Linking Mineral Resource and Ore Reserve Classification with Techno-Economic Study levels and Forecast Relative Accuracy

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Abstract

International mineral disclosure standards and guidelines aligned with the CRIRSCO template were developed to inform stakeholders about the relative accuracy and confidence levels of publicly reported information and to support investment decisions; particularly when advancing projects through different development stages. The traditional development stages range from early to advanced exploration, through pre-development (with Mineral Resources and pre-feasibility and/or feasibility levels of study), before the final development stages, where a decision to proceed with construction or production (or both) is made.

The traditional definition of Mineral Resource and Ore/Mineral Reserve classification categories and techno-economic study levels (including Preliminary Economic Assessment (PEA), Scoping Study (SS), Pre-feasibility Study (PFS) and Feasibility Study (FS)) were defined with pre-development project assessment in mind. As such, these definitions are not necessarily well aligned to the reporting structures required by operating mines which need to consider a range of timelines spanning short- to long-term operating conditions. However, the same terminology and definitions are used, or expected to be used, by both project developers and mine operators when reporting resources, reserves and techno-economic study outcomes.

This paper discusses how various stakeholders in the minerals industry (including Competent/Qualified Persons, mining company leaders, investors, lenders and regulators), generally interpret the definitions of Mineral Resource and Ore Reserve categories in terms of the relative accuracy of the estimates, their link to techno-economic study levels and their contribution to life of mine (LOM) schedules. The paper examines the degree to which mining companies recognise, and apply, enhanced operational knowledge to reflect short-term views of the relative accuracy and confidence levels associated with publicly reported Mineral Resource and Ore Reserve estimates and forecasts. Furthermore, this paper explores how this knowledge is applied to support ongoing Mineral Resource, and particularly Ore Reserve, generation and reporting.

This paper is informed by public data and responses to an internal survey prepared by the authors and completed in 2021 by several mining companies.
Keywords: mineral resource, reserve, pre-feasibility, feasibility study, classification

Introduction

This paper is intended to provide feedback on recent mining industry practice with respect to corporate approaches to disclosures relating to Mineral Resource and Ore Reserve classification and how this relates to techno-economic studies. In particular, this paper will explore how mining companies generally interpret the intended meaning of the definitions associated with Mineral Resource and Ore Reserve classification categories in terms of the relative accuracy of the estimates, their link to techno-economic study levels and their contribution to life-of-mine (LOM) schedules.

For further context, international mineral disclosure standards and guidelines aligned with the CRIRSCO reporting template (such as the JORC Code, SAMREC Code, PERC Reporting Standard, CIM guidelines, SEC S-K 1300 rule, etc.) were designed to inform stakeholders (investors, lenders and project developers) about the relative accuracy and confidence level associated with exploration results, as well as resource and reserve estimates. In particular, they were designed to instil confidence in mineral disclosures and to support investment decisions associated with the advancement of projects through increasingly detailed and complex development stages.

In reality, the definitions of resource and reserve classification categories and techno-economic study levels within these standards were predominantly designed to facilitate the assessment of pre-development projects and disclosures focused on medium- to long-term strategic LOM timelines. As such, the terminology is not necessarily aligned with the levels of accuracy required at operating mines which must reflect operational data and shorter-term mine planning and forecasting timelines to meet these operating performance requirements.

The feedback now presented regarding recent industry practice has been derived from public data and an international benchmarking survey compiled by the authors, supplemented with the authors' exposure to these topics through direct work experience and involvement in relevant industry forums. This knowledge seeks to address the following key topics:

- The relative proportions of Measured, Indicated, and Inferred Mineral Resources reported by mineral companies prior to, or at advancement of, a project to PFS and/or FS levels of study, as well as the relative proportions of Proved and Probable Reserves, which result from such techno-economic studies.
- The typical development status of projects prior to finalising techno-economic studies and progression towards a final investment decision. In particular, this paper outlines how public reporting may be influenced by project status, which in turn may impact subsequent resource and reserve classification.
- Recommendations for handling varying resource and reserve categories in mine schedules, particularly how resource and reserve confidence is managed or dealt with by companies over time in their LOM schedules.

INDUSTRY PRACTICE: SURVEY

Survey design and participants

The questions in the survey provided to several mining companies were designed to be somewhat generic, rather than overly specific. This design was deliberate, as the authors considered the open nature of the questions would encourage invitees to share their respective company's operational practices, rather than being led by the line of enquiry.

The survey was to be completed online, with results automatically submitted upon completion. Submissions were anonymised (unless invitees specifically added their details; in which case details were not linked to individuals or companies).

The survey was circulated to Competent Persons/Qualified Persons, resource/reserve managers and technical governance professionals at 21 international precious and base metal mining companies with open pit and underground operations employing selective and bulk mining extractions. Responses were received from 14 companies, representing mining companies with operations predominantly in Australia, Africa and North and South America, and reporting mainly in accordance with the JORC Code, SAMREC Code and CIM guidelines, as well as SEC regulations.

Invitees were expected to provide their company's views on the topics surveyed, and not their own individual or personal opinions. Based on the responses received, the authors consider this had largely been the case.

Survey responses

The key questions and results of the survey are summarised in Table 1.

TABLE 1 – Company benchmarking survey summary results

Survey question	Responses proportion	Summary responses
Does your company have internal guidelines on the required proportion of Measured and Indicated Mineral Resources to support a PFS and FS? If yes, what are the proportions? Do the guidelines cover a set period?	7/14 (50%) say 'No'.	Only 3 of the 7 'Yes' respondents have clear guidance on proportion of Measured Resources expected to support a FS (or initial mining area or payback period from FS); the remaining 'Yes' respondents require Indicated or Measured+Indicated (M+I) or a 'significant' portion of Measured.
Does your company insist that Proved Reserves are only possible after an FS level of detail has been completed?	11/14 (79%) say 'No'.	One of the 11 'No' respondents did not report Proved Reserves from a FS (resource continuity too poor), another downgrades the Measured component to Probable Reserves for mining assumptions (block cave). 10/14 allow Proved Reserves from a PFS; while only 3 insist a FS be completed to support Proved Reserves reporting.
Does your company recognise that some deposits or mineralisation styles are more difficult to assign to a Measured level of resource confidence with resource definition drilling alone at PFS or FS stages? (Clarification: ie without having exposure and access to the resource through open pit or underground development to allow for additional mapping and sampling).	10/14 (71%) say 'Yes'.	Several respondents refer to the use of benchmarking comparisons, sensitivity profiling, and/or simulation to compare risks/ classification across projects. None refer explicitly to a requirement for orebody access/ additional mapping/ bulk sampling etc. to improve orebody knowledge, however the authors recognise some do this.

Survey question	Responses proportion	Summary responses
Does your company have guidelines to quantify or semi-quantify what is meant by Measured and/or Indicated Mineral Resource categories (and Proved and Probable Reserves)? If so, please elaborate.	7/14 (50%) say 'Yes'.	While 7 say 'Yes', only 5 respondents provided relevant examples as outlined in the paper.
Does your company have its own detailed standard for PFS and FS content, or rather refer to an industry guideline for this detail?	9/14 (64%) say 'Yes'.	Those responding 'No' follow various industry guidelines without an internal standard.
Do you consider that other peer companies and Competent Persons have the same or similar meanings for Measured and Indicated Mineral Resources as within your company?	11/14 (79%) say 'Similar'.	Those 3 responding 'No' considered peers had a materially different interpretation or meaning for Measured and Indicated Resources.
Do you consider that other peer companies and Competent Persons have the same or similar meanings for PFS and FS as your company? Or are they more or less conservative?	8/13 (62%) say 'Similar'.	4 companies consider that peers are materially less conservative and 2 slightly less conservative. Only 1 considers peers are materially more conservative.

Review of public data

Research of public company disclosures indicates that a majority of companies consider the relative proportions of Measured, Indicated, and Inferred Mineral Resources prior to, or at advancement of, the project to PFS and/or FS levels. Consideration is also given to the relative proportions of Proved and Probable Reserves that are defined as outcomes from such studies.

As well as publicly available literature, the April 2021 review considered a private database collection of public reporting data. Unfortunately, the database used to support this research does not separately report material in the Measured and Indicated Resource categories. The unfiltered dataset contains details of several thousand projects at various stages of development. For comparison purposes, this was reduced by filtering to match companies with a market capitalisation (MCap) less than US$200 billion. Of the selected companies, MCap was not reported for 40% of the companies, 40% had a MCap of less than US$1 billion. Only 1% had a MCap in excess of US$50 billion.

Figure 1 shows the percentage of Measured plus Indicated (M+I) Resource material for various commodities at differing levels of techno-economic study. These results suggest there is little increase in the proportion of M+I to total resources as the techno-economic study level increases from PEA to FS or mine plans (MP). 'UNK' refers to data for which the study level has not been provided. These results are summarised in Table 2.

Figure 2 shows the proportion of M+I to total resources has not increased on an annual basis between 2005 and 2021. The results show an increase in the number of studies completed, or at least reported, in recent years.

Figure 3 suggests there is no relationship between MCap and the percentage of M+I to Total Resources reported.

TABLE 2 – Company benchmarking survey summary results ('UNK' – study level not reported)

Study Level	No. Studies	% M+I
PEA	374	51
PFS	182	56
FS	356	56
MP	161	58
UNK	2,896	33

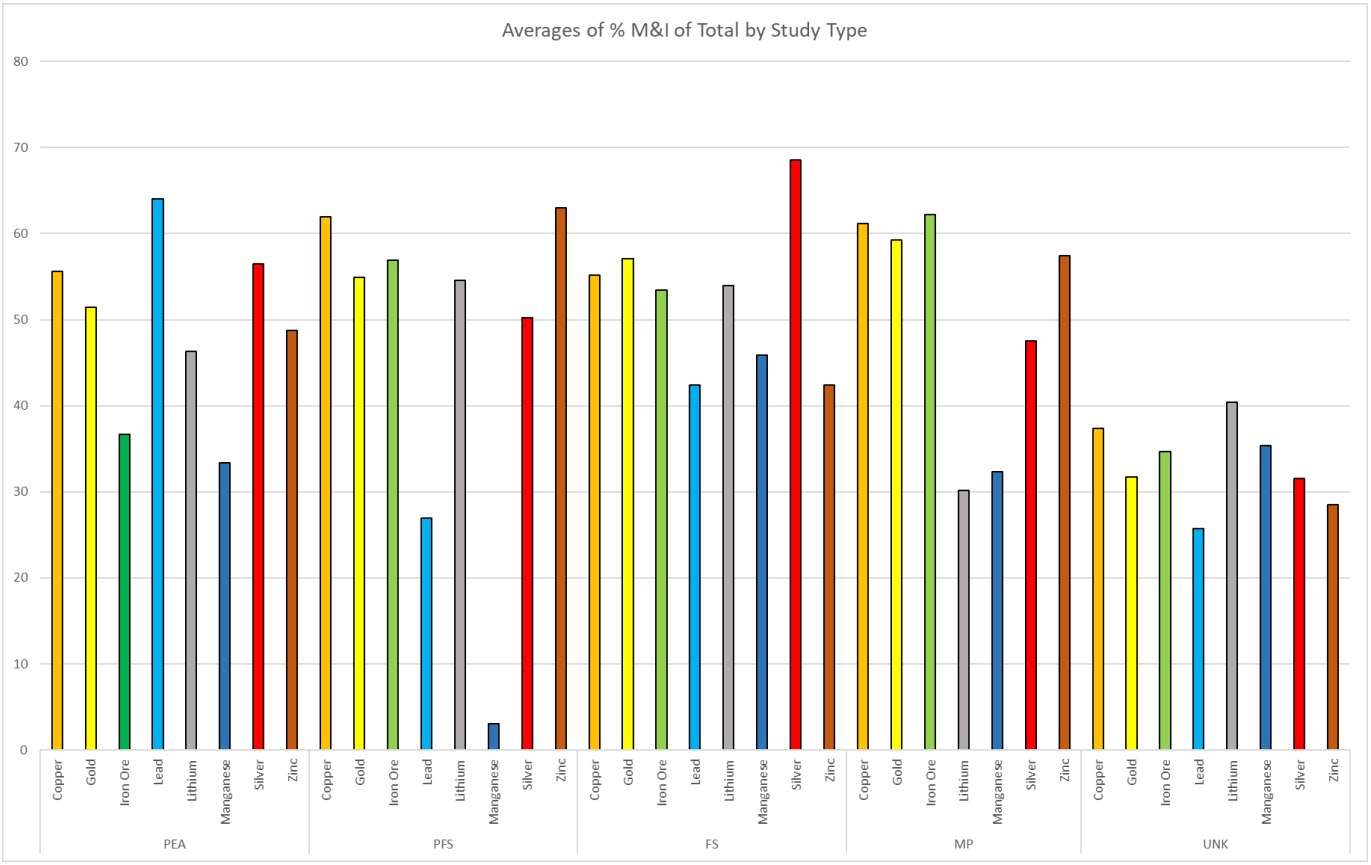
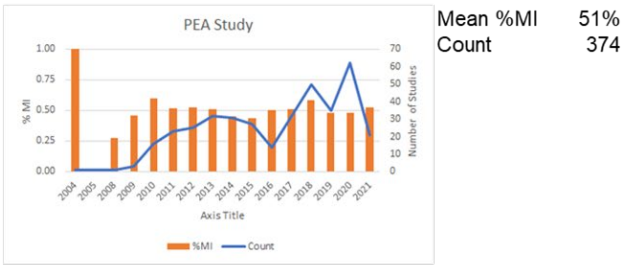
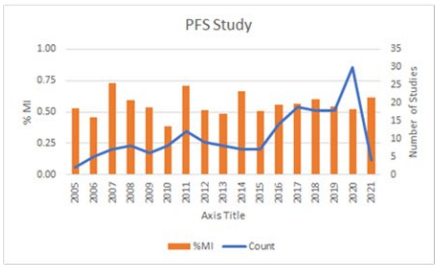


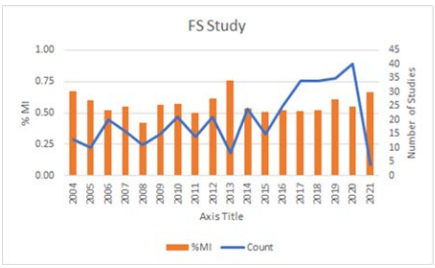
FIG 1 – Averages of percentage Measured+Indicated (M&I) of total resources by study type



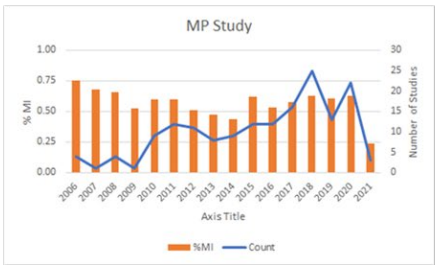
Mean %MI 51%
Count 374



Mean %MI 56%
Count 182



Mean %MI 56%
Count 360



Mean %MI 58%
Count 162

FIG 2 – Trends by Year

FIG 3 – Trends by MCap

Based on the Mineral Resource criteria for advancement of a project, the resource varies widely from deposit to deposit, and relatively few identified projects have significant percentages of M+I material relative to the total declared resource, and several have none. Further, it appears that the amount of geologic de-risking that occurs is unique to each project and company.

The authors observe that among private companies, the criteria for advancement of a project is sometimes even more nebulous and inconsistently applied than for public companies.

Survey discussion

Relative proportions of Measured, Indicated, and Inferred Mineral Resources informing PFS and/or FS levels of study and expectations for proportions of Proved and Probable Ore Reserves as outcomes from such studies

Half the companies surveyed do not have a defined proportion of Measured and/or Indicated Mineral Resources to support a PFS or FS study.

The authors note the very point of embarking on a PFS or FS is to confirm the technical feasibility and economic viability of the resource and define a reserve estimate, namely to determine and apply the modifying factors '*in sufficient detail to support mine planning and evaluation of the economic viability of the deposit*'. The next point talks to this matter of determining whether an Ore Reserve can be defined and reported.

Companies that provide guidance on the relative proportions for Measured and/or Indicated Mineral Resources required to advance a project to techno-economic study level typically link these proportions to the payback period/initial mining areas in some way. Some companies note that the proportion is linked to the source of funding, whether internal or external, implying they may be more willing to accept lesser proportions of high-confidence material if the project is funded internally.

Where required, the proportion of Mineral Resources required to support a PFS is generally considered to be best targeted toward those projects where Indicated material represents the majority of the resource (>50% or >80%) over the payback period. For FS levels, the majority of invitees consider this is best supported by either a majority of Measured or combined Measured+Indicated Mineral Resources over the payback period.

While a number of invitees expect the payback period evaluated at a FS level to be supported largely by Proved Reserves, others simply refer to 'total reserves' (ie Proved+Probable).

Some companies allow the reporting of Proved Reserves following the completion of a PFS, while others require a FS to be completed before reporting any reserves. Others require a final 'board-approved' FS, while two invitees do not report Proved Reserves at all, as discussed below.

Those invitees who do not report Proved Reserves at all disclosed that this is because of either 1) the inherently lower confidence (continuity) in the Mineral Resource (no Measured component), or 2) the selectivity of the adopted mining method (in case of block cave) is such that it is inherently less confident for the prediction of the grade and tonnage (metal content) than they would expect for a Proved Reserve.

Even where there is an expectation for certain levels of confidence to be reflected in the classification for Mineral Resources and/or Ore Reserves supporting or being reported from PFS and FS studies, most companies recognise this aspect is deposit and project specific. As such, companies focus on understanding the relative confidence/risk over the payback period or, in the authors' experience, extended over the 'payback period plus a safety margin'.

The safety margin period is subjective, but typically can be as much as the payback period plus another 50% of time. It is generally introduced as investors and lenders recognise there is uncertainty in certain key technical and external assumptions (such as commodity price, recovery, ramp up, commissioning, etc.) supporting the PFS or FS analysis. This is particularly the case over the initial production period, which may then mean this initial period is a not simply the payback period. The authors are aware of a company which has adopted a study key performance indicator of 'how many payback periods inform the envisaged LOM period'. This approach recognises that the assumptions may not all align in the initial mining period, particularly the commodity prices, and use this simple metric to assess the likelihood of achieving payback over the expected project life.

Typical project development status prior to finalising studies

The majority of companies surveyed recognised resource definition drilling on its own is not necessarily sufficient to define and assign the highest levels of resource confidence classification to support the project status, in this case for a 'development project' status. The authors have used the project development status terms outlined in the VALMIN Code (2015) for 'Development Projects, namely '*Tenure holdings for which a decision has been made to proceed with construction or production or both, but which are not yet commissioned or operating at design levels. Economic viability of Development Projects will be proven by at least a PFS'*.

In the case of open pit and underground projects, some companies require direct access to the deposit to conduct bulk sampling and infill 'grade control' drilling and mapping in the initial start-up mining areas or test areas, and other related assessments prior to completion of the FS or as part of the preparation for the final or definitive engineering design and construction phase. The definitive engineering phase typically follows approval of the FS supported by funding for final studies and/or construction.

Most companies carry out benchmarking of their deposit/orebody against other similar deposits and/or past production to assess consistency, resource and reserve classification, confidence and risk. This is generally an important part of their stage-gating process within the overall project development framework.

As mentioned previously, even with additional levels of sampling, assessment and benchmarking, some deposit styles do not advance to the Measured Resource (or Proved Reserve) categories, regardless of the level of techno-economic study. The additional level of technical uncertainty inherent in these deposits and styles is recognised by the respective companies and their investment panels. However, the authors consider this is more often the case where companies have extensive operational experience in these styles of deposits and their extraction, for example for diamond projects and certain precious metal projects.

As noted previously, some companies permit the reporting of Proved Reserves upon completion of a PFS, while others require a FS to be completed before public disclosure of any reserves. Furthermore, others require a final 'board-approved' FS to be completed prior to such declarations. In contrast, two invitees noted they do not report Proved Reserves at all, regardless of the level of study completed or project status.

The authors note the majority (but not all) of those surveyed stated their company had its own detailed standard outlining the content of PFS and FS level studies. Most companies considered their peers had adopted similar resource/reserve definitions and held similar expectations regarding the preparation of techno-economic studies, particularly those at a PFS and FS level, and subsequent public disclosure/reporting.

Treatment of resource and reserve categories in mine schedules

This topic was not the subject of the company benchmarking survey, however, the following comments below are based on the authors' experiences and industry observations.

With regard to resource and reserve categories, mine schedules and how these reflect the company's estimates of confidence or accuracy over time, the authors note that international mineral disclosure standards provide comprehensive guidance. As an example, the JORC Code (2012), Clause 33, provides the following guidance for the discussion of accuracy and confidence levels: '*Competent Persons are encouraged, where appropriate, to discuss the relative accuracy and confidence level of the Ore Reserve estimates with consideration of both underlying estimation and Modifying Factor uncertainties. The statement should specify whether it relates to global or local estimates, and, if local, state the relevant tonnage. Where a statement of the relative accuracy and confidence level is not possible, a qualitative discussion of the uncertainties should be provided in its place*'.

Table 1 in the JORC Code (2012) expands this as follows: '*Where appropriate a statement of the relative accuracy and confidence level in the Ore Reserve estimate using an approach or procedure deemed appropriate by the Competent Person. For example, the application of statistical or geostatistical procedures to quantify the relative accuracy of the reserve within stated confidence limits, or, if such an approach is not deemed appropriate, a qualitative discussion of the factors which could affect the relative accuracy and confidence of the estimate. The statement should specify whether it relates to global or local estimates, and, if local, state the relevant tonnages, which should be relevant to technical and economic evaluation. Documentation should include assumptions made and the procedures used. Accuracy and confidence discussions should extend to specific discussions of any applied Modifying Factors that may have a material impact on Ore Reserve viability, or for which there are remaining areas of uncertainty at the current study stage. It is recognised that this may not be possible or appropriate in all circumstances. These statements of relative accuracy and confidence of the estimate should be compared with production data, where available*'.

More recently, it has become common for companies to report the proportion of material from each Mineral Resource category (and/or Ore Reserve category) informing the LOM schedule. This is typically completed annually, by way of tables or graphs, even if only for internal purposes (FIG 4). In some cases, for example investor reporting, these categories may be grouped or consolidated as Inferred and Measured+Indicated Mineral Resources and/or Ore Reserves. In some cases, the LOM schedule may include exploration potential (or Exploration Target) material in these production targets for internal assessment purposes rather than for public disclosure.

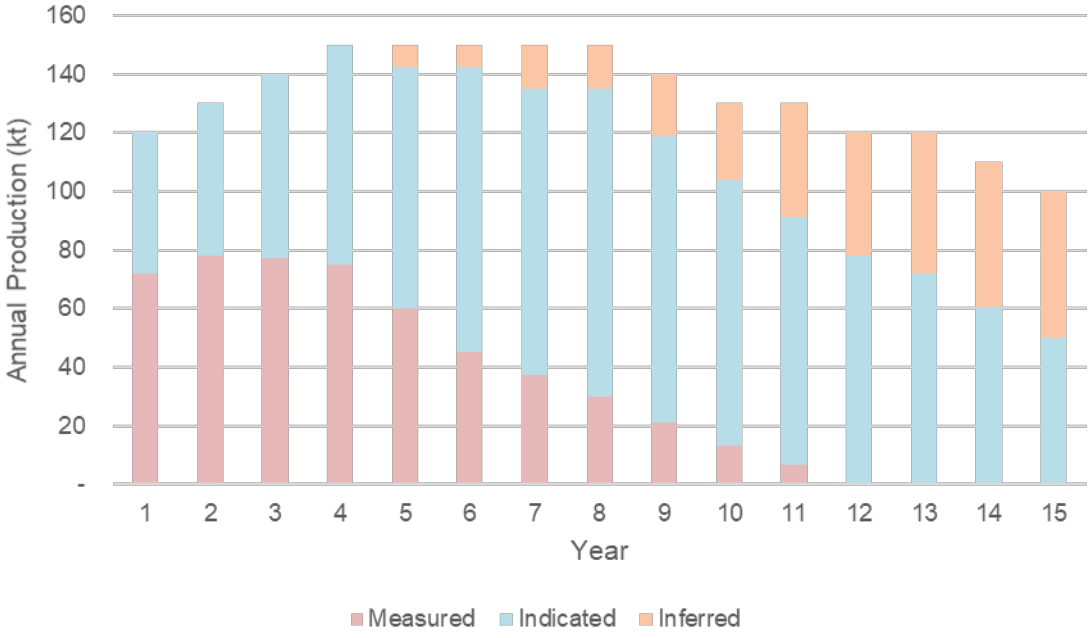


FIG 4 – Example of a LOM schedule with resource category proportions

Companies subsequently discuss, or are expected to discuss, this breakdown of annual schedule mix in terms of the payback period, plans to further define and upgrade the classification, replenish/replace the Ore Reserves, etc. Similarly, the use of Inferred Resources or other material in the LOM plan requires a discussion on its materiality and the extent to which the project economics rely on such material. Companies generally present the sensitivity of the project to the inclusion or exclusion of this material.

As noted previously, most companies make use of benchmarking, including against production data and reconciliation where possible, to assess, explain and report on the reliability of their forward-looking production projections. Here, companies are expected to discuss the expected accuracy and confidence limits for Indicated/Measured Resources or Probable and Proved Reserves, and some companies do so with reference to an annual production basis.

In a few cases, the authors are aware of companies quantifying the uncertainty in the annual schedule estimates by way of conditional simulation to attempt to define the potential accuracy of the estimates within the annual mine plan and schedule.

In other cases, companies use conditional simulation to assess the estimation accuracy for the resource model, either to help inform the allocation of the resource classification or in other cases to quantify the accuracy within previously classified category volumes. This simulation work is often performed only over test sub-areas within the broader modelled mineralised zone to provide an indicative measure of accuracy. This approach provides a comparison or benchmarking between different deposit types. Some companies also use this approach to internally make comparisons between projects/operations.

In order to compare these simulation results across different deposits, the accuracy needs to be reported within similar time periods or over similar volumes/tonnages. Some of the examples presented from the survey were as follow:

- *'It is company policy that Mineral Resource classification is to be based on a definitive and auditable process and is to adhere to the ±15% rule; namely, a Measured Resource should be expected to be within ±15% of the metal estimated at least 90% of the time (on a 3-month period), for an Indicated Resource estimate the annual estimate should be within ±15% of the metal estimated at least 90% of the time (over yearly periods)'*
- *'±10% accuracy in contained metal over a 1-year period for material classified as Measured'*
- *'For Indicated Resources: ±15% accuracy at 90% confidence over 1-year of production*
- *'±15% accuracy in tonnes and contained metal (at 90% confidence) over 1-year production period for Indicated material and over a 1-quarter production period for Measured material'*
- *'Indicated material to be within 10% annually and Measured material somewhat less (by annually we mean for a tonnage that reflects something close to annual mill feed, for example, for Open Pit operations) 2 Mt or 3 Mt'.*

The authors note an example for a company with diamond, precious metal and base metal operations. When this company used condition simulation to compare what its Competent Persons meant for the accuracy in Measured or Indicated Resources, they determined that their diamond operations would never be better classified than Inferred Resources at the time. However, their experience was that the diamond project forecasts could be estimated with reasonable accuracy but over different, typically longer, production scales to the other operations. As such, they could report at best an Indicated Resource over an annual production period, or indeed over a different, perhaps longer production period/tonnage (such as a mining bench/ level).

The authors consider this application of conditional simulation should be interpreted similarly to mine reconciliation reporting, namely, the assessment expected variation between estimates and actual results over say monthly, quarterly and annual production periods to monitor that they are within acceptable control limits.

Conclusion

Review of public data for resource and reserve confidence categories and levels of techno-economic studies indicates that the disclosed information supports the feedback from the industry survey, namely there is a degree of variability, perhaps inconsistency, in the approaches applied and subsequent outcomes. This variability is perhaps not surprising given the reporting standards and guidelines are typically principles-based and not overly prescriptive, and so the Competent Persons/Qualified Persons and their companies determine the approach that applies to their situation.

The authors note that even where there is an expectation for certain levels of confidence classification for Mineral Resources and/or Ore Reserves supporting, or being reported from, PFS and FS studies, most companies recognise the actual decision is deposit- and project-specific. As such, companies focus on understanding the relative confidence/risk within the payback period or, in within the 'payback period plus a safety margin period'.

The authors interpret the survey invitees fall into three groups based on their responses, namely a risk averse end-member group (4 companies), a risk tolerant end-member group (5 companies), and the remaining companies which were not obviously in either category. Further, it appears each company's position is conditioned on the nature of their primary mineral assets as to whether their portfolio comprises projects with high geological and/or mining complexity or not.

The 'risk averse group' held predominantly bulk commodity deposits, have internal guidelines for Measured and Indicated Resource levels for PFS and FS and generally require Proved Ore Reserves over the payback period. Further, they typically have internal detailed standards for PFS and FS content and believe industry peers from other companies have the same or similar meanings for resource categories and PFS and FS levels.

The ‘risk tolerant group’ typically held projects with greater geological complexity, or acknowledges that different levels of project complexity exist; none of the invitees had stipulated payback periods within their consideration. This group generally has detailed internal standards for PFS and FS content, and believe peers have materially different meanings for resource categories and PFS and FS levels.

The authors propose that a further influence on the approaches adopted by industry to resource and reserve classification and reporting from techno-economic studies is driven by the evaluations applied by lenders and investors. While not covered in this paper, the approach to valuations and how the variable mineral asset inputs are interpreted and applied may warrant further review. As an example, it is interesting to note that from a valuation perspective the confidence and weighted contributions for resource and reserve categories are generally simplified into broader categories of 1) Inferred Mineral Resources, 2) Indicated+Measured Mineral Resources, and 3) total Ore Reserves. Similarly, in the case of Ore Reserves, the authors’ experience is that there does not appear to be a particular uplift in values ascribed to projects reported at a FS versus a PFS level of assessment. In part, this may reflect that such studies are addressing the selection of options and project risk mitigation, where the most appropriate development option is still being finalised at PFS level, while the FS is more concerned with optimising the option and less about risk.

The authors conclude that this practical outcome to the approach to value, and therefore confidence, perhaps drives the variable approaches by the industry to the proportions of various Mineral Resource categories informing PFS and FS studies, as well as the current approach by industry that the level of study, namely PFS or FS, does not necessarily inform the classification of reserves as either Proved or Probable Reserves.

Acknowledgements

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