

Simulating Time versus Mass Basis Sampling

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ABSTRACT

Mechanical sampling from conveyors has historically been a staple in the iron ore industry when information related to chemistry, sizing and moisture is required. In order to comply with ISO 3082:2009, samples can be taken either on a mass or time basis provided no bias is introduced by periodical variation in quality or quantity. With the introduction of mechanical sample carousels, you also have the opportunity to collect samples on a mass or time basis. In order to optimise automatic sample stations in a changing production environment, BHP Billiton Iron Ore (BHPBIO) has developed a simulation model that enables the various combinations of mass-mass, mass-time, time-time and time-mass to be investigated.

The sample station model can utilise actual (variable) feed rates to achieve high resolution and enables the simulation of sample size variation. Cutter speeds and other settings can then be adjusted to better optimise the performance of the sample station with regards to optimal sample size as well as ensuring the sample station is in compliance with ISO 3082. The model can also assist process engineers in adjusting settings to better optimise the sample station and reduce unwanted events such as blockages. The model can be easily modified to conform to various sample station designs. This paper demonstrates the use of the model and the benefits that can be achieved.

INTRODUCTION

The use of sample stations in the bulk commodity business serves the purpose of collecting representative samples from conveyors that can be sent to the laboratory for analysis. Sample stations comprise a number of stages that aim to reduce the sample volume and in some cases reduce the particle size. They can also perform physical analysis of the sample by providing basic particle size information.

Sample stations typically comprise a primary cutter that passes through the ore stream (preferably free falling) to collect a primary increment that is fed via conveyor to the sampling tower for further processing (see Figure 1).

The primary increment is fed to a secondary cutter where a number of cuts are made. The secondary cuts send increments to either a chemical line or a physical analysis/metallurgy line. The chemical line sends the sample through a number of further steps that reduce sample size and can include a crusher to reduce particle size. At the bottom of the sample station the final sample is delivered to a sample bucket. The final sample in the bucket is made up of a number of primary increments (ie composite sample) so that it represents a large lot.

The standard that ensures compliant sampling through a sample station is ISO 3082 Iron ores – Sampling and sample preparation procedures. This standard outlines a number of conditions that must be met in order for the sample station and the sample it collects to be deemed ISO compliant and therefore represent best sampling practice, particularly for those samples collected and analysed for commodity trade. This has taken on even more importance when the sample stations are used to take shipping samples as there are now

international maritime regulatory considerations that need to be met (Transportable Moisture Limit).

Contained within the standard is the acknowledgement that sampling can be done on a mass or time basis (see Figure 2). Time basis sampling is carried out at fixed time intervals so that the mass of the increment is proportional to the flow rate of the ore stream. Mass basis sampling refers to the practice where sampling is carried out so that increments are taken at equal mass intervals, increments being as near as possible of uniform mass. In order to achieve a uniform sample mass on conveyors that vary in the mass of product they carry there are certain conditions that must apply; the primary cutter must be operated by a variable speed drive, the conveyor speed can be adjusted or the sample station must have the ability to reject increments of non-uniform mass.

One advantage of taking primary cuts on a mass basis is that it provides a uniform increment mass which leads to the same mass of sample being processed throughout the sample station. This steady state should allow for optimum sample station function. More controls are required to be in place to enable this type of sampling. When taking a primary cut on a time basis, invariably increments are produced with a greater mass variability.

The sample carousel located at the bottom of the sample station can also function on a time or mass basis. When the primary increment is taken on a time basis then the increment landing in the bucket will be of variable size. If the carousel is programmed to index on a time basis, then final samples of varying sample mass will be an outcome. Conversely, if

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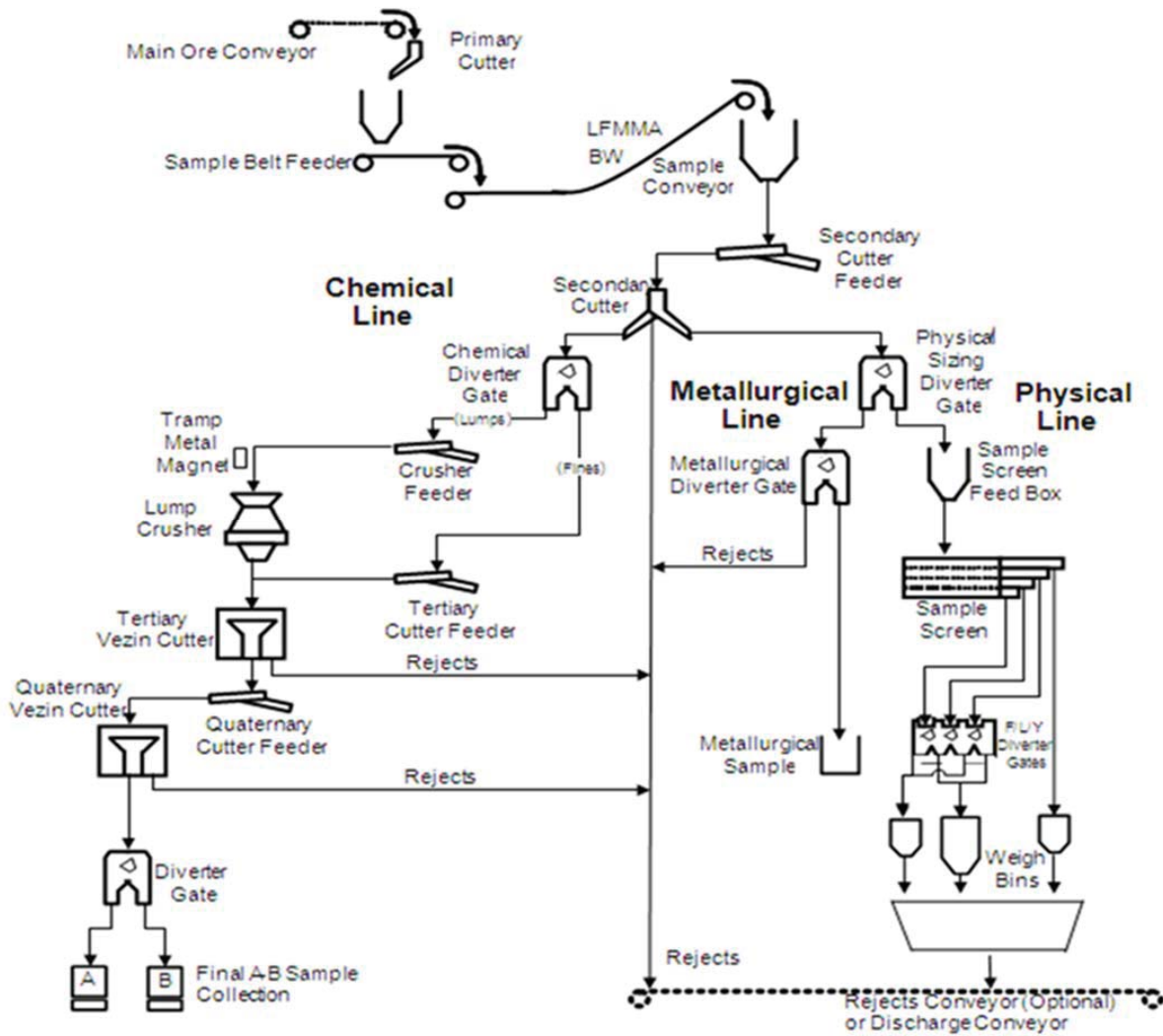


FIG 1 – Typical sample station process diagram.

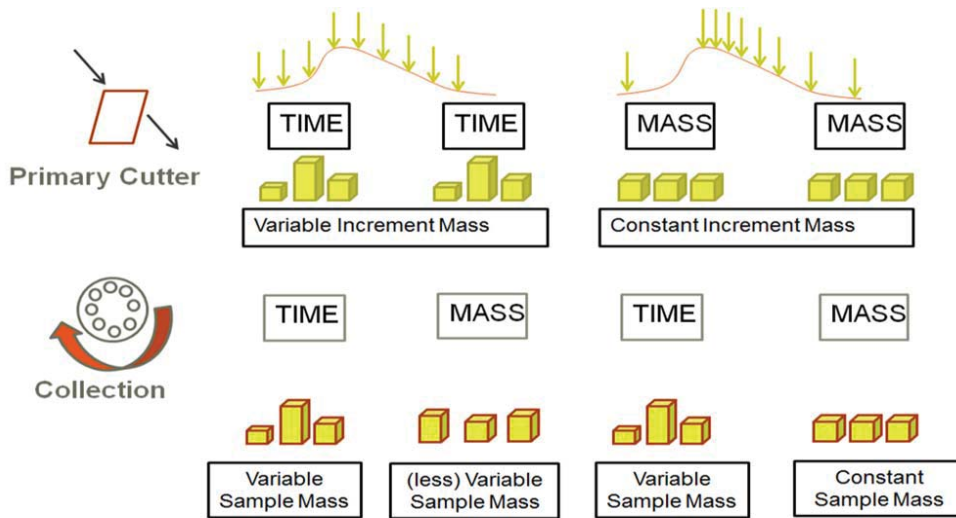


FIG 2 – The effect of time and mass basis sampling on sample mass.

the carousel is indexed on a mass basis (ie when a set mass has passed over the weightometer) then there will still be variation in sample size, but it will be less extreme.

The effect on sample size when taking the primary increment on a mass basis is that the mass should be of uniform size. If the final sample collection is on a time basis then with the

outcome is a high sample mass variability. When the sample collection is on a mass basis however, samples of more uniform mass will be received.

The model that has been developed is able to simulate the different conditions (time or mass basis) that a sample station can operate under.

OVERVIEW OF MODEL

An overview of the BHPBIO sample station simulation model is provided in Figure 3. This section explains the concepts and their implementation in a general purpose simulation package.

The ExtendSim™ simulation package is used within the Product Quality and Metallurgy department and was chosen for this simulation due to its ability to use several modelling methodologies which were identified as potentially required for this work, namely continuous, discrete-event and discrete-rate methods of system modelling. Of note, the latter method proved key to accurately and efficiently modelling highly variable ore feed rates on the main conveyor belt through the sample stations.

The simulation was developed in a modular and hierarchical fashion, ie a library of modelling components was developed. These components included logic 'blocks' representing sample station components such as the primary cutter, secondary cutter, screen feed split boxes, vezin cutters etc. Each of these blocks contain logic, input connectors and

parameters specific to the component. This modular approach allows for multiple sample station configurations and layouts. By developing logic blocks, these blocks can then be added to, removed or modified depending on the specific sample station being modelled. A description of the approach used to model the main ore feed conveyor belt will first be provided.

Modelling the main ore feed conveyor belt

The model is designed to simulate the moving of ore on a main feed belt as it passes through the sample station. Of importance is the representative simulation of the ore feed rates on the main ore belt. The variable nature of these feed rates plays an important role in how each method (mass/time primary cut, mass/time sample collection) impacts primary increment size and final sample size.

In the model, the feed rate can be defined by an input data set or by stochastic input (eg random distribution). Since this model was designed to emulate actual feed rate data, an internal modelling database is used to hold large feed rate data sets (see Figure 4). The higher the feed rate

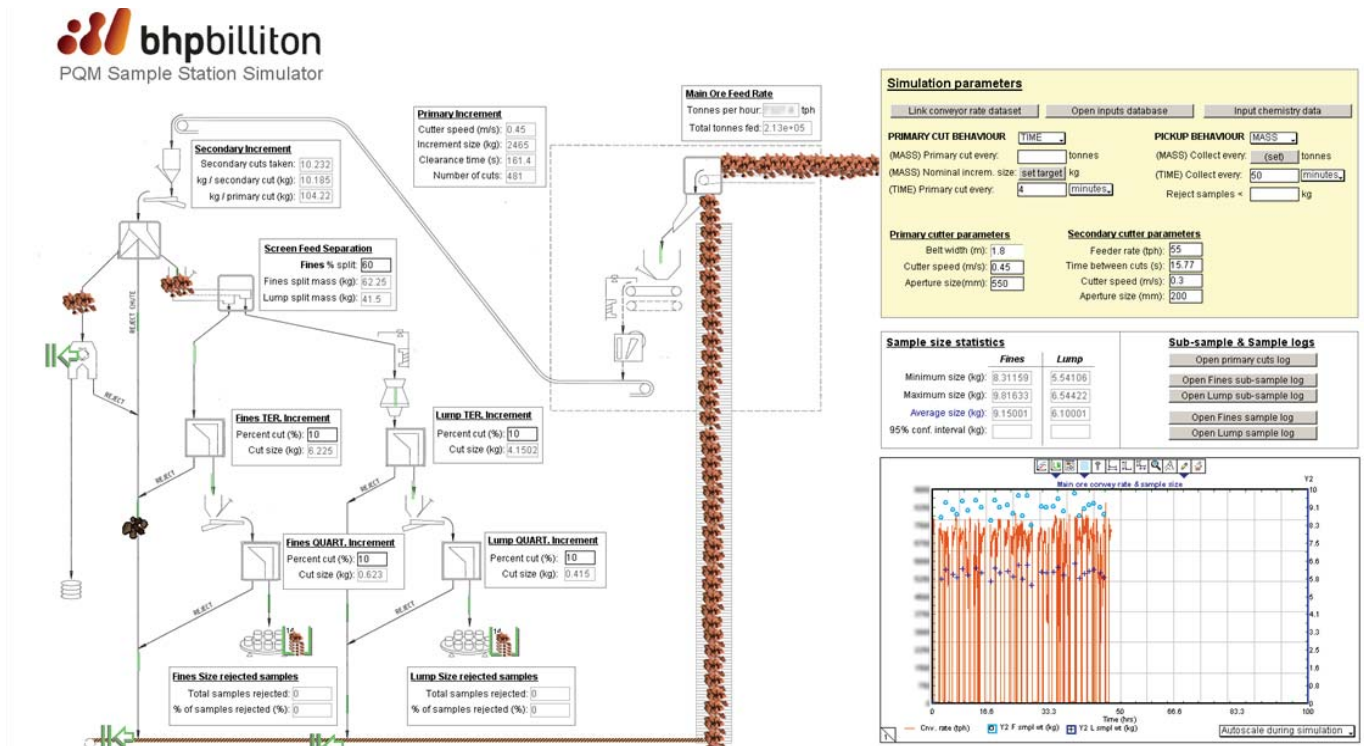


FIG 3 – Sample station simulation model.

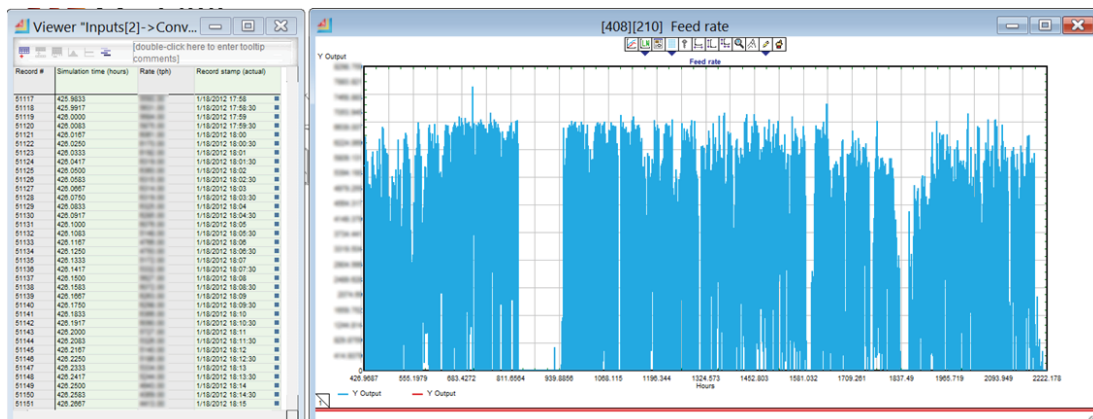


FIG 4 – Example of feed rate input data set and plot within the model.

data resolution, the more accurately the model can emulate feed rate behaviour. Currently, feed rate data from sample station PLCs are extracted and fed into the model. Presently, 30-second interval data are used. Feed rate data sets of up to 2 B records are supported in the simulation.

A discrete-rate approach is used to simulate ore flowing on the main belt. This approach updates the current feed rate according to the input data set as time progresses, ie it is event-based as opposed to a time-based (eg continuous) method. This approach avoids any potential issues around non-uniform time-step resolution (Krahl, 2009). Continuous simulation methods for modelling flow rely on recalculating system states at equal and uniform times-steps. A disadvantage of this is that if, for example, the instantaneous flow rate mid-time-step needs to be changed, the model would not realise this change until the following time-step. One approach is to then take smaller time-steps; however, in an event-based system this can be extremely inefficient.

The approach used here does not rely on constant time-steps and numerical integration to estimate system states. By contrast, it uses a fast linear program (LP) solver to recalculate effective ore flow rates and update the system only when the flow rate is set to change (which are modelled as events in the system) (Damiron, 2008). This proves to be an extremely fast and efficient approach as the effective simulation of time-steps now only depends on system events. In practice, this allowed us to model flow rates in a more 'discrete event' fashion. Increasing computational efficiencies allows the model to dynamically adapt to the resolution defined by the inputs and system parameters.

It was also found that it improved the accuracy of tracking total ore volume over the belt, both globally, between primary cuts, and between sample collection events. This is attributed to its approach which ensures that each flow rate change is addressed precisely when it is scheduled to occur.

Modelling primary cuts

Central to the model is its ability to simulate both mass and time based primary cuts. For the primary cut increment mass, the following mass flow equation is used:

$$primary\ cut\ mass = \frac{flowRate \times apertureSize}{3.6 \times cutterSpeed} \tag{1}$$

where:
flowRate is the instantaneous flow rate (t/h) when the primary cut is taken

apertureSize is the primary cutter aperture size (m)
cutterSpeed is the primary cutter speed linear movement speed (m/s).

Aperture size is a user defined variable set in the model. Primary cut speed can be set explicitly (eg for time-based cuts) or can be set automatically based on the instantaneous feed rate such that a target increment size is achieved (mass-based cut behaviour). However, the model assumes constant linear cutter speed once the cutter starts a cut (ie does not change movement speed mid-cut).

The model tracks both the accumulating mass of ore flow through the simulation (see Figure 5), as well as the flow ore mass between primary cuts and between sample collection (pick-up). Depending on the simulated approach (mass, time etc), it will then initiate a primary cut. The current flow rate of ore over the main belt is used in determining the primary increment mass.

If a time-based primary cut operation is selected, the model will then use the input cutter speed. Alternatively, if a mass-based approach is used, the model will calculate the cutter speed required to achieve a target increment mass given the current flow rate of ore. The calculation required to do this is simply Equation 1 solved for *cutterSpeed*.

We note here that in terms of modelling methodology, we model each primary cut as a discrete entity moving throughout the remainder of the simulation. This primary cut entity contains attributes that represent the properties of the primary cut increment (eg mass, clearance time, estimated chemical properties etc). This change to a discrete-event method allows us to track and log specific properties of each primary and secondary cut, subsample and final sample, as well as the relevant system states at each event.

Primary increment clearance time is also explicitly modelled. This is the time taken for the primary cut to travel to the secondary cutter. It is a function of the increment mass (kg) and the sample feed conveyor capacity (which is a user defined variable in the model). It is defined as:

$$\frac{primary\ increment}{clearance\ time\ (s)} = \frac{increment\ mass\ (kg)}{feeder\ capacity\ (t/h)} \times 3.6 \tag{2}$$

Modelling the secondary cutter

The primary cut increment mass is transported on a feed sample conveyor to the secondary cutter feeder. In the model, the secondary cutter feeder rate is a user defined input setting

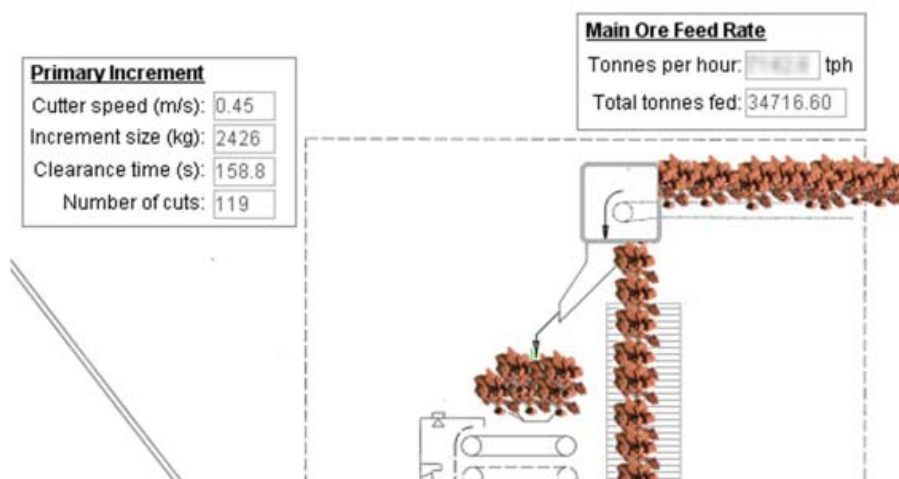


FIG 5 – Sample station model after taking a primary cut.

(see Figure 6). This controls the rate at which the primary cut increment moves through the secondary cutter.

Other secondary cutter input parameters include the secondary cutter speed (m/s) and cutter aperture size (mm).

The estimated mass of each secondary cut is calculated using an analogous equation to equation 1 (see Figure 7). The number of secondary cuts is calculated using the primary cut clearance time and the 'time between secondary cuts' setting of the model.

The modelled secondary cut increment is then the product of the estimated mass of each secondary cut and the number of secondary cuts taken.

Modelling vezin cutters

In the model, vezin cutters are modelled as simple modular logic blocks that can be connected to any path that an increment can follow. This block simply takes the incoming increment,

extracts a per cent (user input) of the increment, and outputs both the estimated cut mass and the rejected mass through the two output paths of the modular block (see Figure 8).

Note that the model supports assigning the 'per cent cut' input value as a constant or as a number drawn from a defined random distribution. Whenever an increment enters a vezin cutter modular block, the block logic ascertains the percentage to cut based on the user input. If the input is a constant, then precisely that amount will be cut (the remaining follows the reject path); however, if a random distribution is defined, then every vezin cutter operation can cut varying amounts of increment. For example, if the user defines a simple triangular distribution with a minimum value of six per cent, maximum value of 14 per cent, and 'most likely' value of ten per cent, then the cut increment mass from the vezin cutter blocks will follow this triangular distribution. This allows the simulation of more realistic and variable cut increment masses coming from the vezin cutter blocks.

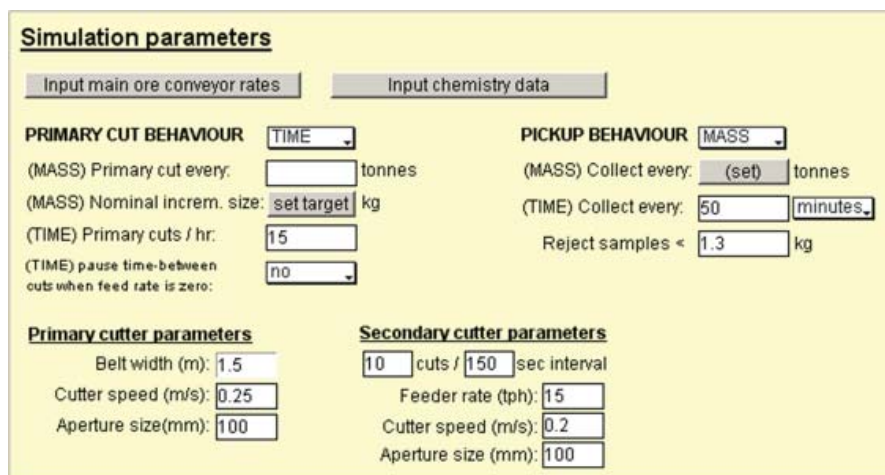


FIG 6 – Example of several input settings for the sample station model.

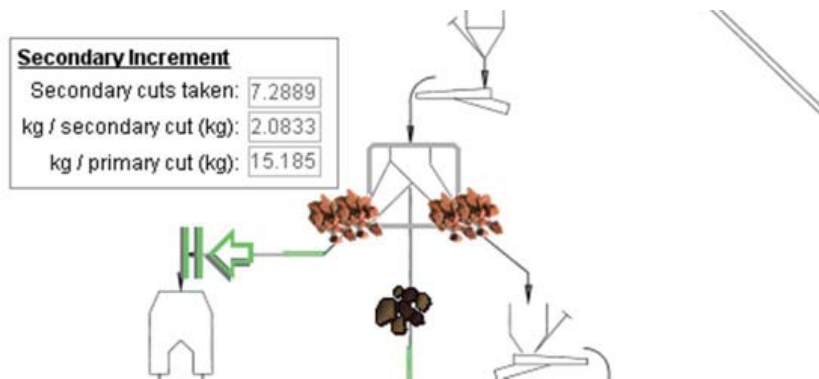


FIG 7 – Sample station model taking a secondary cut. Note the material leaving the reject chute (material moving down).

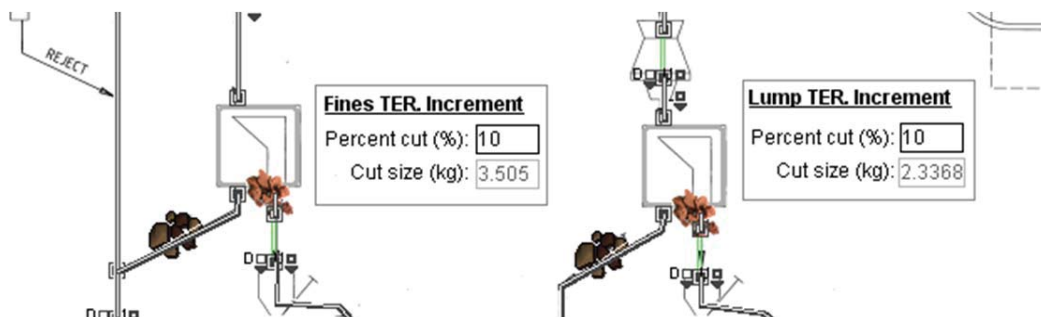


FIG 8 – Sample station model with vezin cutters in operation.

Subsample and sample collection

Each primary cut results in a subsample of ore material (see Figure 9). A sample is the collection of these subsamples. In terms of the model, each primary increment is modelled as a discrete entity as it moves through the simulation – and as this entity moves through the simulation its mass (for example) is decreased as it is split (screen feed separation) or undergoes further cuts (eg vezin cutters). The final state is a representative subsample.

The model holds these subsample entities and awaits a collection signal. Collection is signalled depending on the 'pick-up' behaviour defined. For time-based sample collection, the collection signal will be sent at the specified interval (eg collect every 50 minutes). For mass-based collection, the model uses its discrete rate abilities to track the accumulated ore that has gone over the belt since the last pickup. This allows us to send the collection signal at tonnage based intervals (eg collect every 3.5 kt).

Once a collection signal is received, the model analyses the currently collected subsamples, and logs relevant information to both subsample and sample logs. This includes the mass of the sample (which is now the summation of all subsamples), pick-up time, time since last pickup, number of subsamples which make up the sample, tonnage over the belt since the last sample collection (sublot size) and several other pieces of information, including chemical analyte estimates.

Finally, the model plots sample size against the current main conveyor rate as a standard output. This plot is updated during the model run and illustrates graphically the sample sizes and related variability resulting from the simulated operating modes (mass/time based cuts, mass/time based sample collection).

ILLUSTRATING SAMPLE SIZE BEHAVIOURS USING THE MODEL

Examples of simulated sample size distributions from the model for the following three methods will now be provided, ie time-time, time-mass, and mass-mass. In each method, the first word refers to primary cut behaviour and the last word refers to the sample collection behaviour. Thus 'time-mass' means time-based primary cuts, and mass-based pick-up (sample collection).

For this illustration, a model of a fines sample station from one particular mine site is used. The main ore conveyor feed rate data is common between each of the simulated behaviours. For time-based primary cuts, a primary cut every four minutes will be initiated. For mass-based primary cuts, tonnage-based settings are used to control time between

primary cuts. Likewise, tonnage-based control is also used to vary the primary cutter speed.

Similarly, for time-based sample collection, an interval time of 50 minutes is used. For mass-based collection, all subsamples are collected using a triangular distribution to represent the accumulated tonnage between each collection event. This distribution simulates sample collection every 3.4 kt – 3.6 kt, with a 'most likely' value of 3.5 kt.

Finally, the following plots show the behaviour for a 100-hour simulated period. For context, the model takes approximately 19 seconds to simulate this real-world time frame.

Time-time

Figure 10 shows the simulated sample sizes given time-based primary cut and time-based sample collection operating modes in the model. In Figure 10, the orange line tracks the simulated flow rate of the main ore conveyor belt against the left y-axis (in t/h). The blue dots show the sample sizes against the right y-axis (kg).

Note that in this operating mode, the sample sizes vary widely. In this simulation sample sizes ranged from 1.37 kg to 12.47 kg, with an average sample size of 9.08 kg.

Figure 11 shows a histogram of the simulated sample sizes produced by the model. In this operating mode, primary cuts and sample collection events are initiated independent of the main ore conveyor flow rate. Since a constant cutter speed is used, when the flow rate is low the primary increment mass is likewise low. Hence, the subsample size is also smaller.

In the time-time operating mode, there is uniformity in the number of subsamples per sample. This is due to the uniform time between cuts and sample collection. Consistently low conveyor feed rates (or variable periods with low feed rates) produces smaller primary cuts and subsample sizes. This in turn impacts the final sample size.

These behaviours can directly be seen in Figure 10. The apparent correlation between rate and sample size is noted. In particular, it's interesting to see sample sizes becoming more consistent, as the flow rate varies more consistently around some mean. Similarly, it is apparent how sample size changes and reacts when the feed rate changes behaviour.

All these aspects contribute to the sample size variability shown by the model.

Time-mass

Figure 12 shows the simulated sample sizes given time-based primary cuts and mass-based collection. In this simulation, primary cuts are initiated every four minutes, but sample collection is done on a mass basis. More specifically, all

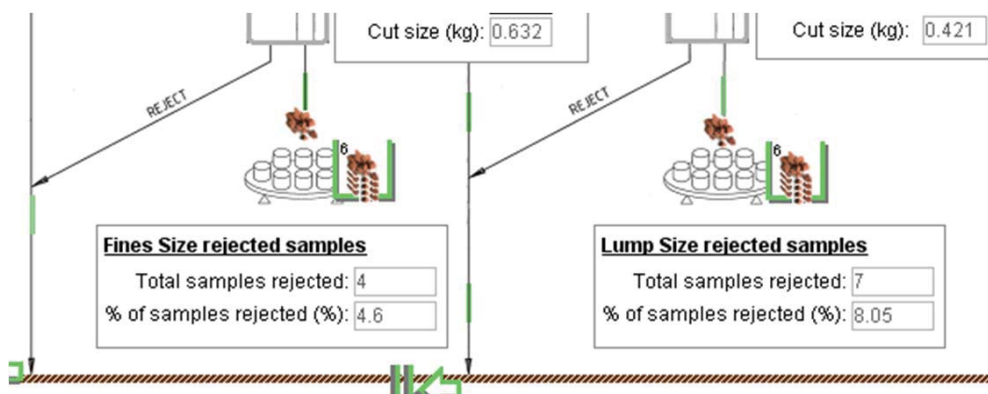


FIG 9 – Accumulated subsamples in the model.

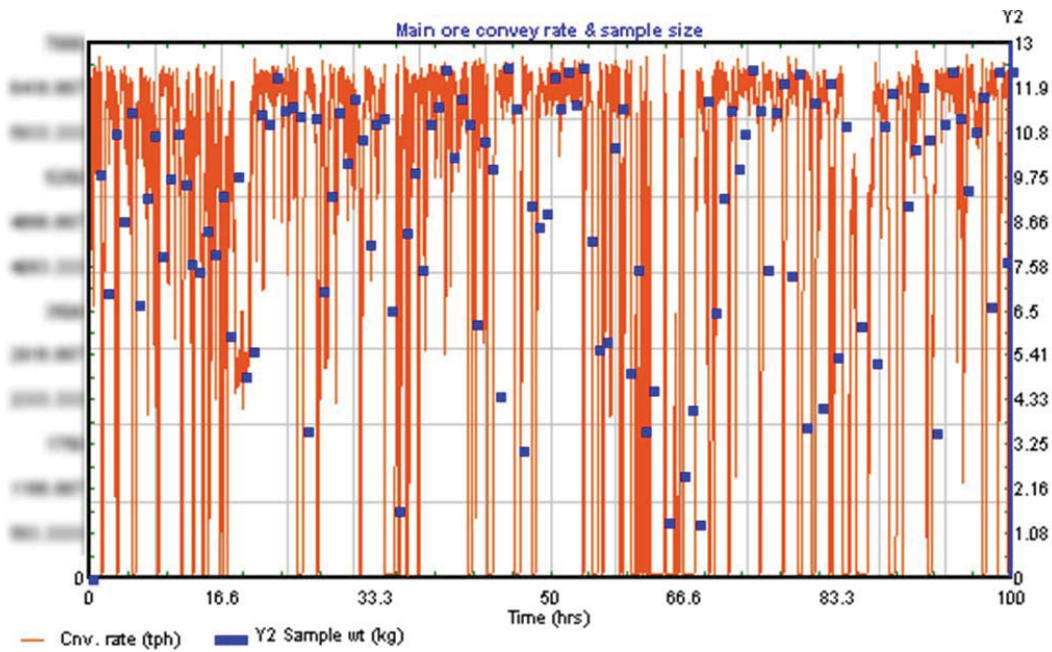


FIG 10 – ‘Time-time’ behaviour of sample sizes over time.

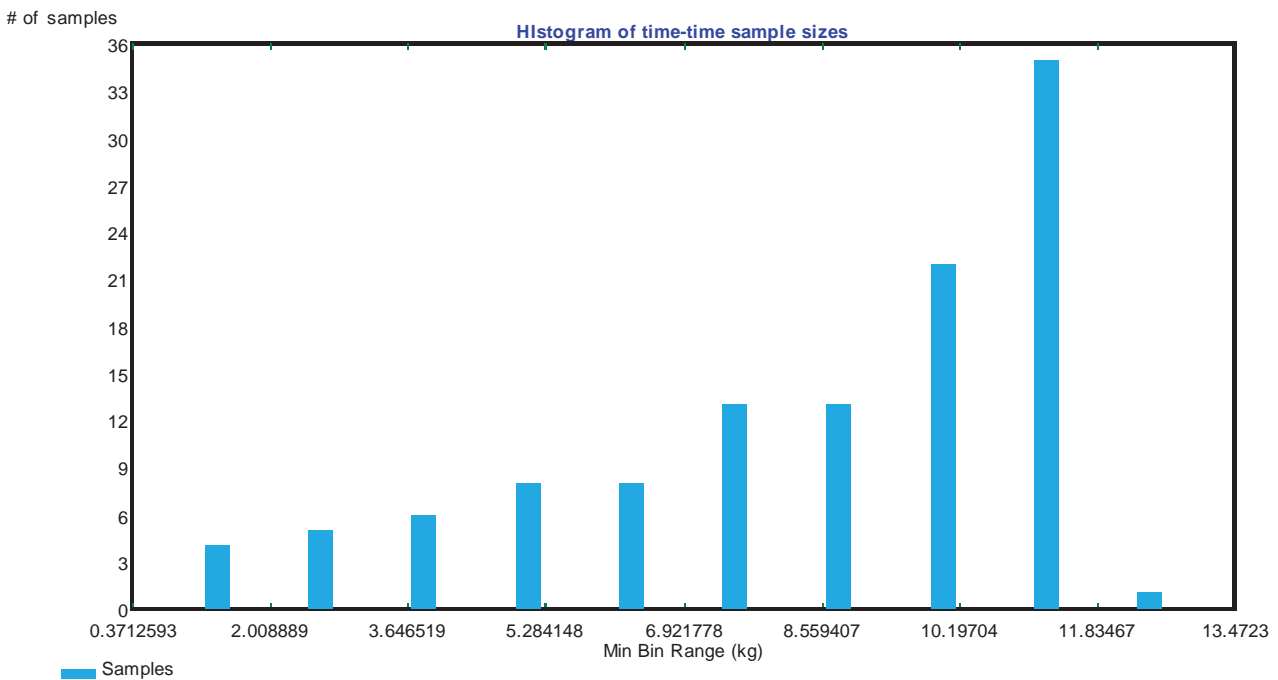


FIG 11 – Sample size histogram for ‘time-time’ behaviour.

subsamples are analysed and collated into a sample for every 3.5 kt that flows over the belt (3.5 kt is the ‘mostly likely’ value in a triangular distribution used for this simulation run as previously described).

The first thing to note is the largely reduced sample size variation in Figure 13. In this simulation sample sizes ranged from 6.44 kg to 8.93 kg with an average sample size of 7.73 kg. This is actually due to the mass-based collection behaviour. The primary cut behaviour has not changed – it continues to cut every four minutes and continues to produce subsamples at approximately that frequency; however, since a sample is now being collected every 3.5 kt, the number of primary cuts per sample varies and is dependent on the main ore conveyor feed rate!

Consequently, when the feed rate is low, the primary increment mass is smaller; however, it now takes longer for 3.5 kt to flow over the main conveyor. This results in smaller subsample sizes, but more of them. Conversely, when the rate is high, primary increments are larger, but, since it now takes less time for the 3.5 kt to flow over the main belt, fewer of these primary cuts are taken!

All these aspects contribute to the sample size variability shown by the model.

Mass-mass

In this simulation, mass based primary cut and mass based sample collection behaviour is set up. This setting varies the primary cutter speed depending on the main conveyor feed rate at the point when a primary cut initiates.

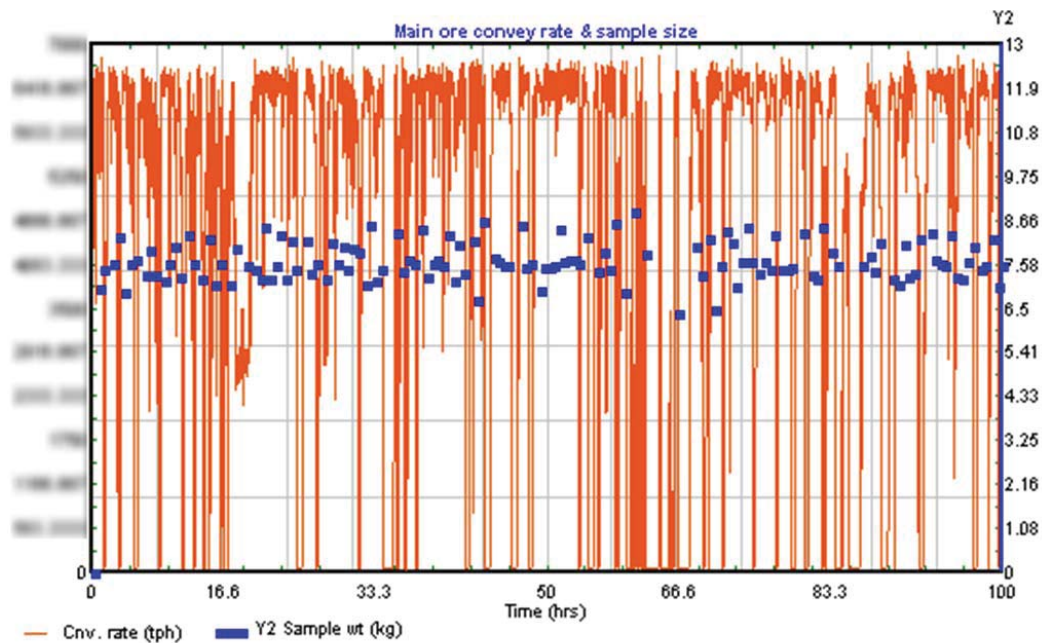


FIG 12 – ‘Time–mass’ behaviour of sample sizes over time.

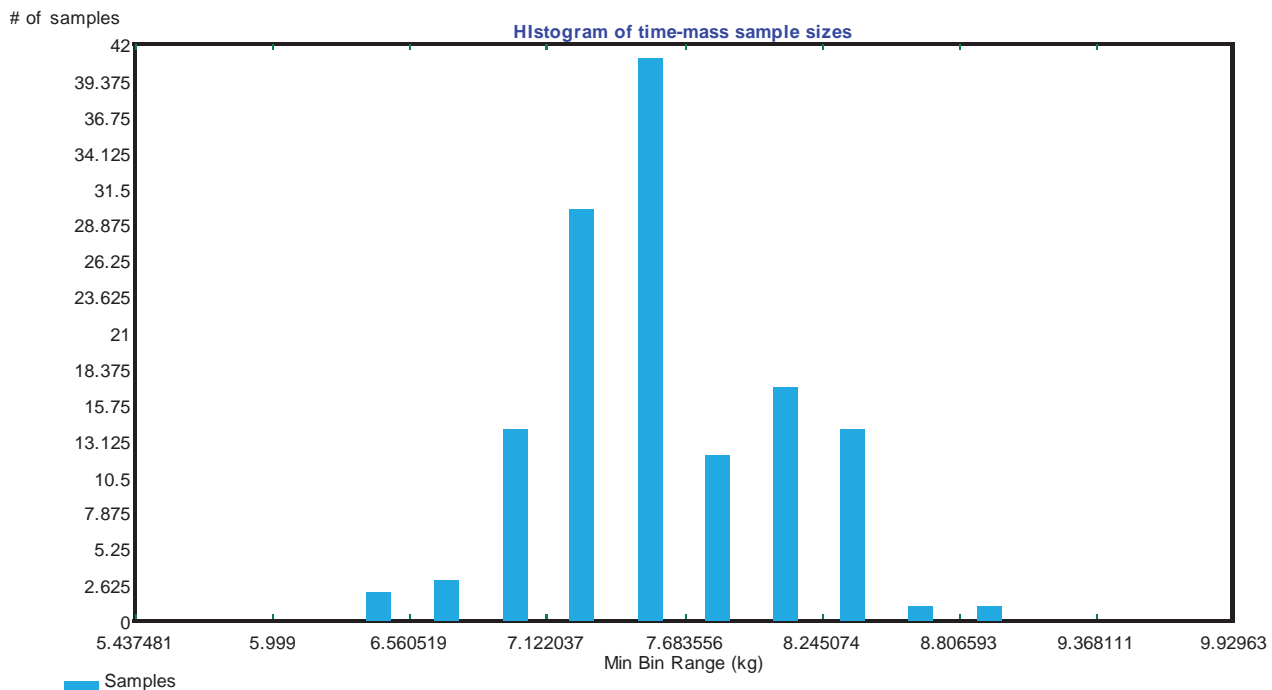


FIG 13 – Sample size histogram for ‘time–mass’ behaviour.

Figure 14 shows the resultant sample size variation. In this simulation, sample sizes ranged from 7.27 kg to 8.51 kg with an average of 7.87 kg. However, as can be seen from Figure 15, the majority of all samples (87 per cent) had approximately uniform sample size.

With respect to the sizes of the remaining samples that weren’t uniform size, this is the result of the highly variable feed rates simulated. What can occur, in reality and in the model, is that the instantaneous rate of ore flow as measured when the primary cut initiates may change during the primary cut. The primary cutter speed is set before each cut based on the current conveyor ore flow rate, but if the rate changes enough during a cut this can cause small perturbations in the uniformity of primary increments and sample sizes.

CASE STUDY

Sample size variation can provide a number of issues for the laboratory responsible for analysing the sample. These issues can relate to minimum sample sizes required in order to be processed, ie a maximum size allowed so as not to introduce health and safety issues when handling the samples, the fact that the laboratory equipment may be optimised to process a certain mass of sample and consistent sample size will reduce the chance of bias being introduced.

At a particular site where sample size variation was evident, there was a drive to optimise the sample size (less variable). At this time the model was identified as a potential way to achieve this.

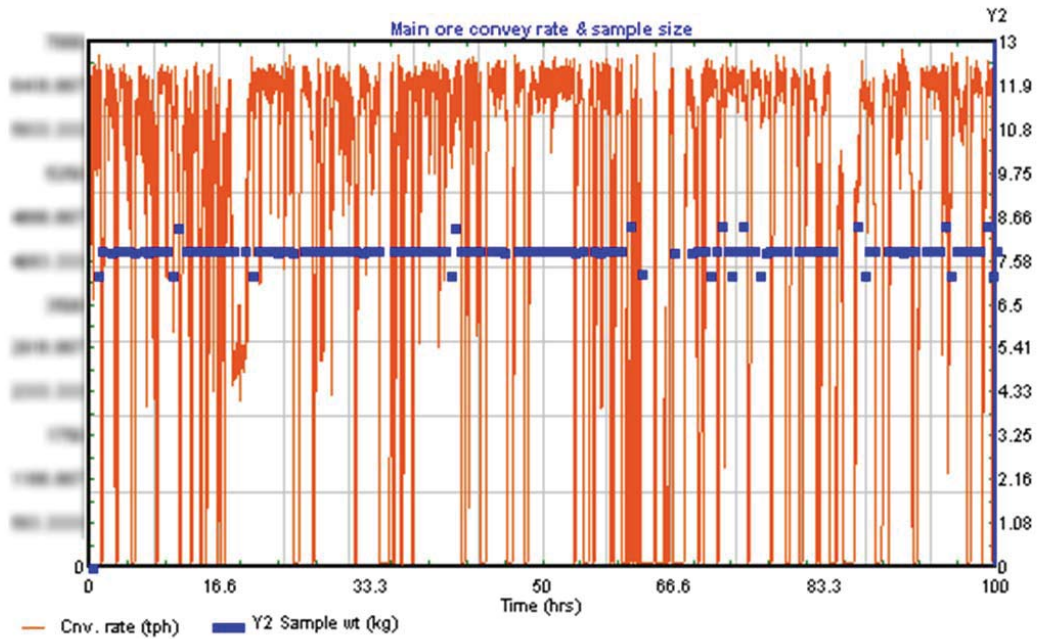


FIG 14 – ‘Mass–mass’ behaviour of sample sizes over time.

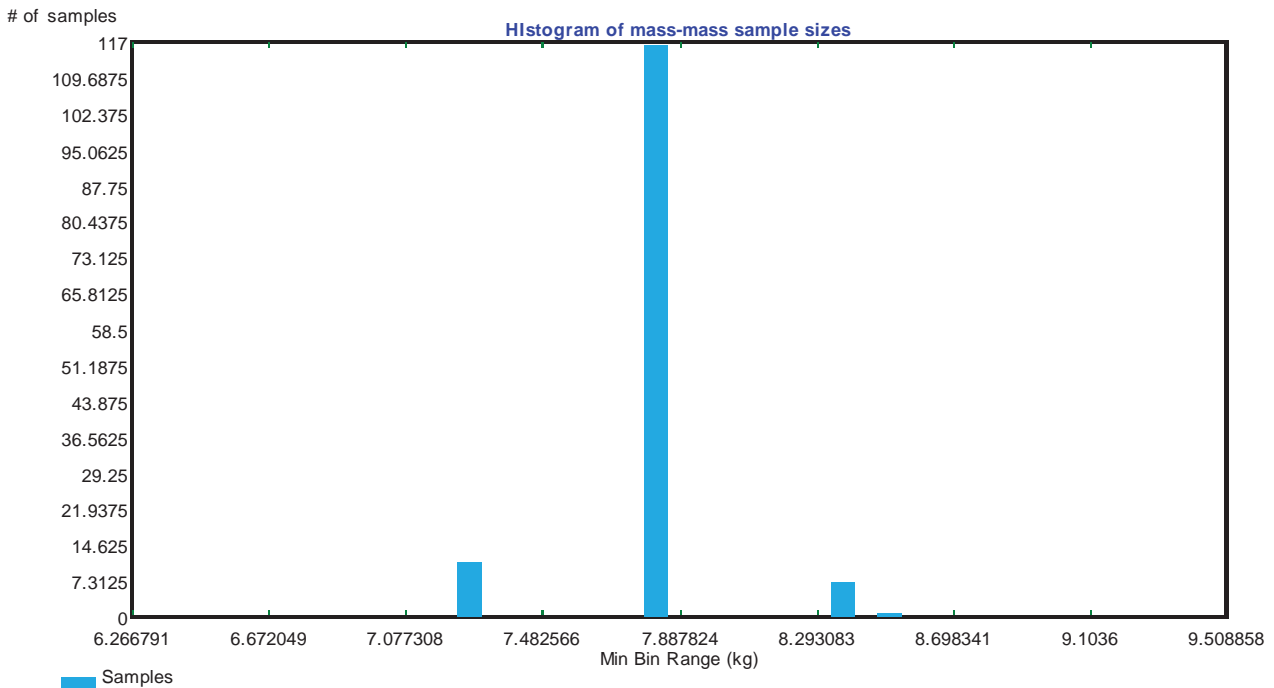


FIG 15 – Sample size histogram for ‘mass–mass’ behaviour.

The first part of optimising sample size was to identify the particular sample station in question and then modify the model to that particular sample collection process. This included the input of all sample station settings and the use of historical feed rates.

Once this was done the model was validated against historical data for sample sizes received by the laboratory. At this point a validated model for the sample station was available to optimise it and adjustments could be made to the settings to achieve a more consistent sample size.

By making adjustments to the primary and secondary cutter (in the model), the predicted sample mass and variability could be modelled. Adjustments were then made to the process control system and the impact on sample sizes at the

laboratory was monitored, which confirmed a less variable sample size.

DISCUSSION

The development of the sample station model at BHP Billiton Iron Ore has provided several benefits including an instruction tool on the differences between mass and time basis sampling, sample station optimisation, the impact of different feed rates on sample mass, and also the impact of making adjustments to settings.

The sample station model has been validated against a number of BHPBIO sample stations with the intent of all operational sample stations having a validated model. The model will help understand the different combination of

mass and time and the advantages and disadvantages of each (while still maintaining ISO compliance). This will provide more certainty about sampling, particularly when meeting certain obligations like transportable moisture limit (TML) requirements.

It is anticipated that the sample station model will be used by process engineers when looking at optimisation and trouble shooting. The model is also being used as part of a training package to help new engineers understand the workings of a sample station and the impact minor adjustments to settings can have on sample mass and therefore compliance.

CONCLUSIONS

The primary driver of the work was to successfully maintain ISO 3082 compliance whilst optimising sample sizes for health and safety requirements. As the model was deployed further benefits included:

- Process engineers having a tool to test parameter changes to understand impacts before deployment and reducing field trials.
- Utilisation as a tool to demonstrate and articulate sample theory and the requirements of ISO3082 compliance.

The discrete rate simulation approach for modelling ore flow was chosen over continuous simulation because:

- computational requirements are minimised, resulting in quicker and more efficient model execution
- the dynamic model can adapt to the resolution defined by the inputs

- it increases the veracity of the model due to its ability to directly emulate highly variable feed rate data; simulating highly varying, realistic ore feed rates allows more accurate reconciliation of volume over the belt from a global, between primary cuts and between sample collection events perspective
- it integrates with the discrete simulation approach used to simulate individual increment related processes and properties.

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REFERENCES

- Damiron**, C and Nastasi, A, 2008. Discrete rate simulation using linear programming, in *Proceedings 2008 Winter Simulation Conference* (eds: S J Mason, R R Hill, L Monch, O Rose, T Jefferson and J W Fowler), pp 740-749 (Institute of Electrical and Electronics Engineers, Inc: Piscataway, New Jersey).
- International Organization for Standardization**, 2009. ISO 3082:2009, Iron Ores – Sampling and Sample Preparation Procedures.
- Krahl**, D, 2009. ExtendSim advanced technology: discrete rate simulation, in *Proceedings 2009 Winter Simulation Conference* (eds: M D Rossetti, R R Hill, B Johansson, A Dunkin and R G Ingalls), pp 333-338 (Institute of Electrical and Electronics Engineers, Inc: Piscataway, New Jersey).