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Survey, ore flow, and reconciliation – MineRP Protocol

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Although a good value chain model reflects a strictly sequential, process-based view of the business, it does not necessarily directly model operational information flow. Specifically in this case, we will examine the ability to track rock movements from the intact orebody to the dump, stockpile, and plant. This requires firstly a survey network then a choice of the appropriate survey technologies. With the ability of taking spatially relevant measurements, routine tracking of rock movements and quantifying location, tonnage, and content becomes possible. Merging this information with the plant production profiles enables reconciliation of plant product recovery and residues with value content. Such reconciliations form the basis of variance analysis and reporting for internal and external purposes.

In South Africa at least, the custodianship of such data lies with the survey discipline. Following the logic of this orebody to plant information flow permits a mapping of the survey discipline's role against a value chain model of the mining business. In this case the role is mapped to the mining enterprise Open Group Exploration and Mining Business Process Reference Model.

Reconciliation requires information

In the context of this paper, reconciliation means tracing verified tonnage and content from the production plant, back through stockpiles of various kinds all the way to the ore reserve model. This necessarily needs a thorough understanding of the rock flow network to ultimately be reflected in the depleted and updated geological block model.

Traditionally, rock flow is the part of the mining value chain where we collect the least amount of data. No data – no information. Reconciliation then becomes an art form based on creative mastery of spreadsheets and trends analysis, understood only by a few resolute individuals.

Every mine's rock flow network is different at the level of detail required for relevant information. This fact alone suggests a generic model will prove useful as a starting point; if only to avoid having to re-invent common understanding every time a reconciliation exercise commences.

This paper describes just such a model, providing the basis for an ability to collect and process the desirable volumes of information, which is not possible when done by pencil and paper. Today, the relevant IT tools and practices enable a more formal and routine approach to data and information management.

The model now forms part of a collection of business models referencing and extending the application of the Open Group Exploration and Mining Business Process Reference Model (EM model) released to the public domain in August 2010. It has subsequently been accepted as an Open Group global standard.

Start with a business process model for reference

The Open Group is a vendor- and technology-independent organization with a vision of access to integrated information based on open standards and global interoperability. This enables an independent platform for collaboration, removing issues related to anti-competitive behaviour and claims related to intellectual property.

In 2007, mining industry collaboration was proposed, resulting in the establishment in 2008 of The Open Group Exploration, Mining, Metals and Minerals (EMMM™) Forum. The stated objective is to realize sustainable business value through collaboration around a common operating model. Doing so enables the differentiation of business-IT investment against standard operating practices, thereby supporting the delivery of technical and business solutions to the industry.

The forum's priority was a Business Reference model created by contributions from mining practitioners based on three continents and representing disciplines across the mining value chain. The result is a comprehensive Core Business Process Model (Figure 1) independent of mining type, method, or scale of operations. It enables conversations across all implementation phases of greenfield, brownfield, and operational phases of a mine's life.

The model is freely available on the Open Group EM Forum Members Site and is supported by a concepts and definitions document (Getting_started_with_the_EM_Business_Model_v_01.00.pdf). Refer to https://collaboration.opengroup.org/emmmv.

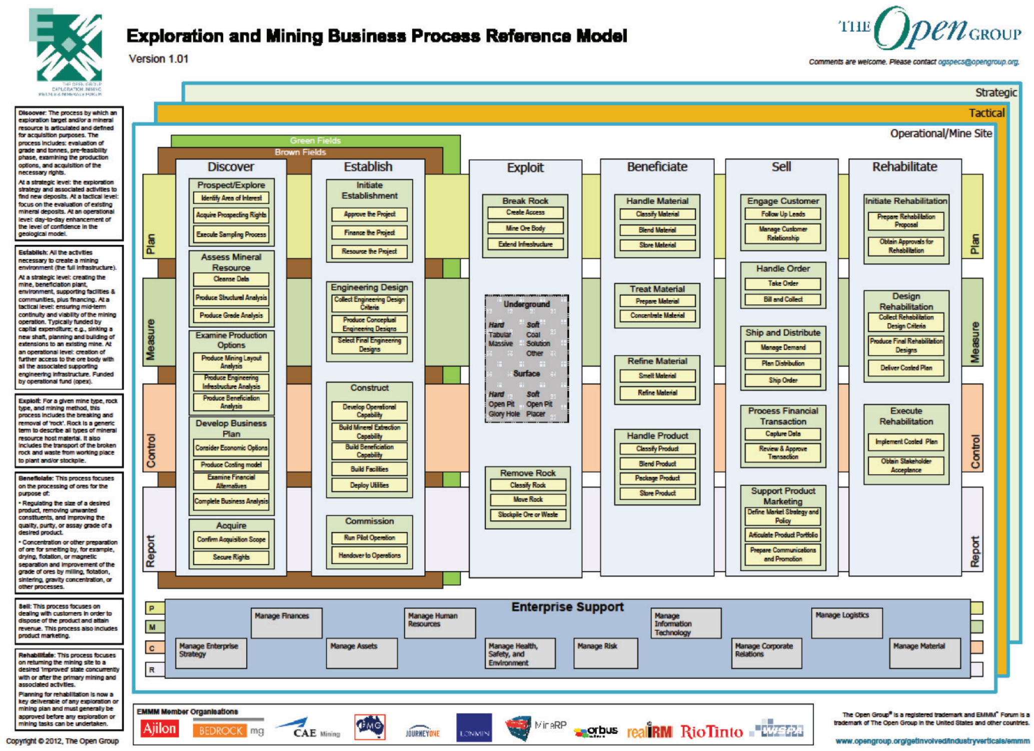

Figure 1. Exploration and mining Business Reference Model

Not a business process but a flow of information

Value chain models typically reflect a strictly sequential, process-based view of the business. They do not necessarily directly model operational information flow. In this case, we will examine the ability to manage a mine's built environment and track rock movements based on the application of a disciplined approach to survey and measurement. The scope of required measurements starts with the intact orebody and measures mining activity from where rock is broken, through multiple rock movements, to the various destinations of dump, stockpile, and plant.

This information flow mapping exercise is a collaboration between miners, engineers, and surveyors with a combined career experience of more than 150 years in shafts, open pit, and underground mining environments (one guy even met Merensky!). Their chief, relevant characteristic is a tidy and efficient approach to information management and the creativity to make information flow visible.

At the uppermost process level of detail, there is a three-stage flow of information. From a starting point of the surveyor's geographic and local reference points, the first stage is the work required to create a survey network, position infrastructure, and measure excavations. This is typically how most would understand the basic role of the surveying discipline.

From this work we now know in 3D space the position of excavations relevant for the next stage, where we engage in the continuous work required to track rock flow. From an information management perspective, this is traditionally the area of the value chain where we collect the least amount of data. To the extent routine operational measurements are made, the frequency of measurement determines the availability of data and tabulation of results in the form of assumed tonnage and content flows during the period under review.

Once we have obtained the production results from the processing plant at the end of the relevant period, we are able to engage in the last stage of work to reconcile product back to the orebody. The final output of this information flow is the ability to provide stakeholder reports, of which there is a never-ending variety.

Visibility of the information flow is enhanced by the use of colour to denote mining technical discipline-specific responsibility. See Figure 2.

The following series of diagrams, each a portion of the complete information flow picture, illustrate the use of this colour coding at the task level of detail.

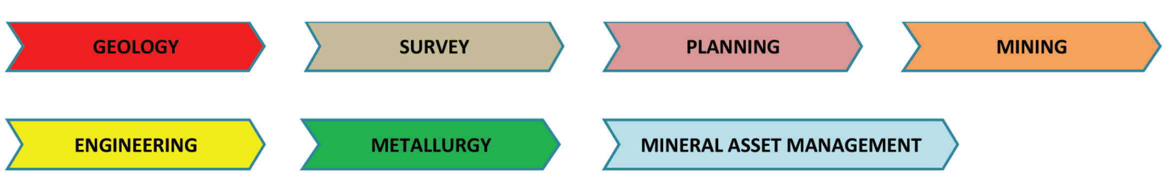

Figure 2.

Create survey network, position infrastructure, and measure excavations

This phase of the information flow begins with geographic and local reference points and ends with knowing the position of excavations relevant to the further collection of data and subsequent reconciliation exercises. There are four sub-processes associated with this phase, each with a further level of detail at a task level.

Sub-process 1: coordinate from known reference points

Firstly, a surveyor's basic skill is to coordinate from known reference points. In a mining context this means to undertake activities such as installing beacons, survey pegs, shaft wires etc. All of these have in common the requirement to begin with those previously defined known reference points and conclude with a collection of data defining new network points and coordinates (Figure 3).

Sub-process 2: Create set-out points and alignment

The next sub-process is to create set-out points and alignment. This includes a diverse range of activities to be able to position line pegs, grade lines, boning rods, batter boards and other set-out points and crank line. These activities all provide the basis of progressing from the previously established new network points and coordinates with a series of references appropriate to the planning done for the area in question and aimed at the marking out of planned line and grade. Figure 4.

Sub-process 3: Pick-up infrastructure and excavations

We now move to the built environment proper. The next sub-process of data collection covers all the tasks required to pick-up infrastructure and excavations, accumulating data in the form of observations, measurements, positioning, outlines, and wireframes. This is a disciplined

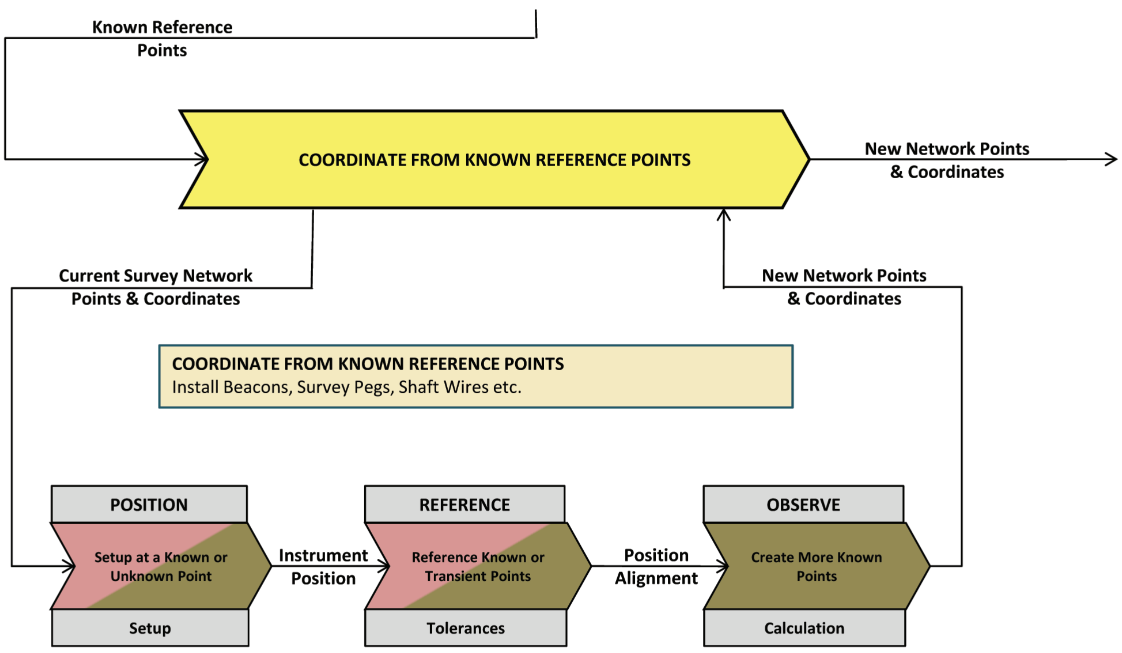

Figure 3. Coordinating from known reference points

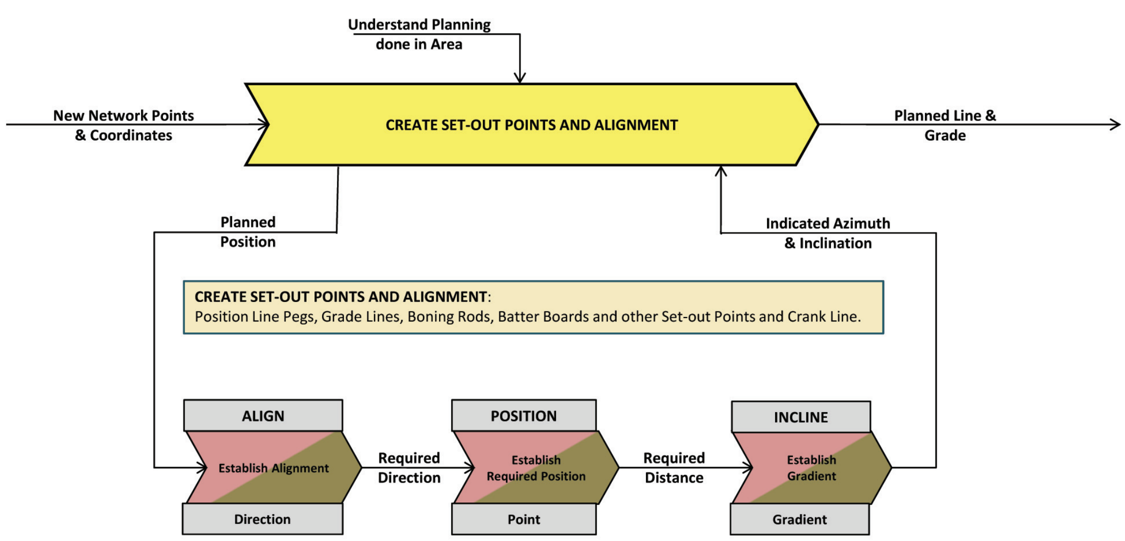

Figure 4. Creating set-out points and alignment

series of tasks designated and controlled by survey-specific documentation confirming or otherwise, relative to the planned line and grade the resulting record of current workings in their spatial orientation. Figure 5.

Sub-process 4: Create survey note (or mining instruction)

This last sub-process marks the completion of the cycle and prime business reason for the surveyor's formal, spatial measurements. Specifically, the surveyor is required to create a survey note (or mining instruction) as a formal record of planned excavation providing the basis of the control process for mining activity i.e. making holes in the ground. And so, we maintain the expansion of mining activities starting with formally located current workings and initiating further activity with equally formal mining instructions. Figure 6.

Track rock flow

Once an excavation is created, depending on the mining method and layout, there may be numerous movements of broken rock. Each movement is an opportunity to take spatially relevant measurements, to engage in routine tracking of rock movements, and to quantify location, tonnage, and content. Rock movements are in the simplest sense a series of cycles of load/haul/dump from one location to another e.g. ore pass, belt, skip, bin, stockpile, truck, train etc. Each location has its own descriptors and relevant measurement parameters.

The focus of this approach is volumetric measurement. Various other technologies for monitoring weight or density may also contribute usefully to required reconciliations. And we do not need to wait for end-of-period measurements, as both weight and volume can be measured at will.

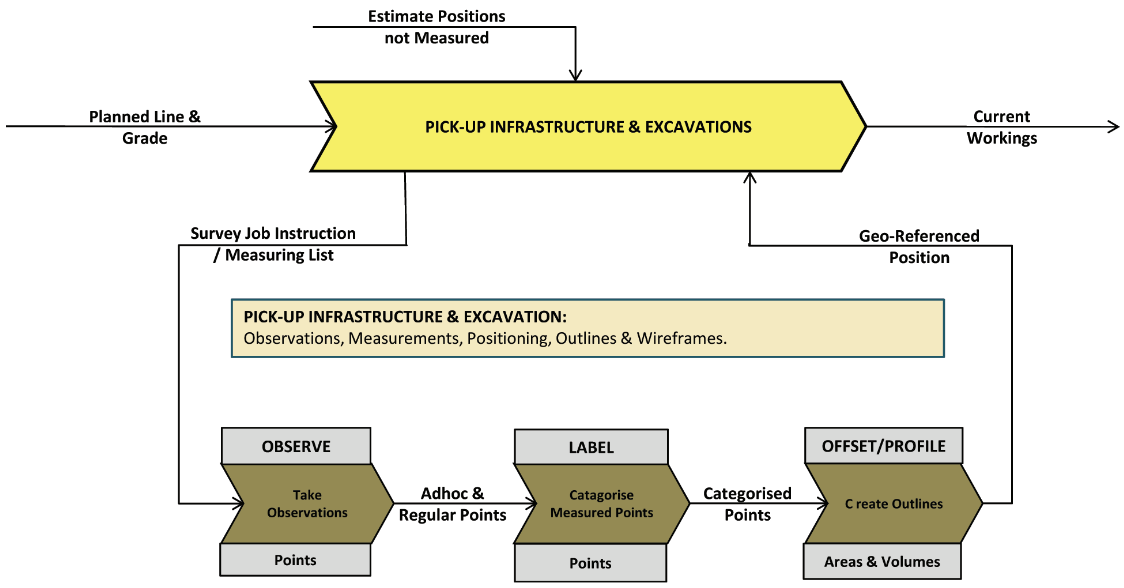

Figure 5. Pick-up infrastructure and excavations

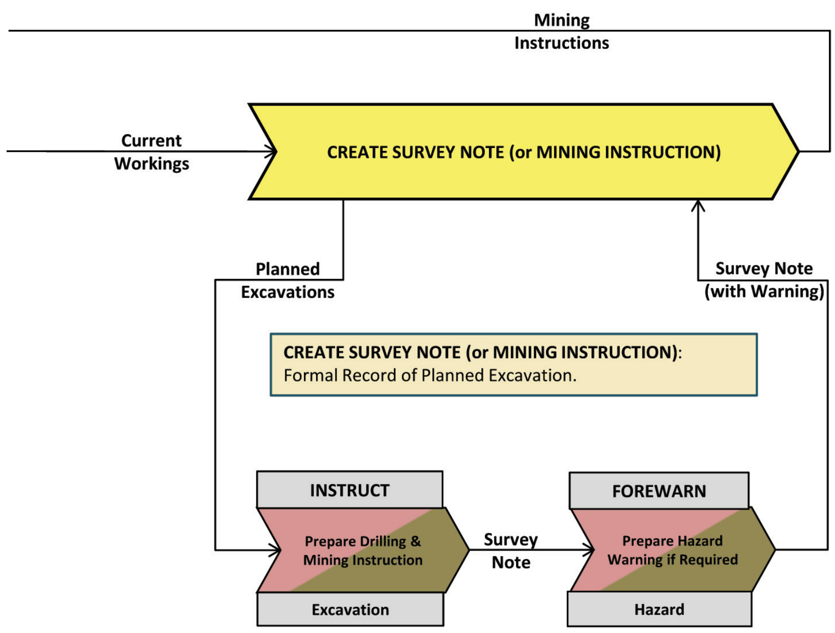

Figure 6. Creating a survey note (or mining instruction)

This phase of the information flow begins with position of excavations and concludes with a collection of information on assumed tonnage and content flows across the rock flow network over the particular measurement period. There are three sub-processes associated with this phase, each with a further level of detail at a task level.

Sub-process 1: Calculate positional tonnage and content

This sub-process of the information flow is based on a calculated positional tonnage and content for each supply of broken rock. In its various information categories it is the build-up of a portfolio of known and reasonably estimated sources of rock. It begins with recording of the workings' outlines as measured by the chosen survey technology, from which we derive a list of source tonnage and content as the basis for the series of rock movements to come. Figure 7.

Sub-process 2: Monitor movements of rock

What follows now is a connected series of measurements to monitor movements of rock. These can be stationary or dynamic, continuous or periodic observations and measurements. Whatever the variety, these measurements are used to provide a record from source tonnage and content through whatever simple or complex rock flow network exists on the mine. Figure 8.

Sub-process 3: Recalculate stockpile status

At every location where broken rock is moved from and to, continuous data collection makes it possible to recalculate stockpile status after every movement. Note: the term stockpile means any temporary or permanent measurable storage of rock. So, as data is collected along the sequence of the rock flow network we have a continuous collection of current stockpile status measurements, all of which can be used for any number of reconciliations and analyses. Figure 9.

Reconcile product back to the orebody

Merging all the rock flow network measurements with the plant production profiles enables reconciliation of plant recovered product and residue with orebody content. Such reconciliations which start with the recorded assumed tonnage and content flows form the basis of variance

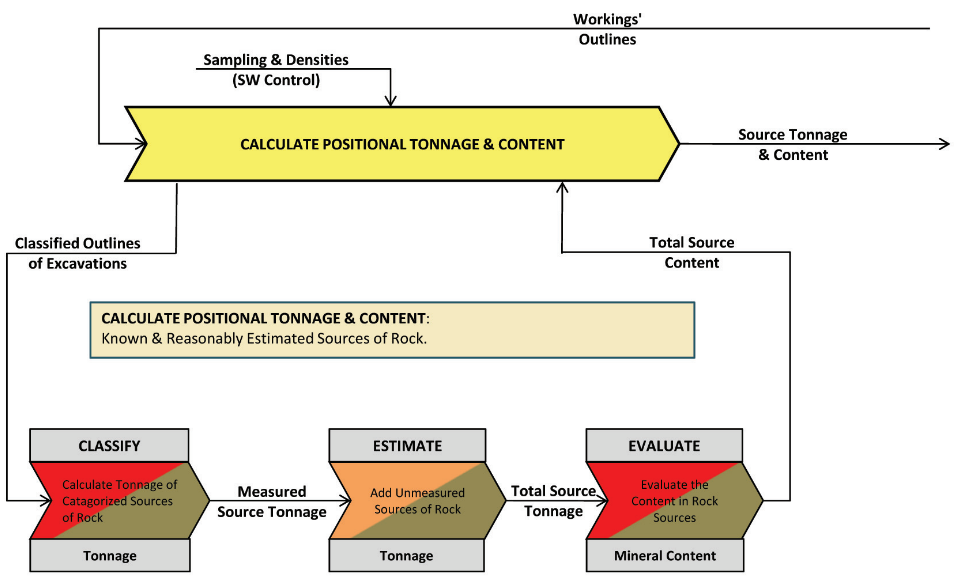

Figure 7. Calculation of positional tonnage and content

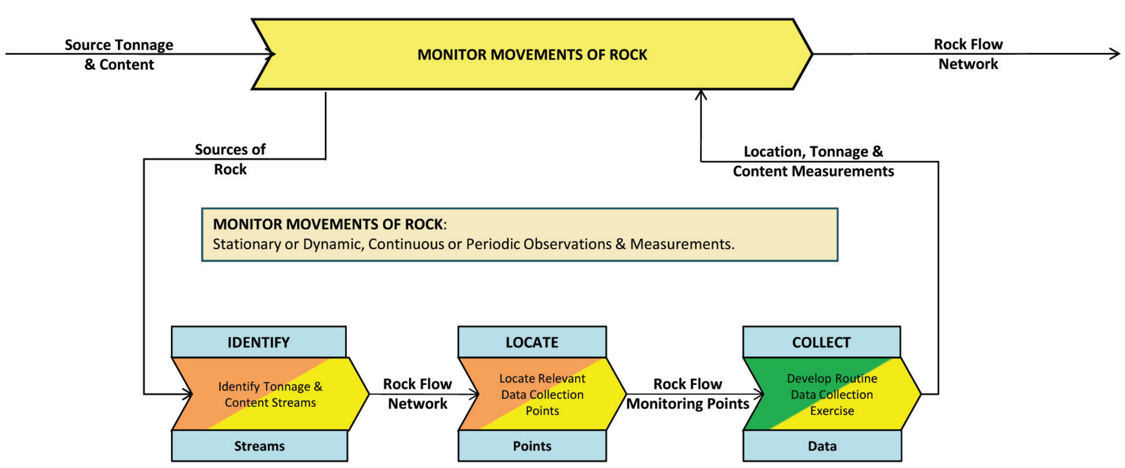

Figure 8. Monitoring movements of rock

analysis and a wide variety of stakeholder reports for internal and external purposes.

Sub-process 1: Quantify recovered product and residue

This sub-process of the information flow deals with the absolute measures taken to quantify recovered product and residue from the relevant metallurgical processes. This marks the end point from which any reconciliation can begin. The source of data is commonly referred to as 'mill mathematics' and is itself often the end result of a high-tech data collection environment. Of all the process plant metrics used in metallurgical processes, we are most interested in the outputs of verified tonnage and content. Figure 10.

Sub-process 2: Reconcile tonnage and content back through stockpiles to ore reserve model

We have now compiled a collection of measurements with which to reconcile tonnage and content back through stockpiles to ore reserve model. This is a recalculation process back through tonnage and grade estimates, measurements, and calculations between points of the rock flow network and across the mining value chain requiring reconciliation. In so doing we cover full or intermediate reconciliations from verified tonnage and content back to the depleted and updated block model where the

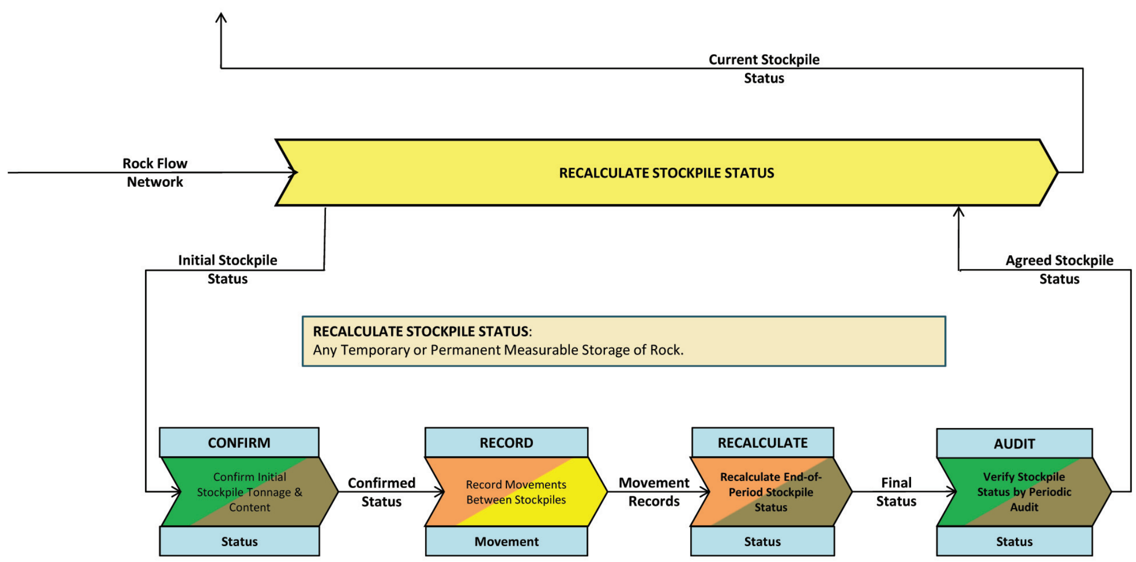

Figure 9. Recalculation of stockpile status

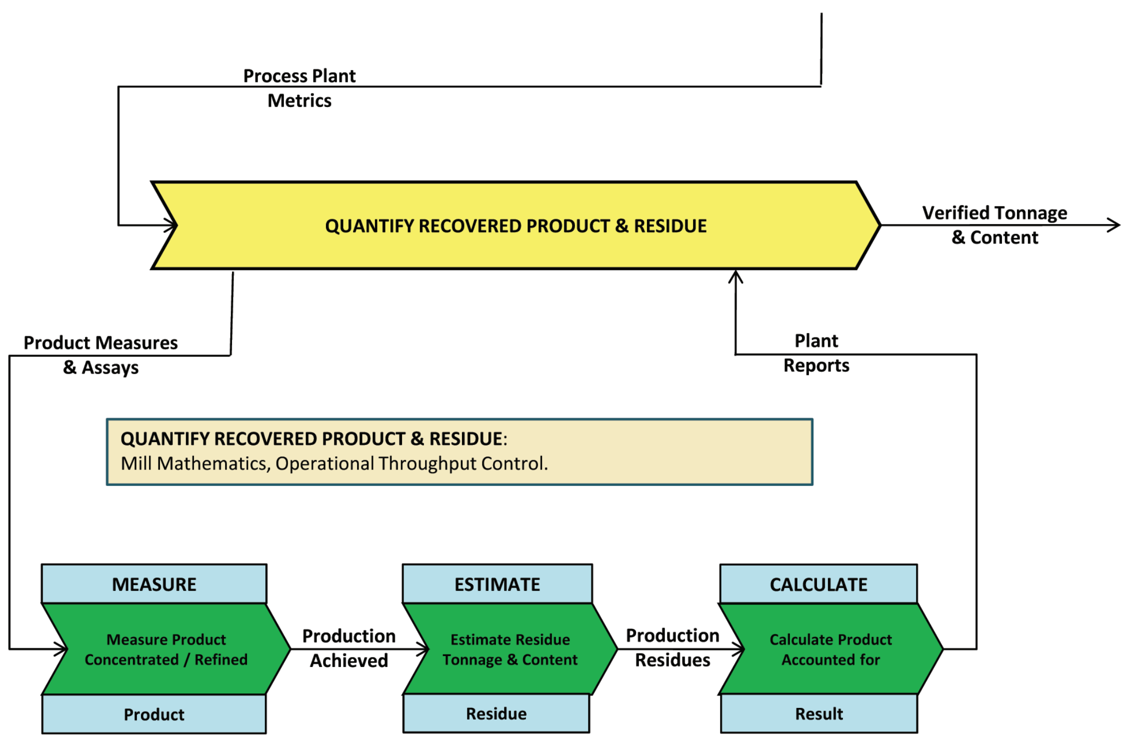

Figure 10. Quantification of recovered product and residue

implications of survey measurements of mining activity were recorded. Figure 11.

Sub-process 3: Report and analyse variance on production achieved

The final sub-process in the information flow is the requirement to report and analyse variance on production achieved. These reports and analyses can be relied upon to the extent we are able to audit data collection and models. Each and every measurement and calculation beginning with the depleted and updated block model is now made available to reliably authorise operational and corporate documents as required by the wide variety of stakeholders. Figure 12.

Choice of survey technology

The type and quantity of available data to conduct a reconciliation exercise depends heavily on the choice and usage of survey technology.

Without going too far back in history, let us examine a few of the survey technologies available to mining companies. The only non-digital technology referenced here is the use of tapes and theodolite; standard tools for a mine surveyor. To a large extent this manual technology is being or has been successfully replaced by the use of a total station.

The total station is an adaptation of the standard theodolite. It still needs levelling and then reads the horizontal and vertical angles from the correctly aligned

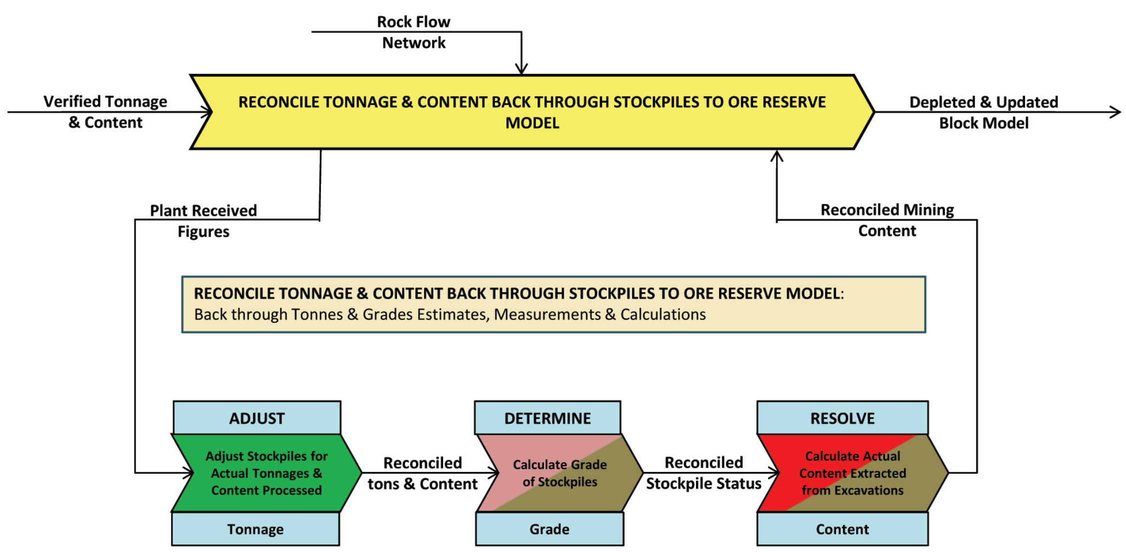

Figure 11. Reconciliation of tonnage and content back through stockpiles to ore reserve model

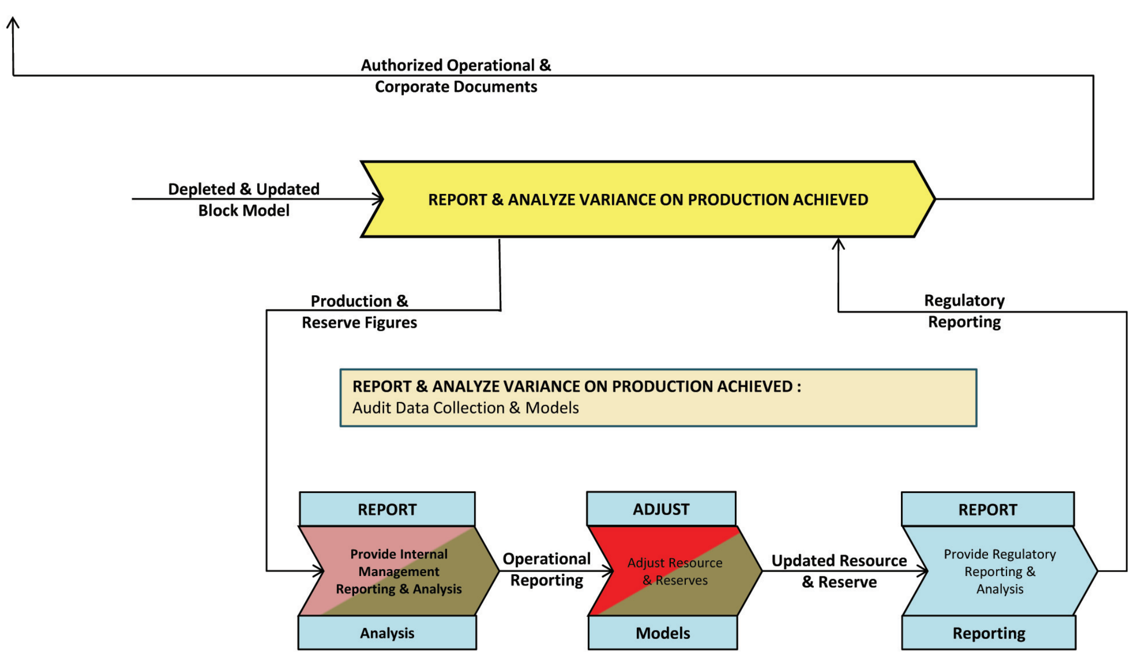

Figure 12. Reporting and analysis of variance on production

circles in the instrument. The total station does, however, incorporate electronic distance meter (EDM) technology, which partially or totally eliminates the use of tapes, hence the description 'total station'. The EDMs predominantly are pulsed laser driven and therefore give a reading from any surface, not just glass reflector prisms. The circles in total stations today are almost exclusively electronic. This means they are read by the machine and reported via LED screen and recorded in the onboard memory.

Optical laser scanners are built on the concept of the total station, but incorporate much faster processing speed. The pivot is motorized and a pivoting mirror allows for fast change of vertical angles. Some scanners will read up to 12 000 shots per second to give a multitude of positional shots of any site. Software is evolving to handle all these points as a cloud, including functionality for display and rotation.

Digital cameras are often incorporated into the scanners so an orthophoto can be produced to position each pixel at its correct geo-referenced position in space. The resultant image is almost like standing inside the picture. The range of these devices varies from high precision sub-50 metre, for modelling built machinery like cars, to about 5 km for pit mapping and avalanche detection. The abovementioned scanners are considered to be 3D scanners, but 2D mobile scanners are becoming popular. They are vehicle-mounted and use the vehicle speed to provide the third dimension. The measurement is very much along a path like a spring – the slower the vehicle travels the tighter the spring. This is the technology used by Google Street Mapper. The technology is often used in mining for stockpile management and measuring open pits, where a vehicle can pass by most of the areas to be mapped.

Radar scanners are very similar to optical scanners but use radar wavelengths instead of pulsed laser to determine the distance to the point they are measuring. The technology is usually used in mining for slope stability monitoring and detects the small movements on a pit slope before failure takes place.

A global positioning system (GPS) uses the twin frequency signals from USA military satellites to determine the instrument's position on the surface of the Earth. It takes the readings from at least four satellites to obtain an accurate fix on the Earth's surface using trilateration. False readings can arise due to rebounding signals reaching the receiver (referred to as canyoning), climatic conditions slowing signals, or a poor arrangement of the satellites in the receiver's constellation. To overcome these problems, most equipment needs a signal from at least six satellites (which allows for redundancy and checking), and for precision work a fixed base-station provides a constant reference point to eliminate satellite shift. The base station is in contact with the rover via GSM to feed corrections to the position read by the rover. Post-processing of data can also be used to correct this, but is time-consuming compared to real-time kinetics (RTK). The survey departments in most countries are providing 'Trignet' beacons, which are much like survey beacons except they emit a radio signal broadcasting their position to GPS rovers and any other corrections required for the climatic and atmospheric conditions in their vicinity.

GNSS is the same as GPS but is not limited to US military satellites. These devices also read from the Russian Glonas, European Galileo, and Chinese Compass satellites. This increased potential constellation means a good fix can be obtained almost anywhere.

Deep pits and positions close to a pit highwall still give problems, however. These are normally overcome by infilling using traditional means, but where machine guidance is involved this is not sufficient. To overcome these odd phenomena, which can take place in limited locations for up to 8% of the time, a system of 'Terralites' is deployed. These are in-house survey stations like the 'Trignets'. They have a master and several slave devices. They are positioned in and around the pit where good satellite reception and inter-visibility is possible. The master and then the slave stations position themselves for GNSS satellites and then broadcast GPS-type signals which convince the onboard receivers in the equipment that they are static satellites. Their low altitude helps to give a much more accurate Z-coordinate fix to the equipment.

Photogrammetry began with aerial photographs as early as the 1800s using the Montgolfiers' hot air balloon. Later this developed with stereo plotting of overlapping photographs to correct for the distortion of the lens and to acquire the height from the aircraft to the points being photographed. Fixed ground control points act as checkpoints to correct for any drift that might happen in a sequence of photographs.

The beauty of a photograph is that thousands of points can be mapped with just two clicks. The processing time is the limiting factor.

Weather conditions have also been a problem, but the photographs do not have to use the normal visual wavelengths seen by humans. A full array of the electromagnetic wavelengths can be used to overcome clouds etc. Satellites are also equipped with cameras and other scanners for this kind of remote sensing. The traditional plan produced by the stereo plotter from aerial photography is being superseded by the orthophotograph. Instead of the drawn symbols used to create a map, the actual pixels from the photographs are positioned and orientated to create an image of the surfaces in true map positions. Digital photography aids this process.

Terrestrial photogrammetry was also developed to map areas that were not accessible for surveyors. Pit walls, steep mountains, and even open stopes were mapped by taking stereo photographs. This practice has mainly been replaced in the last 10–20 years by the use ofLIDAR.

LIDAR – to speed up processing of digital photogrammetry many types of survey locating data have been joined together to give sufficient information to a computer to do what is in effect online mapping. Photographs (digital) are still taken at closer time intervals (almost video frequency). They are combined with scanning as the vehicle passes the points being photographed. The use of full-phase laser scanners means that readings can be taken to determine both the ground and the vegetation height. This allows for the photographs to be turned into orthophotos without stereoplotting. The position of the vehicle is provided by use of GPS/GNSS. The orientation of the vehicle to correct for any twist, tilt, or yaw is done by inertia devices like gyroscopes and inclinometers (accelerometers). All this wealth of data is computed in real time or recorded for post-processing. The computer is equipped with feature recognition to stitch the photographs together but ground control can also be added to correct for drift.

This type of mapping is in general use in aerial mapping either by fixed-wing or helicopter and is the backbone of the technology using unmanned aerial vehicles (UAVs), or drones to some of us.

Terrestrial vehicles like StreetMapper also use this technology.

The Fakawi profiling device is a lightweight, manually operated scanner/total station. It can be used by virtually anyone with a minimum of training. Its accuracy is lower than standard survey equipment but is ideal for measuring mining excavations. It combines the use of a camera tripod, laser tape, and some orientation technology to create what is a low-cost total station. The readings are triggered and recorded by an Apple iPod. The initial orientation at setup is achieved by taking readings to two or more known fixed points (e.g. underground survey pegs). All subsequent points can then be coordinated and fed into a CAD/graphics package along with an attribute to indicate what type of readings have been taken.

A next-generation device that is in the early stages of development will combine the LIDAR components of twist, tilt, and yaw in the device so that it will not be tied to the tripod but will be truly mobile for measurement and coordination while walking.

Who is the keeper of the information?

Typically, the survey discipline is well known and respected for its ability to create, distribute, and sustainably manage data and information flow. The survey database is vital to all core mining processes and many of the support processes as well.

In South Africa at least, the custodianship of the data required to do routine reconciliations lies with the survey discipline. Understanding the logic of this orebody-to-plant information flow then enables a mapping of the survey discipline role against an overall model of the mining business. As part of this exercise we mapped the various roles of the survey discipline to the mining enterprise EM Model.

Interestingly, this made visible the long-standing debate about whether the survey discipline is a core or support function. It actually comprises aspects of both, and these are clearly demarcated in the model with dark outline indicating where surveying is executed and the dotted outline where surveying is partly involved (Appendix A). Both occur throughout core and support processes.

In conclusion

All mines engage in some form of reconciliation of mine product back to orebody content, if only to measure the effectiveness of exploiting the orebody. Typically, a series of reconciliations are done as the basis of variance analysis of execution measured against plan. The results of the reconciliation exercises are used for internal and external reporting purposes.

The choice of survey technology determines the type and frequency of data collection and the availability of data is an absolute constraint on reconciliation activity. No data – no reconciliation. Many choices of survey technology exist, and one thing they have in common is the drive to make 3D data available and visible.

MineRP lives in the 3D world of mining information and is constantly engaged in making business processes and information flows visible. One such effort, based on the Open Group EM Model, is the Survey Network & Measurement, Rock Flow and Reconciliation - Protocol and Solutions Map. This tool enables standardized approaches to reconciliation conversations and the IT tools making it possible.

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English born, Australian bred, South African resident Mining Engineer

After graduating from University of Sydney in 1973, worked around Australia for a year and came to South Africa in April 1975 (for two years to take a look)

Worked on production and projects for Gold Fields, JCI and AngloGold Ashanti until 1998 when he joined GMSI now known as MineRP

Mine Planning was always a passion, keeping pace with the IT tools of the day and now works in the world of 3D graphics, helping miners and IT personnel alike to understand and visualise the realities of mining.

APPENDIX A: Survey discipline mapped to the EM Model