DRILL-TO-MILL PLANT OPTIMIZATION AT ALTYNALMAS PUSTYNNOYE GOLD MINE

*S. Esen[1], M. Daniel[1], B. Dzhalolov[2], B. Bachramov[2], J. Geronimo[2], & A. Kalmatayev[2]

[1]Esen Mining Consulting Pty Ltd
Sydney, Australia

[2]JSC AK Altynalmas
Almaty, Kazakhstan

(*Corresponding author: sedat@esenmining.com)

Abstract

JSC AK Altynalmas engaged Esen Mining Consulting Pty Ltd (EMC) to conduct a drill-to-mill plant optimization project to determine what opportunities exist to increase the mill throughput and improve the overall mine and concentrator performance. The scope of the project included in-situ ore body characterization, drill and blast improvements, run-of-mine (ROM) fragmentation measurement and modelling, and crushing and milling optimization. Pustynnoye Gold Mine's crushing circuit includes a jaw crusher and two secondary cone crushers operating in closed-circuit with classification screens. The grinding circuit consists of a semi-autogenous (SAG) mill with a pebble crusher followed by two ball mills. The SAG mill is unusual, with a low aspect ratio similar to the ball mills. The ball mills currently produce a final grind size of P_{80} of 75 microns (µm).

Pustynnoye Gold Mine plans to increase the throughput from 2.1 to 2.5 Mt/a and possibly more in future expansions. In order to deliver this capacity increase, management initiated a drill-to-mill project in July 2018.

EMC'S drill-to-mill methodology has delivered significant benefits to the mine: increased fines from blasts (approximately 11% more -10 mm fines; reduced ROM F_{80} from ~500 mm to ~150 mm; increased dig rates (about 25% to 30%); improved wall control; reduced ore loss/dilution; and increased crusher throughput (16.2%); increased mill throughput (11.6%). This paper explains the methodology followed and presents the results.

Keywords

Drill-to-mill plant optimization, mill throughput, drill and blast, fragmentation, ore characterization, dig rate, crusher, SAG mill, ball mill

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Introduction

The Pustynnoye gold deposit is located in the southern part of Central Kazakhstan in the Aktogay District of the Karaganda Region. It is located 120 km east of Balkash town, the nearest settlement, to which it is connected by a graded dirt road (Figure 1). This major industrial town on the northern shores of Lake Balkash is home to the Balkash Smelter Complex, a major copper producer in Kazakhstan.

Figure 1 – Pustynnoye Gold Deposit

The Pustynnoye Gold Mine is an open pit mine with six years of mine life remaining (ending in Q4 2024). Approximately 2.5 Mt/a ore is planned to be processed at an average gold grade of 1.60 g/t. Total ore and waste volumes are 25 Mt and 76.7 Mt respectively, based on 2019 life-of-mine (LOM). LOM average stripping ratio is 5.6. Most of the waste movements are in the 2018 – 2021 period. Four cutbacks (CB) were planned to be mined (Figure 2) according to the SRK Consulting (SRK) study (McQueen and Beare, 2018). The CB sequence targets the lower strip ratio, higher grade material (higher value) first under the current pit bottom, followed by a second CB to the east (relatively lower strip ratio, higher value ROM). The third CB expands the pit to the east, and the final CB is to the west (higher strip ratio, lower value ROM).

Pustynnoye Gold Mine processed approximately 2.0 Mt of ore in 2018 and aims to increase ore production to 2.5 Mt/a. Therefore, Pustynnoye wished to explore opportunities to increase the mill throughput by optimizing fragmentation from blasting through crushing and grinding. As a result, EMC was requested to implement a drill-to-mill (D2M) project to optimize the drill and blast, load and haul, and comminution circuit operations in order to achieve an extra 0.5 Mt/a from the benchmarked ore production of 2.0 Mt/a. This implies increasing mill throughput from 260 – 270 t/h to 320 t/h assuming 89% mill availability (23% increase in mill throughput).

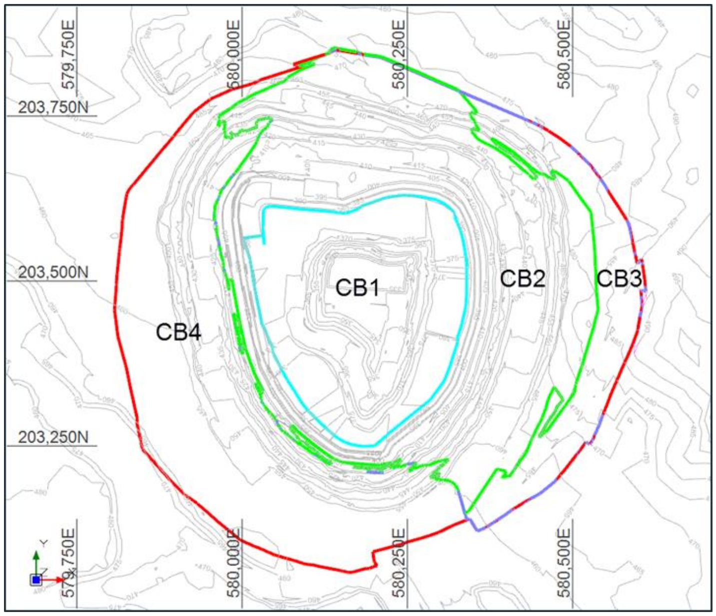


Figure 2 – Cutback Sequence (McQueen and Beare, 2018)

Drill-to-Mill Plant Optimization Methodology

The drill-to-mill methodology can be best defined as the development of integrated operating and control strategies from the mine to the plant that maximize throughput, minimize the overall cost per tonne, and maximize profitability. The methodology involves a number of important steps: benchmarking (mine and plant), ore characterization, measurements, modelling/simulation, implementation, and monitoring of the defined integrated operating strategies. Ore characterization is a key step in this methodology as ore properties are used in drill and blast fragmentation models, and in crusher and grinding circuit models (Figure 3).

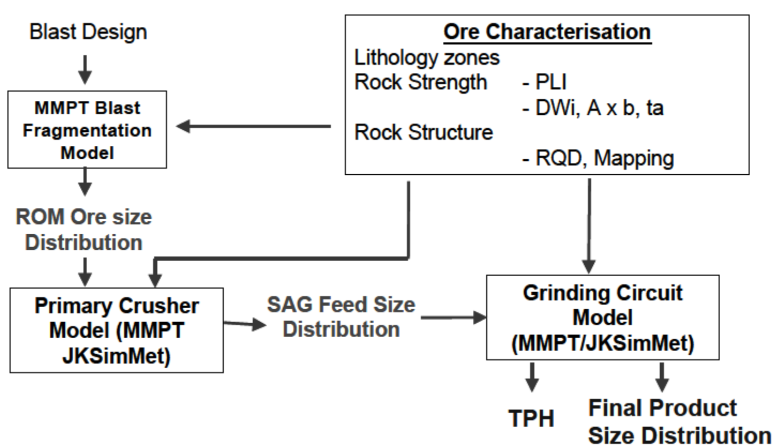


Figure 3 – Drill-to-Mill Methodology (Dance et al., 2006)

Investigations by several consulting groups and researchers have shown that all the processes in the mine-to-mill value chain are interdependent, and the results of the upstream mining processes (especially blast results) have a significant impact on the efficiency of downstream milling processes such as crushing and grinding. Numerous mine-to-mill projects reported in the literature have resulted in mill throughput increases of between 5% and 30% depending on the comminution properties and processing plant conditions (Dance et al., 2006; Esen et al., 2007; Kanchibotla & Valery, 2010; Kanchibotla et al., 2015; La Rosa et al., 2015; Esen, 2017).

A general perception of drill-to-mill optimization is simply increasing blasting intensity to achieve finer fragmentation and improved circuit throughput. However, this may not be the case for many sites because:

- Blasting intensity varies depending on the rock strength and structure. In our methodology, blast intensity varies depending on the rock properties at each mine site.
- QA/QC may be an issue and the drill and blast audit process identify core issues resulting in poor fragmentation results. In majority of the sites that we have visited to date, QA/QC still remains an issue.
- Electronic blasting may offer improved fragmentation results due to shock wave interaction using ultra-fast timings (1 to 3 ms delays between holes while achieving 15 to 20 ms/m burden relief) (Rossmanith, 1997; Vanbrabant & Escobar, 2008).
- Wall control near pit walls is not generally considered. In our approach wall control is considered, and a compromise between fragmentation and blast damage is included. The best solution is identified following the auditing process. Measurements and process modelling are key steps. By following some of the novel concepts in wall control, we can achieve both improved fragmentation and full compliance with pit slope design.
- Waste blast optimization: this is generally overlooked in the optimization process; however, there is significant value delivery if waste blasting is optimized at mines given the large waste amounts and high stripping ratios. We optimize the waste blasts to minimize the total waste mining cost (drill and blast and load and haul).
- Ore loss and dilution: at many mines, different grades of ore and/or ore/waste combinations are blasted together. It is well known that blast movement is significant depending on the blast intensity, rock properties, free face/buffered, and the initiation tie-up. Many mines (especially gold) start to measure the blast movement and adjust the polygons after the blast. If there is no methodology to manage ore loss and dilution at site then methods should be developed to control it visit, we recommend the most appropriate methods to control it.
- Blast movement around the pit edges: blast movement into the pit void is a major concern at many sites, and there are techniques to minimize this issue. Solutions are available these days to manage this critical issue as it affects ore loss/dilution as well as geotechnical (filling the berms) requirements.
- The circuit may be limited by crusher, SAG mill, or ball mill.

Morrell's power modelling is used to evaluate the comminution circuit performance. JKSimMet simulation results are carefully presented based on Morrell's models and due consideration to the software's limitations (Bailey et al., 2009).

The methodology outlined above considers key factors to maximize the value delivery to the mines. This paper presents the Pustynnoye case study to demonstrate our well-structured approach.

Ore Characterization

LITHOLOGIES

The volumetrically significant lithological units present in the deposit are interbedded sandstone and siltstone, sandstone, siltstone, and greenstone (Figure 4). Ore lithologies are predominantly sandstone, siltstone, and interbedded sandstone and siltstone.

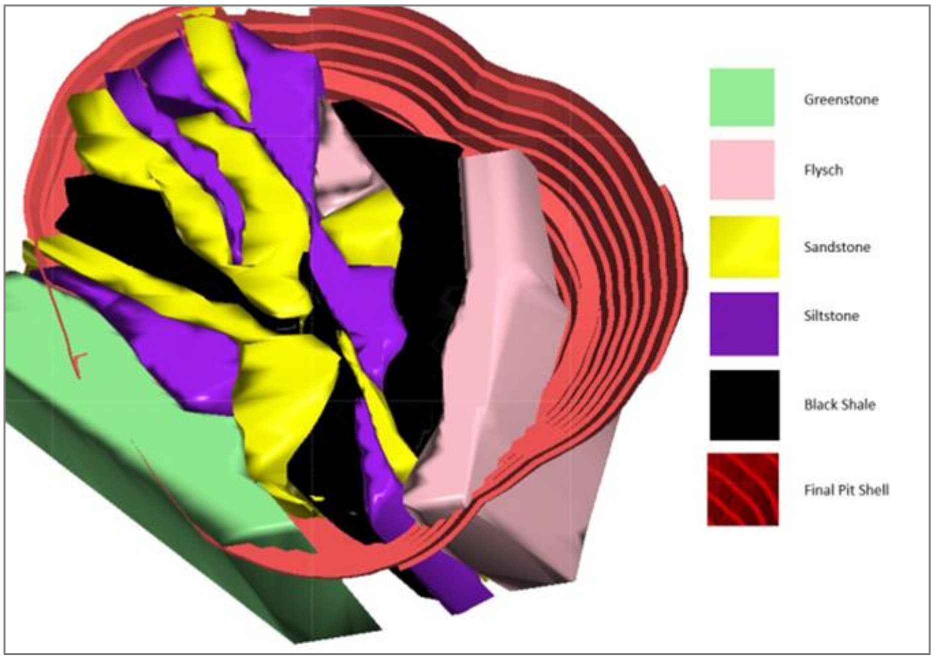
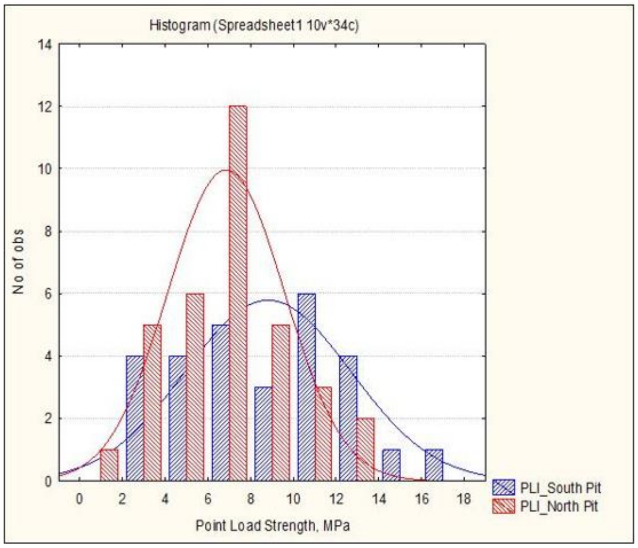


Figure 4 – Lithological Wireframes and Final Pit Shell View to the North (Brown & Marshall, 2017)

ORE TESTING CAMPAIGN

Comprehensive ore characterization work was undertaken during the first phase of the project. Point load index (PLI) or strength, JK drop weight, Axb, drop-weight index (DWi), and Bond work index (BWi) were determined in a sampling campaign that involved 50 tests. Pustynnoye gold mine purchased a point load tester at the beginning of the project. It was planned to develop the relation between PLI and the JK Axb parameter.

Lump point load tests were initially carried out using the point load tester during the Phase 1 site visit. Ore samples were collected from south and north parts of the pit as well as from the stockpile. Average point load strengths are 8.77 Megapascal (MPa) for the south pit and 6.82 MPa for the north pit (Figure 5).



	Valid N	Mean	Minimum	Maximum	Std.Dev.
PLI_South Pit	28	8.77	2.06	16.44	3.86
PLI_North Pit	34	6.82	1.89	12.68	2.72

Figure 5 – Point Load Test Results for Lump Tests

Metallurgical Testing Results

As discussed above, 50 ore samples were submitted for metallurgical testing by the TOMS Institute, which included SAG mill competency (SMC: JK Dwi: Dwi or JK rock breakage parameters: Axb) and Bwi characterization. Seven SMC data sets were discarded as the sample amount was not sufficient. The key results from these tests are presented in Table 1.

Table 1 – Metallurgical Testwork Results

	Valid N	**Mean**	**Minimum**	**Maximum**	**Std. Dev.**
DWi, kWh/m^3	43	6.6	5.0	9.4	0.8
Axb	43	42.0	29.0	53.6	4.7
Specific Gravity, g/cm^3	43	2.72	2.65	2.79	0.04
BWi, kWh/t	25	18.3	15.4	20.2	1.2
PLI, MPa	50	5.8	1.6	10.6	1.8

According to the 50 point load test results, the overall average PLI is 5.8 MPa. Most of the values fall in the 4 – 6 MPa and 6 – 8 MPa categories. However, approximately 12% of the data shows extremely high strength ore (>8 MPa).

The average Axb value is 42.0 with a range of 29.0 – 53.6. Most of the data (48%) falls into the 40.0 – 45.0 category. If we consider an Axb of less than 35 as being extremely hard, then 9.3% of the ore falls into this category. This is in line with point load result, which indicated that approximately 12% of the ore is extremely high strength.

Data collected at Pustynnoye Gold Mine showed that PLI can be related to the drop weight test parameter, Axb (Figure 6). The relation is shown by the blue curve, which closely follows the historical (orange curve) PLI-Axb relation. It was then decided to conduct point load tests every 3 m of the exploration holes for block modelling purposes. Axb values will be predicted from point load data for each blast polygon by using the block model. These tests were completed, and we next plan to carry out the block modelling for PLI and Axb. We plan to use these attributes with grade, recovery, and throughput for better understanding of the plant performance.

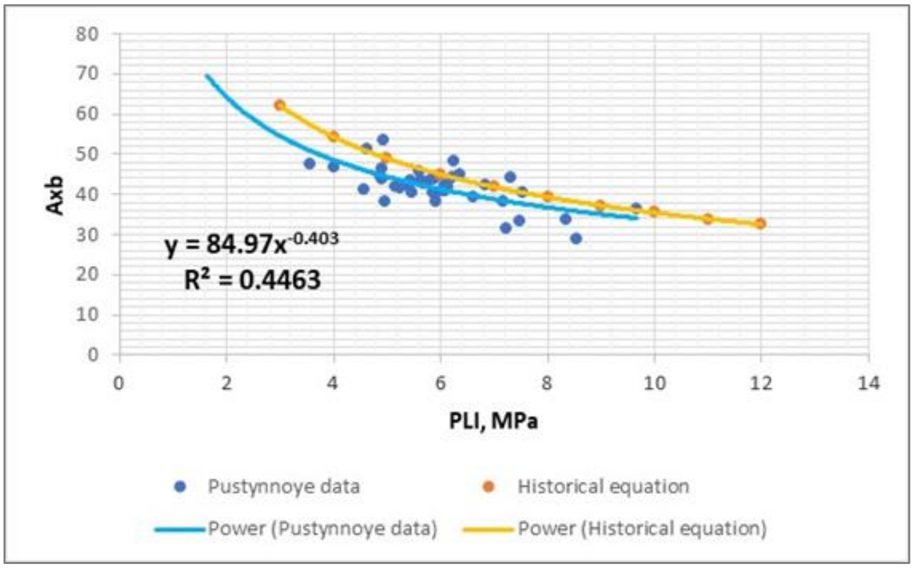


Figure 6 – Point Load Index, PLI vs. JK Drop Weight Test Parameter, Axb

Drill and Blast Optimization

The mining fleet includes two 171 mm (RocL8) and one 216 mm (DML) drills, one Hitachi EX1900 and one Hitachi EX1200 excavator, and one CAT992 front-end loader. One of the small diameter drills (171 mm) was replaced by a larger drill (216 mm) in March 2019.

All benchmark (before July 2018) drill and blast designs were carried out by Orica Mining Services as observed during the benchmarking study carried out by EMC. During the site visit, it was observed that the DML was working at the pit bottom and the RocL8 was working at top benches. The DML was preferred at the pit bottom due to the hole collapses in wet ground when we used 171 mm holes. However, the DML has been used as much as possible for wall-control blasting depending on the mine plans. In general, waste blasts are fired in 10 m benches and ore benches are fired in 5 m and 10 m benches. Common drill patterns for 171 mm diameter are 4.5 x 5.2, 5 x 5.8, and 5.2 x 6 m using 1.25 g/cm^3 bulk explosive product (pumped emulsion). Patterns with 216 mm for 10 m benches are mostly 5 x 5.8 and 5.8 x 6.7 m and for 5 m benches 4.7 x 5.4 m. These designs result in powder factor range of 0.55 – 0.70 kg/m^3. Softer overburden areas are blasted using ammonium nitrate and fuel oil (ANFO) with lower powder factors of approximately 0.40 kg/m^3.

The audit process identified coarse fragmentation as one of the major issues at the mine for both ore and waste. Main causes were inappropriate drill patterns using very high density emulsion product, small blast size, inappropriate blast shapes, long stemming lengths and inappropriate stemming material choice.

Fragmentation from Orica's ore blast designs was rather coarse, and the rock breaker had to be used at the stockpile. Maximum feed size to the jaw crusher is 1 m; therefore, large blocks had to be broken. Fragmentation photos were collected from both pit blasts and the stockpile to evaluate the fragmentation for establishing the base case. Base case fragmentation data is used to calibrate the fragmentation model for the base case blast designs (see Figure 7). The fragmentation model used by EMC was originally developed in 2004 (Onederra & Esen, 2004). It was updated later several times (Esen et al., 2007; Esen, 2013, 2017). It has been used successfully in many mine-to-mill projects globally. Figure 7 shows that the fragmentation model was calibrated reasonably well, and it can be used for the simulations with different blast design parameters. First and ore blasting template was prepared that includes north and south ore types with different blast design parameters.

Figure 8 shows the comparison of the benchmark and drill-to-mill blast results. The fragmentation analysis of drill-to-mill blasts showed that the average F_{80} (80% passing size) is 167 mm with a range of 103 mm and 246 mm. Benchmark F_{80} ranged from 470 – 510 mm. If we compare the crusher product at -9.5 mm fractions, there is approximately 11% increase in fines (approximately 17% before drill-to-mill and 28% after drill-to-mill). Figure 9 shows the primary crusher belt cut results. Average primary crusher product Axb values were 43.1 and 44.4 before and after drill-to-mill, respectively.

Drill-to-mill ROM feed is extremely fine, which should help improve the crusher and mill throughputs. The effects on downstream processes will be discussed in later sections. Approximately 40% of the feed is the final product, SAG feed (-40 mm) indicating that blasting does a crucial role in the comminution process. The drill-to-mill blasts increased the fraction of final product (-40 mm) by a factor of two when compared to benchmark case.

EMC used an electronic blasting system for ore blasts by using ultra-fast delays. Electronic firing of the ore blasts did not change the fragmentation. Electronic blasts with drill-to-mill patterns had an F_{80} of 170 mm (with a range of 136 – 246 mm). The use of ultra-fast timing was not effective in this ore type.

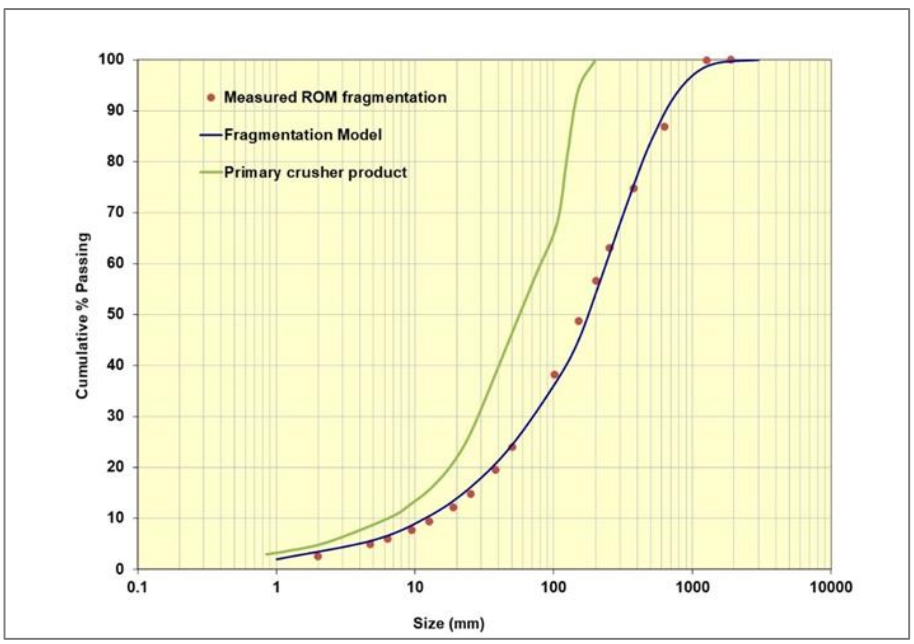


Figure 7 – Calibrated Fragmentation Model for the Base Case Blasts

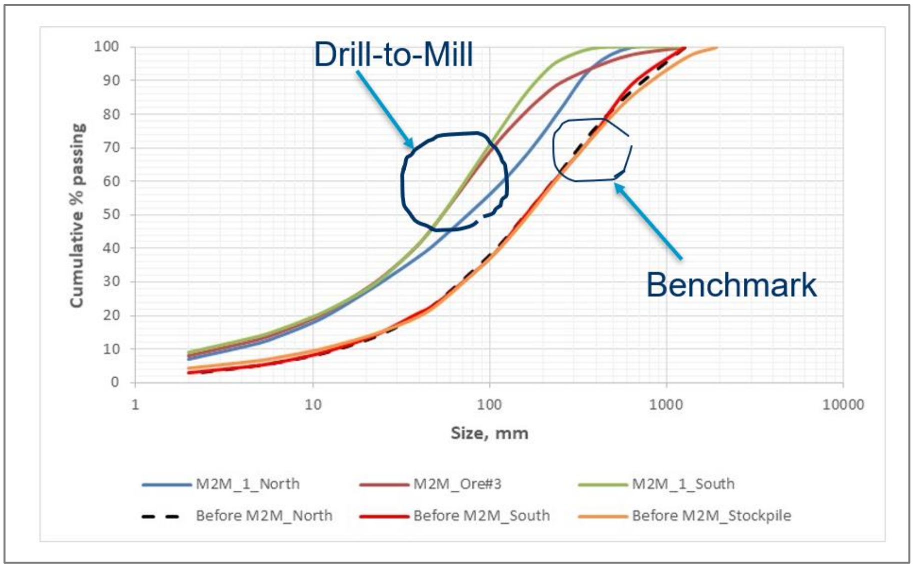


Figure 8 – Fragmentation Data from Benchmark and Drill-to-Mill Blasts

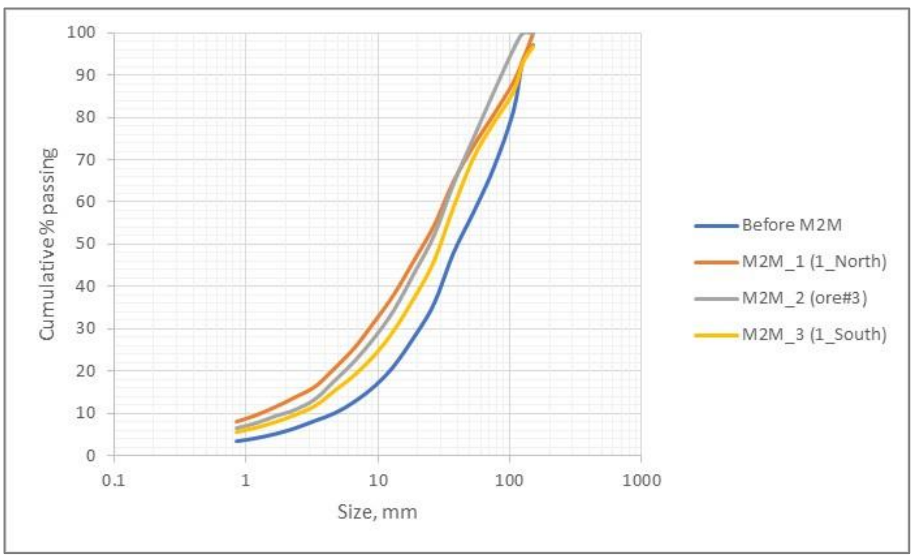


Figure 9 – Primary Crusher Product Data

WALL-CONTROL

The benchmarking study identified significant blast damage to interim and final walls resulting in poor wall profiles (shallow angles due to crest loss and toe gain). Shallow wall angles create difficulties in meeting push-back designs, especially in achieving designed toe positions, which in turn can lead to issues with regards to maintaining production levels and safety standards.

Only around 50% of the current benches meet the production design criteria of 60° bench face angle (or steeper). Specific wall control blast design templates were created for different rock types. Following the implementation of the templates, crest loss and toe gain issues were mostly resolved (Figure 10). In order to achieve more stable walls and easier scaling, the mine has been currently conducting the presplit blasts.

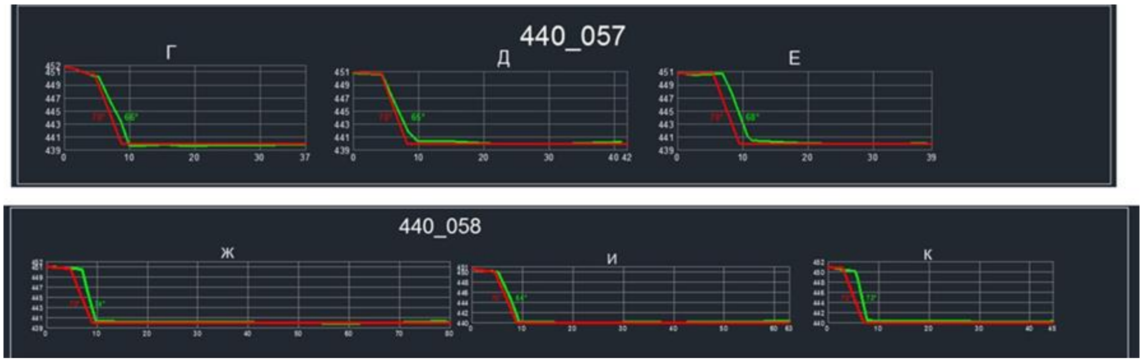


Figure 10 – Wall-Control Blast Results at RL440,
Red and Green Lines Show the Design and Actual Slope Profiles, Respectively.

ORE LOSS AND DILUTION

A detailed dilution and ore loss study was conducted during the first stage of the project. In the absence of blast movement monitors, we used PVC pipes at different heights in dedicated test holes. The data showed that horizontal movement is approximately 8 m. We developed several guidelines as well as made some recommendations to control the ore loss/dilution. Some of the main ones include:

- Buffer blasts for ore basting. Engineers ensure that blast boundaries are choked. Some data from some other gold mines indicate that ore moves approximately two times more with free-face blasts.
- Implement blast designs to minimize inconsistent movement from edge effects, uneven free faces, and cratering, especially along the ore/waste boundaries.
- Where possible plan to blast with either all ore or all waste.
- Ensure high grade/low grade boundaries do not occur near edges and power troughs.
- Drill and blast engineers design the blasts to maximize the energy distribution and minimize the edge effects.
- Deep V tie-up should have the centrelines away from the ore/waste contacts as the movement around the centreline is uncontrollable.
- Electronic initiation technique with multiple initiation points should be adopted where possible to move ore into ore and waste into waste (Figure 11).
- Use blast movement monitors for blasts with complex ore/waste boundaries.

Good understanding and managing of the blast movement should help achieve reduced dilution and ore loss as well as improved mill head grade. Until the blast movement monitors become available on site, we recommend conducting segregation blasting (ore and waste moving in different directions) whenever it is possible (large ore/waste polygons are required for this technique). We have implemented this technique successfully at Pustynnoye Gold Mine. When it is easy to separate ore and waste polygons, segregation blasting should be conducted by using an electronic blasting system. Correct blast timing can achieve highly efficient separation between ore and waste. Figure 11 shows the results from blast 310_003.

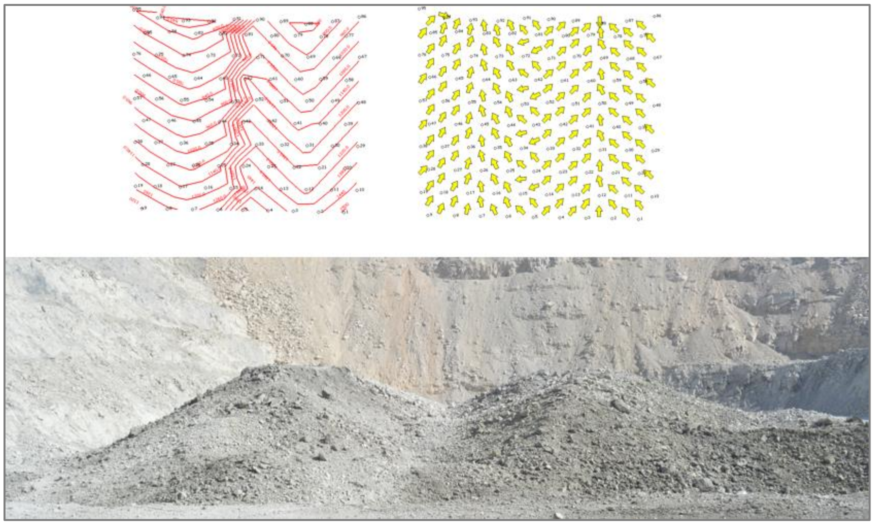


Figure 11 – Ore/Waste Segregation Blasting

The audit also identified that there has been significant blast movement into the pit void causing the berms to be filled (reducing the catch bench capacity) and loss of ore (in the case of ore blasting). Figure 12 shows an example from one of the benchmark blasts. Several blast design alternatives were proposed and implemented including front row loading, face burden, and tie-up to promote the movement away from the pit void. These controls helped minimize the movement into the pit.

Figure 12 – Blast Movement into the Pit Void and Reduction in Catch Bench Capacity

WASTE BLASTING OPTIMIZATION

A waste blast design template has been created for the mine. It was prepared for two hole diameters (171 mm and 216 mm). The designs were tailored to meet muckpile requirements of three excavator types used at Pustynnoye Gold Mine, as well as rock types. The Hitachi EX1200 (6.7 m^3) and CAT 992 (10.7 m^3) require finer fragmentation and loose muckpile when they are compared to the larger excavator, Hitachi EX1900 (12.0 m^3).

Pustynnoye Gold Mine has started implementing waste blasting design templates starting from the last week of July 2018. Since then, the mine has been achieving higher dig rates. Dig rates of the EX1900 and EX1200 excavators increased by 30.2% and 25.1%, respectively (Table 2). The increase in the dig rate resulted in significant cost savings to the mine—estimated to be approximately US$4.0 million considering the LOM.

Table 2 – Excavator Dig Rates before and after Drill-to-Mill Project

	Dig Rate before Drill-to-Mill (t/h)	Dig Rate after Drill-to-Mill (t/h)	% Increase
EX 1900	845	1,100	30.2
EX 1200	638	798	25.1

Historical Significance of the Pustynnoye Mills

The identically sized SAG and ball mills located at Pustynnoye gold mine have a colourful history. The three mills were originally in operation at Rio Tinto's Bougainville operation in Papua New Guinea in the 1980s. At the time they were some of the largest ball mills in operation. Figure 13 shows a picture of a few of the mills at Bougainville.

The mills were refurbished in 2013 by New Concept Projects NCP in South Africa before being shipped to Kazakhstan. The original flowsheet at Pustynnoye Gold Mine was a conventional SABC circuit configuration with a single SAG mill followed by two ball mills. Initial throughput was limited by the SAG mill, which led to the installation in October 2017 of two Metso secondary crushers prior to SAG milling.

The circuit configuration was modified to 2C/SABC which increased the SAG limited plant throughput to the nameplate capacity of 2.1 Mt/a (285 t/h).

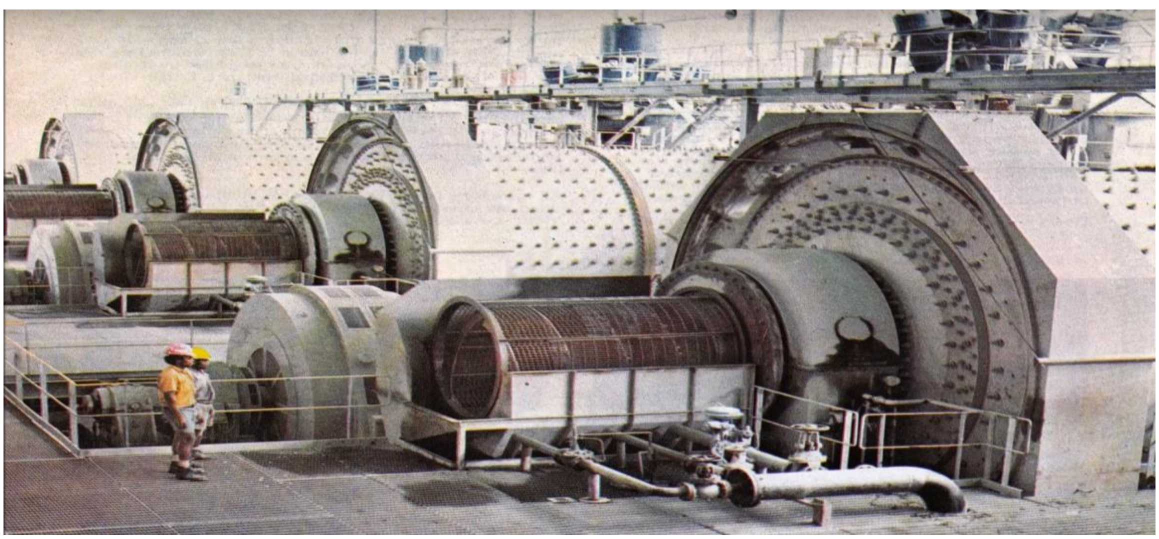


Figure 13 – Original Bougainville Ball Mills Refurbished and Sent to Pustynnoye, Kazakhstan

Crushing Circuit Survey and Outcomes

CRUSHER CIRCUIT CONFIGURATION AND SURVEY

The location of the primary and secondary crusher circuits and survey sample points are shown on the flowsheet (Figure 14). The purpose of the crusher circuit survey (October 2018) was to provide the required modelling input parameters that included the following unit process:

- Primary crusher product size distribution and feed rate
- Primary crusher power (Aymak motor power rated at 185 kW)
- Primary crusher throughput, crusher closed side setting CSS – 130 mm
- Fraction to grizzly undersize (-100 mm)
- Secondary crusher power (~315 kW), secondary crusher throughput
- Crusher CSS currently at minimum setting ~28 mm to 30 mm with X-coarse liners.

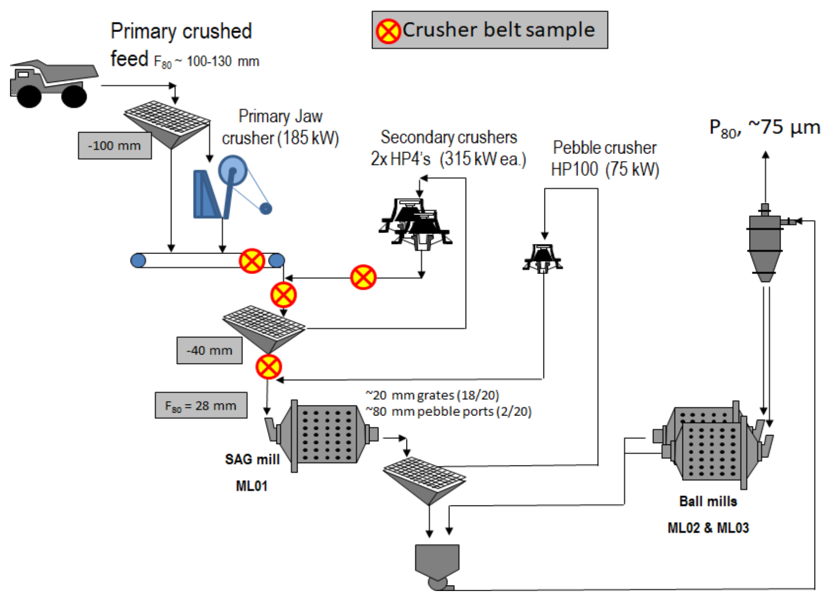


Figure 14 – Flowsheet Marking Points Where Crusher Survey Samples Were Taken

Since the introduction of the D2M program, intensely blasted ore from the now harder and deeper open pit is hauled by truck to the ROM pad and stockpiled. Depending on the ore grade or ore source, i.e., north ore, south ore, or ore #3, the feed to the crusher consists of a blend of these different ore sources. Since the beginning of the D2M project, the feed size has become more consistent and finer. A front-end loader dumps directly into the primary crusher feed hopper. The front-end loader maintains feed in the ROM bin feeding onto the 700 mm grizzly to ensure oversize does not block the crusher and the crusher is continuously being fed. Apertures in the crusher internal scalping screen deck are typically 100 mm wide x 1,000 mm long. Oversize from the vibratory scalping screen reports to a single toggle Jaw Crusher (Aymak 140).

The secondary crusher currently operates at a low power draw of 87 – 106 kW indicating room for improvement. The crusher could be pushed to draw on average about 220 – 250 kW using a coarse or medium liner. This is seen as an opportunity in the Pustynnoye Gold Mine flowsheet. Improvements would see more material onto the stockpile, which in turn will feed the milling circuit at a higher throughput. Spare capacity in the ball mills, which has been identified, will meet the energy demands of a higher throughput.

Performance of the Aymak Jaw Crusher Unit

The Aymak crusher gap has the ability to set the CSS from 100 mm to 175 mm. Currently, it is set at 150 mm. Recent gains by D2M blasting have allowed more tonnes to pass to the undersize and onto the secondary crushers. The motor is sufficiently large enough to cope with a choke feed condition of oversize and undersize material. The crusher does experience trip outs from time to time treating softer ore. It is believed that bridging of the fine feed material is the cause of the trip outs. The liner profiles will require modifications if ongoing softer ore is being fed. However, in the longer term, hard ore from the Pustynnoye open pits will remain as the primary feed. A second Osborne primary crusher installation is also scheduled for Q4 (2019).

Performance of the Metso HP4 Units

The primary crusher products are transferred to the double deck screen. The 40 mm undersize is sent to the final product stream, which reports to the fine ore stockpile. Oversize reports to the secondary crusher HP4 and returns to the feed conveyor and to the double deck screen at ~700 t/h. Secondary crusher product is a circulating load and is added to the feed, which reports to the double deck screen. The circuit feed was ~405 t/h when fine D2M-ON ore was being fed during the survey (Figure 15). If consistent at this level, the SAG mill can process 320 t/h. However, the crusher circuit is currently limited by oversize stockpiles of coarse ore and the primary crusher vibratory grizzly screen, which is limiting the crusher circuit throughput.

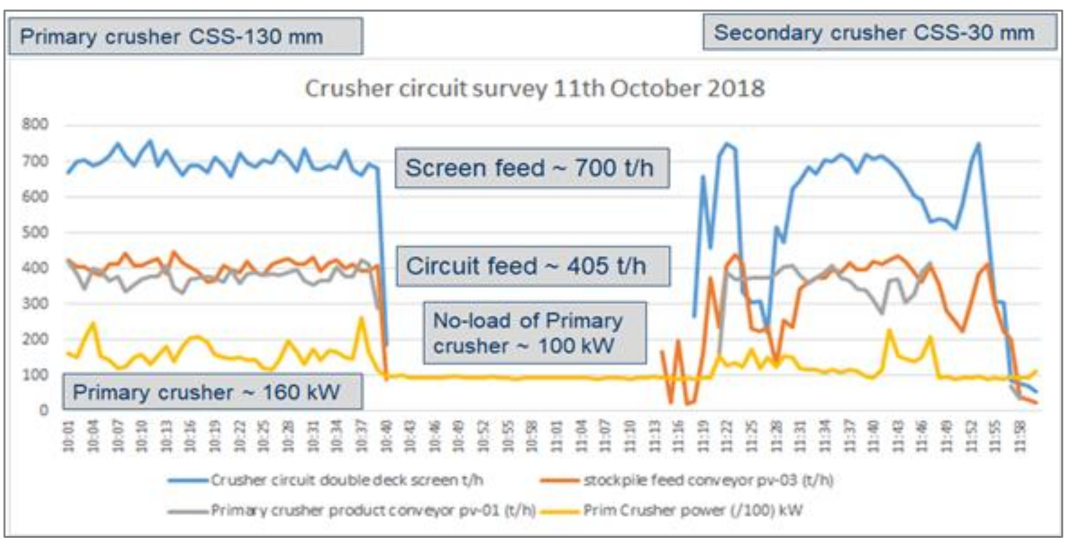


Figure 15 – Plant Information PI data from the crusher circuit survey October 11, 2018

The modelling results were good and conformed with the observed plant data. Overall analysis of the modelled data identified that the primary vibratory grizzly is the crushing circuit and overall plant bottleneck. Continued intense D2M blasting and improvements in the feed presentation to the primary and secondary crusher circuit units will enable the plant to achieve a 12% increase in nameplate capacity.

Milling Circuit Survey and Outcomes

The milling circuit survey was completed in October 2018 and had several process streams sampled, namely, SAG discharge, ball mill discharge, cyclone overflow, and SAG mill feed as shown in Figure 16. Operating PI data provided the milling conditions for the model inputs. Ball charge and total charge in the SAG mill were measured after a crash stop and ore grind outs. The ball mills were not surveyed internally because of the low ball charge and slurry levels make this impractical. The required modelling input parameters included:

- Total charge (%) – after crash stop
- Ball charge (%) – after grind out
- Average mill power, SAG and ball mills (PI)
- Mill mass (PI) and average mill throughput (PI)
- Mill feed size (TOMS sample)
- Pebble crusher power (PI)
- Pebble crusher throughput rate (PI)
- Mill discharge (TOMS sample)
- Cyclone overflow (TOMS sample)
- Cyclone feed volumetric flow (PI)
- Grate open area, grate aperture (measurements)
- Grate/pebble configuration and trommel design (measurements).

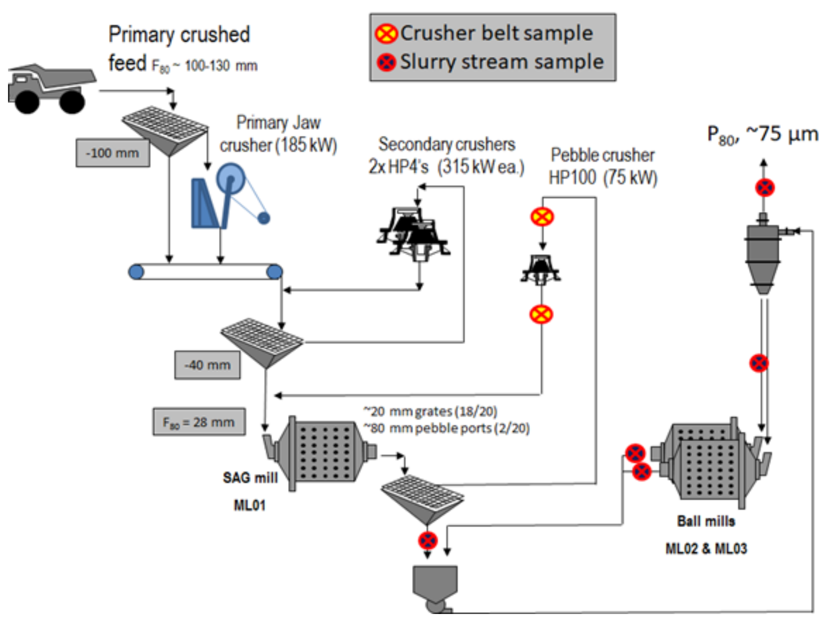


Figure 16 – Milling Circuit Survey Points

During the survey, the ball charge was 18.2% with a total charge of 22.4% giving a low rock: ball ratio. A high rock to ball ratio would promote more attrition grinding that restricts throughput, whereas the lower ratio promotes impact breakage and higher throughput. The survey total charge level (after the survey crash stop) and ball charge (after a 30 minute grind out) were measured using images of the charge levels and then applying either method of exposed liners and/or distance from the centreline to the base of the charge.

A snapshot analysis confirmed the measured, observed, and modelled/predicted circuit-specific energy of 30.4 and 27.8 kWh/t, respectively (Table 3). The cumulative power draw of all combined comminution equipment (8523 kW) and corresponding throughput (280 t/h) account for the measured circuit and unit process-specific energy.

The upper and lower 95th confidence limits (two standard deviations) of the circuit-specific energy is presented in Table 4. Results confirm that the observed circuit and unit-specific power are similar to those modelled and are shown in the data scatter in Figure 17 for two stage crushing, SAG milling and ball milling (2C/SABC) (yellow dot Figure 17) circuit configurations and more efficient three stage crush and ball milling (3CB) circuit (green dot Figure 17). Pustynnoye Gold Mine's circuit is a two stage crush, primary mill followed by ball milling (2C/PM/BM), which is in-between and predicted at 27.13 kWh/t (~27 kWh/t).

Table 3 – Various Plant Equipment Power Draws, Throughput and Unit Specific Energy

Measured/Observed Unit and Circuit Specific Energy	Unit	Plant Observed	Morrell Predicted
Primary (Aymak 140)	kWh/t	0.05	0.15
Secondary (HP4)	kWh/t	0.11	0.32
Milling circuit	kWh/t	30.2	27.36
Total circuit specific energy	kWh/t	30.36	27.83

Morrell's predicted total circuit-specific energy is 27.83 as shown in Table 4. This is within the 95% confidence limit of the measured (observed) total circuit specific energy of 30.4 kWh/t D2M-OFF and 27.4 kWh/t with D2M-ON as presented in Table 3. Pustynnoye Gold Mine's results are presented in Figure 17, the yellow-dot offset but within the confidence limit. The purple dot represents observed circuit with D2M-ON.

Table 4 – Morrell's Web Tools Predict a Circuit Specific Energy of 27.83 kWh/t (www.scmtesting.com).

Circuit Performance Details

Item	Unit	Value
ROM P80	microns	450000
Primary crusher P80	microns	110000
Tumbling mill circuit product P80 - final grind	microns	70

Ore Characterisation Data

Item	Unit	Value
sg	-	2.7
DWi	kWh/m3	7.7
Mia	kWh/tonne	21.8
Mic	kWh/tonne	8.5
Mih	kWh/tonne	16.6
Bond Wib	kWh/tonne	19.0

Total Comminution Specific Energy

Item	Unit	
Mean	kWh/tonne	27.83
Upper 95% confidence limit	kWh/tonne	31.44
Lower 95% confidence limit	kWh/tonne	24.21

Circuit Performance Details

Item	Unit	
Primary crusher circuit specific ene	kWh/tonne	0.15
Pebble crushing circuit specific ene based on headfeed	kWh/tonne	0.32
Tumbling mill circuit specific energ	kWh/tonne	27.36

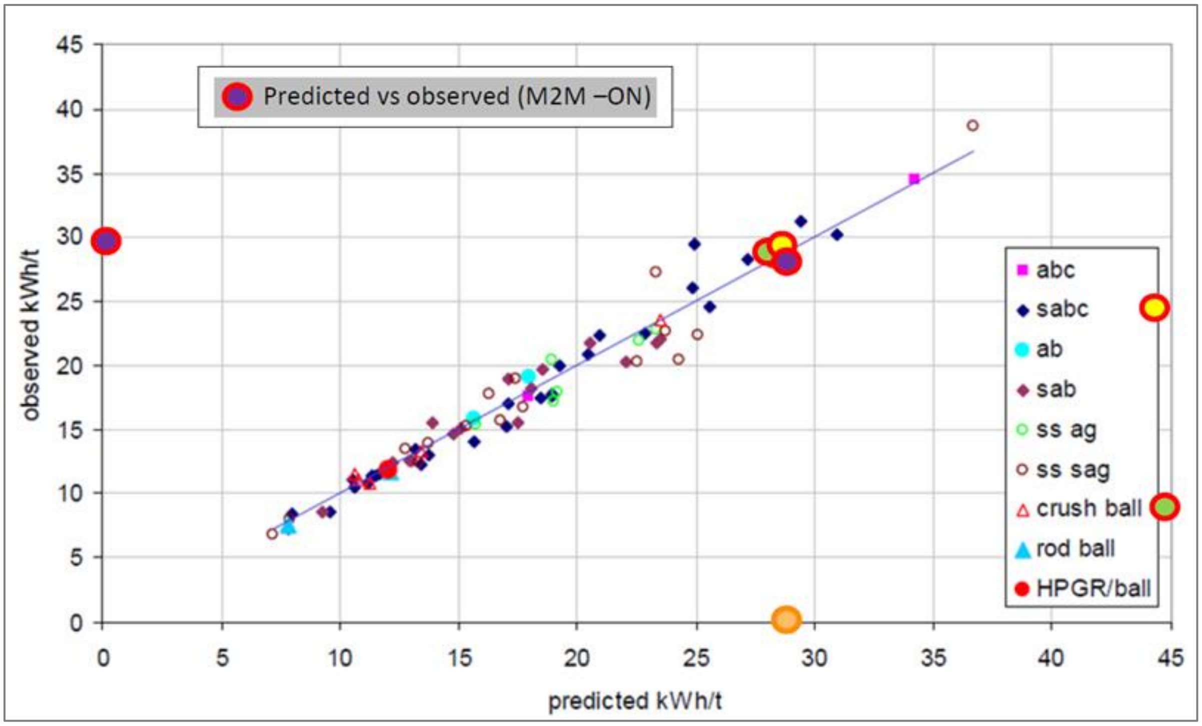
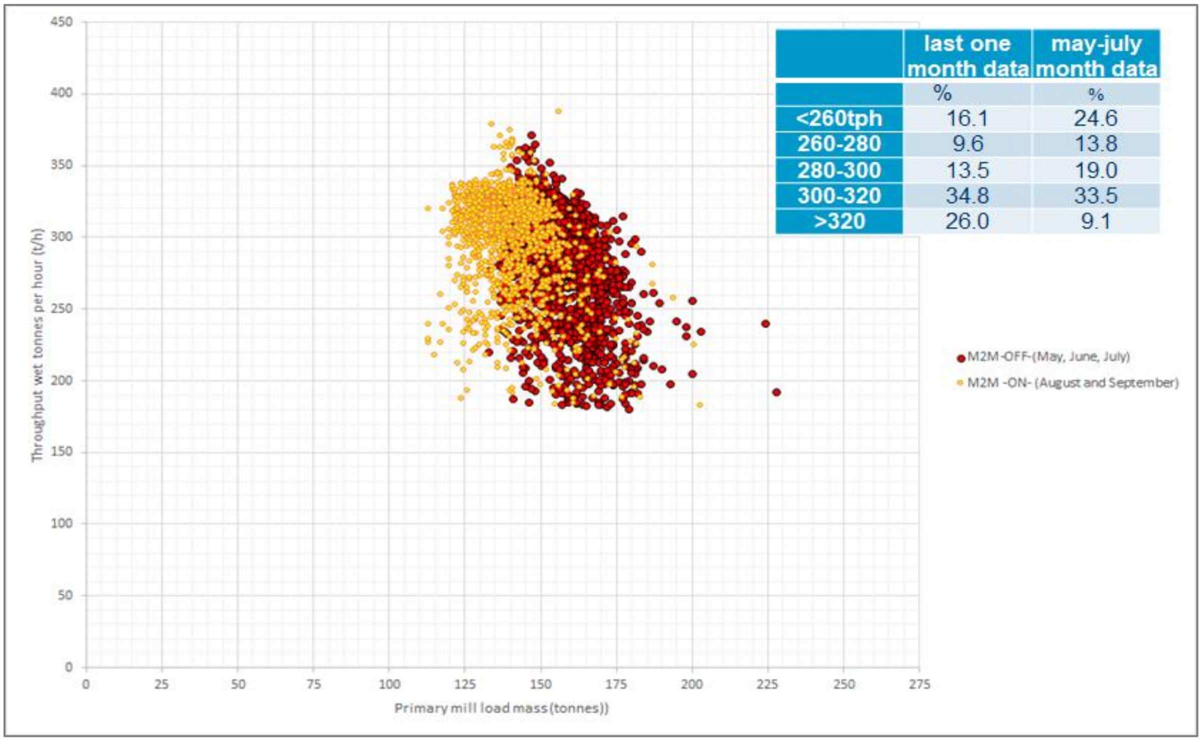


Figure 17 – Predicted vs. Observed Circuit Specific Energy for a 75 µm Target Grind Size

Figure 18 shows the D2M benefit when mill load is compared with SAG mill throughput (PI data). Figure 18 shows the D2M benefit with a lower mill mass and lower mill power. SAG mill power was reduced during the D2M-ON months August/September.

The benefits of the dine-to-mill program to date have indicated an increase in milling capacity from 284 t/h to 298 t/h representing a 5% increase in throughput. Circuit-specific energy has dropped from 31.0 to 27.4 kWh/t since D2M-ON. This represents an 11.5% reduction in specific energy requirements for the same duty (Figure 19 and Table 5).



	last one month data	may-july month data
	%	%
<260tph	16.1	24.6
260-280	9.6	13.8
280-300	13.5	19.0
300-320	34.8	33.5
>320	26.0	9.1

Figure 18 – SAG Mill Load (tonnes) against SAG Mill Throughput (t/h) – D2M ON/OFF

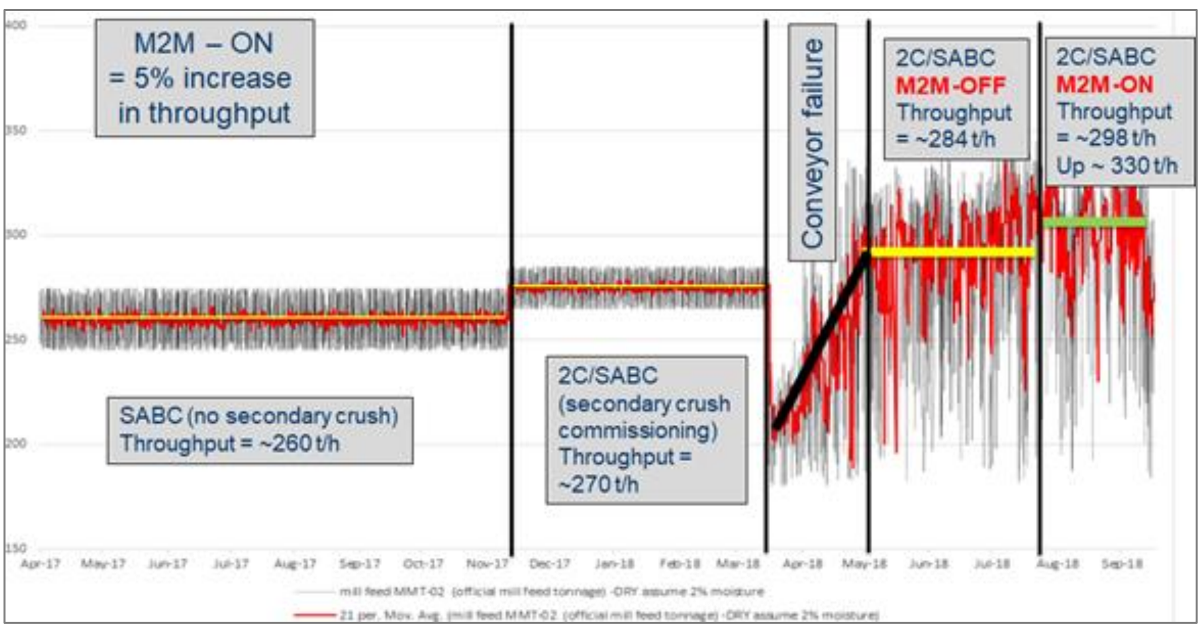


Figure 19 – D2M has Increased Throughput by ~5% to 298 t/h Since August 2018

Comminution Circuit Review Results

Since the introduction of intense blasting (D2M-ON) and progressive changes in the plant, we have seen a marked increase in circuit and equipment performance. Since the commissioning of the secondary crusher in November 2017, the plant has experienced steady performance. Overall, there has been an increase in crusher circuit capacity of 16.2%.

The HP4 crusher is working harder and the power draw of the crusher has increased by 30%. SAG mill throughput has increased by 11.6% and the SAG specific energy has reduced by 25.9% (Table 5).

Table 5 – Morrell Power Model Summary for theD2M ON/OFF

Description	Unit	D2M OFF (May, Jun, Jul)	D2M ON (Aug, Sep)	D2M ON (Oct, Nov) New Liners	D2M ON (Nov, Dec) Primary Crusher Repairs	% Increase D2M OFF/ON
Weightometer from conveyor CVR-02 (crusher circuit)	t/h	309	337	358	359	16.2
Secondary crusher power (HP4)	kW	80	83	96	104	30.0
SAG Mill feed tonnage – DRY (assumes 2% moisture)	t/h	284	298	304	317	11.6
SAG specific energy	kWh/t	10.8	9.4	8.3	8.0	-25.9

SAG mill throughput target (320 t/h) has been achieved intermittently, on average 317 t/h. The crusher circuit throughput lags by ~81 t/h less than the target value of 440 t/h. The new 160 kW Osborne primary crusher is due to be installed in November 2019, and EMC has made a number of recommendations for achieving 440 t/h throughput through the existing Aymak crusher.

Conclusions

JSC AK Altynalmas engaged EMC to conduct a drill-to-mill plant optimization project to determine what opportunities exist to increase the mill throughput and improve the overall mine and concentrator performance. The scope of the project included in-situ ore body characterization, drill and blast improvements, ROM fragmentation measurement and modelling, and crushing and milling optimization. Our drill-to-mill methodology involved comprehensive measurements at both mine and plant; extensive fragmentation and comminution modelling; wall-control for minimizing the pit wall damage; waste blast optimization to minimize the total waste mining cost; and minimization of ore loss/dilution.

EMC's drill-to-mill methodology delivered significant benefits to the site: increased fines from blasts (approximately 11% more fines, -10 mm; reduced ROM F_{80} from ~500 mm to ~150 mm; increased dig rates (about 25% to 30%); improved wall-control; reduced ore loss/dilution; increased crusher throughput (16.2%); and increased mill throughput (11.6%). The project results were achieved within the first six months of the project. The management team extended the study to another one-and-a-half years to further improve the circuit efficiency and explore potential circuit expansion options to deliver target company growth.

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