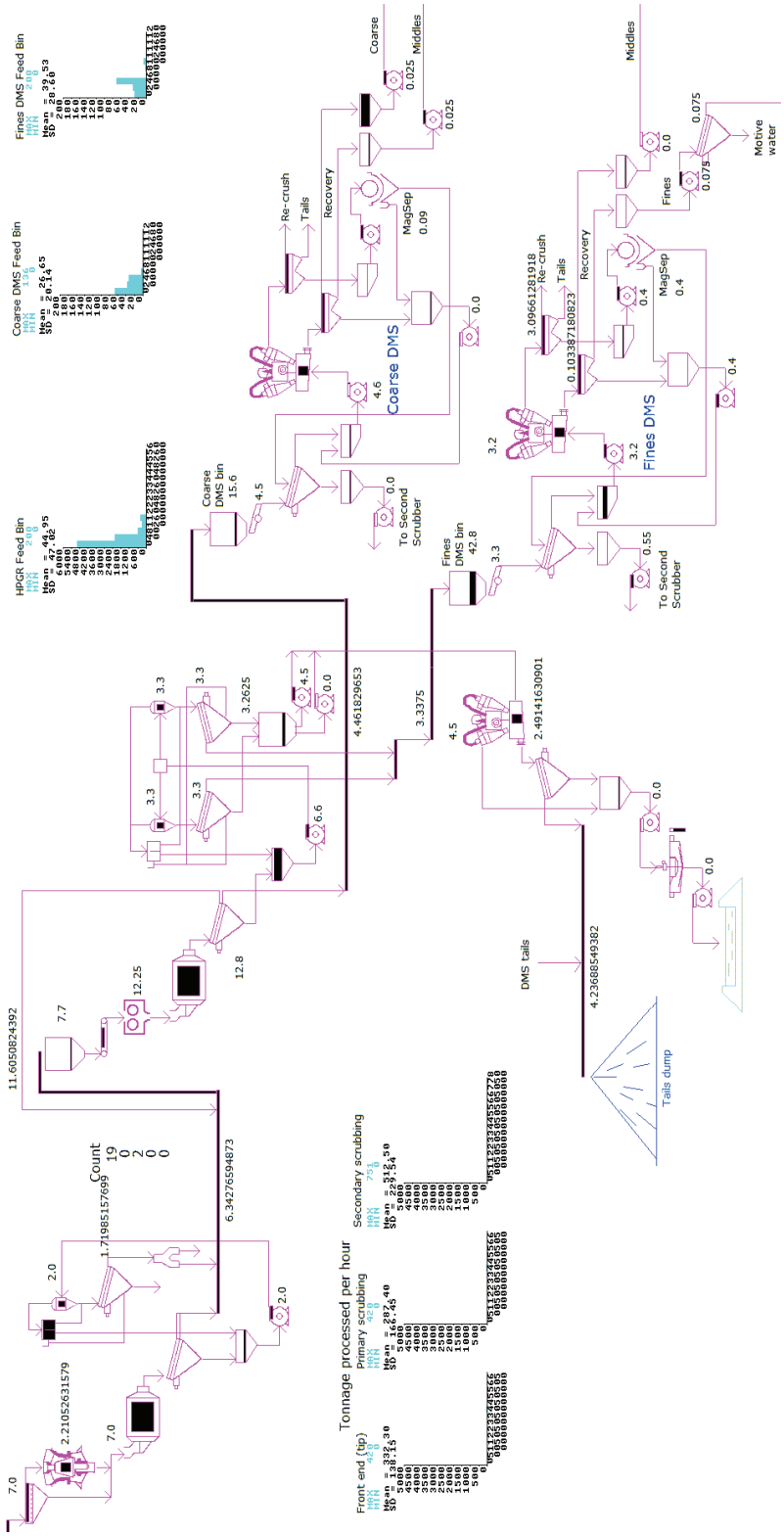


Figure 2. Animation screenshot of secondary crushing, milling and DMS

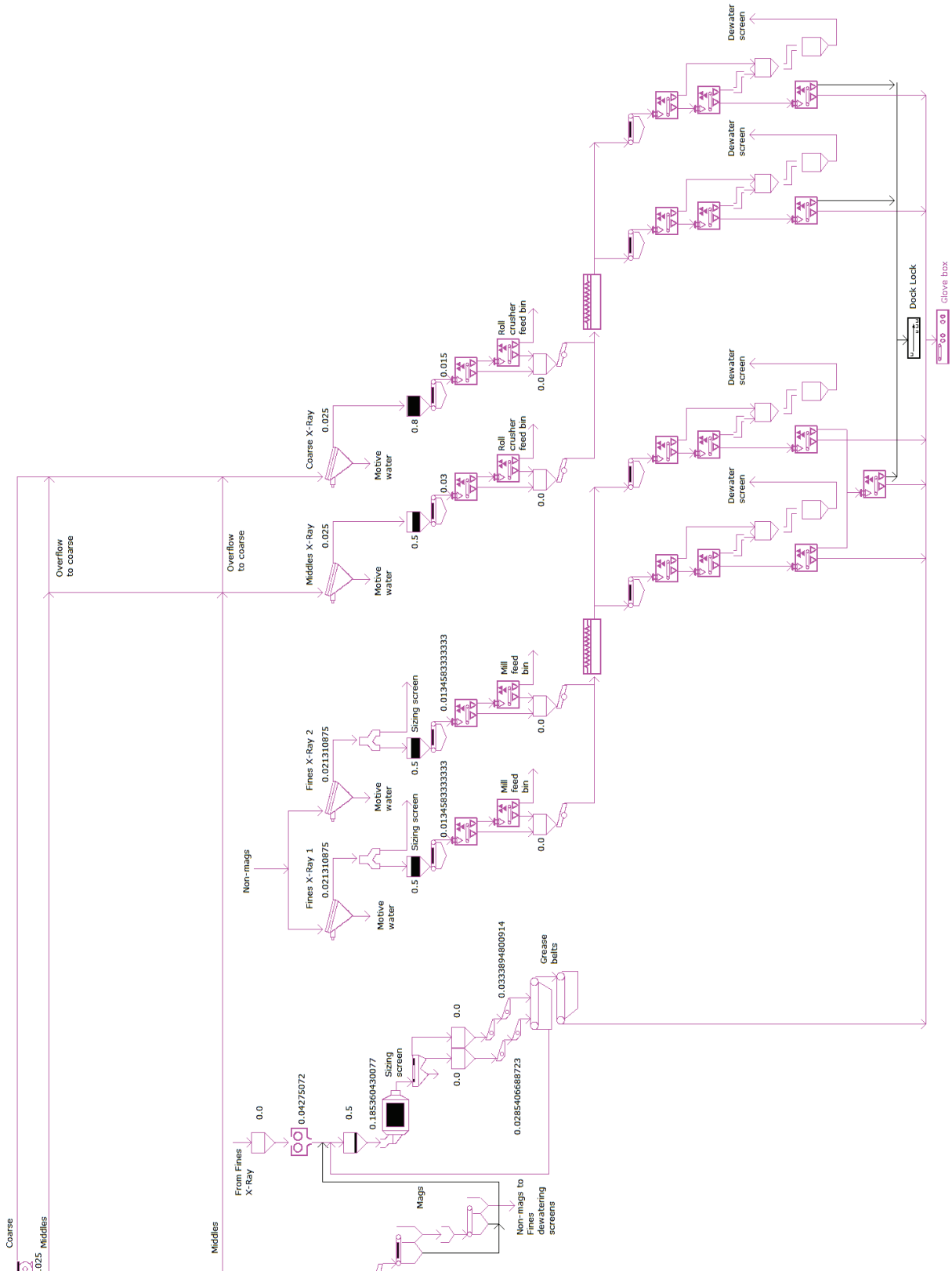


Figure 3. Animation screenshot of Recovery Plant

ORE MINING (LOADING AND HAULING) SIMULATION

The mine schedule was based on ore mining in batches once in several days triggered by the inventory of ore on ROM stockpiles, when trucks deliver the quantity of ore consumed and thus replenish ROM stockpiles in a short time-span. In reality, once ore mining operations are started, the ROM stockpile will be replenished according to the mine plan and to ensure that the ROM stockpile is never below levels that will impact feed to the processing facility. A Komatsu WA1200 loader was used for in pit ore mining operations whilst a Komatsu WA900 loader was used for ore feeding at the Primary ROM stockpile.

The mining simulation focused on ore supply to the stockpile only and not waste mined. It therefore assumed that the waste to be mined was achieved in accordance with the mine plan and that the ore was released as required to ensure the batching of ore from the pit to the ROM stockpile.

On the ROM pad in the vicinity of the primary crusher, ROM stockpiles are established, which can be virtually divided into front and rear portions as shown in Figure 4.

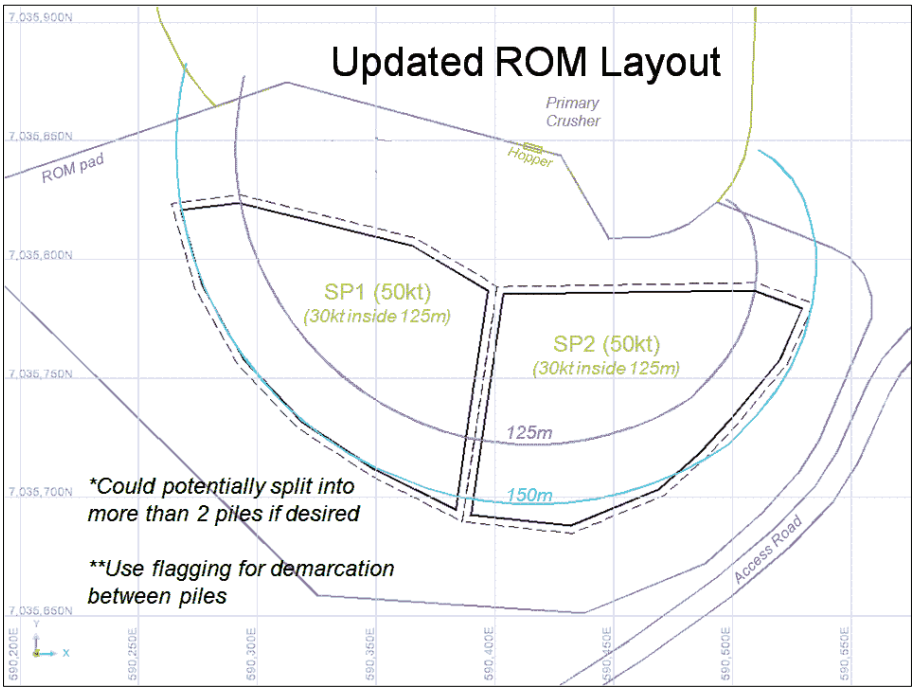


Figure 4. ROM pad layout.

The front portion was demarcated by a 125 m front end loader (FEL) operating radius, which was permanently employed on the ROM pad to feed the main treatment plant (MTP). As it appears in the ROM pad layout, the front portion contains approximately 60 000 t (or 60%) of total stock, while the rear portion contains 40 000 t (40% of total inventory). At time zero, ROM stockpiles were assumed full to avail feed to the plant.

Once the inventory of the front ROM stockpile portion drops to 20 000 t, trucks are mobilized in the pit to start hauling ore. For modelling purposes ore haulage was restricted to day shift only while the plant operation (and, consequently, the FEL) was continuous, therefore trucks did not necessarily start ore loading and hauling immediately as the ore inventory in the front ROM stockpile portion dropped to 40 000 t. It was a combination of ore inventory in the front of 40 000 t (or lower) and dayshift commencement, whatever event happened last, that event then triggered ore loading and hauling.

The procedure described above was replicated for a month in cycles, and typically a cycle involved 40–50 kt ROM reclamation and replenishment with mining trucks from the pit(s). This cycle takes 4 to 5 days and is referred to as 'short' mining cycle.

Once in a month, in order to audit ROM ore balance, the mine entered into a 'long' cycle, which differs from a short cycle not only by its period (30 days instead of 4 to 5), but also by the degree of ROM stockpile reclamation:

1. The front portion of the ROM stockpile is reclaimed completely
2. Once the front portion has been cleared, a second FEL was mobilised to assist, both machines start reclaiming the rear ROM stockpile portion
3. The ore inventory in the rear portion of ROM stockpiles drops to 10 000 t (*i.e.* in total approximately 90 000 t of ROM ore should be reclaimed).

The trucks then start running (restricted to day shift with 10 hours net effective hauling time), and first the front portion of the ROM stockpiles is replenished (approximately 60 000 t).

By the time the front ROM stockpile portion has been replenished, typically the FEL's complete reclaiming the rear portion of the ROM stockpiles. Once this happens, the second FEL is de-mobilised and the prime FEL reverts to reclaiming the front portion of the ROM stockpile, entering into short cycles until the next month's audit. This procedure was applied in the simulation study, in the current reality either a larger loader or a combination of the standard loader and a small truck is mobilised over a tramming distance exceeding 125 m

Depending on the number of trucks allocated to ROM ore hauling, time to replenish the ROM stockpiles varies. A larger number of trucks normally results in faster replenishment, while a smaller number of trucks requires a longer time to refill the stockpiles. The number of trucks should be such as to minimise queuing at the shovel, on one hand, and to have sufficient hauling capacity to deliver ROM ore from the pit(s) at a faster effective rate than the FEL(s) can reclaim it.

Operating parameters of the ore front end loaders are specified in Table I.

Table I. In-pit ore loader parameters.

Description	**Unit**	**Value**
Bucket capacity	m^3	20
Bucket fill factor (heaped)	%	85%
Bucket capacity (heaped)	m^3	17.00
Material *in situ* bank density	t/ m^3	2.47
Material *in situ* to loading unit bucket swell		1.3
Maximum volume bucket payload	t	32.3
Actual bucket payload	t	32.3
Actual bucket payload	m^3	17.0
Number of passes to fill truck	-	6 or 7
Pass cycle time	min	0.8
Average truck loading time	min	**5.22**

Prime hauler characteristics are listed in Table II.

Table II. Truck parameters.

Truck payload	Unit	Truck
Min.	t	177.3
Mode	t	221.7
Max.	t	232.8
Average	t	210.6
Spotting at loader	min	0.7
Spotting at dump	min	0.5
Dumping onto stockpile	min	0.7

With the type of the selected loader and depending on the payload sampled for each of the trucks separately from a triangular distribution with parameters indicated in Table II, six or seven loader passes are required. Depending on the number of passes, the truck loading time will vary. The sequence of events at the loader was therefore as follows:

1. On arrival of a truck to the loading spot, a delay associated with spotting time was sampled from a logarithmic normal distribution with a mean value as per Table II
2. The truck payload was then sampled from a triangular distribution
3. The payload was then divided by the loader average bucket payload to determine the number of passes (six for smaller truck payloads and seven for the larger ones)
4. Truck loading duration was then determined by adding up six or seven cycle times, each sampled from a logarithmic normal distribution with a mean value of 48 second each (the pass cycle time as per Table I)
5. Truck obtained its payload
6. Once the full payload has been obtained, a truck was released from the loading spot.

A similar procedure was applied to truck tipping.

To accommodate variable ore grade, trucks were diverted to one or another ROM stockpile (as shown in Figure 1)

Mining schedules at the time of the study appear in Table III.

Table III. Mining schedule for selected years, million ROM tons per annum.

Operation	UoM	Year 1	Year 2	Year 3	Year 4
Pit 1 ore	M t	2.29	1.66	0	0
Pit 1 waste	M t	19.43	10.56	0	0
Pit 2 ore	M t	0.66	1.33	3.00	3.00
Pit 2 waste	M t	16.31	10.72	19.01	9.80
Pit 3 ore	M t	0	0	0	0
Pit 3 waste	M t	0	0	12.6	17.4
Total ore	**M t**	**2.95**	**2.99**	**3.00**	**3.00**
Total waste	**M t**	**35.74**	**21.28**	**31.66**	**27.21**

Hauling distances and speeds on the laden and return empty hauls were first defined in a specialist load-and-haul scheduler Talpac and subsequently applied in the discussed dynamic simulation.

Key simulation results obtained for the four selected years in the updated mining schedule are summarised in Table IV. Where two loaders are indicated this implies one machine per pit (years 1 and 2), while in years 3 and 4 only one loader was required in Pit 2.

Table IV. Key simulation results for updated mining schedule.

ROM ore loading and hauling	Unit	Year 1	Year 2	Year 3	Year 4
Loaders deployed in pit(s)	-	2	2	1	1
Loader @ Pit 1 utilization	%	10.1	7.8	0.0	0.0
Loader @ Pit 2 utilization	%	4.5	6.8	14.5	14.6
Trucks employed for ore haulage	-	4/3	5/4	4	5
Rom ore delivered from pit(s)	t/a	3 061 408	3 072 384	3 059 040	3 066 112
Truck fleet utilization ore haulage	%	17.9	17.6	18.8	18.1
Average ore haulage time per truck	h/a	1 570	1 544	1 650	1 585
Average distance travelled per truck	km	11 939	10 170	21 006	20 225

In all simulated years the trucks delivered the required quantity of ROM ore to the stockpiles.

The model showed higher ROM ore tonnage delivery than the updated mining schedule calls for. This is ascribed to the fact that the model attempted to test the maximum system capability, and the truck haulage was driven by the plant demand rather than by the schedule itself. It was important to confirm that even with advance of the pits the installed capacity could achieve the target and perhaps exceed it affording a 'safety cushion'. The FEL was therefore 'pushing' ore from the ROM stockpiles into the plant, while the ROM stockpile called trucks when inventory dropped below set points, in other words, the ROM stockpile 'pulled' ore from the pits, and the trucks were expected to meet the requirement to replenish the ROM stockpile.

The dynamic simulation proved that the mining schedule was fit for the purpose and did not have fatal flaws.

MAIN TREATMENT PLANT (MTP) AND DENSE MEDIA SEPARATION (DMS)

The plant was assumed operating on a continuous basis, with the exception of the following scheduled maintenance shutdowns:

1. Major annual shutdown once in a year for 78 hours (one time slot in a year)
2. Biweekly 'ordinary' maintenance shutdowns of 15 hours per event (20 time slots)
3. Biweekly 'extended' maintenance shutdowns of 19 hours per event (6 time slots, every second month).

Total planned downtime was therefore 492 hours per annum.

Twenty-minute FEL driver changeover time, safety check, and refuelling was allowed for per shift, thus reducing the available FEL operating time to 11 hours and 40 minutes per shift. A standby driver was available to temporarily replace the duty FEL driver.

In order to optimise the size of the maintenance department, the primary crusher and the MTP were shut down on different days. When the MTP was shut down, the crushed ore was stockpiled on a Reclaim stockpile, and when the Primary crusher was on planned maintenance, the prime FEL was reclaiming crushed ore from the reclaim stockpile and tipping into a second tipping arrangement.

The ore feed into the plant was by means of a FEL, whose operating parameters appear in Table V.

Table V. FEL parameters feeding ore to plant.

Description	Unit	Value
Bucket capacity	m^3	13
Bucket fill factor (heaped)	%	85%
Bucket capacity	m^3	11.05
Material *in-situ* bank density	t/m^3	2.47
Material *in-situ* to loading unit bucket swell		1.3
Maximum volume bucket payload	t	21.0
Actual bucket payload	t	21.0
Actual bucket payload	m^3	11.1

While the average loader bucket was maintained in the model at 21 t, every trip the wheel loader picked up a variable load in 20 to 22 t range, yet providing the target average payload when total mass delivered was divided by the total number of trips.

As long as one-way travelling distance between the main tip and the ROM stockpile was within 125 m only a single machine was used on the ROM pad. Once the front sector of the ROM stockpile has been reclaimed (which happens only when the plant enters into the audit mode), a second equivalent machine is deployed on the ROM pad for as long as the rear sector of the ROM stockpile is being reclaimed.

Table VI summarizes delays associated with ore handling on the ROM pad.

Table VI. Delays associated with ore handling on ROM pad.

FEL cycle / delay	Seconds
Load bucket from stockpile	48
Spot at tip point	10
Tip bucket and & vacate	20
Push back / break oversize rock	15
Load bucket with oversize	30
Load bucket from coarse ore (reclaim) stockpile	30

FEL maximum travelling speed on ROM pad was 12 km/h.

Blasted rock arriving from the pit(s) invariably contains oversize material not suitable for the primary crusher. Two methods of handling oversize rock were modelled.

The first method was based on making use of the FEL (the very same machine feeding the plant), who would push oversize rock to the back of the main tip. Once a full bucket load has been accumulated in the back, the FEL will pick up the oversize and move it to a small pile at a side. A mobile ore breaker will every now and then come and break the oversize rock on that pile, and once a full FEL bucket load of broken rock has been accumulated, the loader will pick it up and take it to the main tip, but only on a trip when it moves a bucket of 'fresh: oversize material (in other words the FEL will not travel empty specifically to pick up a bucket of broken rock, this trip will always be in conjunction with delivery of oversize rock from the back of the main tip). The pattern of FEL movements is shown in Figure 5.

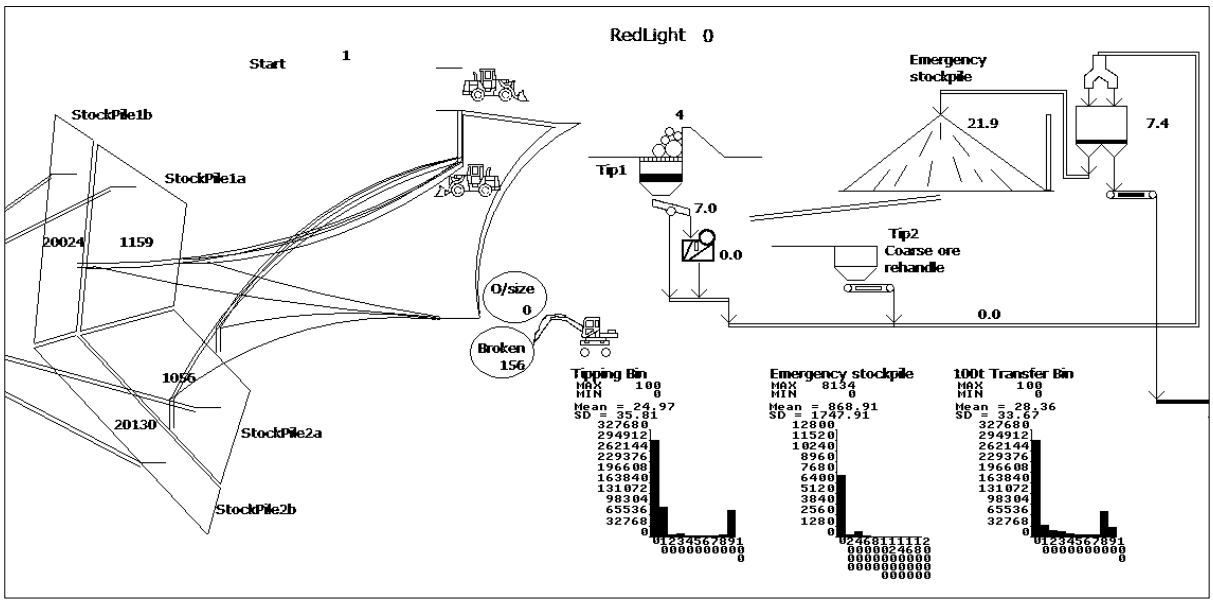


Figure 5. Pattern of FEL movements on ROM pad to handle oversize rock.

The second method involves a hydraulic breaker permanently installed on the main tip, which will break the oversize rock right on top of the static grizzly. This method frees the FEL from the need to handle the oversize rock, which avails more time for handling ROM ore.

In order to test the influence of the oversize rock handling method, scenarios were simulated with and without a static hydraulic breaker (in the latter event the FEL was in charge of oversize rock handling).

The second tipping arrangement with a hydraulic breaker was used when the FEL reclaimed crushed ore from the Reclaim stockpile and fed it into the plant. There are two points where the reclaim feeder can be connected to:

1. Ahead of the 100 t transfer bin (as it appears in Figure 5)
2. Past the 100 t transfer bin transferring onto the primary screen feed conveyor, as it is shown in Figure 1 (attached at the end of this paper).

Both of those two connection options have advantages and shortcomings. The advantage of option (1) is that is provides an additional surge capacity in a form of a 100 t transfer bin ahead of the plant head feed, which affords a little better control of the feed rate into the plant as the secondary tipping bin is small (50 t) and the FEL tipping process is erratic. The disadvantage of this option is however a need to run an additional conveyor and lift ore into the transfer bin thus consuming more power. The advantage of option (2) is that it eliminates the need to run the conveyor feeding the 100 t transfer bin, which saves power, however due to the limited capacity of the secondary tipping bin the plant feed will be driven primarily by the FEL tipping process.

Victor Mine (a De Beers operating open-pit diamond mine in Ontario, Canada) actual availability data were applied for the Gahcho Kué plant, including power failures and white-out events which stopped the entire plant.

Durations of (Mean Time to Repair) and intervals between (Mean Time between Failures) breakdowns for other equipment items were sampled from logarithmic normal and exponential distributions, respectively. These are statistically proven distributions for availability modelling. Examples of such distributions for apron feeder breakdowns appear in Figure 6.

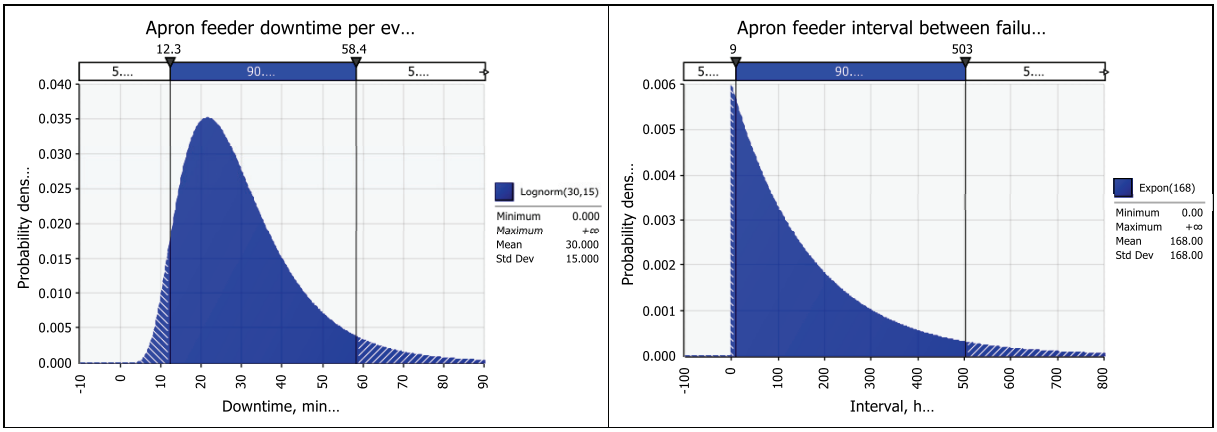


Figure 6. Examples of distributions used to model apron feeder breakdowns.

Two types of feed were identified for the Gahcho Kué plant, namely fine and coarse. Three scenarios were executed:

1. Blended feed with fines and coarse occurring in more or less equal proportions
2. Fines only
3. Coarse only.

Feed rates were obtained from detail mass balances produced by LIMN software (David Wiseman, 2017).

In the plant, multiple equipment items such as screens and cyclones split the incoming flow of ore into two or more outgoing flows. A double-deck screen, for instance, produces three exit streams, namely top deck oversize, bottom deck oversize (also referred to as middlings), and bottom deck undersize. In order to accommodate stream splitting, the relevant equipment items were programmed to cause the division of incoming flow into an appropriate number of outgoing flows. Since flows in the plant were all variable, mass proportions were applied to the incoming flows to split the ore flow into appropriate number of outgoing flows.

Discussion of Simulation Results

In order to define the base MTP model (for identical mining inputs), four scenarios were executed and compared between each in terms of total plant throughput and overall plant utilization (OPU). The conveyor feeding the primary screen ahead of the secondary cone crusher and primary scrubber was selected to represent the plant head feed and to measure the OPU.

Table VII summarizes the key outcomes of the comparative analysis of different plant configurations. The overall plant utilization (OPU) figures in some of the scenarios appear excessive (above design value); however, those figures could still be used for comparison between different plant configurations.

Table VII. Comparison of different plant options.

Scenario	**1**	**2**	**3**	**4**
ROM oversize rock handling	Breaker on static grizzly	Wheel loader	Breaker on static grizzly	Breaker on static grizzly
Position of reclaim bin	Ahead of 100 t transfer	Ahead of 100 t transfer	Past 100 t transfer	Past 100 t transfer
Throughput, t/a	3 057 308	2 756 663	3 064 494	3 085 918
OPU % calendar time	83.85	79.64	84.24	84.83

Should the FEL be responsible for the oversize rock handling, the plant will not be able to meet the production target. The OPU was also below the target of 82% due to the effective plant intake rate below the target 420 t/h as the wheel loader was not able to maintain the required plant feed and move oversize rock at the same time. This option was therefore excluded from further consideration.

Comparing the plant performance with the reclaim bin installed either ahead or past of the 100 t transfer bin, the latter shows slightly better performance in the terms of the plant throughput and the OPU. Taking into account that the conveyor lifting the ore into the transfer bin, maintenance requirements, and that the total power consumption will be lower if the reclaim bin transfers ore directly onto the primary screen feed conveyor, it was decided to install the reclaim bin past the 100 t transfer bin. The lifting conveyor can then be maintained along with the primary jaw crusher.

Statistics for the ROM pad operations are summarised in Table VIII.

Table VIII. FEL operation on ROM pad.

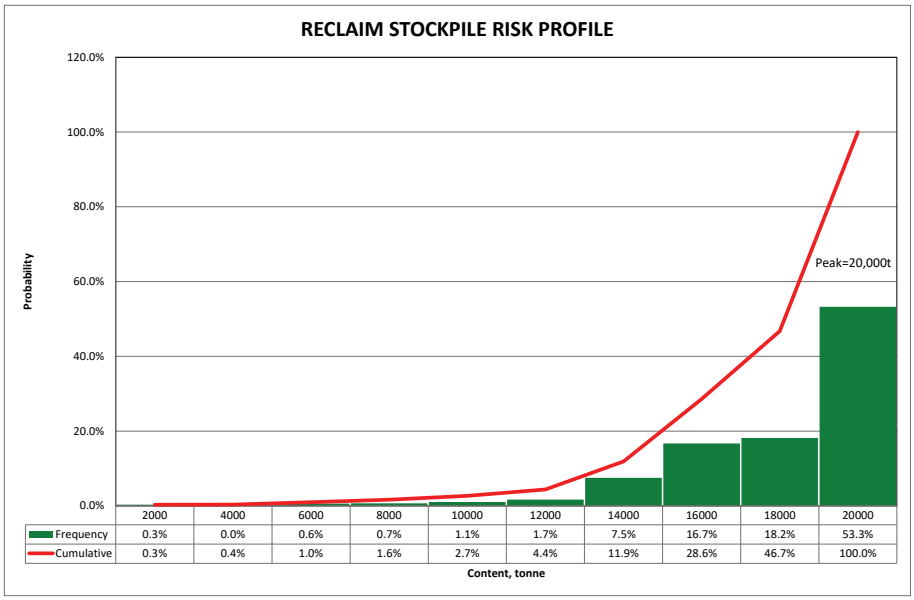
ROM pad operation	**Unit**	**Value**
FEL employed	#	2
Total ROM ore reclaimed	tpa	3 236 077
FEL#1 utlisation (related to available operating time)	%	97.5
FEL#2 utlisation (related to available operating time)	%	14.3
Coarse ore deposited	tpa	200 193
Coarse ore reclaimed	tpa	180 256

FEL#1 was utilised virtually continuously (percent utilization of manned time), the 2.5% off-time relates to 20 minute changeover, safety check, and refuelling time taken out of the 12 hour operating shift. In reality this is difficult to achieve, however there is a standby FEL who can be mobilized in the event of the duty FEL breakdown (the same machine as used for reclaiming the rear part of the ROM stockpile, *i.e.* FEL#2).

FEL#2, was only mobilized to reclaim from the rear sector of the ROM stockpile, which only took place when the plant entered the audit mode, and was utilized only 14.3% of available operating time. It would be on standby for FEL#1 for the remainder of the time.

In total 200 193 t of ore were deposited onto the reclaim stockpile while only 180 256 t were reclaimed. This is ascribed to the fact that there is a lag in the ROM and reclaim stockpile cycles; while the ROM stockpile had initial stock at time zero, the reclaim stockpile had none.

In order to validate stockpile capacity, the model was monitoring total content in the stockpiles and capturing values in a form of histograms which were then used as risk profiles, explained and interpreted below. The risk profile of the reclaim stockpile appears in Figure 7.



	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Frequency	0.3%	0.0%	0.6%	0.7%	1.1%	1.7%	7.5%	16.7%	18.2%	53.3%
Cumulative	0.3%	0.4%	1.0%	1.6%	2.7%	4.4%	11.9%	28.6%	46.7%	100.0%

Figure 7. Risk profile of the Reclaim (coarse ore) stockpile.

The interpretation of the histogram follows:

1. The stockpile total capacity was set at 20 000 t
2. The entire range of 0 to 20 000 t was then divided into 10 virtual 'pockets', the first responsible for the values from 0 to 2000 t, the second one for the [2000–4,000) range and so on with the last one covering [18 000–20,000] t range[1]
3. Every hour the model 'polled' the stockpile and placed an observation into appropriate 'pocket', for example if at time *T* the current stockpile content was 15 000 t, the model would add an observation to the eighth 'pocket'
4. Vertical bars therefore indicate fractions of time during which the stockpile contained a specific range of ore content, for example, 53.3% of time the stockpile contained ore in [18 000–20 000) tonne range (*i.e.* was almost full)
5. The solid red line shows the cumulative probability of the content.

The peak inventory on the reclaim (coarse ore) stockpile was 20 000 t, and for only 2.7% of time it contained less than 10 000 t of ore.

Similar risk profiles were obtained for all bins and stockpiles.

Major MTP and DMS plant utilization is shown in Figure 8.

[1] Round bracket implies boundary value does not form part of the range, square bracket - it does

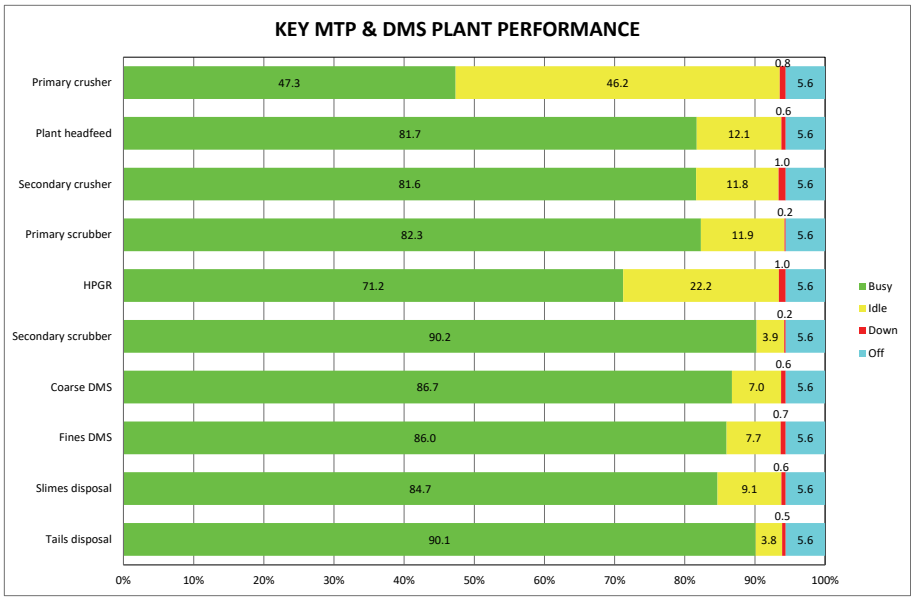


Figure 8. Plant utilization

Notes to Figure 8:

1. Green bar = Utilization referred to as 'Busy' time, a fraction of total time when a production unit was actually performing its duty, *e.g.* a conveyor moving material
2. Yellow bar = Idle time, time when equipment was available (i.e. in operating condition) but did not perform the duty to either upstream or downstream problem, for example absence of feed or stockpile being full. An example is an empty conveyor belt running
3. Red bar = Downtime is the time when the system could not perform its duty due to incidental equipment breakdowns (failures), as opposed to planned maintenance shutdowns, referred to as 'Down' in the utilization charts;
4. Cyan bar = Off-shift time, *i.e.* the time when equipment was intentionally shut down for planned maintenance.

The plant head feed, used as a measure of the OPU, rendered 81.7% utilization including power / white out delays which correlates well with the target of 82%.

A similar utilization chart was generated for the recovery plant.

BENCHMARKING AGAINST REAL MINE PERFORMANCE

The mine has availed actual statistics of head feed tonnes treated per hour, which corresponds fairly well with the same predicted by the simulation model as shown in Figures 9 and 10.

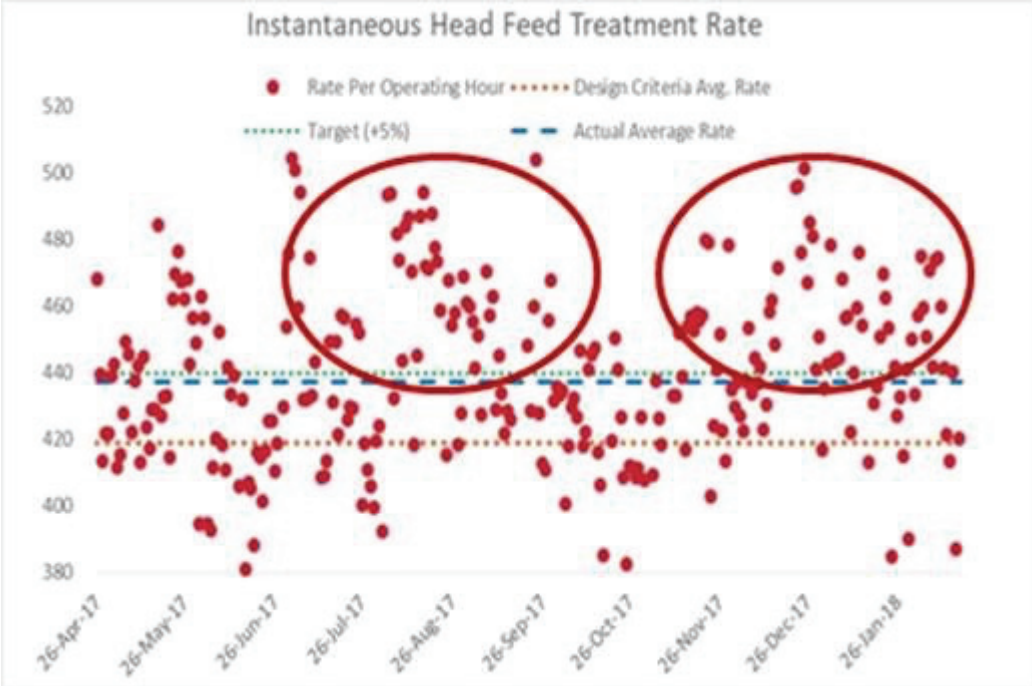
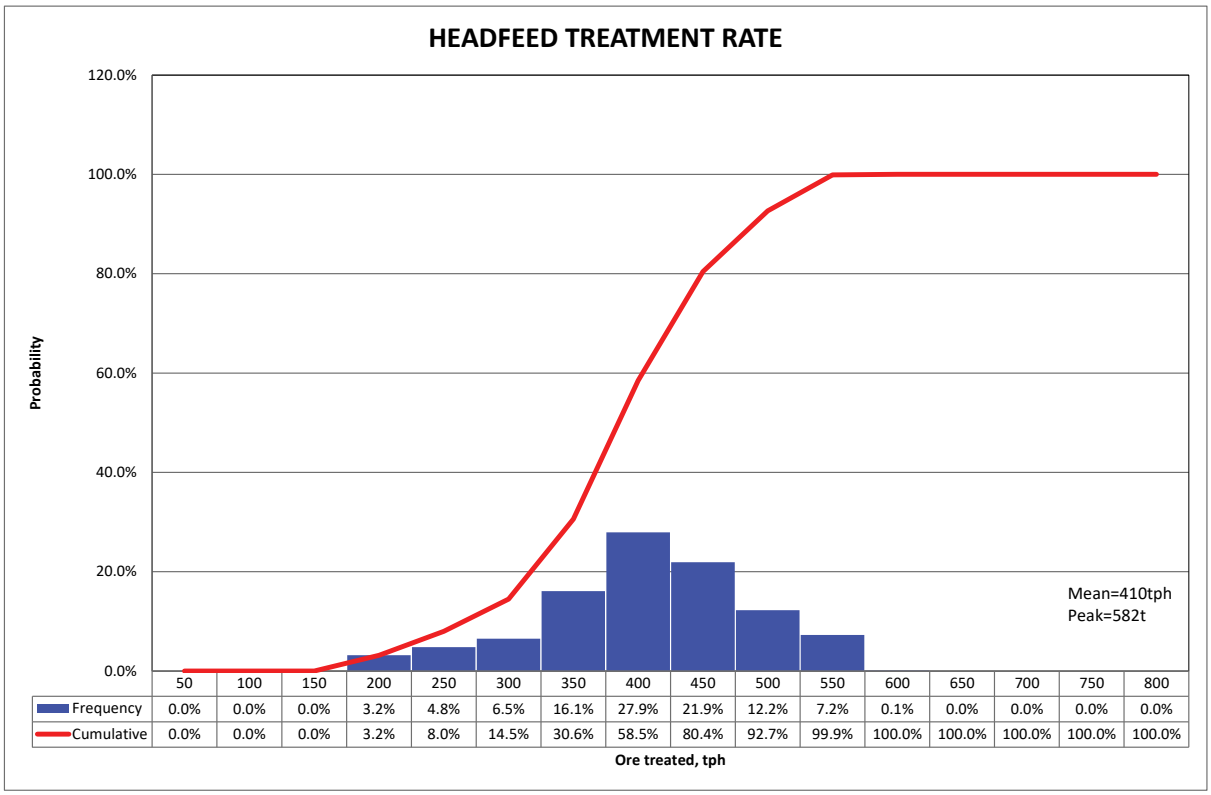


Figure 9. Actual head feed treatment rate.



	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Frequency	0.0%	0.0%	0.0%	3.2%	4.8%	6.5%	16.1%	27.9%	21.9%	12.2%	7.2%	0.1%	0.0%	0.0%	0.0%	0.0%
Cumulative	0.0%	0.0%	0.0%	3.2%	8.0%	14.5%	30.6%	58.5%	80.4%	92.7%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 10. Head feed treatment rate predicted by simulation.

Albeit the model projection was skewed to the lower values compared with the actuals, the mean value is fairly close to the design criterion (410 t/h simulated mean value *versus* 420 t/h design).

The processing facility is now regularly operating well above the design feed rate of 440 t/h. The over performance in 2017 was included in the 2018 business plan with an increase in the process plant treatment tonnage of 5%.

The performance in 2018 Q1 was 4% above budget

CONCLUSIONS AND RECOMMENDATIONS

The dynamic simulation provided the following inputs into the Gahcho Kué Feasibility Study:

1. Optimized plant configuration and minimized footprint
2. Assistance in equipment selection
3. Capacities of storage facilities and of the process equipment
4. Mining fleet checks (fleet associated with ore mining)
5. Confirmed overall plant utilization;

Dynamic simulation also proved that the designs of both the ore mining fleet and the metallurgical plant, comprising the main treatment, the DMS and the recovery plants, were free of fatal flaws and were fit for the purpose.

The mine is meeting its target and dynamic simulation is believed to have made a contribution to the achieved performance.

Every capital project will benefit from simulation of a mine system, be it greenfield or brownfield.

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