An analysis of productivity in sublevel caving mines

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ABSTRACT

A useful way to assess potential productivity of SLC mines is by quantifying tonnes/drawpoint/day to be extracted from the mine. However limited industry information has been published to help mines benchmark this number. This paper assesses industry data which can be used to support estimates of potential productivity from new mines based on tonnes/drawpoint/day.

The information used has been extracted from historical production schedules which indicate what was achieved, rather than what was planned. It has been assessed using an algorithm created for the purpose and is presented with discussion of varying definitions of active drawpoints, analysis of the data and inquiry into some of the underlying contributing factors.

INTRODUCTION

A question commonly asked when planning a sublevel caving mine, or in assessing productivity in an operational mine, is how much should this mine be tasked to produce? One way of assessing this is in terms of production tonnes/drawpoint/day. This measure is conceptually a useful way to assess productivity as it is relevant for all stages of the mine's production cycle (ramp-up, steady state and ramp-down) and can be compared across operations of all sizes. By dividing the production of the mine daily (excluding development tonnes) by the number of drawpoints required to produce it, one can arrive at such a measure.

Over several years, Power Geotechnical Pty Ltd has provided services in the modelling of metal recovery based on production schedules for caving mines worldwide using its proprietary PGCA software. In the process of completing this work, schedules for operating mines have been compiled and analysed. Information from these analyses is used for the generation of benchmark information presented here. The main advantages of this type of analysis are that it looks at actual rather than planned production data, and compiles information from a range of mines to allow a broader base of comparison.

MINES ASSESSED

The names of the mines assessed here are not disclosed, however they have operated in a range of geotechnical conditions and under various production constraints. Figure 1 shows the calculated production for each of the mines daily. Steady state long term production rates range from approximately 4,000 tonnes/day to 17,000 tonnes/day on average, although daily production rates can vary more widely. Of the mines assessed, three are completed and two are still in production. All the mines have predominantly used the transverse SLC mining method.

METHOD OF ANALYSIS

To complete the analysis reported here, a simple computer algorithm was generated. This algorithm reads in each of the rings in the historical production schedule. For each ring it identifies the next ring in the schedule based on production dates and geometrical location of the rings scheduled.

For each of the rings assessed, recorded production tonnes are evenly distributed between the start and finish dates. Based on this process, the algorithm is then able to determine which rings are open for production on each day in the production schedule, and an estimate of how many tonnes were produced on each day, allowing for a calculation of tonnes/drawpoint/day for the life of the production schedule.

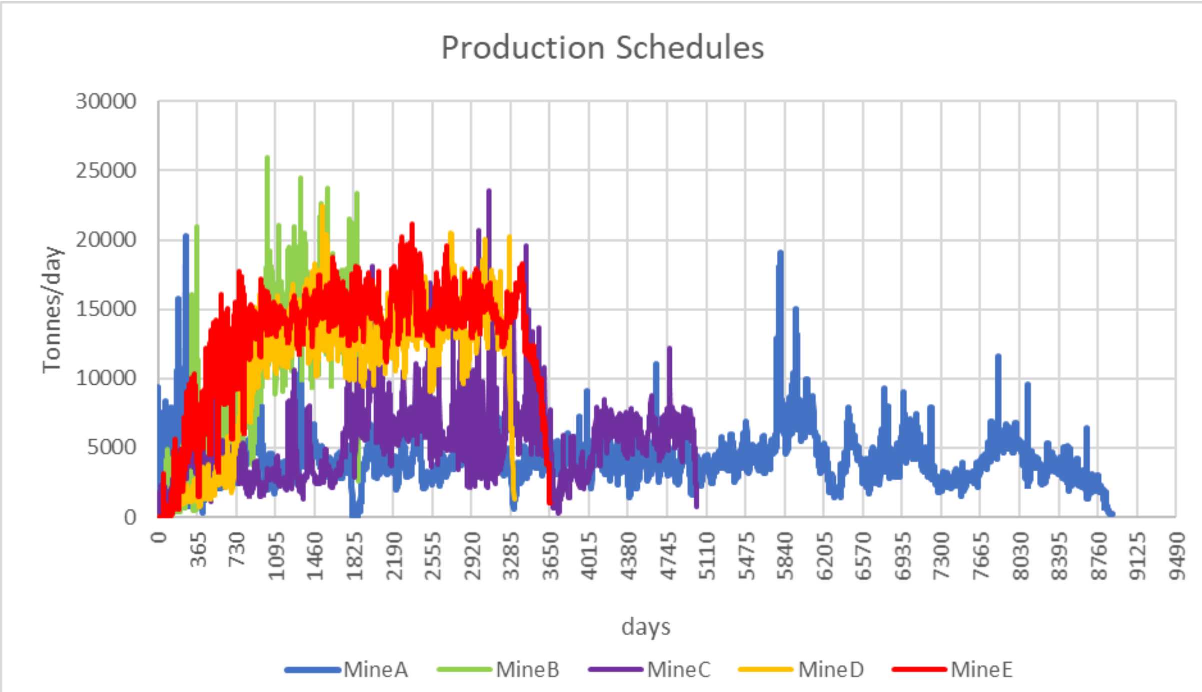

FIG 1 - Production rates for the mines assessed here

Some smoothing in the results is produced by the even distribution of tonnes between start and finish dates for each ring, but this does not affect the overall analysis. It doesn't change start or finish dates or change the count of drawpoints open at any point in the schedule. Estimates of tonnages produced daily will contain inaccuracies, but these will balance out as the long-term averages and trends are the targeted outputs of the analysis.

Historical production schedules often contain errors or missing data, therefore only rings with verified start and finish dates are included in the analysis. About 5% of the rings assessed in the schedules were excluded from analysis on this basis. This is not expected to significantly devalue the benchmark information generated.

This method should be easily replicated by planning teams which would like to check their proposed production schedules against the data presented here. The data for planned schedules should be much simpler to assess than historical data from operational mines, which can be difficult to compile if good record keeping of production history has not been carried out.

RESULTS OF ANALYSIS

Figure 2 shows a plot of tonnes/drawpoint/day calculated for each of the mines. It indicates significant fluctuations in tonnes/drawpoint/day over time for most of the mines, but a relatively stable longer-term profile in most cases. It also indicates differences between mines in overall production rate, length of production, and variability in tonnes/drawpoint/day. This is a result of specific factors in play at each of the mines, some of which are discussed further below.

Table 1 and Figure 3 show summary information for the mines assessed. These indicate an average value for tonnes/drawpoint/day of 255 across the life of all the mines assessed. Average production rates for the individual mines are lower than peak production rates as some of them include ramp-up periods as long as three years (as can be seen in Figure 1). Minimising time required for mine ramp-up in a new mine is important in generating early revenue and pay back on investment (and a significant advantage of SLC as a top down mining method). While a fast ramp-up is desirable, the time required for this should not be underestimated.

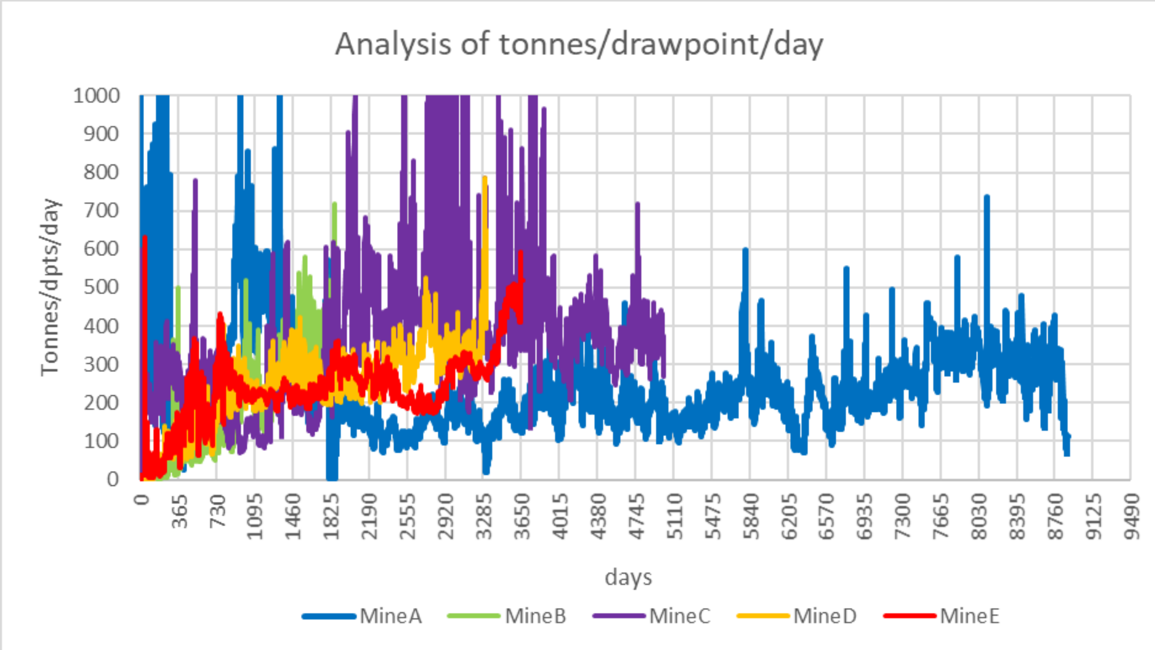

FIG 2 - Plot of tonnes/drawpoint/day over time

TABLE 1 - Summary information on tonnes/drawpoint/day for the mines assessed

	5th percentile	50th Percentile	95th Percentile	Average	Average tonnes/day	Draw control method
Mine A	103	212	446	237	3,950	Geological
Mine B	5	180	428	191	9,788	Tonnage
Mine C	124	349	638	360	5,135	Geological
Mine D	60	258	378	246	10,538	Tonnage
Mine E	42	233	413	240	12,767	Tonnage
Average	67	246	461	255	8,436	

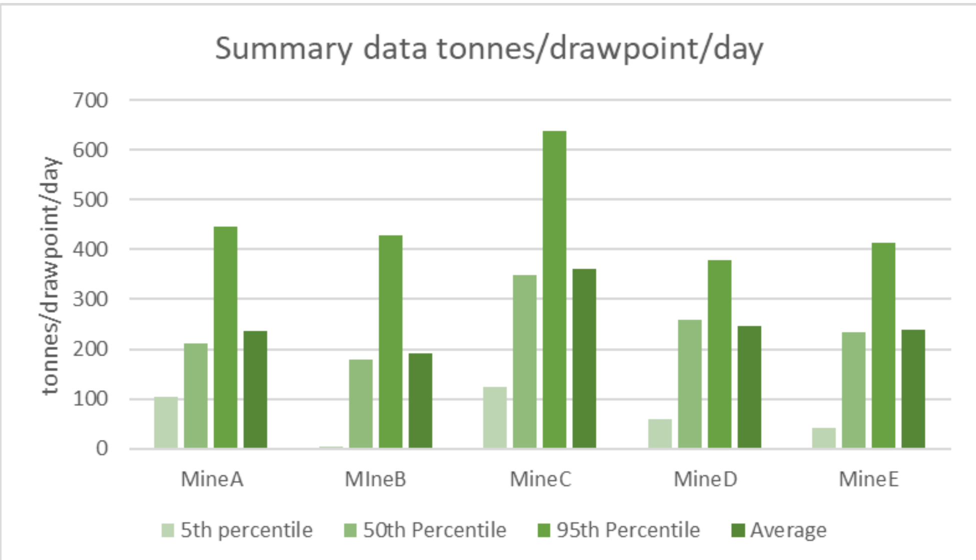

FIG 3 - Summary information form mines assessed

DISCUSSION

It is important in interpreting this information to understand the limits of the data in its specific context, and the limits of the use of benchmarks in general. The information presented here is most useful at the early stages of a mine design. At more detailed study levels, it is more useful to find and if possible, visit mines which are like the mine being planned in terms of layout, ground conditions and draw control strategy to be followed. If an operational mine is being assessed, and data from this mine is available, then information from this mine should always be used in preference to benchmarks generated under a range of different conditions elsewhere.

One of the most important issues in generating a value for tonnes/drawpoint/day is the definition of an available drawpoint. If this data is to be used for benchmarking of other operations, it is important that the same definition for available drawpoint be used for the mine being assessed as has been used here. In this case, due to the method of analysis used, a drawpoint is deemed as available if it has been fired, and the succeeding drawpoint has not yet been fired.

In reality, a drawpoint deemed available by this method, may not actually be available. It may be hung-up, geotechnically unstable, undergoing ground support or in preparation for the next ring to be fired - or for several other reasons. Using a calculation technique which rules drawpoints as un-available for these reasons results in tonnes/drawpoint/day values which are appreciably higher. Some benchmarking carried out in the past has used this methodology (Power and Just 2008).

The method presented here is considered more rigorous because the data required for calculation is much more widely available over the history of the life of the mine. For instance, mines often don't keep good records of which drawpoints were shut down due to ground instability or ground control work over the life of the mine. Further, predictions of this nature can't be accurately made for planned mines, whereas the method shown here is simpler and can be used for analysis of scheduled of future as well as historical mines.

Figure 1 indicates that the mines assessed here have a reasonably wide range of production rates. Ground conditions across the different mines also vary widely. Even so, the average production rate across all the mines assessed ranged between 191 and 360 tonnes/drawpoint/day. Therefore, if a mine is being planned, and has its schedule assessed in the same way as has been described here it can be checked against this range. If its assessment generates an estimate of tonnes/drawpoint/day outside this range then it could be concluded that the schedule is not within the benchmarked range, and possibly unrealistic.

It should also be noted that none of the mines assessed here were iron ore mines. As the density in iron ore is significantly higher than ores in other SLC mines, this should be factored in if assessing an iron ore SLC mine. Similarly, the layouts in the benchmarked mines were all similar (around 15m crosscut spacing and 25m sublevel spacing). Assessment of an iron ore mine with much larger ring volumes and tonnages (e.g. 10,000 tonnes vs approximately 2,500 – 3,000 for the benchmarks here) would potentially be outside the limits of this benchmark data – at least until some operational iron ore mines were to be added to the database and analysed).

Impact of specific conditions at the mines assessed on the results achieved are sometimes not what would be expected. For example, it might be assumed that mines achieving tonnes/drawpoint/day values at the lower end of the range shown would be those with the more challenging ground conditions, equipment constraints, or lower overall production rates. However, if anything, the converse seems to be the case.

Figure 4 is a plot of tonnes/drawpoint/day against production rate (tonnes/day) and indicates that there is no clear correlation between production rate and productivity. Mine C (having the highest value for tonnes/drawpoint/day) is in fact the second lowest in terms of production rate, indicating that available drawpoints are being pushed as hard as possible to meet production targets.

If Mine C is treated as an outlier, it can be argued that all the mines sit between approximately 200 and 250 tonnes/drawpoint/day. This is quite a tight range and is considered useful for the planning of new mines. Anonymity of benchmarked mines prevents a more detailed analysis of specific production conditions at individual mines; however the author has visited all mines in the benchmark and considers it reasonable to take this approach.

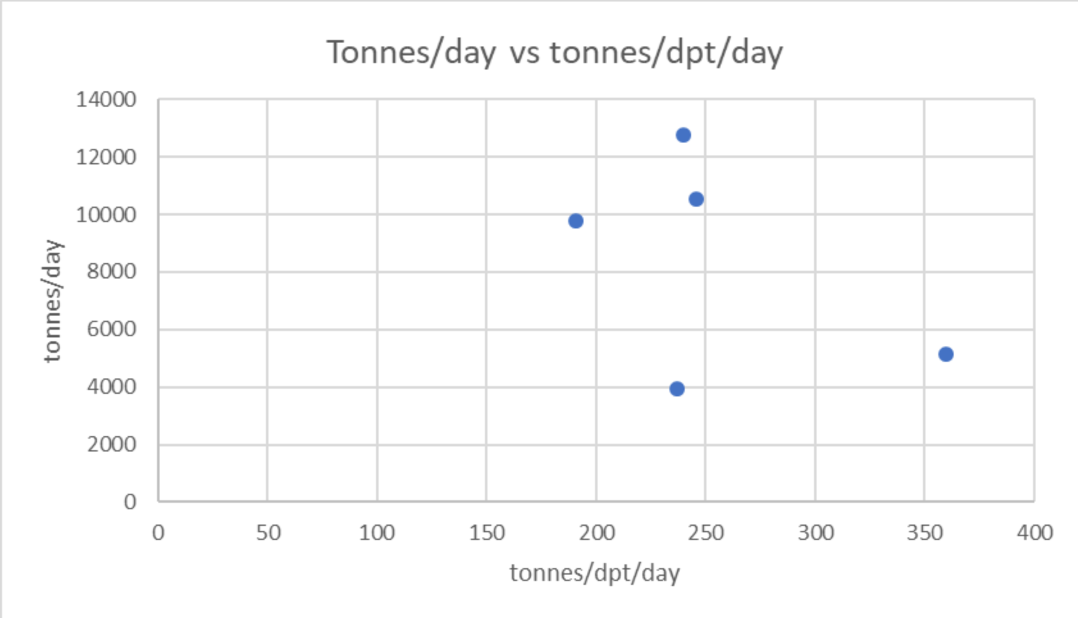

FIG 4 - Plot of tonnes/day vs tonnes/drawpoint/day

Another interesting observation is that the two mines with the lowest production rates are also the two mines which operated under a geological draw control system while the three mines with the higher production rates worked on a tonnage control draw control system (Table 1). These geological control mines were also older mines with longer production histories and older production fleets.

A geological control draw system requires a geologist to physically check each drawpoint at prescribed intervals to determine whether the geologist's estimate of the current grade in the drawpoint is high enough for draw from this drawpoint to continue. A tonnage control system uses some calculation method (spreadsheets, numerical modelling etc) to pre-determine what should be drawn out of each drawpoint without the absolute need for a geologist to physically visit the drawpoint. The practical advantages tonnage control systems are that they:

- Allow the entire life of mine recovery on a drawpoint by drawpoint basis to be estimated from the beginning, and updated as calibration information comes in from operational mine production;
- Minimise personnel moving around in the production levels (a safety and productivity advantage);
- Simplify management of daily production because loader operators know where they will be operating and how much they will be drawing from all production sources for the full shift at the beginning of that shift;
- Reduce variability in draw on a ring to ring basis and the likelihood that individual drawpoints will be significantly overdrawn pulling spikes of waste through ore blankets;
- Can account for ore that is not actually visible in the drawpoint, and allow for waste to be drawn through if economic amounts or ore are known to lie above;
- Allow simulation of different draw control scenarios to assess the impact of different strategies on dilution and recovery and select the strategy which best suits to companies' economic priorities;

For these reasons, the mines in this dataset with the higher production rates use a tonnage control system, and these mines produce recovery factors which are at least equal to the geological control mines. As shown in Figure 5, metal production forecasts from tonnage-based draw control systems can be remarkably accurate (Campbell and Power 2016)

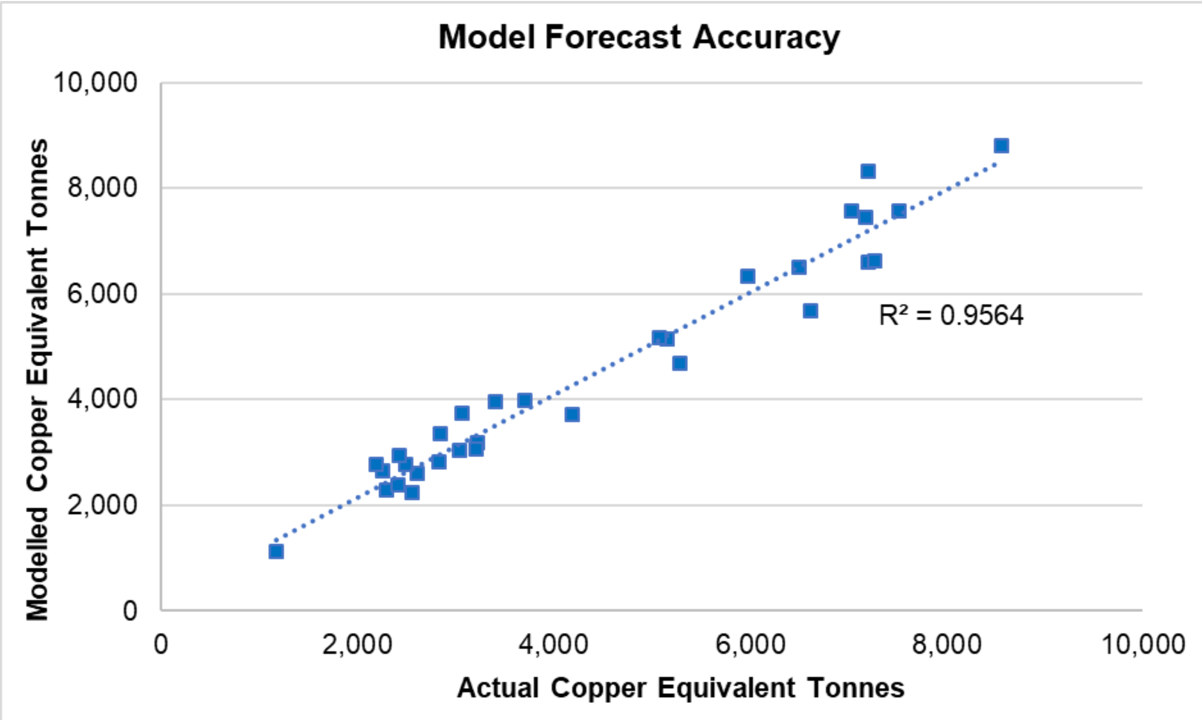

FIG 5 - Modelled copper equivalent tonnes compared to actual copper equivalent tonnes, monthly from March 2013 to September 2015 (after Campbell and Power 2016).

In the discussion above, it is mainly average values which have been discussed. This is because this work is mainly targeted at the planning of new mines, where average values will be most useful. However, within individual datasets, the average number does not tell the whole story. Figure 6 below shows information from the analysis of the schedule for Mine D.

In this case, the ramp-up period of approximately three years is evident in the plot of open drawpoints, with open drawpoints being increased at a rate of approximately 20 per year before stabilising in this case at around 50. Tonnes/drawpoint/day increases over the ramp up period as the mine's production systems are bedded in, remains relatively stable for the next 4 years or so, and then increases at the end of the mine life. This is because over draw strategies are being adopted to recover as much metal as possible from the mine before it closes. At the same time, the number of drawpoints available is being slightly reduced (in this case because of reductions to the mining footprint). The limited variation in the plotted values is characteristic of a tonnage controlled mine and is important in preservation of dilution blankets and deferment of dilution entry.

Figure 7 shows the same information for Mine A. This indicates a lot more variability, which is customarily associated with a geologically controlled mine. This draw control variability (with rings in cases drawing more than 1000% draw) has potential negative impacts for dilution control and also mud rush, if other contributing factor are also present (Butcher, Stacey and Joughin, 2005). In this case the mine started beneath a pre-existing operation which allowed high levels of overdraw at the start of the mine, rather than the ramp-up associated with a new mine. Available drawpoints were fewer than Mine D, leading to a lower production rate, however the averages in terms of tonnes/drawpoint/day are similar, and increase in a similar way at the end of the life of the mine.

Significant further information could be gained from the benchmarking of the characteristics of a wider range of SLC schedules. This would be rendered more valuable if it were possible to present accompanying information on conditions at the mines involved, and if a wider range of SLC variations, ore types and layouts were considered.

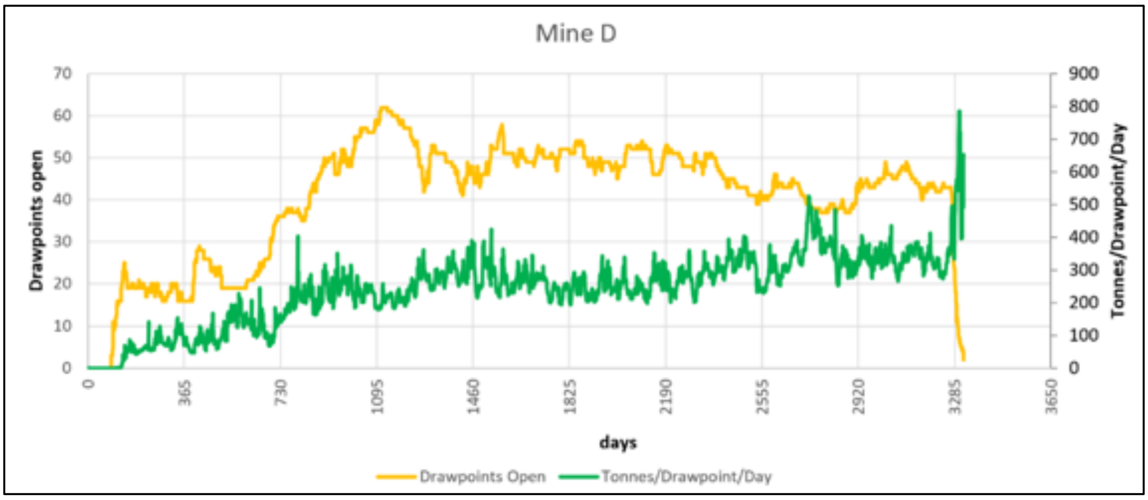

FIG 6 - Information from analysis of schedule from Mine D.

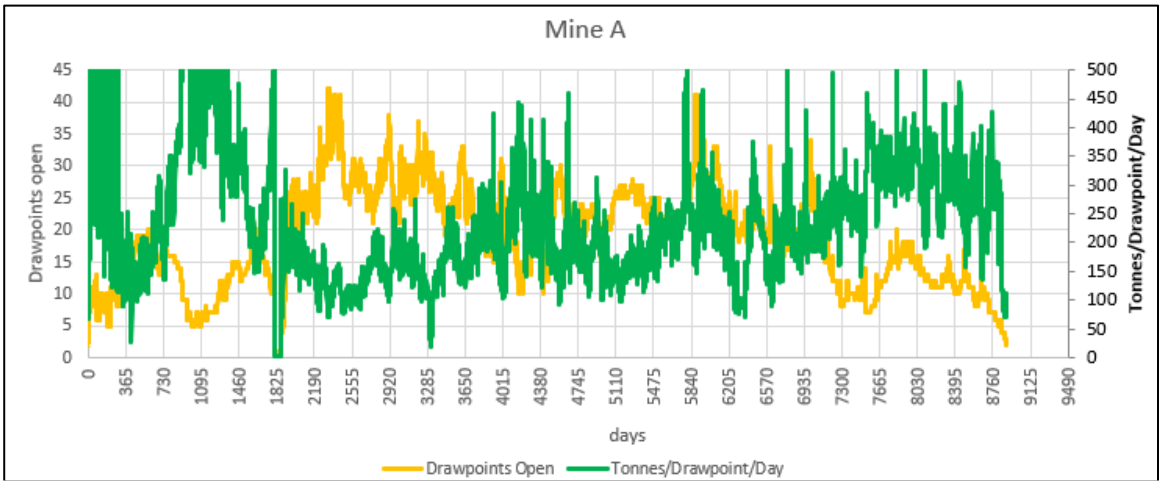

FIG 7 - Information from analysis of schedule from Mine A.

CONCLUSION

A method has been presented for calculating tonnes/drawpoint/day for transverse mines which can be checked against benchmarked mines which have had the same value calculated in the same way. This allows schedules for new mines to be more accurately benchmarked to indicate whether the assumptions driving them have generated a realistic schedule. Since no longitudinal mines are included in the benchmarked mines, use of this benchmark for a longitudinal mine would be less applicable until more data from such mines is analysed.

Of interest would be the generation of a more extensive historical database for further benchmarking using this technique, both in terms of more transverse mines, and a collection of data for longitudinal mines, for which the statistics are likely to differ.

Analysis of the data has shown that for a variety of transverse SLC operations in different orebody geometries and rock mass settings, a tonnes/drawpoint/day value of 200 – 250 is a reasonable assumption for early planning studies, as long as the method used to calculate this value is identical to that set out here. Some advantages of a tonnage-based draw control system have been demonstrated and linked to the data presented here.

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