Case study: Capital equipment and operational price savings by using different lot size / period for ISO 3082 compliant iron ore sampling

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Iron Ore is necessary for economic growth and therefore Iron Ore trade is important for global industry. Shipment volumes are large, product grades are critical and environmental negative elements are monitored hence contract values between the trading countries are complex and of high value. To mitigate trade risks and renumeration disputes, representative sampling is paramount to measure Iron Ore accurately and precisely. Previous research studies have indicated that the cost of sampling is high, from initial capital cost to operational costs. But good sampling plants have cost benefits, solidified corporate governance, and defends contractual disputes. ISO compliance modelling, sampling system design and financial modelling is done to prove that vital understanding of the effect of Lot period and careful selection therefore can result in significant cost savings without the sacrificed sampling precision. The investigation is done on systems that produce between 100 ton/h and 35, 000 ton/h to measure Fe, SiO_2, P, Al_2O_3 with precision levels of 0.4, 0.4 and 0.0068, 0.14 respectively. The capital and operational costs for the 12-hour Lot period are generally higher than the 72-hour Lot period across the range of throughputs investigated. The alignment of the sampling equipment manufacturer, production, sampling regime and contractual supply agreements must be considered at the start of a project and sampling system design must undergo the necessary engineering study phases that consider these types of trade-offs.

Keywords: ISO 3082 compliance, Lot size, cost of sampling, cost benefit, trade offs

BACKGROUND

Iron ore is an important raw material used in the steel industry to support sustainable and rapid development of the global economy. It is a critical commodity for all sectors of the economy, about 98% of the iron ore mined in the world is used for steel production and used in construction, engineering, automotive, and machinery industries. Australia and Brazil have the largest iron ore mines in the world and large quantities are also mined in countries such as Guinea, Congo, Sierra Leone, and Liberia (Trade and inspection for Iron Ore, 2018).

Research economic studies indicate that the global iron ore trade is projected to increase to an annual average of 2.0% by 2025 due to the strong production rises in Australia, Brazil, and Africa (Resource and Energy, 2023). The demand of Iron is on the rise in most countries and therefore, in the next years iron ore trade is expected to increase significantly.

International trade involves commercial agreements between all stakeholders to ensure that the product supplied is of the expected quality and quantity (Trade and inspection for Iron Ore, 2018). It is therefore important that quality measurements are accurate to avoid any non-conformance.

The project owners need to invest in implementing good sampling practise and systems to reduce financial losses due to paid penalties (Bruce and Minnitt, 2021). They conclude that, as much as the initial cost for a good sampling plant is high, it has a significant long-term financial gain.

Various other contributors and members of the International Pierre Gy Sampling Association (IPGSA) have also commented on the potential savings from proper sampling (Rendeman et al., 2020; Dominy et al., 2024; etc.)

LITERATURE STUDY

The following sampling parameters must be calculated to design an ISO 3082 (2017) compliant sampling system.

Increment Sample Mass as a Function of Particle Size, Production Throughput and Cutter Speed

The increment mass, m_1, in kilograms required per Lot size can be calculated using Equation 1 of ISO 3082 for falling stream sampling.

$$m_1 = \frac{ql_1}{3.6v_C} \qquad [1]$$

Where:
q is the flow rate, in ton per hour, of ore on the conveyor belt.
l_1 is the cutter aperture, in meters, of the sampler.
v_C is the cutter speed, in meters per second, of the sampler.

The minimum increment mass that can be taken, while still avoiding bias, is determined by the minimum cutter aperture of at least three times the nominal top size of the ore, or 30 mm, whichever is greater.

Number of Primary Sample Increments Needed to Achieve the Required Sampling Precision for a Known Quality Variation

The material quality variation classification, Table 2 of ISO 3082 can be used to read off the applicable quality variation for each element of interest as an absolute percentage. For example, Iron content for large quality variation is ≥ 2.0, medium quality variation 1.5-2.0 and for small variation < 1.5. Similarly, other elements and physical size variations can be read off the table.

The number of primary sample increments required per lot duration is calculated using ISO 3082, equation 8, where the absolute percentage of quality variation (σ_W) is known, the number of primary increments (n_1), can be calculated for the desired sampling precision (β_S) in absolute percentage with the below equation:

$$n_1 = \left(\frac{2\sigma_W}{\beta_S}\right)^2 \qquad \{2]$$

Composite Sample Mass

The composite sample mass produced by a sampling scheme can then be calculated as the increment mass multiplied by the number of increments. Later parts if the ISO 3082 standard lists the minimum composite sample mass of division required as a function of particle size and required precision and must also be satisfied in the sampling scheme design.

CASE STUDY

A case study is done by proposing a fictious iron ore system and designing ISO 3082 compliant sampling schemes with the following constants, variables, and calculated sampling parameters.

The Required Number of Primary Increments

The system assumes a medium quality variation, where the absolute percentage value was assigned as the lower of the range of values listed in ISO 3082 (2009), Table 2. For instance, the range of iron content for medium quality variation is 1.5-2.0, and for the case study, 1.5 is selected.

The sampling precision is constant despite the varying lot sizes explained below, to represent a supply agreement where the buyer is interested in a fixed precision of reported analytical data, despite buying different lot sizes from various suppliers.

Given the definitions of quality variation and desired sampling precision, the number of primary sample increment required for ISO 3082 compliance, is calculated (from equation 1 above) and tabulated for the various elements of interest in Table I, below.

Table I. Summary of sampling precision, quality variation and number of primary sample increments

Element	Sampling precision	Medium quality variation	# of Increments (Low range)
Fe	0.4	1.5	56.3
SiO_2	0.4	1.5	56.3
P	0.0068	0.011	10.5
Al_2O_3	0.14	0.4	32.7

It should be noted that the required precision level for Fe and SiO_2 will be achieved with 57 sample increments. The required precision level for P and Al_2O_3 can be achieved with lower increment sampling. Therefore, the system is designed to comply to the requirements for Fe and SiO2 sampling which means that the precision levels achieved for the other elements, when taking 57 sample increments, will be improved.

The Required Composite Sample Mass for the Simulated Particle Size

The case study is done using -10mm particle and despite various stages of sampling (ranging from 1 stage to 3 stage sampling) no interstage particle size reduction is proposed for this case study. The case study also only allows for chemical analysis of the main elements, without considering moisture and size characteristics. The case study assumes 0.1% standard deviation of division (σ_D as absolute percentage) and then, the required composite sample mass can be read of ISO 3082, Table 4 to be 10 kg of sample mass after division (at 10mm nominal particle top size).

Other System Constants, Variables and Parameters

System constants include a selection of throughput capacities (q) ranging between 100 and 35 000 ton/h (metric). The maximum throughput of 35 000 ton/h it is not realistic, but it was used for the purpose of this study.

The lot period is varied over 12, 24, 48 and 72 hours. The sampling scheme is time-based. The different constant lot durations then result in variable lot size as the product between throughput and lot duration. To allow direct comparison of parameters in this case study, no sub-lots were used. The primary increment sampling frequency was calculated by dividing the lot duration by the number of required sample increments.

Constant parameters of the study were the assumption of using a linear cross stream sampler (as recommended by ISO 3082). The cutter speed (υ_C) is constant at 0.6 m/s for the time-based system and cutter aperture of 50 mm. The cutter aperture does not correlate to the theoretical cutter opening of three times particle nominal top size, because our practical experience advises that 30mm cutter openings are prone to blockages and not easily cleared of blockages due to limited access through the cutter opening; a 50mm cutter opening is a more practical recommendation (l_1 = 0.05 meter). From these constants, the primary sample increment mass can be calculated using equation 1 above.

The case study confirms, as expected, that the composite sample mass quickly increases to above ergonomic weight for physical sample collection by operators and the system design allows for two options, to bring composite sample masses to <25kg:

1. The sample collection frequency is manually altered between 11.5 hours to 30 minutes. It is important to note that the increment sampling frequency remains unchanged, only more frequent operator involvement will allow collection at ergonomic sample weight.
2. Where more regular sample collection frequencies are demanded (<30 minutes), and because more frequent collection is considered impractical, additional stage(s) of sampling is introduced to sub-divide the sample increment to more ergonomic weight, while still meeting/exceeding the ISO 3082 required composite sample mass of >10kg.

The secondary and tertiary sampling stages are modelled to use a fixed division ratio at 10%. No inter-stage crushing particle sizes reduction were modelled in this work.

With the sampling parameters, constants and variables governing the equipment selection, number of sampling stages required and collection frequency – the sampling system design is complete and allows calculation of capital and operating expenses (Capex and Opex, respectively).

Financial modelling of Capital and Operational Expenditures for the Sampling Systems

Capex

The capital expenditure (capex) is for a single stage sampler, integrated into the production conveyor head chute. Some additional financial allowances are made for interconnecting chute work, equipment mounting and sample collection/storage equipment.

When graduating from single to double (or triple) stage sampling, the cost does not merely double because there is additional equipment required other than the secondary sampler. These additions include, but are not limited to: segregation combatting equipment, collection hoppers, sample feeders, chute work, increases in operational philosophy and electrical, instrumentation and control cost and complexity, etc. The secondary sampling cost works out to be 2.5 times the primary stage costs and tertiary sampling is 4 times the primary stage costs.

Opex

The operational expenditure (opex) estimates assume:

1. The sample will be collected using one vehicle with a driver and worker. The round trip is estimated to take 1 hour including all vehicle checks, refuelling, preparation, actual work, inductions, etc. Typical, different global labour rates are used for the driver and semi-skilled labourer, respectively.
2. The vehicle will travel a 20km round trip from the laboratory to the sampling plant collection station and back. Vehicle running costs and fuel are calculated to South African accepted rates and then converted to the USD (at ZAR 19.50: 1 USD).
3. Typical industry costs of 15 USD per sample analysis is assumed as sample prep and analysis costs.

All other Capex and Opex costs are then calculated as real financial values according to our market experience.

Period of financial modelling

The period of financial modelling is a duration of 5 years.

The capex costs are fixed and firm over the period as the onset investment costs of the sampling plant. The capex cost includes from our experience, an annual 7% of the initial cost for maintenance and running, per year (totalling 35% over the 5-year period). The sampler equipment operational costs are included in capex because it forms part of the equipment price where users are initially limited in capex and often debates more automated sampling stages' total life cycle costs – versus smaller sampling plants with more manual labour.

The opex is also calculated over a 5-year period. All opex costs are calculated so that a price per sample result, which includes collection, transport, offloading, prep and analysis, reporting and interpretation, is used in the modelling. As the sample collection frequency period decreases (e.g., from 2 hours to every 1 hour) the number of sample results will increase, and the capex costs would double. No time-value of money or inflation costs are allowed for over the 5-year period because it is different for different global territories. Opex costs may therefore be slightly underestimated.

Intangible costs

The intangible costs of errors introduced by manual labour affecting overall sampling precision is not included in the financial modelling. It has been proven that automation can result in significant intangible cost savings (Bruce and Minnitt, 2021). Costs associated to injury, or manual labour related safety, health and environmental incidents are not included in the modelling.

RESULTS AND DISCCUSSIONS

The modelled costs for the investigated cases are summarised in the following sections.

Capex analyses

Figure 1 illustrates the relationship between the capital cost of various Lot sizes for the range of throughputs under investigation.

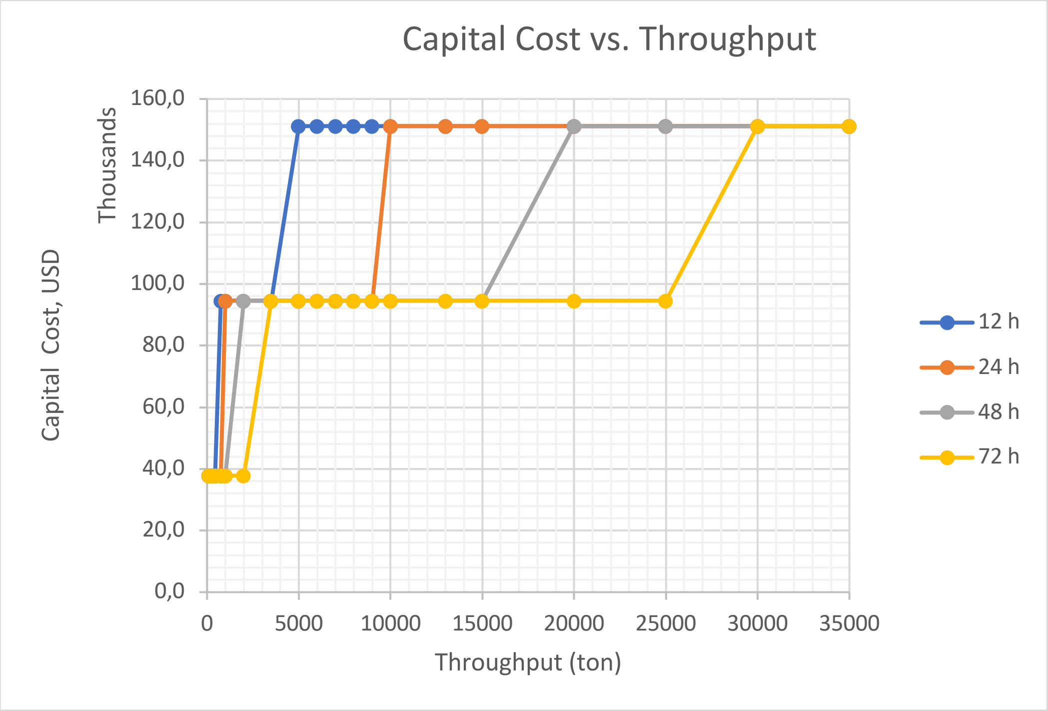

Figure 1. Once off capital cost plus 5-year maintenance and running cost of sampling equipment for different lot periods, as a function of throughput which governs the number of sampling stages and interval of progression from 1 to 3-stage sampling.

The graph illustrates that for all lot periods, a single stage sampling system would suffice to provide compliant ergonomic samples at low throughput rates (<1000 ton/h). As the throughput increase, all modelled lot durations eventually require a 3-stage sampling system.

However, the requirement to increase from 1, to 2 and then 3-stage sampling systems happens at different throughputs.

The 12-hour Lot period capex increases to 95,000 USD at 450 ton/h where a secondary sampling stage is required. At this throughput the 24, 48 and 72-hour Lot periods still require a single stage sampling and ergonomic sample sizes can be achieved by manipulating the sample collection frequency only. For the 24-hour and 48-hour Lot periods a second sampling stage is added at 750 ton/h and capex increased accordingly. The 72-hour Lot period secondary stage was added at 3, 500 ton/h.

The addition of a tertiary stage for the 12-hour Lot period is required at 5, 000 ton/h with the capital cost increasing to 150,000 USD. Meanwhile the 24, 48 and 72-hour Lot periods only added a tertiary stage at 6, 000 ton/h. The total cost benefit for increasing the Lot period from 12-hour to 24, 48 and 72-hour at 5, 000 ton/h will be in the range of 50,000 USD.

Furthermore, operating at lower Lot periods could results in time saving for collecting samples, receiving analytical results and ultimately decision making. As some mitigating action will result from receiving analytical results sooner than later, the cost saving of this would be dependent on the process, commodity, and contractual supply agreement of each operation. This would be a separate study not focused on in this paper.

To conclude, the capital costs for the 12-hour Lot period are generally higher than the 72-hour Lot period across the range of throughputs investigated; lower Lot period sampling systems will graduate to higher capex at lower throughput rates. Increasing the lot period relaxes the capital cost demand of a project.

Operational cost analyses

Figure 2 illustrates the relationship between the opex of various Lot sizes over the throughput range.

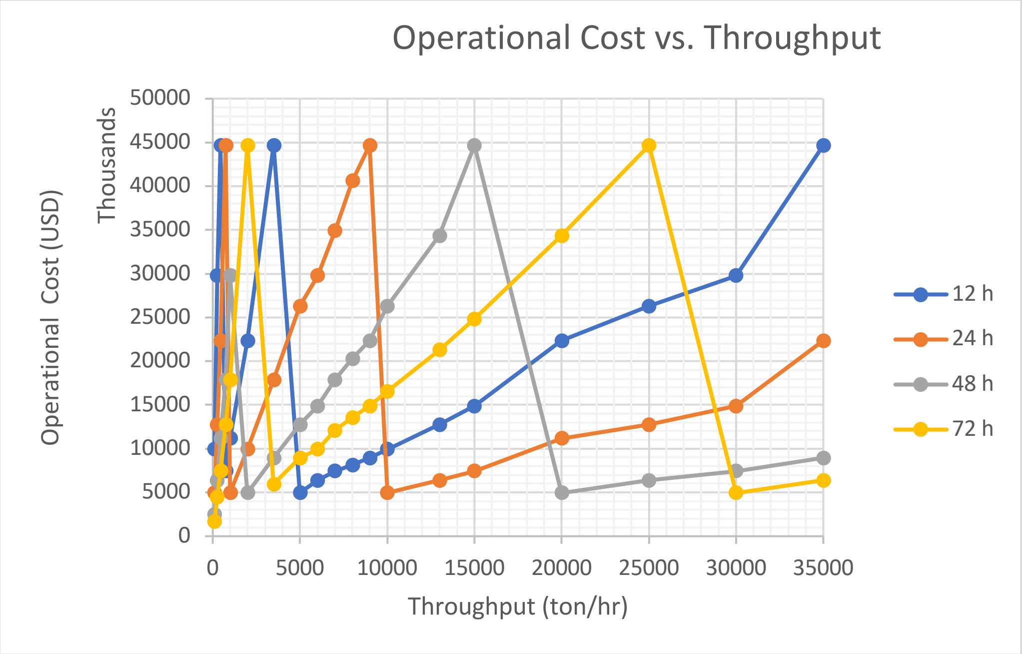

Figure 2. Operational cost modelling over 5 years for different lot periods, as a function of throughput which governs the number of sampling stages and sampling collection frequency/cost.

The financial modelling is done on a base price per sample result. It can therefore be expected that the operational cost would start out low, at low tonnages where a single stage sampler is still in use and the collection frequency is low. As the throughput increases, the single stage sampler will linearly proportional sample more often and the operational cost would also linearly increase because the sample collection and analysis frequency would increase. When a subsequent sampling stage is introduced (i.e., secondary, or tertiary sampling) the composite sample mass would drastically decrease (down to 10% division ratio) and therefore sample collection frequency will also decrease. It can be concluded that an increase in capex (more sampling stages) significantly and proportionally decreases opex costs.

To this accord for the 12-h lot period, the opex costs reaches a first maximum at 750 ton/h where samples are collected at a 30-minute interval. With the introduction of a second sampling stage for the 12-hour period, the collection frequency is relaxed to 3 hours and the opex costs reduced. Beyond 750 ton/h, the opex linearly increases as the throughput increases until a third sampling stage must be introduced. Beyond 5, 000 ton/h the opex gradually increases as the throughput increases. The other lot periods (24, 48, 72-hour) follow the same general trend, however the maxima are delayed on the x-axis, for the 24- and 48-hour lot periods, because the primary sampler increment intervals are relaxed, and sample collection not needed as often.

The 72-hour lot period transition point from primary to secondary sampling stages, do not peak at the same opex cost as the other 3 lot periods. Similarly at the transition point between secondary and tertiary sampling plants, the 12 and 24-hour lot periods again reaches a high opex cost, while the 48 and 72-hour costs peaks at lower values. These trends can be explained when considering that the relaxed lot period, at a given throughput, results in ergonomic samples at lower collection intervals while the lower lot periods require more frequent collection. Overall, relaxing the lot period, results in lower opex cost inflection points again (like capex) proving that increased lot periods result in lower sampling cost.

Overall, there is a progression of opex cost, as throughput increases indicating that sampling plants serving high throughput production facilities, naturally have higher opex costs.

Given that increased capex reduces opex, the nett effect on total cost of ownership (capex versus opex) must be quantified for this model.

Total cost analyses
Figure 3 illustrates the relationship between total cost as a function of throughput and different lot size.

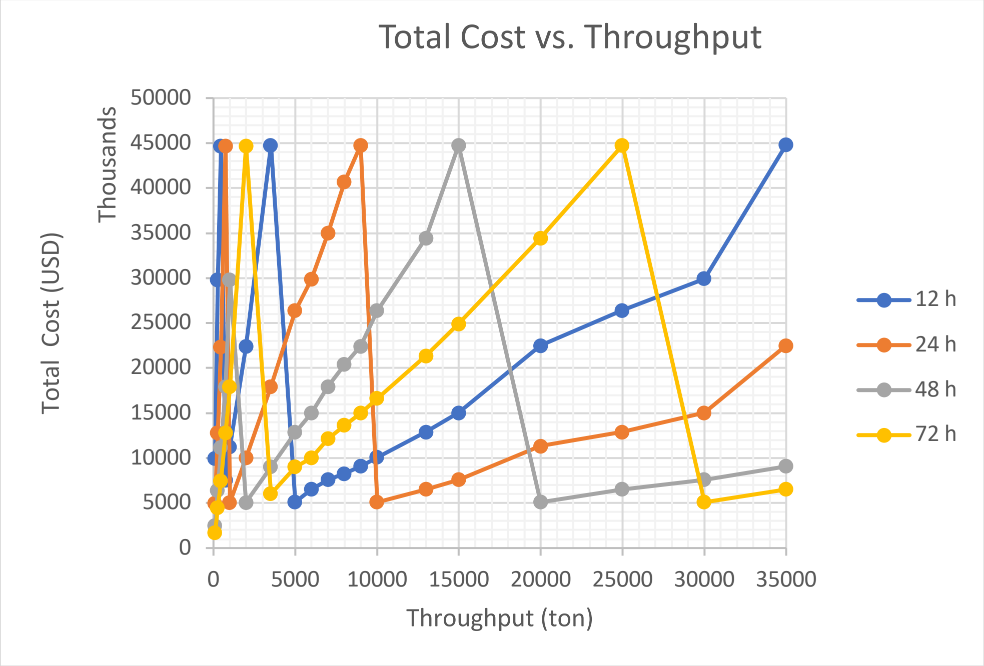

Figure 3. Total Cost modelling (capex plus opex) over 5 years for different lot periods, as a function of throughput.

The total cost trend is like the operational cost Figure 2 and indicates that the operational cost is the driving factor for the sampling cost over the period. The total cost of the 12-hour Lot period is always higher compared to the systematically decreasing 24, 48, and 72-hour lot periods, over the progression of the investigation.

Generally, at lower tonnages, the cost saving between a 72- and 12-hour Lot periods could be high. The largest cost saving between these Lot periods at 5000 ton/h could be as much as 130,000,000 USD over 5-year period. Given that the initial capital cost could be in the order of 40,000 USD over a 5-year period, the cost saving is significant.

Understanding the impact of Lot period on overall iron ore sampling costs, could save a company significant money over a 5-year period (and beyond). This work, coupled with other valuable inputs from the sampling academics – if understood, changes the financials of sampling bulk commodities from a grudge purchase to an affordable necessity that can save operations money to the extent where the bottom line can be impacted.

CONCLUSIONS AND RECOMMENDATIONS

The capital costs for the 12-hour Lot periods are higher than the 72-hour Lot period across 100 ton/h to 35, 000 ton/h throughputs.

Operating at lower Lot periods, results in time saving for collecting samples, receiving analytical results and ultimately decision making.

However, relaxing the lot period, results in lower opex cost inflection points and because opex costs are the driving parameter for total cost, increased lot periods result in lower sampling cost.

Therefore, Lot periods (for time base sampling) and Lot size (for mass base sampling) has an impact on iron ore sampling costs and could save a company significant money over a 5-year period and beyond.

It is recommended that sampling systems must undergo the necessary engineering study phases that consider these types of trade-offs.

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