Mineral Resource Estimation: Recent Advances and Current Best Practice

V I R T U A L  C O N F E R E N C E

19 October 2020

Convenors

Ben Lepley Senior Resource Geologist
Lucy Roberts Principal Resource Geologist
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VIRTUAL CONFERENCE PROGRAMME
Via Zoom during BST

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PERC’S ROLE IN CRIRSCO AND ITS IMPORTANCE TO THE EUROPEAN MINING AND MINING SERVICES INDUSTRIES

Ruth Allington & Edmund Sides (Orebody Risks/PERC)

PERC, the Pan-European Reserves and Resources Reporting Committee, is the European member of CRIRSCO, an international association of fourteen similar organisations from around the world. PERC’s primary responsibility is the maintenance and development the PERC Reporting Standard, but it also promotes competence in minerals reporting and provides accessible training and guidance to practitioners and investment communities. The CRIRSCO-family of codes and standards for the reporting of exploration results, resources and reserves of solid minerals is recognised internationally by investors and financial institutions. In addition to the PERC Standard, the CRIRSCO family includes the more widely known Australasian (JORC), Canadian (CIM Definition Standards underpinning NI43-101) and South African (SAMREC) codes.

This presentation will provide an introduction to PERC and explain PERC’s role in CRIRSCO. An overview will be provided of the roles and responsibilities of the Competent Person and the necessary professional qualification and experience requirements for acting in that role. It will also highlight the importance of the Recognised Professional Organisation (RPO) concept to the maintenance and development of international reporting standards and the mobility of professionals working as CPs/QPs.

All the CRIRSCO codes and standards (including the PERC Reporting Standard) are aligned with each other in order to facilitate international consistency and comparisons. This is achieved by basing them on a common classification scheme with common definitions that are set out in the CRIRSCO international reporting template. A comparative summary of the different CRIRSCO codes and standards will be provided to highlight their shared common elements, as well as identifying some of their distinctive features.

An explanation will be provided of how the CRIRSCO template has evolved since it was first published in 2006, with examples being given as to how some of the features in the 2019 version of the CRIRSCO template were first introduced in the PERC Reporting Standard. The value of the PERC Reporting Standard in providing a framework for effective project risk assessment will be illustrated.

An update will be provided on CRIRSCO’s current initiative (being led by PERC as part of the next update of the PERC Reporting Standard) to incorporate additional guidance on the reporting of environmental, social and governance (ESG) issues into the CRIRSCO template.
THE CIM BEST PRACTICES GUIDELINES: BETTER ESTIMATES THROUGH BETTER PRACTICE

Reno Pressacco, Principal Geologist, SLR Consulting


A fundamental requirement of a Mineral Resource as defined by many of the world-wide Definition Standards is that it must have “Reasonable Prospects for Eventual Economic Extraction” (RPEEE). Of particular importance is the assurance that Mineral Resource statements for underground scenarios consider the spatial relationships of not only those areas of mineralization above the nominated cut-off grade, but the necessary diluting materials as well. Among the many sections of new items, the 2019 MRMR BP Guidelines provide specific information on means and methods for achieving the “RPEEE” requirement in these situations.

Validation of the data used in the preparation of Mineral Resource estimates, particularly data that has been acquired by previous owners of a mineral property, is also a fundamental step in the estimation process. In conjunction with the updated CIM Mineral Exploration Best Practices Guidelines released in 2018, the 2019 MRMR BP Guidelines provide suggestions for best practices for the validation of historical drill hole information in the preparation of Mineral Resource estimates.

As these two items are some of the key areas of improvement identified in the recent study completed by the Canadian Securities Administrators (CSA), viewers of this presentation will be able to gain knowledge for ways to improve the quality of Mineral Resource estimates in these areas. Copies of the 2018 Mineral Exploration Best Practices Guidelines and the 2019 MRMR BP Guidelines are available from the CIM at https://mrmr.cim.org.
RECOGNISED PROFESSIONAL ORGANISATIONS: OPPORTUNITY OR BURDEN?

Leigh Slomp

The role of Recognised Professional Organisations has evolved over many years and they perform a critical role in reporting and compliance for publicly listed Mining & Exploration companies and, by default, industry consultants large and small. But many in the industry remain cynical when it comes to the requirement to be a member of a Recognised Professional Organisation.

Already architects for the various international standards committees and accepted by regulatory bodies, it is up to these organisations to prove to their ‘grass roots’ members and industry professionals that they are not just a necessary burden, but rather they present real opportunities for meaningful development and a valid connection to the wider industry.

In response, the AusIMM has recognised that it has a significant cohort outside of Australia, and increasingly these professionals are not only expatriate Australians or members who have worked in Australia. As a Recognised Professional Organisation in a global industry of ever increasing regulation and compliance, it is not enough to just be some letters behind a name, a tangible presence is required to support, inform, develop and advocate for members.

The recent introduction of International Representatives and Committees in key regions such as Indonesia, the Americas and EMEA aims to provide that presence to strengthen representation for local AusIMM members living and working in these areas. While technology and communications make access to resources and membership services easier, it is important for members outside of Australia to have local opportunities for networking and professional development.

To provide this meaningful support it is up to RPO’s to collaborate at a much greater level. Competition for the membership dollar will always exist and debate about which organisation is best will remain prolific. But it is only by working in conjunction with each other, leveraging off our strengths and existing regional networks, that we can effectively support our members and maintain
INTRODUCTION TO S-K 1300 REGULATIONS PRESENTATION

Deanna Wolfe, P.G. MAusIMM CP (Geo)

The United States Securities and Exchange Commission (SEC) has adopted new information disclosure regulations for mining companies listed on the U.S. stock exchanges. The new regulation will dramatically transform the way U.S. listed mining companies disclose mining property results to the public. Commonly referred to as S-K 1300, these regulations apply to property disclosures and results of exploration results, mineral resources, and mineral reserves. In order to meet the impending compliance deadline in a timely and cost-effective manner it is essential that mining companies understand the new disclosure requirements, develop study and disclosure strategies to determine the impact of the new S-K 1300 reporting requirements on previously reported mineral resources and reserves.

This Golder Associates Inc. (Golder) presentation by Deanna Wolfe, P.G. MAusIMM CP (Geo) Senior Resource Geologist, outlines the new S-K 1300 regulations, timelines for compliances, details those who must comply and when, and attempts to inform the wider mining community how the rule may affect mining companies.
IMPLICATIONS OF CRIRSCO FOR IMPROVEMENTS IN ESG REPORTING REQUIREMENTS

Fiona Cessford, MSc, PrSciNat – Corporate Consultant ESG, SRK Consulting UK Ltd

The 2019 CRIRSCO template reflects the increased attention on environmental, social and governance (ESG) factors that we are seeing globally. The new guidance acknowledges ESG issues have more and more potential to be significant modifying factors and therefore require appropriate report, particularly at the earlier stage of mineral resource reporting. We will start by exploring which of the CRIRSCO criteria are influenced by ESG considerations. The talk will then consider how ESG factors could influence reasonable prospects for eventual economic extraction, the nuances between ESG reporting for resources and reserves and how to assess the materiality of the ESG factors.
STRUCTURAL GEOLOGY – THE MISSING SKELETON IN THE RESOURCE GEOLOGY CLOSET

Ron Reid Harmony Gold (PNG Services)

If the underlying structural model is incorrect then the whole shebang comes down around your ears. Spend some time looking through the news on resource model disasters and you get headlines like; “…announced an almost 50 percent downgrade in gold…”, “…some 1.5 Moz of gold assumed to be in the ground was never there…”, “The new geological interpretation…reduced grade by 21% and ounces by 24%…represents a reduction of almost 50% in minable ounces…” and “…ounces slashed by an astounding 88pct…”. Such disasters result in company stock tanking, shareholders demanding answers and banks knocking on doors. In many of these cases, the disasters have been blamed on software used (“t’was Leapfrogs fault!”), misinterpreted mineralisation zones, misread structural data, or even “it was Fred’s fault – but he left”. Read any textbook on resource geology and like rote it will quote the line “Geology is fundamental!” and launch straight into statistics. If the Resource models reflected the geology then these major issues should not occur. When you pull apart the reports, investigate the geology and look at the estimates, a common cause rarely if ever discussed is that the Resource model just does not match the geology and thus it is the Resource Geologists fault – in all cases. The resource model is the scaffold of the mining study, the geology model should be the foundation of the resource model and the structural model should be the skeleton of the geology model. When you look in detail at the grade data for a lot of deposits you can see some fundamental, basic structural geology that drives the metal distribution that has absolutely nothing to do with deposit type, certainly nothing to do with statistical voodoo and everything to do with the rocks in the ground. In the time available I hope to show you how you can elicit some basic structural geology framework from the grade data. Use this to build a testable hypothesis and go forth and test it against mapping, drilling, core photos etc. Once you have this fundamental basis formed you can begin to build a model that will hopefully be at least wrong as possible – until the next drillhole anyway – but that’s another story!
MACHINE LEARNING FOR RESOURCE MODELLING - REVOLUTIONISING WORKFLOW AND OUTCOMES FOR GEOLOGISTS WORKING WITH BIG DATA

Gary Buchanan / Steve Sullivan (Maptek)

Improving the timeliness of geological data delivery and its potential impacts on upstream applications, such as mine planning and scheduling, liberates geologists to focus on the interpretation and analysis of results. Machine learning is revolutionising geological modelling by helping to remove the bottleneck from processes at mining operations.

A resource model should portray the best understanding of geological observations and facts. The resource does not change over time, just the understanding of its characteristic idiosyncrasies. Computer-based modelling has traditionally replicated hand-drawn methods. Recently, other approaches - simulation of categorical variables and implicit techniques - have been adopted.

Maptek DomainMCF uses machine learning to generate domain boundaries directly from drillhole sample data for rapid creation of resource models. The deep learning approach correlates geological database codes directly into a 3D block model, and then uses resulting domain codes to constrain grade estimation. The deep learning domain determination is fast, taking minutes to assess and generate the results from thousands of drillholes.

Machine learning is a particularly effective approach to big data projects that are challenging for geologists using traditional methods. The methodology introduces rigour from the outset, requiring the resource modelling team to ensure data, which consists of geolocated geocode and grade data, to be free from errors and logged with a high degree of confidence. Once processed, the machine learning software outputs the results as a 3D block model, a format familiar to industry resource geologists, that can be further interrogated for upstream applications in mine planning.

The authors have modelled many deposits from around the world and most can be modelled using deep learning to a competent standard within 30 minutes, with the largest orebodies completed in just hours. Examples will be presented which show the application of deep learning in different geological settings - stratigraphic, vein, porphyry and breccia deposits - with comparisons against traditional techniques.
MINERAL RESOURCE ESTIMATION OF KIRUNA IRON ORE MINE

Can Aydogan, Lazaros Dalampiras, Sanna Olsson, Alpar Kovacs

The Kiruna Mine is located in Kiruna, northern Sweden, one of the biggest and most modern underground iron ore mines in the world. This type of ore deposit is also known as Kiruna-Type Iron Oxide Apatite (IOA) deposit. In this mineral resource estimation (MRE) of Kirunavaara deposit, the first step was to have a sound geological interpretation of Kiruna’s large tabular ore body. The ore body of Kiruna is 4 km long, from 100 meters to 200 meters thick and reaching a confirmed depth of at least 2.2 km. A good geological understanding and well-understood genetic model of the mineralization of the ore deposit is underpinning the MRE study and one of the most important steps particularly when the ore body has such a huge dimension and volume. Data quality and QA/QC protocols are another critical and crucial part of our study. The data set evaluated within QA/QC protocols and validated for use in the MRE. The Kiruna iron ore consists of two different main ore types, classified on the Fe and P content of the ore, they are B-Type Magnetite (Fe >66% and P <0.1%) and D-Type Magnetite (Fe >50% and P >0.1%). During the geological interpretation, the estimation domains were defined according to these ore types for the grade estimation. Domaining and stationarity are important terms for understanding the distribution of the data populations. In this part of the study, each estimation domain was investigated according to the exploratory data analysis (EDA). Moreover, all estimation domains considered boundary analysis and defined "hard boundaries" for all of them. When the EDA study is completed for all estimation domains, the next step is to focus on geostatistical analysis. The giant ore body of Kiruna reveals a good spatial continuity supported by dense production and exploration drilling. Geological and grade continuity of the deposit are essential to understand and were evaluated. Geostatistical analysis of the main estimation domains (B&D-Type Magnetite) produced robust variogram models, particularly for Fe. Directions of the Kiruna ore body and the grade continuity are highly consistent except in peripheral zones that have limited data. Due to the general robustness of the variograms, Ordinary Kriging (OK) was selected for the estimation method. OK is already known as "BLUE" (best linear unbiased estimator) and it is currently deemed the most appropriate estimation method for our study. Anisotropy, unlike isotropy, is the feature of being dependent on direction. Variable orientation (VO) is another significant component in the estimation and in order to get more reliable estimates, VO was used in the grade estimation. All steps of the MRE study of the Kiruna deposit have been reviewed in detail and an optimized block model for the Life of Mine Plan (LOMP) has been created.
HIGH PRECISION SUB-BLOCK MODELS WITH AN UNSTRUCTURED GRID; A SOLUTION FOR COMPLEX DEPOSITS

Alexandre Boucher (Advanced Resources and Risk Technologies, LLC)

With complex deposits, discretizing a volume of interest with regular blocks is challenging and often inaccurate. The industry has provided some work-around with fractional blocks and sub-blocking. Both of these approaches are flawed. The fractional approach does not locate the grade values. Sub-blocks create very large models without accurately matching the cutting surfaces and are typically only used for visualization since the sub-block takes the values of the parent cells. In this presentation, we offer a proper sub-blocking solution that conforms to the target volume, can be used for estimation and simulation of grades, represents the true variability of the grade within the region of interest and of the parent cell.

Take the case of a block cut by a surface, instead of sub-dividing that block into a series of smaller regular hexahedra, the block is divided into either regular hexahedra, tetrahedra, or wedges. These simple volumetric elements can efficiently divide a parent block into a minimal number of sub-cells while conforming to the cutting surface. The resulting unstructured grid is a mix of regular cells untouched by the surface and irregular small cells that conforms to the cutting surface. Each decomposed parent cell can then be accurately reconstructed through its sub-cells.

From a geostatistical perspective, block (co-) kriging and block (co-) simulation is done through a tessellation of each irregular cell to match the underlying support of the discretization of the regular cells. The resulting grades reflect the volume of the cells; a smaller cell has higher kriging variance and higher simulation variance than the parent cell. Through volume-adjusted aggregation, the parent cell will have the correct variance. The grade computation is parallelized both for simulations and estimations and can be run on a cloud-based distributed computing platform. Preparation of surfaces and regular grids for this presentation was performed in Leapfrog Geo with Edge extension, and the results were obtained with AR2Gas running with Seequent Central.

This unstructured gridding approach for high accuracy grids provides all the benefits of the standard sub-gridding without their drawbacks. It is of particular interest in vein-type deposits and sedimentary deposits with stratigraphic unconformities.
When we are speaking about exploration drilling or drilling grid for the resource estimation, or even defining the effectiveness of grade control at operating mines, we are always facing questions like: how many drillholes should we drill and what would be the drilling pattern particularly for that deposit? The JORC Code does not give us indication of the level of confidence. The general approach in the mining industry is to use certain drill spacing or number of samples to classify resources by level of confidence in categories. Therefore, before investing in your drilling there are a few approaches to measure the risk of misclassifying ore and waste, being one of them the application of conditional simulation methodology.

The current study applies the drill grid optimisation methodology defined by Martinez-Vargas (2017) on a nickel laterite deposit to define the optimum drill grid spacing for Mineral Resource estimation. It consists of getting from a realization done on a closed spaced grid, a set of patterns with an increasing horizontal drill spacing. For each drill grid pattern, the attribute grade was estimated. Then, the cost of drilling is computed as well as the cost of misclassification. This misclassification cost is defined by two parcels one considering the misclassified ore blocks sent to the mill and another considering the misclassified waste block sent to the waste dump. Consequently, the optimum drill pattern can be obtained when the misclassification costs equals the cost of drilling.

This methodology is based on the assumptions which the simulated grades represent a possible image of the simulated domain. As a result, one can draw samples with different spatial patterns from a realisation on a close spaced grid to estimate grades and compare its results with the same realisation, which is a possible representation of the reality.

A script was developed to simplify the routine that involves manipulation of huge amount of data and to generate reports. Some recommendations were added as complementary steps for helping one to have access to both uncertainty and level of confidence for production scale units, after having defined the best drill pattern for each domain.
THE ROLE OF RESOURCE RANGE ANALYSIS IN EXPLORATION TARGET REPORTING

Matt Mullins, (Tecoma Strategies)

According to JORC Clause 17:

An Exploration Target is a statement or estimate of the exploration potential of a mineral deposit in a defined geological setting where the statement or estimate, quoted as a range of tonnes and a range of grade (or quality), relates to mineralisation for which there has been insufficient exploration to estimate a Mineral Resource.

The guidance goes on to state that where the Exploration Target statement includes information relating to ranges of tonnages and grades these must be represented as approximations, and that explanatory text must include a description of the process used to determine the grade and tonnage ranges used to describe the Exploration Target.

Resource Range Analysis (RRA) is a formal process used by many companies to estimate the range of tonnages and grades, and has been well described by Mullins et al.\(^1\) in one of these companies. The process involves compiling geological information related to the deposit, usually in a workshop environment involving participants from a number of disciplines and including people external to the project, to reduce bias. In this workshop facts, interpretations, assumptions and unknowns, are clearly defined, ranked and examined.

Following the construction of an influence diagram, which highlights controls on the size and continuity of \textit{in situ} mineralisation, deterministic cases are modelled to demonstrate the full range of possible outcomes. By assigning a probability distribution to the deterministic cases an expected case can be estimated.

This process will be illustrated by application to a zinc-lead deposit in South Africa. At this deposit, remaining Measured, Indicated and Inferred resources have been clearly identified and reported. Mineralisation is present outside the classified resources, and the information generated through the creation of a influence diagram was used to define the range of tonnages and grades of this mineralisation, with the geological modelling been conducted in Leapfrog Geo™ software. These results have been used to design an effective exploration program, primarily focused on testing the maximum and minimum outcomes.

Besides providing the process substance to exploration target public reporting, the RRA process is applicable to many situations, from the design of an effective brownfields exploration programme, to the rapid resource assessment for a proposed transaction.
THE GEOLOGY SOCIETY – MINING - THE ULTIMATE VALIDATION: PRODUCTION DATA AND THE MINERAL RESOURCE ESTIMATED

Greg White, (CSA Global UK Ltd)

Prior to production on any mine site a mineral resource is estimated, and this model is used to make important financial decisions and support life of mine planning. Often the resource model is informed by wide spaced drill data and, depending on the project, a combination of field mapping, geophysics, trenching results and historical reports. But once these mines go into production a significant amount of additional data is generated, featuring much closer spaced drilling (grade control) as well as detailed production mapping as the ore body becomes further exposed. Using these data in combination with the existing dataset can create a wealth of opportunity to enhance confidence in the resource model through integrating a better understanding of both geological and structural controls; but too often, these opportunities are missed.

It is a requirement of international mining codes (e.g. NI 43-101, JORC, Samrec) that comparisons be made against production data and this is a critical and valuable validation tool in our arsenal. But how can we use this information to improve our mineral resource estimates? Often grade control models will be reconciled against the resource model on a periodic basis (monthly, quarterly, and annually) to assess performance of the long-term model against the mill. These observations are an essential indicator of past performance, and the primary focus should be to determine the ability of an operation to deliver on the tonnage, grade and metal estimates in mineral resources/reserves and not just on optimising the production systems and grade control model.

Having the grade control model and reconciliation data at the core of decision-making during resource estimation is explored through various examples from global projects. Benchmarking MRE volumes using wide spaced data against GC volumes using close spaced data, as well as integrating geological trends and short scale structures encountered (and better understood) through mining increases the confidence of the estimate. Assuming no material changes in the character of the mineralisation, the ability to assess the MRE model against the past allows the geologist and engineer to better predict the future.
GSL CODE OF CONDUCT FOR MEETINGS AND OTHER EVENTS

INTRODUCTION
The Geological Society of London is a professional and learned society, which, through its members, has a duty in the public interest to provide a safe, productive and welcoming environment for all participants and attendees of our meetings, workshops, and events regardless of age, gender, sexual orientation, gender identity, race, ethnicity, religion, disability, physical appearance, or career level.

This Code of Conduct applies to all participants in Society related activities, including, but not limited to, attendees, speakers, volunteers, exhibitors, representatives to outside bodies, and applies in all GSL activities, including ancillary meetings, events and social gatherings.

It also applies to members of the Society attending externally organised events, wherever the venue or online platform (virtual event).

BEHAVIOUR
The Society values participation by all attendees at its events and wants to ensure that your experience is as constructive and professionally stimulating as possible.

Whilst the debate of scientific ideas is encouraged, participants are expected to behave in a respectful and professional manner - harassment and, or, sexist, racist, or exclusionary comments or jokes are not appropriate and will not be tolerated.

Harassment includes sustained disruption of talks or other events, inappropriate physical contact, sexual attention or innuendo, deliberate intimidation, stalking, and intrusive photography or recording of an individual without consent. It also includes discrimination or offensive comments related to age, gender identity, sexual orientation, disability, physical appearance, language, citizenship, ethnic origin, race or religion.

The Geological Society expects and requires all participants to abide by and uphold the principles of this Code of Conduct and transgressions or violations will not be tolerated.

BREACH OF THE CODE OF CONDUCT
The Society considers it unprofessional, unethical and totally unacceptable to engage in or condone any kind of discrimination or harassment, or to disregard complaints of harassment from colleagues or staff.

If an incident of proscribed conduct occurs either within or outside the Society’s premises during an event, then the aggrieved person or witness to the proscribed conduct is encouraged to report it promptly to a member of staff or the event’s principal organiser.

Once the Society is notified, staff or a senior organiser of the meeting will discuss the details first with the individual making the complaint, then any witnesses who have been identified, and then the alleged offender, before determining an appropriate course of action. Confidentiality will be maintained to the extent that it does not compromise the rights of others. The Society will co-operate fully with any criminal or civil investigation arising from incidents that occur during Society events.