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Improved Drilling Controls Through Forecasting

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ABSTRACT

Larger mines spend millions of dollars annually on rock drilling tools, but often purchase based on historic consumption. The results vary from excess inventory to acute tools shortages. These lead to emergency sourcing, sometimes mixing products that don't perform optimally. Boart Longyear analyzed the usage pattern of 96 thousand drill bits at thirteen different underground mining contracts, showing very high variability. The monthly standard deviation on a product level was 42%, with the highest for development and low volume bits. A new rule of thumb is suggested to carry only one month of safety stock for high volume bits, but increase to three months for low volume bits. This balance will reduce the risk of outages with less inventory. The accuracy can be improved by considering the specific conditions at each mine and reclassifying individual bits for a different safety stock level. Root cause analysis and collaborative forecasting between mines and suppliers can lead to further optimization of availability and inventory levels.

PROBLEM STATEMENT

Measure-While-Drilling is used to predict downstream impacts, but mine operators do not reverse the flow of geomechanical knowledge and production plans to forecast rock tools usage. Conventional wisdom has it that historic consumption is a good enough predictor of future rock tools needs. The average monthly consumption from the past is used to forecast what is needed in the following months. A common practice is to purchase one month's expected usage while having another two months' worth of safety stock. Theoretically, the inventory level will fluctuate for between two and three months of usage. While this sounds sufficient, we know empirically that mines often under forecast. No mine is shut down because of a lack of rock tools, but shortages impact both sourcing teams and operations. Emergency sourcing takes away from other priorities and typically increase costs, while product substitutions or mixing of brands can lead to poor drilling performance.

Boart Longyear decided to challenge the old rule of thumb by analyzing reliable, actual consumption data from mining contracts. To limit the scope, we focused on drill bits since bit consumption has the highest degree of variability. The analysis is exclusively based on tophammer drill bits used in underground metals mining. Leveraging sound statistics, the objective was to identify better ways to forecast, to manage inventory, and eventually drive longer, more consistent bit life. Conceptually the logic is a proxy for all rock tools and types of drilling applications.

BASIC METHODOLOGY

The starting point was to base the statistical analyses on as much compatible bit data as possible.

- Thirteen underground mines in Peru, all metallic and using tophammer drilling for both development and production drilling.
- All sites under Boart Longyear tooling contracts.
- Mix of small to large operations, with tools contracts ranging from less than US$250k to more than US$2M per year.
- Identical reporting processes with monthly inventory tracked by Boart Longyear.
- Planned constant production or amount of drill meters.

The analysis followed the following steps:

1. Narrow the list to the regularly used bit designs. This eliminated test, specialty, or rarely used bits. It reduced the "high runners" to between two and seven bit part numbers (SKUs) per mine.

2. Scrub the data by eliminating time periods or bits where there is an obvious change in operations.
3. Calculate average monthly consumption per SKU and site. These ranged from 13 to 1191 bits per month. The mean of the averages was 123 bits per month.
4. Calculate standard deviation of monthly consumption, per SKU and site. The standard deviations ranged from 5% to 82% of each individual average.

Table 1 shows the range and sheer volume of data underlying the analysis. The tabulated standard deviations are weighted averages of all the tracked bits at each particular mine. It was calculated as a measure of predictability by site. The range clearly shows that all mines are not created equal. Any rule of thumb for variability, or by extension the required drill bit safety stock, must be taken in the context of each mine. This analysis does not attempt to identify the underlying causes by mine, but the root causes likely trace back to consistency of ground conditions, drill maintenance, and operator training. In the table, it can be seen that more data tends to reduce the standard deviation, but the correlation is quite weak.

DETAILED CORRELATIONS

One might want to dismiss some of this data as too limited in time to establish good averages and standard deviations. Unfortunately, as shown in Figure 1, variability does not reduce with time. The standard deviation is just as high for bits with 2 years of history versus ½ a year! This means that the variability is intrinsic and based on true variability in drilling conditions. For example, any site may range from relatively solid and non-abrasive rock to highly abrasive and broken ground.

Table 1. Consumption of 96,451 drill bits, 60 SKUs, at thirteen mines over a 22-month period

Mine	Primary metals mined	Bit designs tracked	Months of data	Total bit volume	Standard deviation
A	Zinc, lead	5 SKUs	19 to 22	6386 bits	28%
B	Silver, gold	4 SKUs	7 to 22	5446 bits	40%
C	Silver, gold	7 SKUs	4 to 22	7216 bits	35%
D	Silver, gold	7 SKUs	6 to 22	9156 bits	29%
E	Gold	5 SKUs	11 to 21	8894 bits	24%
F	Silver, gold	3 SKUs	13 to 15	957 bits	54%
G	Gold	5 SKUs	4 to 10	1287 bits	29%
H	Gold	2 SKUs	21	33200 bits	22%
I	Silver	5 SKUs	8 to 21	6926 bits	46%
J	Gold, copper	5 SKUs	11 to 17	4856 bits	57%
K	Silver	3 SKUs	9 to 21	3028 bits	60%
L	Copper, lead	7 SKUs	3	7955 bits	24%
M	Silver, lead	2 SKUs	16-19	1144 bits	39%

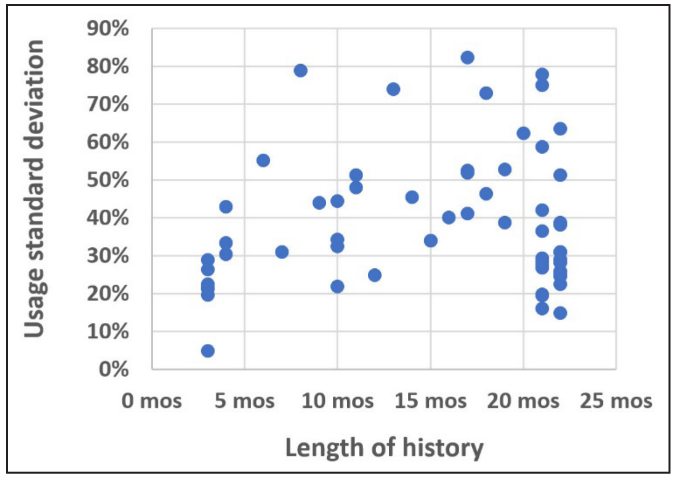

Figure 1. Standard deviation of monthly bit usage by SKU and site plotted against the months of data. A longer history does not make consumption easier to predict

By contrast, the monthly volume correlates very highly with variability. As shown in Figure 2, high volume bits have a fairly steady usage. This is quite logical since the same SKU is likely used on multiple drills across different areas of the mine in any given month, providing a natural and continuous averaging. In contrast, low volume bits can have anywhere from low to extremely high variability. For later use in inventory modeling, it was decided to divide bits into three categories:

- Low volume, <50 bits per month
- Medium volume, >50 but <200 bits per month

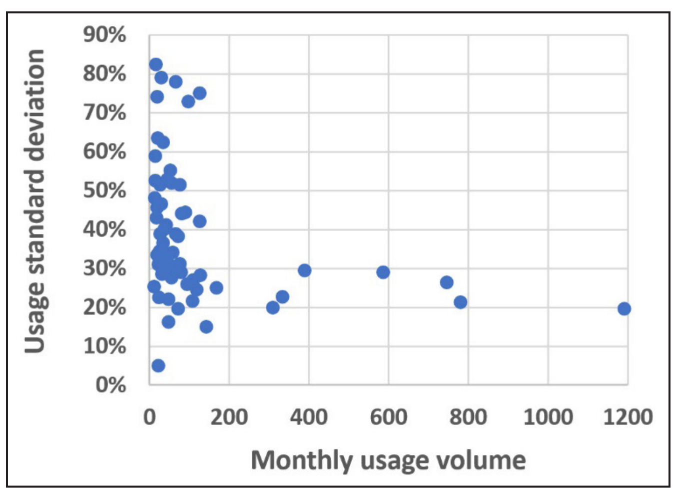

Figure 2. Standard deviation plotted against average monthly bit consumption

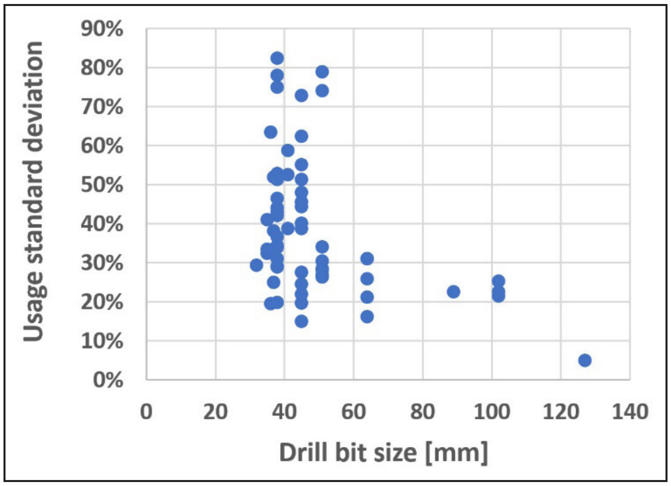

Figure 3. Standard deviation shown against bit size diameter, including smaller development bits and larger longhole or reaming bits

- High volume, >200 bits per month

In Figure 3, the standard deviation is compared to the bit size. It shows a strong correlation with larger bits having much smaller variability. Bits 64 mm [2 ½"] in diameter and larger are used for longhole drilling alternatively reaming in development drilling. For the longhole bits, two factors may contribute to relatively stable consumption:

- Drill meters in ore production is likely somewhat flat driven by the tonne capacity of the downstream processing operations.
- Compared to the amount of drill meters, there are relatively little collaring for longhole bits.

The 51 mm [2"] and smaller bits are used for development drilling. Statistically, there is no difference between bolting bits and face drilling bits. For inventory planning purposes, the data indicates that development bits should be assumed to be more variable than the larger bits.

TOTAL CONSUMPTION VARIABILITY

All data by SKU and site were normalized to make the monthly average consumption 100%. Actual consumption in each month was then calculated as a percentage. For instance, if a particular average is 123 bits per month but the consumption in June was 86 bits, that generates a 70% data point. If the consumption in July was 148 bits, that data point is 120%. Combining all SKU, sites, and months leads to the histogram shown in Figure 4.

Monthly variability has a staggering standard deviation of 42%. Bear in mind that this data has been scrubbed, only the "high" runners with regular use are kept, and the mines all claim to have stable production. With Vendor Managed Inventory (VMI), this data has an inherent bias towards less variability; it can be expected that many mines have even greater variability.

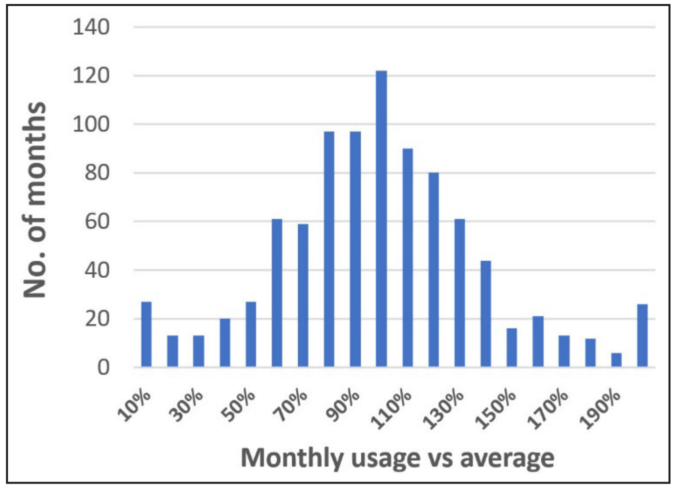

Figure 4. Histogram of monthly bit consumption around each bit's average

An appealing explanation for the high standard deviation would be that one month is too short a time period. The arguments would be that situations with exceptional rock conditions don't persist or rigs are repaired and returned to service. Over- or underconsumption of drill bits in one month should be compensated with the opposite in the following month. There is obviously some truth to these arguments, but as shown in Figure 5, variability remains high at a 29% standard deviation even when using a three-month sliding average.

Based on these variabilities, it would be tempting to write off forecasting based on historic averaging as a fruitless exercise. That cannot be the case – knowing that a bit averages 50 vs 500 per month has value – but it means that

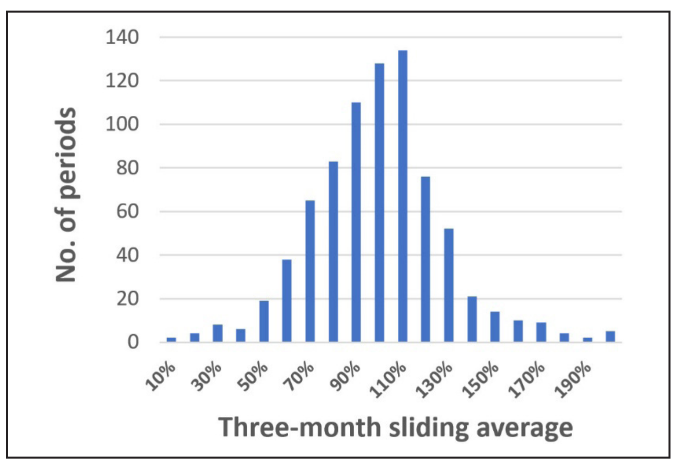

Figure 5. Bit consumption based on three-month sliding averages

a better forward outlook is required if the goal is to ensure availability with the least amount of inventory. The full data set implies that forward looking forecasting should allow for up to ±60% monthly demand variability and quarterly about ±40%.

INVENTORY MODELING

To develop better forecasting, the data was used to model inventory levels. Figure 6 illustrates the monthly inventory levels for three representative low, medium and high volume bits. It appears like a "random walk" as consumption is sometimes above and other times below average. The consumption rate is from actual data whereas the bit inventory is modeled, starting with two months of safety stock and replenished at the monthly average, following the old rule of thumb. The purpose of this model is to show how often manual intervention is required to prevent outages. A negative inventory is obviously not possible but is used to count the occurrences of emergency sourcing.

In Figure 6, one of 64 data points is negative, giving a 1.6% outage rate. A different safety stock would simply shifts the curves up or down, affecting the percentage of outages. Although just examples, the curves also illustrate how lower volume bits have higher variability. Following the old rule of thumb, the high volume bit appears overstocked while the low and medium volume bits appear understocked. In this illustration, the medium volume bit stocked out in one month, while the low volume bit almost stocked out over several months.

Based on all 60 SKUs across the thirteen mines, different safety stock levels were experimented with to evaluate the effects both on outages and total inventory volume. The base case is to have two months of safety stock for all bits – low, medium, and high volume. As modeled, the base case results in outages 3.5% of the time. The logic is the same as in Figure 6, except with 60 curves. The corresponding inventory level is normalized to 100%. Not surprisingly, running the inventory leaner, basically shifting the curves down, increases the outages, while excess inventory reduces the outages. One month safety stock results in 10.0% outages, while three months safety stock reduces it to 1.3%. The balanced case simply cuts the safety stock of high volume bits from two to one month while increasing the safety stock of low volume bits from two to three months. Medium volume bits are left with two months of safety stock. The result is 14% less inventory while reducing the outages by 30% (from 3.5% to 2.5%). These percentages are directionally meaningful but should not be taken as real-world outages in any particular mine.

It can be argued that the high volume bits are most important to mine operations. It therefore may seem counter-intuitive to shift safety stock to the low volume bits. Nevertheless, this is what the data tells us if we want to balance availability and inventory. The new rule of thumb then becomes:

- Low volume – *3 months' safety stock*
- Medium volume – *2 months' safety stock*
- High volume – *1 month safety stock*

Although this "rule" is directionally supported by large amounts of data, it should be adapted for each site, e.g.:

- The general variability of a mine may be higher or lower
- The cut-offs of 50 and 200 bits per month may be changed
- Longhole bits may be reclassified for less safety stock
- Development bits may be reclassified for more safety stock

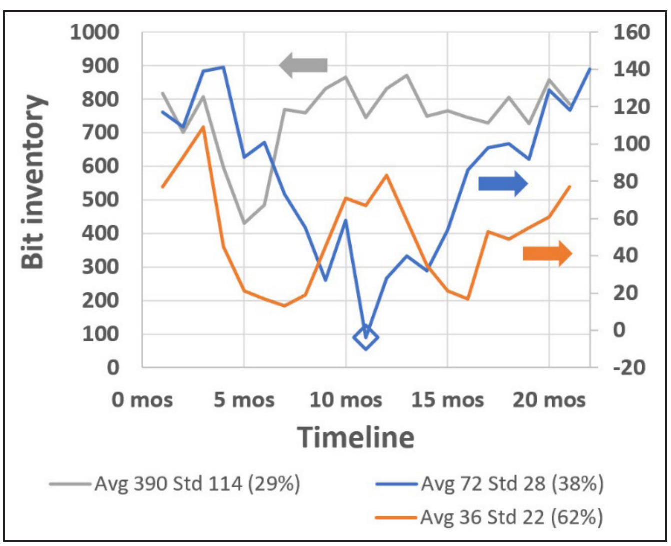

Figure 6. Model of inventory levels based on select bits and actual consumption data

Table 2. Impact on outages and inventory with selective safety stock levels for high, medium, and low volume bits

Case	Months of safety stock			Inventory outages	Relative inventory
	<50 bits	<200 bits	>200 bits		
Base	2	2	2	3.5%	100%
Lean	2	1	1	10.0%	71%
Excess	3	3	3	1.3%	133%
Balanced	3	2	1	2.5%	86%

FUTURE DEVELOPMENTS

A better forecasting model would be to actually plan bit consumption based on future drilling demands. This ties back to the geomechanical properties of the rock, which to some extent are known to Mine Planning. To keep it practical, the following framework is suggested:

- Plan rock tool demands three months forward
- Engage Mine Planning for future drill meters and anticipated rock conditions
- Adjust 1-month demand ±30% if drill meters are lower or greater than normal
- Adjust 1-month demand ±30% if ground conditions are less or more demanding than normal (abrasive or broken ground)
- Close the loop to check the forecast three months prior for biases towards over or under forecasting

These adjustments to the forecast could possibly allow safety stock to be reduced to one month for all drill bits.

CONTINUOUS IMPROVEMENT

Mathematics alone does not increase tool life, but use of statistics allows for analyzing and tracking. By addressing the root causes behind premature or avoidable tools damage, the average life increases while the variability is reduced. Graphically, the objective is to tighten and shift the bell curve as illustrated in Figure 7.

Addressing root causes requires technical expertise in materials technology, stress analysis, and best practices. Even if miners have the expertise, focus is often on other pressing operational issues. Most mines would benefit from engaging suppliers, drillmasters, or other third parties to improve drilling and specifically tool performance. For various reasons, a staggering amount of tools are discarded before reaching their wear limits. Figures 8, 9, and 10 illustrate some of the premature failures that, if addressed through operator training, could increase average life and reduce variability.

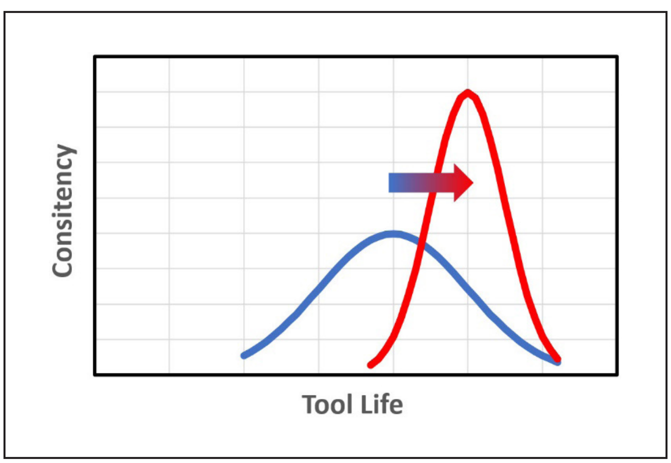

Figure 7. Leverage statistics to track and increase tool life

Figure 8. Lost buttons, resulting from poor collaring using too much power and/or no rotation

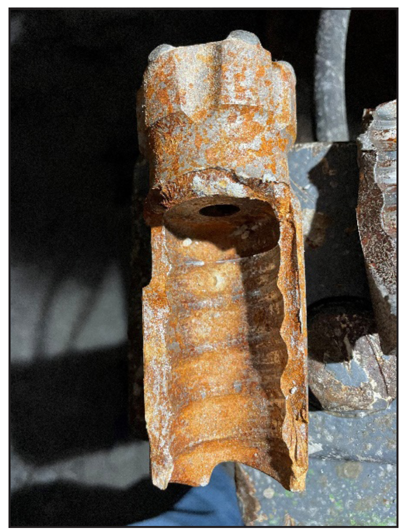

Figure 9. Broken thread, resulting from insufficient torque and/or excessive side loading

Figure 10. Premature button breakage, resulting from too slow rotation and/or broken ground

CONCLUSION

The conventional wisdom of having two months' worth of drill bit safety stock is not a good rule of thumb. Even with the benefits of a VMI, changes in drilling conditions drive a very high variability from one month to the next. The monthly standard deviations of 42% only falls to 29% on a three-month sliding average. In practice, this means that there is a risk of tools outages even with the safety stock.

Low volume bits have much higher variability than high volume bits. An improved rule of thumb is therefore to limit high volume bits to one month of safety stock, while simultaneously increasing the safety stock of low volume bits to three months. Boart Longyear's data indicates that this balance will reduce the risk of outages while simultaneously reduce the inventory. A practical implication is to standardize on as few SKUs as possible.

This new model should be adapted for the more variable or consistent conditions in each mine. The suggested cutoffs of 50 bits and 200 bits between low, medium, and high volume bits can also be changed. Bits for longhole drilling may require less safety stock and bits for development may need more safety stock.

It may be possible to replace the backward looking model with a simple forecast based on the mine plan. The data indicates that a forecasting model could be as simple as planning three months ahead and tweak the expected consumption by ±30% to account for ground conditions and ±30% for changes in drill meters.

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Innovative Approaches to Building Technical Capability for a Modern Mining and Metals Organisation

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ABSTRACT

Rio Tinto has a large globally distributed technical workforce and needs to ensure these employees have the requisite skills to not only manage technical risk and enable safe efficient production, but also ensure they are keeping pace with a fast-changing technological landscape. Traditional approaches to learning struggle for scale and an inability to respond to the extreme diversity of capability development needs. In response, Rio Tinto has successfully introduced innovative approaches to learning and employee engagement via leveraging the power of globally distributed networks for peer-to-peer knowledge transfer and providing mechanisms to recognise, reward and retain the individual technical contributors.

INTRODUCTION

Like other mining and metals organisations, Rio Tinto is dependent on high quality technical expertise to find, study, build, operate and close the mines and processing facilities that provide the metals and minerals that underpin our modern society. Arguably, the calibre of the technical workforce together with the quality of the mineral resources represent the core sources of competitive advantage for any minerals company. As one of the largest minerals producers in the world, Rio Tinto employs a large global technical workforce, currently around 10,000 professionals, which comprises many engineers and scientists and makes up approximately 20% of the total Rio Tinto workforce.

The following table and figures present some of the basic demographics of the technical professional workforce.

In addition to the traditional mining and metals professions of geologist, mining engineer and metallurgist, Rio Tinto today employs a vast array of scientific and

Table 1. Distribution of technical professionals by category

Category	% of Total Technical Workforce	Selected Professional Backgrounds
Asset Management	37	Assorted engineers especially Mechanical
Geoscience	6	Geologists, Hydrogeologists
Processing	19	Metallurgists, Chemical Engineers, Process Engineers
Mining (Surface & underground)	18	Mining, Software, Geotechnical, Civil, Environmental, Tailings engineers, Surveyors
Integrated Operations	9	Assorted engineers and data scientists
Capital, Closure and R&D Projects	11	Assorted engineers, scientists and researchers

Source: Rio Tinto