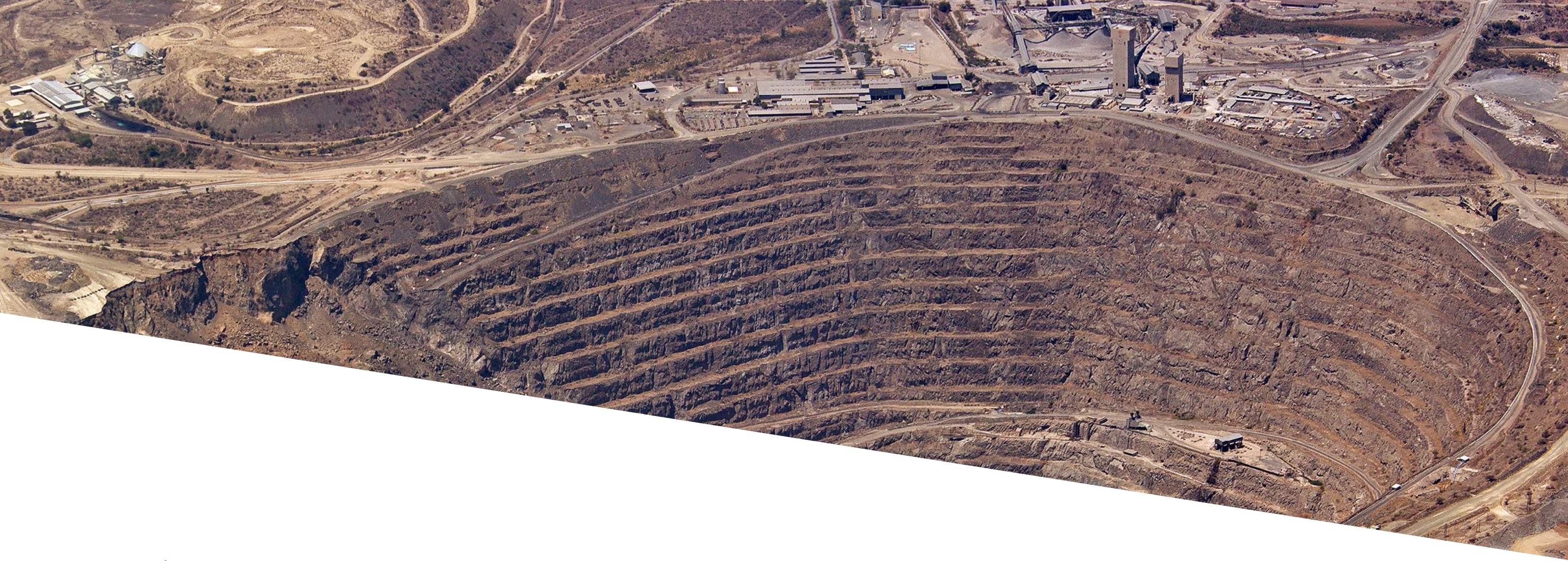

Managing the medium term mine scheduling challenges at Bingham Canyon Mine after the slide

Case Study

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Abstract

A massive slide at Bingham Canyon, in April 2013, wiped out a side of the pit and covered the main haul road in and out of the pit. All pre-slide mine designs and schedules were no longer valid. New designs and schedules needed to be developed quickly to provide management with information regarding the immediate post-slide production potential and the time needed to ramp back up to full production. At the time of the slide, an effort was already underway to convert Bingham's in-house Medium Term Scheduling Process to MinePlan (formerly MineSight) Schedule Optimizer (MPSO). One of the main reasons for doing that was to reduce the time needed to produce Medium Term Schedules at Bingham, which involves a complex shovel-based scheduling approach with shovel productivities based on shovel type and the types of mining cuts to which the shovel is assigned over each planning period. The objective of the schedule was to maximize shovel usage, satisfy mill feed requirements of four SAG mills with variable milling rates, and have flexibility in setting truck constraints.

This paper describes how the MPSO mine scheduling process met the challenge of producing new schedules for Bingham in a minimal amount of time.

Introduction

The Bingham Canyon Mine is an open-pit copper mining operation located southwest of Salt Lake City, Utah, USA, in the Oquirrh mountains (see Figure 1). The mine is owned by Rio Tinto Group, an international mining and exploration company headquartered in the United Kingdom. The copper operations at Bingham Canyon Mine are managed through Kennecott Utah Copper LLC (KUC), which operates the mine, concentrator plant, smelter, and refinery. The mine has been in production since 1906, and has resulted in the creation of a pit over 1 km (0.62 miles) deep, 4 km (2.5 miles) wide, and covering 770 ha (1,900 acres) (see Figure 2).

A collaborative effort with KUC mine planning department to convert Bingham Canyon's in-house spreadsheet-based Medium Term Mine Scheduling Process to MPSO utilizing database technology started in November 2012. The main reasons for the conversion were to reduce the time required to produce a Medium Term Mine Schedule at Bingham and to be able to generate alternative schedules. The ability to produce alternative schedules quickly was put to the test when a massive slide occurred at Bingham Canyon in April 2013. This paper will describe the MPSO-based medium term mine scheduling process now in use at Bingham Canyon. Attention will be given to several of the scheduling challenges cause by the slide and how these were handled to quickly produce updated schedules. Swift turn-around was essential to provide management with information regarding the immediate post-slide production potential and the time needed to ramp back up to full production.

Figure 1. Location of Bingham Canyon Mine, Utah, USA

Figure 2. Panorama View of Bingham Canyon Mine

Medium term scheduling requirements

Mine scheduling at Bingham Canyon emphasizes incorporating detailed truck and shovel performance data into the scheduling process. Coupling this with the need to provide mill feed to four different SAG mills, with differing throughput characteristics, and over 40 different material types and 15 different grade bins, results in a complex scheduling problem.

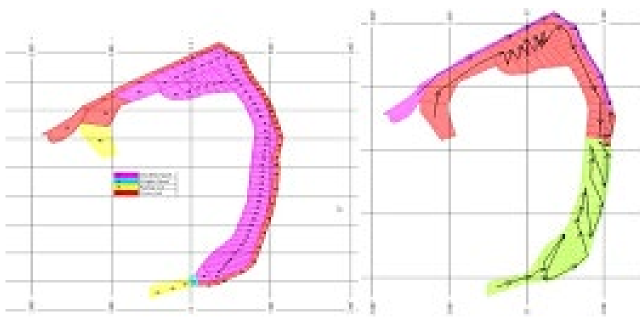

Figure 3. Types of Shovel Cuts

Shovel productivity data at Bingham Canyon is tracked by individual shovel, cut type and geometry. There are four different types of mining cuts, namely, 1) Ramp cuts, 2) Single spot cuts, 3) Double spot cuts, and 4) Trim cuts. Figure 3 illustrates different types of shovel cuts on a bench. Figure 3a shows the cuts on the bench with the various spot types. Figure 3b shows the three different shovels working on that bench and the shovel advance line for those shovels. Up to thirteen shovels work at Bingham at any one time. Mapping the shovels with the four different mining cuts results in 52 different productivity figures (expressed in terms of tons loaded/day) that can be used during scheduling. These productivity assumptions can vary over time. These assumptions, which included projected operating time, operating delay, downtime, availabilities and utilizations were stored in the MinePlan Planning Database (MPPD), a Microsoft SQL database.

Truck haulage is an important part of successful scheduling at Bingham with over 90 trucks in operation at any one time. The mountainous location of the mine, winter snow and poor visibility can slow and even stop production. Historical data on the effect of weather conditions are factored into the scheduling forecasts with a number of weather days to allow for in each period in the schedule. Slippery road conditions are also accounted for by specifying seasonal loaded and empty haul factors on a period by period basis. Multiple haulage attributes, such as the projected haul days, weather delay days, non- productive days, seasonal loading and empty factors were also stored in the MPPD. Similarly, truck availability data also varied by truck fleet type and time period. These availabilities and capacities were also stored in MPPD.

Detailed haulage calculations must be incorporated as part of the scheduling process at Bingham. This process used manufacturer rimpull curves derated by a certain percentage. In-pit haul profiles had to be maintained and updated during the scheduling process. Multiple paths out of the pit are common and the shortest path out from any shovel cut is not necessarily the path used depending on operational activities. Any haulage simulation based on shortest path out has to be controlled to allow alternative routes to be selected during a particular scheduling period. Temporary in-pit stockpiles of waste, out-of-pit ore stockpile locations, waste dumps and an in-pit crusher location comprise the material destination matrix with the stockpiles acting as both sources and destinations for haulage calculations. Multiple lift dumps with multiple dumping points on each lift and a specific dumping sequence on each lift had to be considered in the haulage simulations run as part of the scheduling process.

Four SAG mills are used to process the crushed mill feed provided by the mine. The SAG mills are located in Copperton and receive ore material from the in-pit crusher/ underground conveyor ore handling system. The number of milling days per planning period, the availability of each SAG mill (which also varies by planning period), and the tons milled/hour for each SAG mill based on material type govern the maximum amount of mill feed that can be scheduled each period. The individual SAG mills have different milling rates, which varied based on material type. These milling rates in (hours/ kTons) have been stored in the block model for each individual block. To accommodate the 4 SAG mills running in parallel at the Copperton plant, an equivalent SAG mill was simulated, which had the same milling capacity of all the four SAG mills running in parallel. The productivity of this equivalent SAG mill was calculated for each individual block in the model and based on availabilities the amount of hours needed to process the block by the equivalent SAG mill was computed. This was used as a constraint in the scheduling process.

Bingham scheduling reports require the reporting of three different types of concentrate tonnages and concentrate grades (weighted by the concentrate tonnages) in addition to the reporting of mined tonnages and grades. This required 25 additional block model items to allow this information to be tracked on a cut by cut basis during scheduling.

New Medium Term Scheduling Process

After the gathering of assumptions, preparing the designs, and coordination between all departments at the mine, the MPSO medium term scheduling process consists of three main steps:

1. Prepare the shovel cuts and associated information needed for scheduling the cuts

2. Update the haulage network and associated truck cycle times to be used during scheduling

3. Run the schedule and report the results

The shovel cuts are digitized on each bench and each cut polygon is attributed with codes indicating the shovel code assigned to the cut and the type of shovel cut (ramp cut, single spot, double spot, trim cut). Productivity information in the MPPD Shovel Productivity database table is then used to calculate the number of shovel days required for the assigned shovel to mine the cut. The shovel days stored in the database include the delays associated with mining the cut, such as blasting delays, delays due to shovel movement to the next bench, etc. As additional cuts for the shovel are digitized, accumulated tons and accumulated shovel days are updated and displayed. These running totals help the planner to properly design and attribute the cuts.

Upon completion of shovel cut preparation, the cuts are grouped by shovel number on each bench and a shovel advance line is digitized to define the order of cut extraction for each shovel on each bench. The order does not have to follow adjoining cuts. A shovel could start a sequence of single spot cuts on a bench, stop and mine a ramp cut, and then return to complete the sequence of single spot cuts (see Figure 3b).

The complete mine haulage network is set up, stored in the MPPD Haulage data tables, and updated as changes occur with mining activity and dumping activity over time. Figure 4 shows the typical haulage network for Bingham Canyon mine. In-pit ramp exit points on each bench are automatically linked to the centroid of each digitized shovel cut on each bench. The automatic link will adjust when necessary to ensure the on-bench path stays on solid ground. If a bench has multiple ramp exit points the shortest path to the destination will be selected, unless its selection is locked out by the planner. In other words, the planner can control on a cut-by-cut basis, which ramp exit point to use for the haulage simulation performed during scheduling.

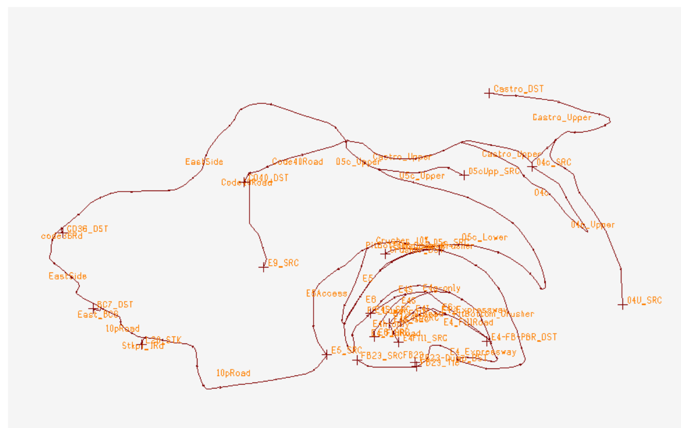

Figure 4. Haulage Network Used in Bingham County Mine

The haulage network to the multi-lift, multi-sub-zones on the lift dumps can be set up to cover the entire life of each lift on each dump or restricted to the lifts that will be active during the medium term scheduling time frame. MinePlan's Waste Dump Sequencer tool populates the MPPD Haulage database tables with a filling sequence on each lift and the tonnage capacity of each increment in the sequence (see Figure 5). Figure 5a shows the typical lifts and subzones in a dump as well as the dump road, while Figure 5b shows the filling sequence and other parameters filled in by the Waste Dump Sequencer. This filling sequence can also be user-defined. During scheduling each incremental area filled in the sequence is tracked on a period-by-period basis and the capacity flagged as used (or partially used) to simulate dump expansion while scheduling.

Figure 5a. Typical Configuration of a Waste Dump with the Haul Road on the Dump

Lift	Subzon	Capacity	Cumm	Capacity	Cumm	Elevation	Easting	Northing	H Dist(Feet)	Prox Dist(F	Prox Speed	Roll Resist	Preced
BC7-6490-DF	1	1137119	0	0	0	6490	6085.67	9774.67	1031.17	100	10	1	1
BC7-6590-1	1	1017648	0	0	0	6590	6085.67	9774.67	1031.17	100	10	1	2
BC7-6590-2	2	1020788	0	0	0	6590	6614	10399.77	1849.63	100	10	1	3
BC7-6690-1	1	1019610	0	0	0	6690	8130.6	8551	1465.84	100	10	1	4
BC7-6590-3	3	8594100.	0	0	0	6590	7809.44	10858.96	3130.23	100	10	1	5
BC7-6690-2	2	1008201	0	0	0	6690	8073.14	8886.17	1805.9	100	10	1	6
BC7-6690-3	3	1025387	0	0	0	6690	8228.54	8160.46	1868.48	100	10	1	7
BC7-6690-4	4	1011167	0	0	0	6690	8065.24	9202.51	2122.34	100	10	1	8
BC7-6690-5	5	1015904	0	0	0	6690	8201.14	9467.17	2419.85	100	10	1	9
BC7-6790-1	1	8500665.	0	0	0	6790	9130.6	8594.09	1204.23	100	10	1	10
BC7-6690-6	6	1012067	0	0	0	6690	8271.58	9727.92	2689.95	100	10	1	11
BC7-6790-2	2	9065428.	0	0	0	6790	9178.12	8357.13	1445.9	100	10	1	12
BC7-6690-7	7	1017940	0	0	0	6690	8400.54	9978.25	2971.55	100	10	1	13
BC7-6690-8	8	1010846	0	0	0	6690	8445.58	6900.47	3147.03	100	10	1	14
BC7-6790-3	3	9576371.	0	0	0	6790	9149.02	8091.6	1713.03	100	10	1	15

Figure 5b. Precedence, Capacity and Other Parameters Calculated by Waste Dump Sequencer

Truck cycle times for all paths in the haulage network are calculated by MinePlan's Haulage tool using equivalent rimpull and braking modeled curves. An equivalent rimpull and braking curve was created from different truck type to account for the multiple equipment fleets. Typically, with multiple equipment fleets, the scheduler would assign the best possible fleet to the best possible source-destination pairs (unless restricted by user) so as to maximize the NPV. However, for this schedule to be practical, it would necessitate the dispatch at the mine to send the trucks to mining area/destination pairs as shown by the scheduler instead of sending it to the next available destination.

The individual truck manufacturer rimpull curves were combined to make up a composite rimpull curve. The rimpull data converted into speed bin data (speeds at different road grades) for multiple truck types were combined such that the resulting equivalent truck with an equivalent speed bin curve would carry the same amount of material in the same amount of time as the combination of the various truck types running at their individual speed bin curves derived from the historical performance data. For example, if we have two fleets with two and three trucks respectively, such that fleet 1 carries 100 tons in 1 hour and fleet 2 carries 200 tons in 1 hour, then 5 units of the equivalent truck with the weighted average tare weight and carrying capacity will carry the same amount of tons (300 tons) in the same amount of time (1 hour). These equivalent rimpull curves were used for calculating the cycle time for the equivalent truck. Additional times were also used in the cycle times, such as load time, dump time, wait time at the crusher due to crowding, etc.

The cuts and haulage times are imported into MinePlan Schedule Optimizer (MPSO). Operational constraints on the schedule include:

- Number of shovel days for each shovel during each planning period in the schedule.

- Number of available truck hours for the equivalent fleet during each planning period in the schedule.

- Number of mill hours during each planning period in the schedule.

A script is used to generate the scheduler constraints based on productivity data in the MPPD database. The script exports the constraints to EXCEL which can then be imported into the scheduler from EXCEL.

Mill material quality ranges are also included as targets in the scheduling results. These include:

- Concentrate grades (i.e., copper con grades, etc.)

- Ratios of concentrate grades for different concentrates (i.e., cu grade con 1/cu grade con 2, etc.)

MPSO uses a Mixed Integer Linear Programming optimizer with an objective to maximize the shovel productivity while satisfying all of the operational and product quality constraints. The equipment capabilities (shovels, trucks, and mill) control the schedule results which ensures a production forecast that the mine and mill operators can achieve (unless something like a major slide gets in the way).

The scheduling results produced by MPSO are transferred into the Bingham SAP ERP database and combined with other data for final reporting in accordance with company standards. Reports include mine production by period, concentrate production by period and truck/ shovel hours by period. End-of-Period maps are also generated directly by MPSO using the shovel cut polygons and their scheduled removal times.

Figure 6. Slide Failure at the Bingham Canyon Mine (Courtesy: www.ksl.com)

Post Slide Challenges

The conversion of the Bingham spreadsheet-based scheduling process to the faster database oriented process was in the final phases of testing and verification when a major slide occurred at the Bingham mine (Figure 6). The slide wiped out not only a side of the pit but also all pre- slide mining plans and schedules for the operation. Several previously scheduled shovel cuts were now buried under the slide, and several haulage routes used in the previous schedules were no longer available. Mine management needed revised schedules quickly and the new process delivered. The following are examples of scheduling challenges caused by the slide and how they were handled in the new process.

One of the major impacts of the slide, apart from the spillover, was that it took out a portion of the main haul road. This main haul road was the only major haul access into the pit. This left the pit with two mining areas: one area below the removed portion of the haul road, which contains the ore; and the area above, which is mostly waste. Equipment couldn't be shared between the two areas and no equipment could be moved from one area to the next. Thus, the haulage now had to be planned as two separate fleets with trucks stranded inside the pit called the InPit fleet and the trucks outside called the XPit fleet. Since the main haulage road was scheduled to open up at a particular time, a third fleet was made called the Combined fleet. The scheduler was instructed to use the InPit and XPit fleets in their respective areas until the main haulage road was re-opened, and to then transition to the combined fleet for the remainder of the schedule. Figure 7 shows the transition period in the schedule set-up from using two separate fleets into a single fleet. The numbers have been blurred because of data confidentiality.

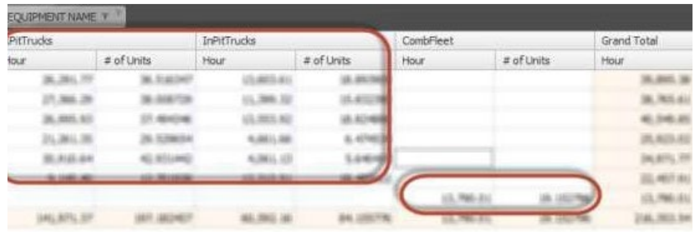

Figure 7. Transition of the Schedule from Using Two Fleets to a Single Combined Fleet

The collapse of the road added another dimension to the ore removal logistics since the ore crusher was inside the pit (in-pit crushing) while the ore stockpile was outside the pit, leaving no connection between the two. To account for this the stockpile had to be reclaimed to a different ore location and then fed into the SAG mills. Thus the scheduler had to now look at the combination of both the feed locations (in-pit crusher and stockpile feed) to check the constraint on the amount of material that the SAG mills can process. Also, all of the constraints on the concentrate grades and concentrate ratios were to be satisfied based on the combination from both the feed locations.

Hindered access also led to problems with waste dumping since all the dumps were outside the pit and had no access from mining areas below the removed portion of the haul road. Thus, the waste had to be dumped in the pit. Since the in-pit dumping areas were quite small, care had to be taken during scheduling to track dump progress so as not to fill all the areas before the scheduled reopening of the main haul road. Also, some of the in-pit dumping made additional road access points possible, and thus, the need of the haulage network to keep track of the dump to allow for these new access points to be used in the periods they became available. The in-pit dumping covered up future exposed ore. Thus, the scheduler had to give precedence to remove the dump as soon as the main access road opened up to allow the ore beneath it to be mined. Figure 8 shows the material flow among the various locations in the mine as set up in the MinePlanSchedule Optimizer canvas.

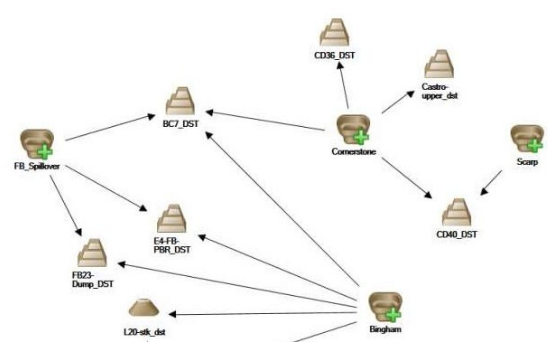

Figure 8. Material Flow Canvas Setup in MPSO

Due to very limited mining areas because of the slide spillover, roads had to be very carefully constructed. Some of the roads were constructed so that the direction of the loaded travel depended on which phase was being mined. Thus, after a particular phase is mined and the ore and waste are moved in a certain direction, the same road could be reversed to mine a different phase. Some roads were shared between multiple phases while other roads could be opened up after certain periods of time. To accommodate these operational adjustments during scheduling the individual roads were assigned phase and period constraints governing when and where they could be used. Also, the closest ramp entrance point for a cut may not always be available and thus there was a need to take a different path from the cut even though the path may not be the shortest time path. This was allowed by letting the user lock out specific cuts to specific ramp entrance points and then let MineSight Haulage pick the best path.

The spillovers were to be mined sometimes with shovels and sometimes with dozer push. When the spillovers were mined by dozer push, the dozers would push the loose material to a point below dozer working level where a shovel would then pick it up and load it onto trucks. Thus the mining cuts would be on one level while the truck haulage would start from a lower level in the pit. This situation was handled by forcing the cycle times to be computed from the lower level shovel locations rather than the original cut level. In essence, the cut material was allowed to "fly" to the shovel location (dozer push option).

Conclusions

The conversion of the Bingham Canyon spreadsheet-based medium term scheduling process to the database oriented MinePlan Schedule Optimizer process has been completed and is now being used by KUC mine planners. The new process significantly reduced the engineering time required to produce medium term schedules at Bingham without compromising the level of detail. In addition, it allows alternative schedules to be developed quickly by incorporating multiple case information in the design of the database tables containing the scheduling assumptions. The mine planner simply specifies a "Case ID" to generate schedules that can mix and match optimistic operating assumptions, standard operating assumptions, or pessimistic operating assumptions for example. The ability to adjust scheduling inputs to operational changes quickly was proven during initial use of the new process immediately after the April 2013 slide.

Acknowledgments

The work described in this paper was the result of a joint effort between KUC mine planners and MinePlan specialists. Nathan Armstrong and Denee Hayes worked closely with MinePlan to convert the medium term planning process and help MinePlan understand the intricacies and requirements of this process. Without their help and extensive participation, MinePlan would not have been able to understand and meet the needs of Bingham Canyon. The perseverance, patience, and hard work of all involved in overcoming the inevitable hurdles involved with planning process conversions to see the projct through to fruition is greatly appreciated. The support of KUC upper management, and in particular Cody Sutherlin and Brad Ross, is gratefully acknowledged.

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