A CROSS-FUNCTIONAL VALUE CHAIN APPROACH TO GEOSPATIAL INFORMATION: A GUIDE TO PRACTICE FOR THE MINERALS INDUSTRY

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A research dissertation submitted to the Faculty of Engineering and the Built Environment, of the University of the Witwatersrand, in the fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this research dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in Mining Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Michael Gordon Livingstone-Blevins

This 22nd day of March 2018

“We now accept the fact that learning is a lifelong process of keeping abreast of change. And the most pressing task is to teach people how to learn.”

Peter F. Drucker

ABSTRACT

Reproducing a mining project life-cycle in the form of a value chain, from exploration to mine closure, provides a graphical representation of the interdependencies between functions or activities, both upstream and downstream of a particular process. This can be used to develop the concept of geospatial context, i.e. high-level situational awareness. By understanding and responding to geospatial context, geospatial information can be enhanced in direct support of investment decisions and/or operational control.

The risk of deficient geospatial information requires effective mitigation and management throughout the full life-cycle of a project, starting with exploration where the geospatial foundation is laid for all work which follows. Therefore, geospatial information is a primary, not secondary consideration at the commencement of a project.

The role of mine surveying in protecting the surface and workings of a mine, through the provision of accurate maps, plans and associated geospatial records, protects people and the asset, spanning mine and public safety. Additionally, measuring, monitoring, reconciling and reporting key performance indicators which drive value, enables value creation through improved foresight, efficiency and effectiveness.

This dissertation discusses the critical role of geospatial information in risk mitigation and business performance monitoring, with specific reference to the interdependencies between functions such as exploration, mining, processing, environmental protection and mine closure. The value potential is significant.

In memory of my parents

Gordon and Pat Livingstone-Blevins

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Finally, to my wife Isobel for her support, editing and constructive criticism.

ABBREVIATIONS and ACRONYMS

BIM	Building Information Management.
CADD	Computer Aided Design and Drafting.
Codes	Collective term used for various international codes for reporting of exploration results, mineral resources and reserves.
EM Model	The Exploration and Mining Business Reference Model (EM Model) published by The Open Group (2010) Exploration, Mining, Metals and Minerals Vertical, a collaborative industry forum.
EPCM	Engineering, Procurement and Construction Management.
GBP	British Pound (currency).
GIS	Geographical Information System.
GNSS	GNSS – Global Navigation Satellite System (used interchangeably with GPS).
GPS	Global Positioning System (used interchangeably with GNSS).
JORC	The Australasian Code for Reporting of Exploration Results, Minerals Resources and Ore Reserves.
KPI	Key performance indicator.
LOM	Life of Mine.
MSL	Mean Sea Level.
NI 43-101	National Instrument 43-101 Standards of Disclosure for Mineral Projects (Canada).
PERC	The Pan-European Code for Reporting of Exploration Results, Mineral Resources and Reserves.
Reserve(s)	Upper or lower case – general term for mineral reserve(s) or ore reserve(s) as defined by various codes.
Resource(s)	Upper or lower case – general term for mineral resource(s) as defined by various codes.
RICS	Royal Institution of Chartered Surveyors.
SAMREC	The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves.
SME	Society for Mining, Metallurgy and Exploration, Inc. (USA).
SME Guide	The SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves.

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1. INTRODUCTION

1.1 Aims and Objectives

Geospatial information is used by several functions and in several processes throughout the life-cycle of a mining project. By understanding the geospatial requirements of upstream and downstream geospatial information users along a mining project value chain, and the points of transfer of information, there is significant opportunity to adapt output to anticipate the needs of the next process, or conversely, to understand the accuracy limitations of data received. This approach can not only avoid duplication or rework, it can also improve confidence in the work produced (such as improved confidence in the location of geological features which must be considered when designing a mine).

The objective of this research is to:

- Document the role of geospatial information as a cross-functional value enabler in the business of mining;
- Create an understanding which enables cross-functional or inter-discipline synergies by improving the intelligent application of geospatial information; and
- Serve as a guide to practice for the minerals industry.

To achieve this objective, the following principal question has been formulated: *Can a cross-functional value chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?*

This principal question leads to a number of secondary questions, namely:

- What should surveyors, managers and users of geospatial information know in order to understand geospatial risk?
- Is there adequate understanding of geospatial accuracy requirements for processes across the business?
- Is there adequate understanding of the risks of deficient geospatial accuracy across the business?
- Are the cross-functional links and points of information transfer between functions understood?

- What level of understanding of surveying principles is required to assess the accuracy, quality and integrity of geospatial information?
- What qualities, knowledge and skills would constitute a person to be suitably qualified or competent to examine, approve and sign off on the accuracy, quality and integrity of geospatial information?
- What systems and controls would be required to mitigate geospatial risk, ensure defensibility of practice and support operational efficiency?

The research aims to:

- Develop the concept of geospatial context to inform and guide practice. This “context” is pivotal in the assessment of geospatial risk, potential consequence, risk mitigation and assurance, and value contribution;
- Provide a broad overview of the relevant fundamental principles of surveying, accuracy and how these directly influence the quality and integrity of geospatial information along a mining value chain;
- Develop a cross-functional value chain approach to geospatial information to serve as a guide for minerals industry practitioners;
- Apply the value chain, aligned with typical functional and mining activities, to provide a broad reference to improve understanding of the geospatial information flow throughout a project life-cycle; and
- Provide practical examples of how to assess and plan and deduce geospatial quality from implicit indicators in geospatial source data.

To answer the principal question of this research, a value chain representing a mining project life-cycle is used. This will draw on Michael E. Porter’s Value Chain theory, as well the Open Group’s *Exploration and Mining Business Reference Model* (2010).

Reproducing a mining project life-cycle in the form a value chain provides a graphical representation of the interdependencies between functions or activities, both upstream and downstream of a particular process. This can be used to develop the concept of geospatial context, i.e. high-level situational awareness (at a point on the value chain). By understanding and responding to geospatial context, geospatial information can be enhanced in direct support of investment decisions and/or operational control.

Furthermore, specific points on the value chain can be used to develop detailed guidelines for specific activities. Applying geospatial context at this level of detail will enable proactive structuring of geospatial information to enable greater functional integration and support business performance, i.e. increased intelligence is introduced into the work stream. Context is therefore a pivotal driver of practice.

For the purpose of this research dissertation, surveying is regarded as a discrete specialist activity (requiring a formal tertiary qualification and/or license to practice), as opposed to a process or group of processes. However, whether regarded as a specialist activity, or a group of processes, the objective is common. The research will demonstrate the critical role of geospatial information in risk mitigation and business performance monitoring, with specific reference to the interdependencies between functions such as exploration, mining, processing, environmental protection and mine closure.

It is particularly challenging to condense the activities of a mining project life-cycle into a research dissertation of this length. The focus will therefore be on a guide to practice which identifies and demonstrates areas of risk and opportunity, but will not attempt to quantify economic benefit.

1.2 Background information

There is a geospatial thread which runs through the minerals business, from exploration to mine closure. From the first exploration hole drilled or sample taken, coordinates defining the position of points are used to build a graphical representation of the environment or features of that environment that are of relevance, for example, a geological model. Furthermore, position, defined by coordinates, is used to define mineral and surface rights, and as the foundation for deposit delineation, resources and reserves, mine establishment, operation and closure.

Surveying is core to the minerals industry, linking both downstream and upstream processes (of a project) as geospatial information of differing inherent accuracy are applied to specific processes, e.g. the accuracy required for geological modelling is significantly less than that required for volumetric measurement and reconciliation of mine production. Fit for purpose geospatial accuracy is therefore variable, depending on its application and may range from metres to millimetres.

Deficiencies or errors in maps, plans and geospatial information pose safety, financial, legal and reputational risks. For example, a geospatially deficient geological model could result in positional error being interpreted as geological structure. Depending on the magnitude and distribution of the error(s) the mining method and extraction strategy may be inappropriate, with consequent financial and reputational impact (reduction in return on investment and drop in share value). To mitigate these risks, geospatial information must be appropriately accurate, defensible (if legally challenged or subjected to external scrutiny), and supportive of operational and business process risk mitigation (as defined in the Business Plan).

Due to the direct relationship of geospatial information to mine safety, mine surveying or the keeping of accurate mine maps/plans is highly regulated in several countries. This is principally to address "protection of the surface and workings" and is aimed at; accurately establishing the mine design in physical space; guiding/directing mining through or past hazards; stopping mining at prescribed limits or boundaries; showing all known physical hazards; all objects or areas which require protection from mining; the full measured extent of all excavations (for future reference for mining or surface development); and finally, the certification as accurate and correct of all information represented on such maps/plans. As a consequence of this operational focus on safety related compliance, the potential contribution of quality geospatial information to the performance of the business is typically overlooked or underestimated.

1.3 Significance of the topic

Geospatial information is the foundation of all mining projects. It is used by several functions and in several processes throughout a project life-cycle. Physical, geological, geotechnical, economic and environmental attributes are attached to coordinate points which form the basis upon which investments are made, and mines established and operated. Despite the fundamental importance of geospatial information (to mining), the author has not encountered any publication which addresses geospatial practice requirements across the full life-cycle of a mining project.

A combination of factors has contributed to a general decline in thought leadership and enterprise-wide oversight of the surveying function in the minerals industry, with consequent impact on the quality and consistency of geospatial information in use. Such factors include the lower margins resulting from upward cost pressure compounded by downward price pressure, technology substituting competency and specialist skills, and changes to organisational structures introduced to improve functional control and performance.

Geospatial risk in the exploration phase of a project is significant and requires specific awareness and surveying competency to ensure the accuracy and integrity of geospatially referenced information. Despite this significance, geospatial rigour is typically low at this foundation phase of a mining project, hence the elevated risk status. No amount of downstream processing can improve the accuracy of geospatially deficient data, therefore it is imperative to ensure appropriate standards, practice and assurance from the start.

Various mineral reporting codes discuss the requirements of a competent person, but never in the context of geospatial information. These codes, irrespective of country of origin, are similar, aligned and address common fundamental criteria to ensure transparency, materiality and competency for public reporting. The JORC (2012) Code (The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves), for example, makes specific reference to geospatial information criteria for "Location of data points" and "Drill hole information". The code also refers to other criteria which have geospatial relevance, but with less specific geospatial explanation, such as "Mineral tenement and land tenure status", "Diagrams", "Database integrity" and "Discussion of relative accuracy/confidence". The codes are silent on what constitutes a competent person in a surveying or geospatial context.

According to Ludvigsen (2017), a natural solution to narrow profit margins, is that one person must solve multiple tasks that were previously performed by several specialists, engaging in activities that cross former organisational or professional boundaries. While this comment is made in the context of Mineral Resource Management in Norway, it is equally relevant to this problem statement as an example of the decline of specialist knowledge and its substitution with generalist practice. Technology plays a significant role in enabling this practice.

Global mobility and diversification, particularly of senior management, has influenced organisational structure in resource companies. This is primarily to improve operational effectiveness, efficiency and return on investment, as well as transferring locally effective practice across businesses. However, the regrouping of processes into different or discreet functions results in the redefinition of functional silos. Whether this results in more, or less specialists is moot, as the issue remains one of (redefined) boundaries between functions and the potential disconnects which can result in sub-optimal performance or issues of non-compliance. Often, institutional memory is lost.

Technology has enabled the substitution of specialist knowledge required to perform certain work. The acquisition and processing of geospatial data and information no longer requires specialist skill – anyone can use technology such as GNSS (Global Navigation Satellite System) to determine position and CADD (Computer Aided Design and Drafting), GIS (Geographical Information System), or mine design software to produce a map of apparent high quality, despite the high level of complexity underlying these processes, thus resulting in the regression of the underlying scientific knowledge required to assess the quality of such information. This regression applies equally to the legal and risk framework of operation. A further adverse impact of technology is the availability of too much information which can dilute focus on core metrics. It is the opinion of the author, that the use of technology for geospatial measurement and processing, without understanding the fundamental principles of surveying, is a source of significant geospatial error and risk. It is a form of incompetence.

The above-described factors represent a structural change in how work is done and by whom. This situation is likely to continue (with some possible exceptions). Typical industry and/or company-specific guidelines for developing mineral assets (concept, prefeasibility and feasibility studies, and implementation) should take cognisance of this new reality.

Therefore, the overarching issue (in this context and that of statutory compliance) is the understanding of the geospatial interdependencies throughout a mineral project life-cycle, and how to enable effective cross-functional integration to mitigate risk and improve business performance. This issue is addressed in this research as geospatial context, an approach which appears from literature review to be unique.

1.4 Benefit to industry

Details of the aims and objectives of this research have been discussed briefly in section 1.1 of this chapter and should be considered with reference to benefit to industry.

To ensure broad relevance, the scope of this research is global. It will serve as a general cross-functional reference document for the minerals industry, for use by surveyors, geologists, engineers, other relevant disciplines and technical managers.

To-date, extensive review of available literature has not yielded any published work that addresses geospatial context linked to functional and process interdependencies, accuracy, risk and the value potential of geospatial intelligence to the business of mining. The author believes that this research is unique in breadth (exploration to mine closure) and topic (the role of geospatial information across the business).

Fundamental principles of surveying are described, in order for these to be understood in the context of a specific activity on a value chain, for example, what influences geospatial accuracy for exploration and how these should be addressed. Understanding of these principles will provide insight into the underlying properties of geospatial information (which is often simply expressed as coordinates and elevation which define the position of a point on the earth), thereby improving "transparency" required by mineral reporting codes.

Aligning chapters with specific activities, groups of activities or sub-activities (of the value chain) will provide ease of reference, allowing focus on a specific area of practice or activity. This alignment is discussed in greater detail in this chapter under the heading "Preview of the organisation of this dissertation". A further benefit of this approach is that chapters will link downstream and upstream processes, thereby highlighting process or functional interdependencies and enabling geospatial intelligence.

Specific activities, or groups of activities which capture, process, disseminate or simply use geospatial data and information are identified. These activities are placed into geospatial context and assessed for geospatial risk and potential consequence (of deficient or erroneous information), for analysis and discussion.

To demonstrate the severity of consequence, reference will be made to actual incidents. For particularly severe incidents resulting in single or multiple fatalities, or significant damage to property or business, reference will be made to the subsequent legal process, liability and damage to the business. Practical recommendations are developed to guide assurance measures.

In summary, the benefit of this research is the publication of a comprehensive guide to practice, spanning the full mining project life-cycle, that describes aspects of good practice, risk and the value potential of geospatial information in the business of mining.

1.5 The existence of similar work

The use of a mining value chain to replicate the typical life-cycle activities of a mining project is common (there are a multitude of examples of the mining value chain available in publications on the internet), hence the referral to the value chain concept described by Porter (1985), and more specifically to the EM Reference Business Model published by The Open Group (2010) to which the structure of this research is closely aligned. The use of the value chain in mining is not at all unique.

Many authors have published work linked to a model of the mining value chain, where the value chain is used as a reference for a specific topic of discussion. Subject matter is diverse, ranging from a pan-African framework for legal compliance as developed by Bennett (2011) which covers the full mining life-cycle, to operational metal accounting and reconciliation practice described by Macfarlane (2013) which covers a portion of the value chain (from the geological model to product sales).

Regarding the value potential of a geospatial information to the business of mining, Cawood and Richards (2007) discuss the "…need for surveyors to measure, process and report material in a manner consistent with the business drivers of the company", in the context of coal mining in South Africa. The statement is equally relevant to all mining.

The author is not aware of any other work that is of similar breadth, approach and content.

1.6 Funding

No budget is required. Research activities are primarily from literature review, accessing of notes and records from a 34-year career in mine surveying. Any costs which arise will be fully funded by the author.

1.7 Preview of the organisation of the dissertation

The dissertation will be structured to align topics with a value chain which represents the major activities of a mining project life-cycle. Excluded from this value chain is the activity of "Sell" or selling of a product, as this has no relevance to geospatial context and the body of this research.

Preceding the value chain aligned chapters are an introductory chapter and a chapter detailing the literature reviewed in researching this topic.

Chapter 1 provides a general introduction to the topic, a brief discussion of what differentiates this work (or makes it unique) and how geospatial risk and intelligence can contribute to value realisation over the life-cycle of a mining project.

The concept of geospatial context is introduced, which will be used consistently throughout value chain aligned chapters (chapters 4 to 8) as a means of providing high-level situational awareness (at a point on the value chain). By understanding and responding to geospatial context, geospatial information can be enhanced in direct support of investment decisions and/or operational control.

Chapter 2 will describe the literature reviewed in researching this topic. The review is broad, due to the scope of the topic which covers the full mining project life-cycle, from exploration to mine closure. The review includes scholarly and journal articles; conference proceedings; industry fora discussion documents; legislation, codes, guidelines and standards; books; and personal notes accumulated over a period of more than 30 years in the mining industry.

Chapter 3 will discuss the fundamental principles of surveying, the value chain and geospatial risk, i.e. key information for geospatial understanding and developing geospatial context which are essential requirements for understanding this body of work.

The fundamental principles of surveying will cover topics such as measurement; projections; datums; grids; cadastre; survey systems (national and local); and map accuracy.

Discussion of map accuracy will be linked to international mapping standards, to demonstrate the relationship between map scale and the ground accuracy of features represented on a map. This fundamental relationship can be used to understand the inherent accuracy of a map (and its limitations).

Chapter 4 – Explore, will cover geospatial considerations during the exploration phase of a mining project in the context of laying the geospatial foundation for all work which may follow. Its purpose is to describe essential geospatial practice to enable exploration geologists (and surveyors) to ensure appropriate (fit-for-purpose and fit-for-next-purpose) surveying and geospatial practice. Geospatial context will be described in terms of national or international geospatial standards, codes and guidelines; legislation; and risk.

The potential risk legacy of exploration activities is that geological drill holes or subsurface bulk-sampling voids may become hazards to mining. The position and extent thereof must be accurately measured and recorded, requiring the exploration geologist to have an awareness of mining risk.

An example, from the author's personal experience, of the impact or potential impact of geospatial errors on geological interpretation will be presented as a brief case study to demonstrate risk and consequence.

Chapter 5 – Evaluate, will discuss increasing geospatial accuracy requirements and strategy development through the evaluation phase of a project, (the study phases of Conceptual, Pre-feasibility and Feasibility), and the increasing level of geological and economic confidence which define Resources and Reserves. The key element throughout these activities is the underlying geospatial confidence and whether this has been improved together with geological confidence.

The involvement of engineering and design functions which require high geospatial accuracy will be discussed, with specific reference to typical feasibility study guideline recommendations, to demonstrate value potential and possible financial risk of deficient geospatial information.

Chapter 6 – Establish, will discuss geospatial control, positioning, monitoring and reporting during the construction and development of a mine in the context of supporting the project schedule and budget. This is the major capital expense phase of every project (ranging from hundreds of millions to billions of US Dollars), where the design is being established in physical space.

Effective monitoring of spatial and temporal compliance with design, for activities such as shaft sinking and equipping, underground development and surface earthmoving, is a key role of the surveyor during this phase, and one which has significant economic value.

High geospatial accuracy is required in almost every aspect of construction and development. The requirement for and advantages of an engineering coordinate system (which does not include any projection, mean sea level or earth curvature corrections) will be explained.

Chapter 7 – Operate, will discuss the role of geospatial information on an operating mine. It will cover the typical role of mine surveying and the regulatory environment (legislation, codes, guidelines and standards) during this phase. As stated earlier in this chapter, a consequence of operational focus on safety related compliance, is for the potential contribution of quality geospatial information to the performance of the business to be overlooked or underestimated.

However, in terms of the mining value chain, this is where there is the highest concentration of parallel, adjacent and coincident activities and sub-activities, which present numerous opportunities for cross-functional and cross-discipline synergy. Examples of such synergies will be presented, together with the discussion of measuring, monitoring, reconciling and reporting in support of compliance, foresight and value.

The role of geospatial information in mine safety will be discussed, with specific reference to risk mitigation and management. Examples of mine accidents and disasters, in which geospatial information was pivotal (positive and negative contribution), will be presented as brief case studies to demonstrate risk and consequence.

Chapter 8 – Close, will discuss geospatial considerations for mine closure. Restoration of topography is an obvious closure activity however, it is one aspect of a number which must be successfully addressed before a mine can receive a closure permit. Until a closure certificate is issued, it is still considered to be a mine.

A permanent geospatial record/archive needs to be established and held by appropriate authorities. The geospatial context here extends beyond actual closure of a mine. Certified accurate and complete geospatial records are required for possible resumption of mining; development of an adjacent mine; alternate uses of underground voids; and future land use, such as agriculture or development of surface infrastructure. This requires a geospatial strategy, as discussed in Chapter 5, to extend in scope beyond mine closure.

Chapter 9 will summarise major findings of the research, to answer the principal question *"Can a cross-functional Value Chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?"* and the secondary questions presented as consequence thereof.

Chapter 10 will be a concluding chapter in which conclusions and recommendations are discussed. Attention will be drawn to the significant potential for further work.

1.8 Conclusion

This chapter provided an introduction to the research topic, its intent and the breadth of its scope. It has introduced the mining value chain, geospatial risk and consequence, and geospatial thread which runs through the mining business. Furthermore, it has demonstrated the cross-functional geospatial interdependencies which run through the full life-cycle of a mining project (by applying a value chain representation of the project life-cycle).

Geospatial information used and gathered during the exploration phase of a project becomes the foundation for all work which may follow. Deficiencies in geospatial information can become embedded in the geological model, flowing through to Resource, Reserve, mine design and mine planning. Geospatial confidence is linked to geological confidence. It is essential therefore, to have the competency to plan, execute, examine, approve and sign off on the accuracy, quality and integrity of geospatial information at this early stage of a project.

Risk mitigation and value creation can be achieved by applying the concept of geospatial context to improve the understanding of upstream and downstream applications of geospatial information, that is, a more intelligent approach to how information is compiled and applied. Fit-for-purpose and fit-for-next-purpose is encapsulated in this concept.

A comprehensive geospatial strategy should guide practice from the earliest phases of a mining project to beyond mine closure.

Extensive review of available literature did not yield any published work that addresses geospatial context linked to functional and process interdependencies, accuracy, risk and the value potential of geospatial intelligence to the business of mining, which spans the full project life-cycle. The next chapter will provide detail of the literature reviewed.

2. LITERATURE REVIEW

2.1 Introduction

Chapter 1 demonstrated the breadth of scope of this research, which spans the full mining project life-cycle, from exploration to mine closure.

This chapter, Chapter 2, documents literature reviewed which is of central interest to answering the principal question of this research, namely: *Can a cross-functional value chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?*

The objective is to present existing knowledge on this topic. Where appropriate, comments will be made, to ensure that the context of literature presented is directly linked to the central theme of this research. This is deemed essential, due to a lack of direct reference to geospatial practice in numerous instances.

The review includes scholarly and journal articles; conference proceedings; industry fora discussion documents; legislation, codes, guidelines and standards; books; and personal notes accumulated over a period of more than 30 years in the mining industry.

Where practicable, the review will be presented as a natural progression along the mining value chain, however, this is not always possible as some literature is pertinent to more than one area of activity (value chain link). The progression will replicate the structure of this dissertation, as the central chapters represent the principal activities of the value chain, namely Explore, Evaluate, Establish, Operate and Close.

As mentioned in Chapter 1, extensive review of available literature did not yield any published work that addresses geospatial context linked to functional and process interdependencies, accuracy, risk and the value potential of geospatial intelligence to the business of mining. Furthermore, there is very little explicit geospatial detail in literature in the exploration, evaluation and closure phases of a mining project. This demonstrates a typical (and natural) functional focus by subject matter experts. While it restricts the quantity of literature presented, it also presents opportunities to establish links to the intent of activities described in published current knowledge, thereby demonstrating the functional and process interdependencies which are central to this research dissertation.

Mapping accuracy standards and geospatial theory and practice literature is included in this review, to describe areas of complexity, potential geospatial deficiency and consequent risk.

Similarly, discussion of significant mining accidents or incidents which have a direct geospatial link were reviewed to provide reference to safety, financial and reputational risk associated with deficient geospatial information.

2.2 Review of relevant work by other authors and published documents

2.2.1 Porter's Value Chain

Porter (1985) developed Value Chain theory, which states that every business/enterprise has a collection of activities which are performed to design, produce, market, deliver and support its product. By mapping these activities sequentially, a value chain is formed. According to Porter, "The value chain disaggregates a firm into its strategically relevant activities in order to understand the behaviour of costs and the existing and potential sources of differentiation." By constructing a value chain, a graphical representation of activities which feed processes is formed, thus identifying interdependencies within the business/enterprise. The value chain approach represents a break from work being broken down into functional areas.

Porter further states that "An industry or sector-wide value chain is too broad, because it may obscure important sources of competitive advantage." In Porter's context, the value chain is therefore a means of enabling strategy for the creation of competitive advantage.

This value chain approach has since been widely adopted across enterprises and industries, including the mining/minerals industry, not only as means of enabling value creation, but also as means of creating a common understanding of the key processes of a business or industry sector.

2.2.2 The Exploration and Mining Business Reference Model

The Open Group (2010) Exploration, Mining, Metals and Minerals Vertical, a collaborative industry forum, published The Exploration and Mining Business Reference Model (EM Model) with the following objectives:

- "Provide an overarching standard for business activities in the exploration and mining sectors focused on all metals and minerals.
- Provide a common definition for describing business processes (activities) in the industry.
- Create a common understanding of the information that will be required to execute the business activities.
- Enable sharing through understanding, amongst exploration and mining organisation and internally within these organisations."

The EM Model uses a value chain structure which links processes and sub-processes. According to the model, "core enterprise processes for the Exploration and Mining industry are described by the six vertical…boxes, forming the central component of the model. These six core enterprise processes are Discover, Establish, Exploit, Beneficiate, Sell, and Rehabilitate, and they describe the sequential nature of the exploration and mining business. This sequential nature does not imply that the sequence will always be followed rigorously, but merely that in most cases the activities will occur in this sequence."

Execution of these core processes can be "Strategic", "Tactical" and "Operational/Mine Site" depending on the level within a business at which the core process is addressed, for example:

- Strategic "covers life of mine and mining business";
- Tactical "relates to medium term mine planning for validating the strategic plan, including resourcing and re-planning";
- Operational/Mine Site "relates to the efficient use of the resources in order to execute the tactical plans."

Each core process can be broken down into "value chain processes". Depending on the level of detail required, value chain processes could be further broken down into discreet activities within the process.

Further provision is made for "Enterprise Support" under the activities of "Plan", "Measure", "Control" and "Report".

The above described attributes of the EM Model are shown in Figure 2.1.

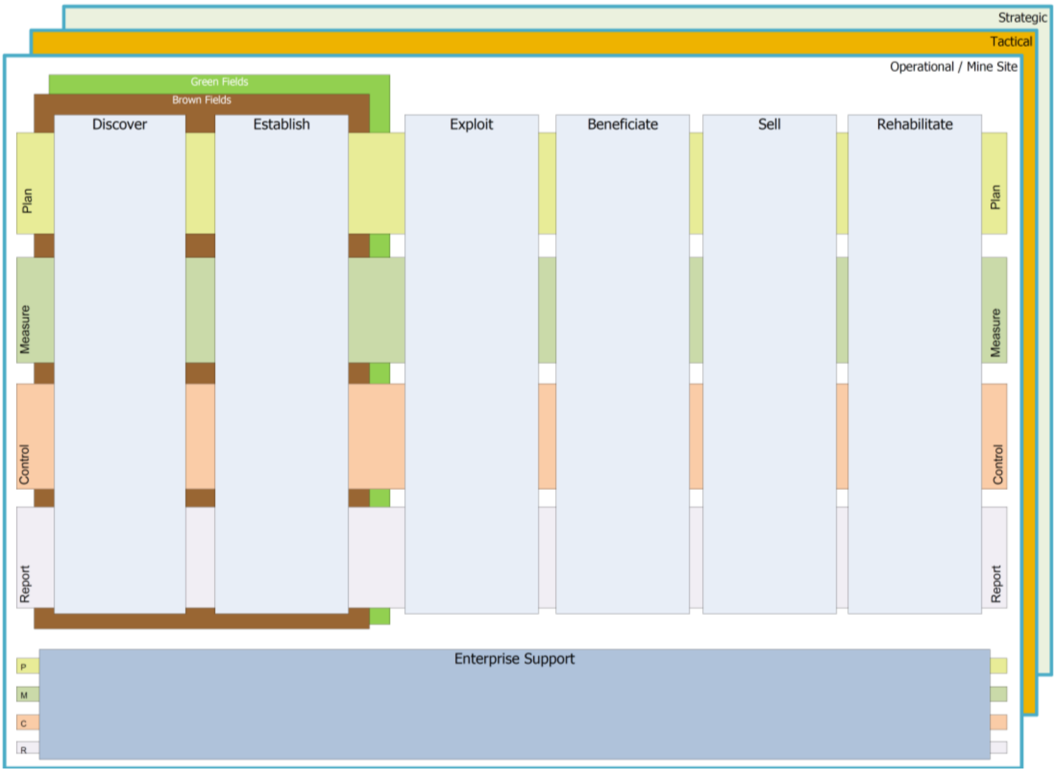

Figure 2.1 Conceptual EM Model (prior to the inclusion of value chain processes).

From the above summary, the EM Model is clearly a business tool. Contrary to Porter's theory, the value chain of the EM Model is as an industry or sector wide reference model.

The EM Model describes what is to be done, but not how or by whom. It is silent on the functions or disciplines which are involved in core and value chain processes, such as Geosciences, Surveying and Mining, Engineering. This is understandable, as these can vary from company to company or by geographical/country preference.

Therefore, the principal differentiator between the EM Model and this research is the concept of geospatial context along the activities of the mining/minerals value chain, cross-functional interdependencies and leveraging value in geospatial information.

2.2.3 Mine Surveying in Ghana: A Framework for Compliance

Bennett (2011) in his MSc research report Mine Surveying in Ghana: A Framework for Compliance focused on mine surveying, legislative compliance, common standards and a mining legal register. By researching applicable legislation in numerous African countries, international codes of practice and company internal technical standards, Bennett's framework has international relevance as an "African Register" for comparing mining legislation across the continent. (It must be noted that the framework was developed for AngloGold Ashanti.)

In his research, Bennett stated "A review of the 'mining value chain' together with mine surveying integration in that chain will be tabled. Then, the key extracts from the current standard instructions and activities for mine surveying are discussed." Bennett also used the mining value chain to identify "supporting activities that may or may not require research".

A major finding of the research was the numerous interfaces of mine surveying "with several other mining departments, legal structures and possible international codes", thereby demonstrating cross-functional interdependencies within a legal context.

2.2.4 Down-hole surveying

The proceedings of the Institute of Mine Surveyors of South(ern) Africa Borehole Surveying Colloquium (2005) present the findings of numerous controlled tests of down-hole surveying tools, conducted at the De Beers Voorspoed Mine.

A PVC pipe of appropriate diameter was laid down an access ramp and then over the pit crest into the (then) disused open pit, to replicate a geological drill hole of ~400m (389.6m) in length. The pipe was secured by means of plinths and brackets, to ensure its stability. Sufficient horizontal and vertical deviations were included in the design to replicate a typical down-hole survey. More than one magnetic source was present.

The drill path (PVC pipe) was accurately surveyed (by mine surveyors) using conventional ground survey methods, to provide a geospatial benchmark against which various down-hole survey tools were evaluated. Such tools included optical, magnetic and north-seeking sensors. A total of nine different instruments were tested; 7 magnetic sensors (Electronic Multi-Shot); 2 non-magnetic sensors (1 Optical and 1 gyro).

Down-hole survey errors (vs. benchmark) were used to assess the impact on geological modelling. According to Nordin (2005) the impact of a 10% deviation in down-hole survey on the volume of the geological solid model of the kimberlite pipe, ranged between 29.1% ("10% Shrunk") and -33.1% ("10% Expanded"). At 4% deviation, the change in volume already exceeded 10%, which according to the various international codes for reporting mineral resources and reserves, is "Material" and must be reported. The fundamental principles of surveying required for on-site calibration of down-hole survey instruments, and their alignment, are not addressed in the colloquium proceedings.

Regarding levels of error and geospatial uncertainty in down-hole surveys, Wolmarans (2005) stated that "Resource classification can be downgraded if uncertainty in location of contacts and volume are too big". In his analysis of the down-hole survey results, Wolmarans was able to isolate and adjust for local magnetic anomalies affecting survey accuracy (by comparing to benchmark and non-magnetic sensor survey results). Linear displacement vs. benchmark, expressed as a percentage of hole length ranged from 0.2% to 19.7% and presented as "spheres of (geospatial) uncertainty", again drawing attention to the potential impact on Resource classification. He also questioned where individual responsibility and accountability for borehole orientation surveys should lie, with direct reference to the mine surveyor.

Sindle *et al* (2006), in investigating and explaining frequent and common sources of error in down-hole trajectory surveys, notes that "The value of any information gleaned from exploration boreholes is increased enormously when this information can be accurately placed within the three-dimensional model of the mine site. It is not uncommon to find trajectory data to be out by tens of degrees causing compounding errors at the end of long holes. This misinformation can end up being extremely costly when mine plans and resource estimates are based upon it."

2.2.5 Reconciliation

The value chain is routinely applied in mining at a high level of process and individual activity, as a means of representing a sequence of inputs, activities and outputs/products.

According to Fouet *et al* (2009) "reconciliation is about measuring the variance between two like measures at different points along the mining sequence. It can be undertaken between predictive models, forecast plans and actual measured performance". Fouet *et al* continue "Mining companies use the calculation of reconciliation factors as key performance indices (KPIs) to provide a 'health check' of their operation, with variances often pointing to issues either with the accuracy of the original estimate or the quality of the measurement being used in the comparison". Additional detail is provided regarding the definition of reconciliation being "…the comparison of an estimate (a mineral resource model, a mineral or ore reserve model, grade control information, or a mine production plan or schedule) with a measurement (survey information, material movement records or the official production, usually from the processing or treatment plant) (after Morley and Moller, 2005; Schofield, 2001)". Significant content is dedicated to describing specific reconciliation points of measurement and associated factors, tabling methods/formulae for calculation of such factors, and assigning set nomenclature – all to create a common understanding across mines/businesses.

Macfarlane (2013), states that; "Metal accounting and reconciliation is an increasingly important governance issue in all mining operations, in that it is required, from a risk management perspective, that the company is in control of its product throughout the whole mining value chain." He describes operational metal accounting and reconciliation practice which covers a portion of the value chain (from the geological model to product sales), using a value chain approach to identify the natural sequence of information sources and processes for a typical base metals mining operation, beginning with the post-exploration geological model, progressing through mineral resource, mine planning, mineral reserve, mining, extraction and recovery processes, ending with sale of product. The relationships between processes where reconciliations should take place are described for purposes of "…management control, which are from the model to the plant delivery, and reconciliations that are required for commercial reconciliation between the plant dispatch and the customer. These are required in terms of commercial agreements and contracts, and in case of dispute and litigation".

Fouet *et al* and Macfarlane are addressing reconciliation to analyse and understand operational variances (key performance indicators) to improve operational control and business performance. What is not stated in their work reviewed (understandably due to the focus on the topic of reconciliation) is that reconciliation factors should be regarded as lagging or historic indicators. This leads to the question of what can be done to improve performance through expanding reconciliation to provide leading indicators which can influence operational control decisions.

Regarding the value potential of geospatial information to the business of mining, Cawood and Richards (2007) discuss the role of the coal mine surveyor (in South Africa), a statutory appointment, which typically focuses on compliance with regulations as defined by the Mine Health and Safety Act and the Mineral and Petroleum Resources Development Act, "together with their secondary legislation and regulations.", as well as compliance with other relevant legislation. The authors describe the role of the surveyor in measuring and reporting production activities, measurement of accidents (for investigation/official inquiry) and general responsibilities of keeping accurate mine plans. The authors propose that the typical focus on statutory duties by the mine surveyor limits his contribution to the business and that there is a "…need for surveyors to measure, process and report material in a manner consistent with the business drivers of the company". This statement is highly relevant to all mining operations and, in particular, to the topic of this research dissertation.

2.3 International codes, standards or guidelines for reporting mineral exploration, resources and reserves

The following codes, standards or guidelines for reporting mineral exploration, resources and reserves were reviewed, with the principal objective of identifying any differences in wording which may have specific bearing on geospatial context, confidence or criteria, i.e. an interpretive review.

- **JORC** (2012) – Australia: The Australasian Code for Reporting of Exploration Results, Minerals Resources and Ore Reserves, prepared by the Joint Ore

Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia.

- **NI 43-101** (2016) – Canada: National Instrument 43-101 Standards of Disclosure for Mineral Projects.

- **PERC** (2013) – European Union: The Pan-European Code for Reporting of Exploration Results, Mineral Resources and Reserves prepared by the Pan-European Reserves and Resources Reporting Committee.

- **SAMREC** (2016) – South Africa: The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves prepared by the South African Mineral Resource Committee (SAMREC) under the Joint Auspices of the Southern African Institute of Mining and Metallurgy and the Geological Society of South Africa.

- **SME Guide** (2014) – United States of America: The SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves prepared by the Resources and Reserves Committee of the Society for Mining, Metallurgy and Exploration, Inc.

The above-mentioned documents are all highly similar in content and are intentionally aligned, to ensure mutual understanding and compatibility.

To explain this alignment, CRIRSCO (Committee for Mineral Reserves International Reporting Standards) in 2005 summarised the development of the JORC Code and related reporting standards over the period 1971 to 2004. The following key information is pertinent:

- 1971 – the formation of JORC
- 1971 to 1985 – JORC guidelines on classification were developed
- 1989 – the 1st edition of the JORC Code was published
- 1994 – present day CRIRSCO was established
- 1997/98 – CRIRSCO and the United Nations Economic Commission for Europe agreement results in "virtually uniform definitions for Mineral Resources and Reserves."

- 2000 to 2003 – “Virtually identical reporting codes and guidelines adopted by South Africa, Canada, USA (SME), UK/Western European Countries, Chile and Peru, all based on 1999 JORC Code.”

SAMREC (2016) states that “Transparency, competency and materiality are the overriding principles that determine what information should be publicly reported”.

Each of these codes, standards or guidelines recommended content of Competent Person’s reports, refer in various forms and detail to geospatial information. Such information can be found under reporting criteria such as topography, plans maps and diagrams, legal tenure, data location (regarding the accuracy and quality of surveying related to drill hole collars and down-hole surveys), survey data verification, and audit and reviews. The focus of Competent Person’s reporting is on mineral exploration, resources and reserves, with increasing levels of geological confidence ultimately leading to the application of techno-economic modifying factors required for ore reserve classification and mine establishment.

No detail is provided for what constitutes a competent person in a surveying or geospatial context. The context of geospatial “materiality” is not addressed. For example however, there are references in individual codes to “quality and adequacy of topographic control” (PERC), “specification of the grid systems used” and “….(elevation above mean sea level) of the drill hole collar” (JORC), “Survey data verification, audits and reviews” (SAMREC), “the location, azimuth, and dip of the drill holes and the depth of the sample intervals” (NI 43-101), and “Maps and cross sections and other two or three-dimensional representation of results should exist, showing location of samples, drill holes, exploration pits, underground workings, geological data, etc.” (SME).

The contribution of geospatial confidence to geological confidence appears to be either assumed or overlooked.

2.4 Accuracy standards for large-scale maps

The Specifications and Standards Committee of the ASPRS (American Society for Photogrammetry and Remote Sensing) Accuracy Standards for Large-Scale Maps (1990) prescribes horizontal and vertical accuracy of maps at ground scale. An important feature of the standard is that “data of known ground-scale accuracy can be related to the appropriate map scale…”. This is of great practical relevance, because it links map scale to accuracy of data represented on the map, e.g. for a Class1 (the highest accuracy classification) map scale of 1:20 000, the limiting planimetric error is 5 metres – the map user can therefore understand the accuracy of a map, simply by referring to its publication scale. Maps with lower spatial accuracy are accommodated under Class 2 and Class 3 definitions (which are directly linked to a Class 1 mapping accuracy). To support the standards, guidance is provided on survey control network standards, check surveys and assessing map accuracy. “Large Scale” is defined as mapping which is between the scales of 1:20 000 and 1:50.

The USACE (United States Army Corps of Engineers) Engineering and Design Photogrammetric Mapping manual EM 1110-1-1000 (2002) incorporates ASPRS standards and further quotes practical vertical accuracy criteria: the RMSE (Root Mean Square Error) “for Class 1 mapping contours is one-third of the contour interval; for Class 1 spot-heights is one-sixth of the contour interval”. It continues, “For Class 2 and Class 3 accuracies are twice and thrice those of Class 1, respectively”.

From the above two documents, the user of a (standards compliant) map can immediately deduce the geospatial quality of features on the map from the scale of publication for which the map was prepared and its contour interval. As stated in Chapter 1, this fundamental relationship can be used to understand the inherent accuracy of a map (and its limitations) as a geospatial quality indicator and will be discussed in Chapter 3.

2.5 Survey and geospatial theory and practice

This section is of importance due to the widespread use of GNSS/GPS for position fixing and as a surveying tool.

2.5.1 Ellipsoids, datums, mean-sea-level and projections

The terms spheroid and ellipsoid are used interchangeably in surveying literature to describe a simple mathematical figure which represents a uniform shape of the earth. The figure is defined by a major axis, a minor axis and a flattening factor. The Royal Institution of Chartered Surveyors (2003) states that unless otherwise specified, the Ellipsoid is "a mathematical figure formed by revolving an ellipse about its minor axis".

In contrast, the geoid is a non-uniform model of the shape of the earth if sea level were to extend across the earth (therefore an imaginary shape). The Royal Institution of Chartered Surveyors (2003) describes the geoid as "The particular equipotential surface which most closely approximates mean sea level in the open oceans and which may be imagined to extend through the continents. This surface is everywhere perpendicular to the force of gravity".

The Massachusetts Institute of Technology lecture notes for Earth's Gravity Field and Sea Level (2004) discusses the variation of the gravity field of the earth caused by the earth's rotation (and centrifugal force), and importantly for geodetic surveying "…that the mass of the earth is not uniformly distributed: it is not a perfect oblate spheroid." The notes continue and state the following, "The combination of factors which affect mean sea level result in spatial variations of 100m over the oceans".

Wonnacott and Merry (2011) explain the role of mean seal level (in surveying), its relationship to mean sea level, and the customary practice "to define the vertical datum [for surveying and mapping] with respect to tide gauge measurements of MSL".

According to the Royal Institution of Chartered Surveyors (2003) a Geodetic datum is "A mathematical model designed to best fit part or all of the geoid. Conventional datums depended upon an ellipsoid and an initial station on the topographic surface established as the origin of the datum. Such datums were defined by the dimensions of spheroid, by the geodetic latitude, longitude and the height of the geoid above the ellipsoid at the origin…".

The National Imagery and Mapping Agency of the USA (NIMA) records 23 Ellipsoids which are referenced to approximately 220 geodetic datums to define geodetic datums for national or regional surveying and mapping across the world.

Up until this point in the review, coordinate points from surveying have been represented on the surface of a reference ellipsoid. For representation on a map and for general surveying use, these must be projected onto a plane surface (grid) with heights referenced to mean sea level. Allan *et al* (1975) describes two commonly used projections, the transverse Mercator projection and Lambert's conical orthomorphic projection and the computational requirements for projecting spherical coordinates onto plane surfaces for each of the above-mentioned projections. The Universal Transverse Mercator (UTM) projection system is discussed in depth.

In summary, there are national and regional variances in horizontal and vertical datums which define national control systems for surveying and mapping. There are local variations in gravity which can cause variance from an adopted/national geoid.

Mean sea level is variable, depending on where it is measured, thus affecting the vertical datum adopted (by different countries or regions) as the basis of measuring heights for surveying and mapping purposes.

2.6 Relevant surveying regulation and codes

Geospatial practice is regulated through legislation, or discretionary or mandatory standards or codes. The common intent is to mitigate risk of geospatial error or deficiencies and to ensure consistent standards of practice.

The following legislation has been reviewed with specific reference to maps, plans, diagrams, surveyor, accuracy, error, and qualified or competent (person). General comparisons have been made to prescriptive vs. non-prescriptive regulation. Significant differences have been noted.

- **S.I. No. 78_1970** – Mines (Surveyors and Plans) Regulations, 1970, of the Ministry of Labour, Ireland
  The regulations are comprehensive and prescriptive. They call for the manager of a mine to appoint a competent person to be the surveyor for the mine responsible for mine surveying and plans, with qualifications in mine surveying acceptable to the Minister (of Labour).
  Of major significance under "Duties of surveyors", S7. (2) requires that "It shall be the duty of the surveyor for a mine to establish the accuracy as regards any matters which may involve substantial error or danger, of any such plans, drawings and sections of the mine which have not been prepared by him or to ensure that such accuracy is established by a person who is qualified to be appointed the surveyor for that mine".

S8. (1) states that "It shall be the duty of the surveyor for a mine to ensure that working papers recording all observations or calculations which were necessarily made for the preparation or checking of any plans, drawings or sections kept by the manager by virtue of Part III of these Regulations are signed by the person making them and are preserved".

- **Mineral Tenure Act Regulation** [includes amendments up to B.C. Reg. 78/2008, June 2, 2008] – British Columbia, Canada
  The regulations prescribe the requirement for control surveys during physical exploration and development, and that precision survey techniques such as global positioning or surveys are conducted by a practising land surveyor (a practising land surveyor is defined under the Land Survey Act).

  Regarding "Reports of physical exploration and development on a claim" S15. (1) (g) calls for "a plan prepared by the land surveyor from a precision survey;".

- **Mines Act** [RSBC 1996] CHAPTER 293 (2004) – British Columbia, Canada
  The act does not prescribe the appointment of a surveyor, therefore the manager of the mine or his designate carry this responsibility. S27 Mine Plans states that "Each manager must keep in the office at the mine site accurate plans that
  (a) are updated every 3 months,
  (b) are prepared on a scale that accords with good engineering practice, and
  (c) contain particulars established by the regulations or the code."

- **Mine Health and Safety Act**, (Act 29 of 1996) Regulations – Republic of South Africa
  The regulations are generally prescriptive, but do include non-prescriptive clauses where action must be taken based on risk assessment.
  Chapter 14 and Chapter 17 of the act address protection of the surface and workings, and surveying, mapping and mine plans respectively.
  Chapter 14 addresses significant risk associated with ingress of water or fluid material into workings and "the protection of the surface of a mine or structures or objects thereon."

Chapter 17 addresses the requirement for the appointment of a competent person “to be in charge of surveying, mapping and mine plans”, prescribes qualifications, standards of accuracy, plans and records to be kept, and the lodgement of plans and records upon mine closure.

- **Mining Titles Registration Act**, 1967 (Act 16 of 1967) as amended – Republic of South Africa
  The regulations include direct reference to the Land Survey Act (Act 8 of 1997) and the Mine Health and Safety Act (Act 29 of 1996) in its definition of “Co-ordinated point”. The act prescribes what detail must appear on all plans and diagrams submitted for registration of a mineral right and who may prepare such diagram (a professional land surveyor or a mine surveyor registered in terms of Act 40 of 1984). The Mining Titles Registration Act also makes direct reference to the Mineral and Petroleum Resources Development Act (Act 28 of 2002).

- **Land Survey Act, 1997** (Act 8 of 1997) – Republic of South Africa
  The act and its regulations are prescriptive and cover all aspects of cadastral survey practice, including accuracy, diagrams and plans, registration of a “real right in or to land in terms of the Deeds Registries Act”, boundary verification and dispute resolution.
  The act is linked indirectly to the Mineral and Petroleum Resources Development Act, The Mining Titles Registration Act and the Mine Health and Safety Act (therefore the practising land surveyor or mine surveyor must be aware of pertinent requirements of all such acts).

- **Geomatics Profession Act, 2013** (Act 19 of 2013) – Republic of South Africa
  The act provides for the establishment of the South African Survey Council (repealing in whole, the Professional and Technical Surveyors Act, 1984, Act 40 of 1984, thereby replacing the South African Council for Professional and Technical Surveyors).
  The purpose of the act is to promote and regulate all matters connected to the geomatics profession by providing for different categories of registration in specific fields of specialisation, identification of work which may be performed per category of registration, protection of the public from unethical practice, the establishment of measures to maintain high standards of professional conduct

and integrity, including disciplinary mechanisms and an enforceable code of conduct.

- **Survey and Drafting Directions for Mine Surveyors** (2007) – New South Wales, Australia
  The directions address surveying and the preparation of plans for mines and are aligned with relevant regulations and state guidelines.
  As a consequence of the Gretley disaster, S1.3.4 (of the directions) addresses old mine workings, stating, "Where old workings exist it shall be assumed, for the purpose of marking the Mine Survey Plan, that they constitute a danger until the contrary is proven. In this situation, all plans should be regarded with suspicion until their accuracy has been verified…".
  The mandatory appointment and liabilities of a registered mining surveyor are addressed, including all aspects of the drafting on mine plans, the requirement for void plans and void sheets, coordinate systems, horizontal and vertical datums.

- **Code of Practice Mines Survey**, Second Edition – Government of Western Australia
  The code of practice provides guidance to the licensed/certified mine surveyor for compliance with the Mines Safety and Inspection Act 1994 and the Mines Safety and Inspection Regulations 1995, both of which include significant content on surveyors, certification, duties, liability, mine plans, general and specific practice, coordinate systems, horizontal and vertical datums.

  The legislation aligns well with that of New South Wales and South Africa.

2.7 Accidents and incidents

The mine surveyor's role in risk mitigation, is to accurately measure, map, monitor and report on factors which are potential causes of major safety incidents which could result in harm to people, damage (to property, infrastructure, or the environment), breach of law and loss. This includes, but is not limited to; showing all known physical hazards (including geological structure) on mine plans; geospatially guiding/directing mining through or past hazards (including possible concentrations of water and gas); stopping mining at prescribed limits or boundaries; preparing plans showing the full extent of current, old and adjacent workings; preparing mine ventilation and rescue plans; and ensuring effective communication of geospatial information which has a bearing on mine health and safety.

A mine disaster is generally defined as an accident or incident in which there have been multiple fatalities. There are four principal causes of mine disasters, namely, fires, explosions, inundation (ingress of water) and falls of ground.

The following examples of major accidents and incidents have direct geospatial relevance.

2.7.1 Gretley Colliery – New South Wales, Australia (1996)

Nature of the incident: multiple fatality caused by inrush of water from adjacent abandoned mine workings.

The report of a formal investigation under Section 98 of the Coal Mines Regulation Act 1982 by his Honour Acting Judge J.H. Staunton (1998), provides a description of the accident:

“At about 5.30 am on 14 November 1996…Four men of a team of eight were in the process of developing a roadway…, operating a continuous mining machine. The remaining four members of the team were in a crib room a little distance away.

“Suddenly, with tremendous force, water rushed into the heading from a hole in the face made by the continuous miner…The four men were engulfed by the water, swept away and drowned…

“The water came from the long-abandoned old workings of the Young Wallsend Colliery. The mine was working to a plan, which had been approved by the Department of Mineral Resources. The plan showed the Young Wallsend Colliery more than 100m away from the point of holing-in. It is now clear that the plan was wrong. At the commencement of the night shift at 11.00pm on 13 November 1996, the Young Wallsend Colliery was only 7 or 8 metres away”.

2.7.2 Quecreek underground coal mine – Pennsylvania, USA: 2002

Nature of the incident: non-fatal entrapment caused by inundation of the mine.

According to the overview of the report of investigation into the Quecreek #1 mine by the United States, the Department of Labor Mine Safety and Health Administration (2003), “On Wednesday, July 24, 2002, at approximately 8:45 p.m., a nonfatal entrapment accident caused by a water inundation occurred at Quecreek #1 mine,…Water broke through the working face of No. 6 entry on 1-Left section from the abandoned Harrison No. 2 mine…The 1-Left crew attempted to escape but was blocked by water at the mouth of 1-Left panel. The 1-Left miners were trapped from 76 to 78 hours. Seven miners from 2-Left section and two outby miners were able to escape.”

“The primary cause of the water inundation was the use of an undated and uncertified mine map of the Harrison No. 2 mine that did not show the complete and final mine workings...The root cause of the accident was the unavailability of a certified final mine map for Harrison No. 2 mine in the State of Pennsylvania’s mine map repository.”

2.7.3 San José mine – Atacama Region, Chile (2010)

Nature of incident: non-fatal entrapment caused by fall of ground (collapse).

Livingstone-Blevins (2010) commented on the San José mine incident in an article titled “Getting it right saves lives and mitigates risk”. In the absence of an official report as reference, the following summary has been extracted from the article.

“To summarise the events, on the 5th of August [2010] an area of unstable ground caused the collapse of the main access decline of the San José mine. 33 miners were trapped some 700 metres underground…The extent of the collapse, some 400 to 500 metres below surface, was so large and the instability of the collapse area so great that there was no chance of excavating the hundreds of metres through broken rock to reach the depths of the mine. A decision was made to drill from surface into a chamber adjacent to a refuge bay located 670 metres below surface – if they [there] were any survivors they should have made their way to the refuge bay. Several methods of survey were used to check mine plans (maps) and down-hole survey instruments were used measure drill-hole direction and inclination...After 17 days of drilling, a 14cm diameter hole 701 metres in length holed into the chamber. When the drill was withdrawn, a note had been attached to the drill bit that read that all 33 missing miners were alive! This hole became the conduit for communication and sustenance for the miners…Three simultaneous boreholes were commenced (Plan A, B and C), targeting different routes through the rock and different terminal points in the mine…Special equipment was designed and fabricated which included special large diameter drill-bits (710mm) needed to create holes large enough to accommodate the escape capsule. Plan B reached its target first on the 11th of October, after commencing drilling on the 5th of September. On the 12th of October hoisting of the miners to surface commenced. All miners were rescued".

2.7.4 Gleision Mine incident – South Wales, United Kingdom (2011)

Nature of incident: multiple fatality caused by inrush of water from old mine workings.

The report of a formal investigation by the Health and Safety Executive (2015), the following summary provides a description of the accident: "On the morning of 15 September 2011…around 9.30 am, the first round of explosives was fired…The blast released a large body of water from old workings which rushed into the working stall, which was the part of the mine from where coal was being extracted…Such was the volume and speed of the water inrush that four…men …died. [A fifth man] was injured but managed to escape through the old workings and emerged on the surface about an hour later. [Two other men who were] further away from the stall, just managed to escape to the surface and raise the alarm".

"During the investigation, the mine was re-surveyed to assess the accuracy of the plans used at the time of the accident. The report states: "An outcome of the resurvey was that the edge of the bottom-most of the Old Central Workings was about 7 m further to the south-east than shown on the mine plan; in other words 7 m closer to where the miners were tunnelling. This would not be wholly unexpected given what is known about potential inaccuracies in mine plans as described in 'Mine plans and the mine survey' of this report".

The report includes a significant body of detail related to mine plans, survey practice and risk management. It also states that "…the circumstances leading up to the incident were considered and taken into account during the development of the Mines Regulations 2014 which are now in force".

- Three of four of the incidents described above (Gretley, Quecreek and Gleision) can be directly linked to deficient geospatial records which resulted in inrush of water.
- Two of the incidents (Gretley and Gleision) resulted in multiple fatalities. Lessons from both incidents were addressed in subsequent revisions of regulations.
- Two of the incidents (Quecreek and San José) demonstrate the role of accurate geospatial information and surveying in the successful rescue of all trapped miners.
- Two of the incidents (Quecreek and San José) resulted in mine closure, demonstrating socio-economic consequences (formal inquiries and investigations have a health and safety focus and typically do not consider other consequences).
- Two of the incidents (Quecreek and San José) in which the trapped miners were rescued were made into films.
- In all four incidents, personal and company/employer reputational damage was significant (in some cases coupled with civil lawsuits and prosecution).

2.8 Risk assessment

Literature related to risk and consequence assessment were reviewed. Due to the very close alignment, further review was not deemed necessary.

2.8.1 Risk consequence (2002) – Dr Hendrik Kirsten

(From the author’s personal experience and notes from work done on surveying and mapping risk in 2002.)

The risk and consequence assessment system is simple and effective, tabling Event, Category (of risk), Type, Frequency, Impact, Cause and Lesson. Monetary value is not assigned (therefore not subject to subjective assignment of value or depreciation over time). The type of risk accommodates all risks which may have Safety, Financial or Reputational risk and therefore has broad application.

2.8.2 Guidance Note QGN 17 (2010) – Government of Queensland, Australia

Guidance Note QGN 17 (2010); Development of effective Job Safety Analysis, is a comprehensive document which provides "practical guidance for holders, operators, site senior executives, supervisors, contractors and persons generally who have obligations under the legislation" in how to conduct Job Safety Analysis within a set framework.

It addresses Consequence, Injury, Property damage or process loss (in financial terms) and Environmental Impact, for a particular event. It also provides a rating scale, with examples, to determine likely frequency of the event occurring.

While the framework is sufficiently flexible to enable broader application, its focus is on job safety.

2.8.3 Anglo American plc risk matrix

The Anglo American risk matrix is the most comprehensive of the three risk and consequence assessment systems reviewed and is designed for the broadest application. Business units may adapt the matrix to ensure situational fit.

Consequence Type has seven categories, namely, Financial, Safety, Occupational Health, Environment, Legal & Regulatory, Social / Communities and Reputation.

Consequence has five levels, namely, 1 – Insignificant, 2 – Minor, 3 – Moderate, 4 – High and 5 – Major.

Likelihood has five levels, namely, 5 – Almost Certain, 1 year, 4 – Likely, 3 years, 3 – Possible, 10 years, 2 – Unlikely, 30 years and 1 – Rare, >30 years.

Consequence and Likelihood levels (each between 1 and 5) are multiplied to determine a risk rating between 1 and 25 to determine a risk level (Low, Medium, Significant and High) based on the range in which the risk level falls.

Table 2.1 shows the risk matrix detail and the response required per risk rating range, adapted (from the above description) and approved by Anglo's Coal business unit.

Table 2.1 Anglo American Coal Risk Matrix

Anglo American Plc Risk Matrix		Hazard Effect / Consequence (Where an event has more than one 'Loss Type', choose the 'Consequence' with the highest rating)				
Loss Type (Additional 'Loss Types' may exist for an event; identify and rate accordingly)		**1 Insignificant**	**2 Minor**	**3 Moderate**	**4 High**	**5 Major**
(S/H) Harm to People (Safety/Health)		First aid case / Exposure to minor health risk	Medical treatment case / Exposure to major health risk	Lost time injury / Reversible impact on health	Single fatality or loss of quality of life / irreversible impact on health	Multiple fatalities / impact on health ultimately fatal
(EI) Environmental Impact		Minimal environmental harm – L1 incident	Material environmental harm – L2 incident, remediable short term	Serious environmental harm – L2 incident remediable within LOM	Major environmental harm – L2 incident remediable post LOM	Extreme environmental harm – L3 incident irreversible
(BI/MD) Business Interruption/Material Damage and Other Consequential Losses		No disruption to operation / 5% loss of budgeted operating profit	Brief disruption to operation 10% loss of budgeted operating profit/listed assets	Partial shutdown / 15% loss of budgeted operating profit/listed assets	Partial loss of operation 20% loss of budgeted operating profit/listed assets	Substantial or total loss of operation / 25% loss of budgeted operating profit/listed assets
(L&R) Legal and Regulatory		Low level legal issue	Minor legal issue; non-compliance and breaches of the law	Serious breach of law; investigation/report to authority, prosecution and/or moderate penalty	Major breach of the law; considerable prosecution and penalties	Very considerable penalties & prosecutions. Multiple law suits and jail terms
(R/S/C) Impact on Reputation/Social/Community		Slight impact - public awareness may exist but no public concern	Limited impact - local public concern	Considerable impact – regional public concern	National impact – national public concern	International impact – international public attention.
Likelihood	**Examples (Consider near-hits as well as actual events)**	**Risk Rating**				
5 (Almost Certain)	The unwanted event has occurred frequently; occurs in order of one or more times per year & is likely to reoccur within 1 year	**11 (M)**	**16 (S)**	**20 (S)**	**23 (H)**	**25 (H)**
4 (Likely)	The unwanted event has occurred infrequently; occurs in order of less than once per year & is likely to reoccur within 5 years	**7 (M)**	**12 (M)**	**17 (S)**	**21 (H)**	**24 (H)**
3 (Possible)	The unwanted event has happened in the business at some time, or could happen within 10 years	**4 (L)**	**8 (M)**	**13 (S)**	**18 (S)**	**22 (H)**
2 (Unlikely)	The unwanted event has happened in the business at some time, or could happen within 20 years	**2 (L)**	**5(L)**	**9 (M)**	**14 (S)**	**19 (S)**
1 (Rare)	The unwanted event has never been known to occur in the business; or it is highly unlikely that it will occur within 20 years	**1 (L)**	**3 (L)**	**6 (M)**	**10(M)**	**15 (S)**

Risk Rating	**Risk Level**	**Guidelines for Risk Matrix**
21 to 25	(H) – High	A high risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised immediately.
13 to 20	(S) – Significant	A significant risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised as soon as possible.
6 to 12	(M) – Medium	A moderate risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised as part of normal management process.
1 to 5	(L) – Low	A low risk exists that management's objectives may not be achieved. Monitor risk, no further mitigation required.

Source: Annual Environmental Management Report 2011, Drayton Mine, Page 135 of 171

2.9 Conclusion

This chapter has provided a summary review of existing knowledge related to this topic that has already been published. It has drawn from diverse sources and has therefore not been confined to scholarly books and articles by recognised experts, and has included legislation, codes and standards from numerous countries, as well as personal notes.

The value chain review concluded that the principal differentiator between the value chain models reviewed and this research, is the concept of geospatial context along the activities of the mining/minerals value chain, cross-functional interdependencies and leveraging value in geospatial information. Additionally, the review demonstrated that the use of the value chain in mining by other authors was in support of work which is distinctly different from the purpose of this research.

Literature on downhole borehole surveying demonstrated that geospatial error could result in Mineral Resource classification being downgraded, thereby highlighting geospatial risk during the exploration and study phases of a mining project. The literature also noted the extreme cost risk potential when mine plans and resource estimates are based on deficient geospatial information.

The review of international codes, standards or guidelines for reporting of mineral exploration results, resources and reserves demonstrated the understandable focus of Competent Person's reporting on transparency, competency and materiality, with increasing levels of geological confidence ultimately leading to the application of techno-economic modifying factors required for ore reserve classification and mine establishment. No information is provided for what constitutes a competent person in a surveying or geospatial context, or the contribution of geospatial confidence to geological confidence which appears to be either assumed, or overlooked.

Leading from the above-mentioned issue of competency in a surveying or geospatial context, the underlying theory and principles of surveying were reviewed, to demonstrate the required understanding of ellipsoids, geoids, gravity, datums and map projections, and accuracy standards for mapping, noting that without such competency in surveying, it is possible to propagate errors, or even blunders, into geospatial data sets.

The review of relevant survey legislation and codes presented a summary of content and/or intent of statutory instruments, from a number of countries, directed at mineral and land tenure, and mine surveying and mine plans. The common intent is to mitigate risk of geospatial error or deficiencies and to ensure consistent standards of practice.

Noting the focus of mine surveying legislation, standards and codes on safety and health, four recent and prominent mine accidents, two of which resulted in multiple fatalities, were reviewed. The review demonstrated the role of deficient geospatial information as the cause or aggravator in the incident, and the role of good, accurate geospatial information in the successful rescue of people trapped underground.

Finally, the chapter concluded with a review of methods to determine risk and consequence, which are carried as a theme throughout this research.

The content of the literature review will be referred to in greater detail in the chapters to follow.

3. FUNDAMENTAL GEOSPATIAL PRINCIPLES AND INTRODUCTION TO THE MINING VALUE CHAIN

3.1 Introduction

Chapter 2 documented the literature reviewed to determine existing knowledge on the topic of this dissertation. It also demonstrated a general lack of direct reference to geospatial practice along a typical mining/minerals project life-cycle, thereby supporting the purpose of this research.

This chapter, Chapter 3, describes fundamental geospatial principles for surveying, an understanding of which is essential to providing geospatial context to guide practice and mitigate associated risk, particularly for non-geospatial or non-surveying practitioners.

In considering geospatial risk, it is important to consider geospatial context. During exploration, it is likely that deficient geospatial information becomes imbedded in databases and is then propagated through to the geological model and its future application as a foundational source of information. Consequences are likely to be financial and reputational. However, during the operational phase of mining, particularly underground mining, the consequences may be fatal (followed by financial and reputational).

Included in the above-mentioned principles will be the components of a survey control system (such as horizontal and height datums, projections and units of measure) which form the basis of geospatial representation of coordinate points and/or map features. Survey measurement, error theory and corrections will be discussed in the context of propagation of error (into geospatial databases), to provide some insight into the competencies required to do this correctly and defensibly (if subjected to peer or statutory review).

Operational principles of GNSS/GPS (satellite positioning) and surveying techniques will be briefly described.

Understanding of the above will provide a foundation for effective geospatial scoping, specifications and practice at the earliest appropriate point in a project, and enable the assessment of fit-for-purpose and fit-for-next-purpose.

The mining value chain (adapted from the EM Model) which forms the structure of the central chapters of this dissertation, namely Explore, Evaluate, Establish, Operate and Close, will be described to demonstrate functional and process interdependencies which can leverage the value potential of geospatial intelligence to the business of mining. Relevant portions of the value chain will appear in the central chapters of this dissertation, to provide greater detail (than can be shown in the full value chain).

The structure of the chapter will begin with key definitions for understanding subsequent content, followed as far as possible by a natural/intuitive progression of such content.

3.2 Brief explanation of surveying and mapping

In the minerals industry, people are accustomed to working with maps/plans and coordinates, be they geologists, mining engineers, civil engineers (construction phase), environmentalists or surveyors. Geospatial information runs through the business and survey professionals are responsible for the provision of such information.

Underlying this geospatial information are a number of conventions and principles on the science of measurement, processing and representing of such information, which are important to understand.

All coordinates and maps are represented within some form of survey control system (also referred to as a coordinate reference system). Typically, this is comprised of the following:

- Ellipsoid (of reference);
- Horizontal Datum (point of origin);
- Height Datum (surface of origin);
- Projection (map grid);
- Coordinate System; and
- Units of measure.

Point coordinates, or features on a map, are typically projected from a curved surface (ellipsoid) to a plane surface (map grid) and referenced to mean seal level, unless otherwise specified. To achieve this, a number of mathematical adjustments are applied to survey measurements. As a result, direction, distance and area are not expressed in their original measured quantum.

When using geospatial information from different sources, particularly when combining or comparing historical records with newly acquired and processed data, it is critical to understand the survey control systems to which each is referenced. For example, old cadastral records defining surface rights may be totally incompatible with current surveying, due the differing units of measure, datums, projections and coordinate systems. Therefore, to transform (convert through one or more calculation processes) old records to be compatible with current format would require a thorough understanding of the origins and geospatial processes for each set of records (and the competency to do this).

The accuracy of maps (and geospatial information generally) which comply with recognised standards, is linked to the intended scale of the map and the purpose for which it is to be used. This determines the accuracy of the source data (coordinates) required and hence the accuracy of the surveying used to measure features represented on the map. This relationship of scale and ground accuracy provides the map user with an understanding of the inherent accuracy of the map, and its limitations. The larger the scale, the higher the inherent accuracy (e.g. 1:1000 should be ten times more accurate than 1:10000).

By extension, coordinates or maps should have an accuracy directly related to purpose of use. Using geospatial data from a source which required lower accuracy, for an application which requires higher accuracy, is not permitted. However, the converse is.

The principal corrections or adjustments to measurements that are applied to survey measurements are described below, reduced to approximate formulae which are suited to general surveying practice. When dealing with surveying over distances of more than 20km, more precise formulae may be required.

3.2.1 Mean sea level correction

Point coordinates and maps are represented on a plane surface referenced to mean sea level. Occasionally a different height datum applies, which is either a requirement of legislation (e.g. S.I. No. 78/1970 – Mines (Surveyors and Plans)

Regulations, 1970; Ireland, which prescribes a datum 3048.00m below Ordnance Datum), or for the convenience of developing a local coordinate reference system.

Heights above mean sea level (or other nominal height datum) are mathematically reduced. Heights below mean sea level (or other nominal height datum) are enlarged.

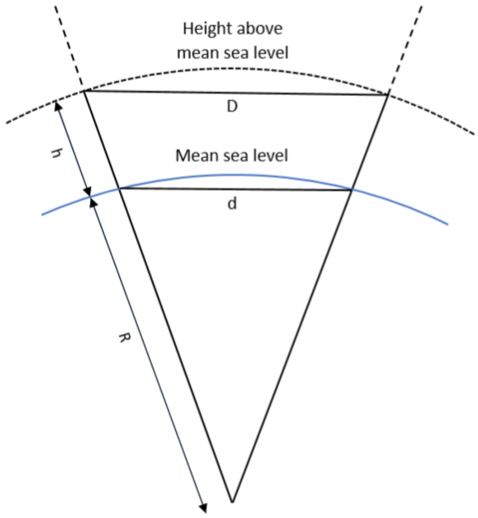

Figure 3.1 **Mean sea level correction** (source: Author's collection)

Mean sea level distance *(d) = D(h/R)*, where D is the distance measured, h is the height above mean sea level (datum), and R is the radius of the Earth, as shown in Figure 3.1.

3.2.2 Scale enlargement correction

The following description of the correction applies to the Transverse Mercator projection which is described in 3.4 and 3.5.1 below. Different formulae would be applied for other projections.

The Transverse Mercator projection projects a curved surface (the Ellipsoid) onto a plane surface (coordinate grid). Converging lines of longitude become parallel on the map grid. Distances must therefore be corrected to fit the projection.

The correction (or scale factor) is a function of distance from the central meridian of the coordinate system, and the radius of the Earth.

Scale enlargement correction applied to distance = $D(y^2/2R^2)$, where D is the distance measured, y is the distance from the central meridian and R is the radius of the Earth, as shown in Figure 3.2.

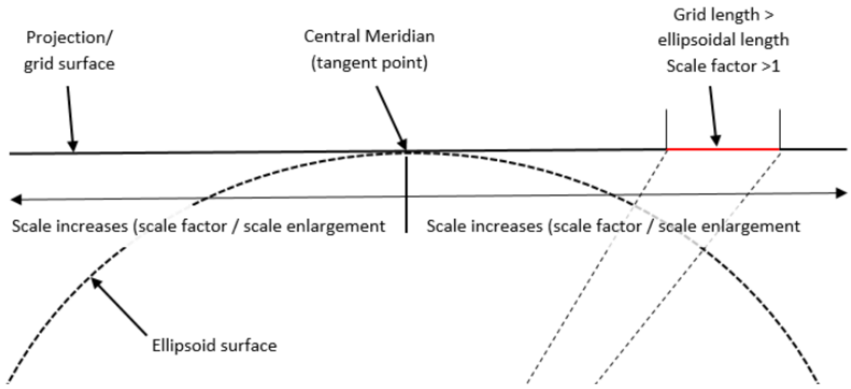

Figure 3.2 Scale enlargement correction (source: UCAR.edu)

3.2.3 Meridian convergence

Projecting converging lines of longitude to become parallel means that Grid North does not equal True North (geodetic north), except on the central meridian.

Meridian convergence is a function of the distance from the central meridian and the distance from the equator (assuming that the equator is the latitude of origin). Expressed differently, meridian convergence is a function of the difference in longitude, and the latitude of a point. It is therefore zero at the equator (or latitude of origin) and zero at any latitude along the central meridian. It increases with distance from the equator and with distance from the central meridian.

Meridian convergence (MC) is True North minus Grid North.

Expressed as a formula:

MC = Δ longitude (Sin. latitude), where Δ longitude is the difference in longitude from the central meridian in radians.

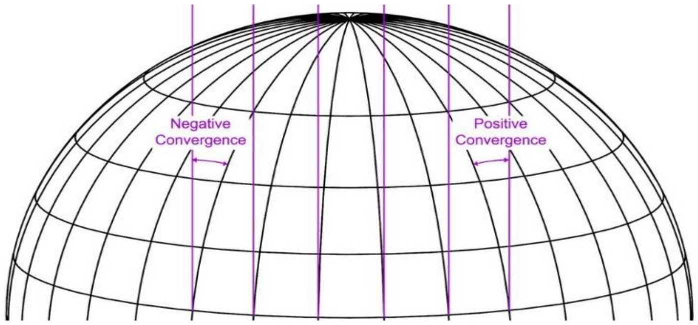

Figure 3.3 **Meridian convergence** (source: Autodesk University 2010)

3.3 Orthometric height

Orthometric height is the height of a point above the geoid. Due to the geoid being an irregular equipotential surface which best approximates mean sea level, orthometric height is regarded as height above (or below) mean sea level.

However, local adjustments to orthometric height may be required to correspond to a specific height datum, most commonly the height datum defined by a national coordinate reference system, such as mean sea level at a specific location as determined from tide gauge measurements over an extended period, typically years (where one tidal cycle or epoch is 19 years).

GPS measures ellipsoidal heights (h) referenced to the WGS 84 ellipsoid. To accurately convert ellipsoidal height to orthometric height, requires either a high resolution geoidal model to provide geoidal height (N), or the calculation of a local model based on ellipsoidal height and orthometric height differences at common points in the area being surveyed, as shown in Figure 3.4.

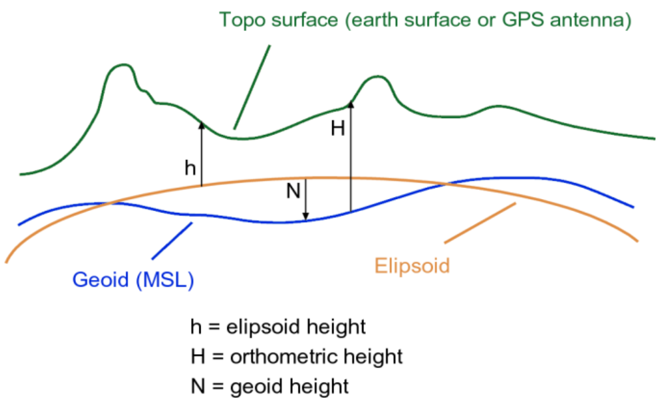

Figure 3.4 **Orthometric height** (source: Esri.com)

3.4 Projections

A projection is the mathematical system of projecting from the ellipsoid (curved surface) onto a plane (flat surface) for representation on a map. The term 'projected coordinate system' is sometimes used.

Numerous projections exist, some with specific advantages in geospatial representation. For example, to represent areas of large extent in an East/West orientation, a Conformal Conic projection may be preferred over a Transverse Mercator projection which favours a North/South orientation. The term 'conformal' means that angles and shape are well preserved, i.e. there is minimal distortion to the projection. The Transverse Mercator projection is also conformal, although it is not implied by its name.

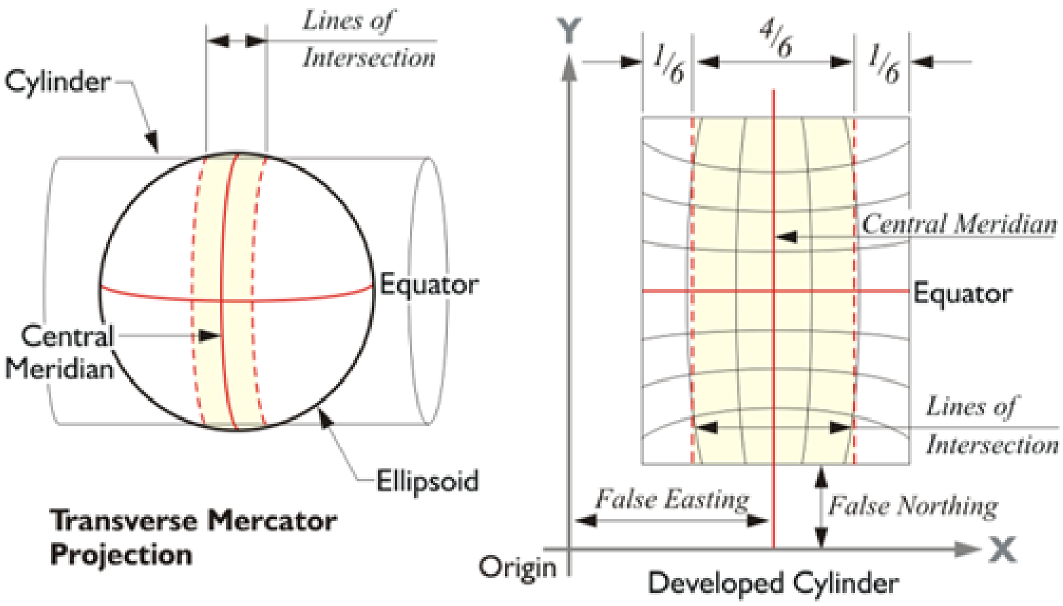

Figure 3.5 Transverse Mercator Projection (source: Pennsylvania State University)

3.5 Coordinate reference systems

"A coordinate reference system is a set of mathematical rules for specifying how coordinates are to be assigned to points that are related to the real world by a datum" (ISO 19111:2007(E)).

There are numerous terms in use that are taken to be synonymous with 'coordinate reference system', but may theoretically differ. Care should be taken to understand the components which define such systems.

Four examples follow below, to demonstrate differences as defined by national statutes or regional conventions. The Transverse Mercator projection is common to all examples, (therefore the underlying mathematical rules are common).

There are literally hundreds (national) to thousands (local) of coordinate reference systems.

3.5.1 Universal Transverse Mercator coordinate system (UTM)

The Universal Transverse Mercator coordinate system has been widely adopted internationally (Langley, 1998), due to its global coverage and relative simplicity of coordinates. As implied by its name, it uses the Transverse Mercator projection.

By using false coordinates of origin, Eastings and Northings (coordinates) are always positive, (as opposed to South Africa for example, where Y-coordinates are positive west of the central meridian and negative east of the central meridian).

It is comprised of sixty, six degrees (60, 6°) wide longitudinal belts or zones which enable 360° coverage of the Earth, between the latitudes of 80° S and 84° N, as shown in Figure 3.6.

To reduce scale error towards the edges of the 6° wide longitudinal belts or zones (the eastern and western extremities), a scale factor of 0.9996 is applied at the central meridian.

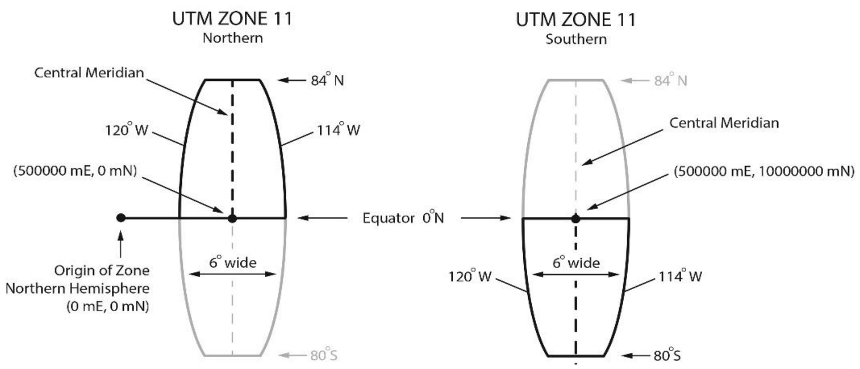

Figure 3.6 UTM coordinate system example (source: GIS4Geomorphology.com)

Table 3.1 summarises the defining components of the UTM coordinate system. Note the country/region dependent fields.

Table 3.1 The UTM coordinate system

Ellipsoid	Country/region dependent
Horizontal Datum	Country/region dependent
Height Datum	Typically mean sea level but country/region dependent
Projection	Transverse Mercator (TM)
Latitude of Origin	0° (Equator)
Longitude of Origin (central meridian)	The central meridian of each zone falls on an odd line of longitude, e.g. 3°, 9°, 15°, 21°, etc.
Zones	60 zones of 6° wide, each being an identical TM projection.
Coordinate of Origin – northern hemisphere	0m at Equator. Numerical value increases northwards
Coordinate of Origin – southern hemisphere	10 000 000m at Equator. Numerical value decreases southwards
Coordinate of Origin – central meridian	500 000m on every zone central meridian. Numerical value increases eastwards and decreases westwards
Scale at central meridian	0.9996
Unit of measure	International metre

3.5.2 South African Coordinate Reference System

The South African Coordinate Reference System is a South oriented Transverse Mercator projection, i.e. North = 180° (as used in Namibia and numerous other southern African countries), known as Gauss Conform.

The system is known as the Lo System, in reference to the longitude of origin, e.g. system Lo 17 denotes a longitude of origin of 17° E.

Y-coordinates are positive West of the central meridian and negative East of the central meridian.

Prior to 1st January 1999, the South African Coordinate Reference System was based on the modified Clarke 1880 ellipsoid and the Cape Datum, with a point of origin on the farm Buffelsfontein near Port Elizabeth.

Table 3.2 The South African coordinate reference system

Ellipsoid	WGS84 (World Geodetic System 1984)
Horizontal Datum	Hartbeesthoek94 (ITRF91 (epoch 1994.0))
Height Datum	Mean sea level (Cape Town, Port Elizabeth, East London and Durban)
Projection	Gauss Conform (south oriented Transverse Mercator)
Latitude of Origin	0° (Equator)
Longitude of Origin (central meridian)	Every odd degree of longitude (resulting in 2° wide bands, 1° E and W of each central meridian)
False origin of coordinates	None
Scale at central meridian	1
Unit of measure	International metre

3.5.3 United Kingdom Ordnance Survey National Grid (1993)

This is a Transverse Mercator projection, where false coordinates of origin are used to ensure that Eastings and Northings (coordinates) are always positive. An Easting origin of 2° W is assigned the coordinate value of 400 000m, and the Northing origin of 49° N is assigned the coordinate value of 100 000m.

Due the width of the system differing from the standard 6° width used by UTM, the scale on the central meridian differs marginally from the 0.9996 used by UTM.

Table 3.3 The Ordnance Survey national grid

Ellipsoid	Airy (1830)
Horizontal Datum	OSGB36 (1936)
Height Datum	Mean sea level (Newlyn, Cornwall)
Projection	Transverse Mercator
Latitude of Origin	49° N
Longitude of Origin (central meridian)	2° W
False origin of coordinates	400 km west, 100 km north of True Origin (2° W, 49° N)
Scale at central meridian	0.99960127
Unit of measure	International metre

3.5.4 Namibia National Control Survey System

This is a South oriented Transverse Mercator projection, i.e. North = 180° (as used in South Africa and numerous other southern African countries), also known as Gauss Conform.

Like in South Africa, the system is known as an Lo System, in reference to the longitude of origin, e.g. system Lo 17 denotes a longitude of origin of 17° E.

Y-coordinates are positive West of the central meridian and negative East of the central meridian.

Table 3.4 The Namibian national control survey system

Ellipsoid	Bessel (1841)
Horizontal Datum	Schwarzeck (22º 45' 35".820 S, 18º 40' 34".549 E)
Height Datum	Mean sea level (Luderitz)
Projection	Gauss Conform (south oriented Transverse Mercator)
Latitude of Origin	22° S
Longitude of Origin (central meridian)	Every odd degree of longitude (resulting in 2° wide bands, 1° E and W of each central meridian)
False origin of coordinates	None
Scale at central meridian	1
Unit of measure	German Legal metre (1GLm = 1.0000135965 International metre)

3.6 GPS (Global Positioning System) and how it works

The term GPS (Global Positioning System) will be used below, due to its widespread recognition, rather than the current term of GNSS – Global Navigation Satellite System. The principles of operation are the same.

Fixing position using GPS uses the basic surveying process of trilateration (triangulation by distance, not angular measurement), i.e. measuring the distance from an unknown point to a number of known points (survey beacons, or in this case, orbiting satellites).

Simply expressed, GPS satellites are moving survey beacons. Their paths and positions are constantly monitored from Earth observation stations. Satellites orbit the Earth at heights of approximately 20 000km above Earth at a relative speed of approximately 14 000km/h (or 3.9km/s). The orbital path (ephemeris) of each satellite is known to an extremely high level of precision and monitored by a global network of ground tracking stations (the control segment).

The satellites transmit signals which are picked up by a GPS receiver on the ground. The signals go through a phase synchronisation process, and by using the atomic clocks onboard the satellites, the time-of-flight (of the satellite signals) is determined. Using the time-of-flight multiplied by the speed of light, the distance from the satellite to a ground receiver is calculated. Using distance measurements from a GPS receiver to at least four satellites, the position of the receiver is calculated.

GPS receivers range from inexpensive handheld devices capable of determining position to within tens of metres, to expensive ‘geodetic grade’ receivers for high precision surveying.

3.6.1 Differential GPS measurement

Underlying the GPS measurement process are numerous complex mathematical (systematic error correction) processes to improve positional accuracy, such as modelling and correcting for:

- Ionospheric and tropospheric (atmospheric layers) impact on signals;
- Ephemeris error; and
- Signal multi-path error (signals which reflected off another surface prior to reaching the GPS receiver, resulting in a false range).

Differential positioning is a method of improving the accuracy of GPS positioning for surveying, by indirectly nullifying the above-mentioned errors (except multi-path error which can occur at the receiver). Differential positioning requires two or more GPS receivers, one of which, the base station, must be on a known point such as a survey beacon, and the other receiver(s) being used as a rover. It is assumed that the receivers are tracking the same satellites, and that error in GPS position on the known point is the same (simultaneously) as at the rover. This difference is applied as a ‘differential correction’ to the rover’s GPS coordinates.

Real time positioning, commonly referred to as real-time-kinematic (RTK), is achieved via a radio transmitted differential correction from the base station to the rover.

Static differential surveying does not require the transmission of a correction. Baseline vectors between pairs of receivers (e.g. the base station and the rover) are used to calculate the position of the rover from the known coordinates at the base station.

3.7 Significant figures

Schofield (1993) notes that "engineers and surveyors communicate a great deal of their professional information using numbers". In the case of geospatial information in a minerals/mining context, this communication of numbers is extended to several other disciplines, including geologists and environmentalists.

To systematically communicate the underlying quality of numbers, particularly geospatial coordinates or distance, the principle of significant figures should be understood and applied. For example, 2.00m implies estimation (rounding) to the nearest 10mm, whereas 2.000m implies estimation to the nearest millimetre. The former would have required measurement and calculation to at least three decimal places, and the latter to at least four decimal places. Similarly, 2, 2.0, 2.00, 2.000 imply estimation to the nearest metre, 100mm, 10mm, and 1mm, respectively.

Schofield (1993) further explains that "…the number of significant figures in a value is the number of digits one is certain of plus one, usually the last, which is estimated". Applying this practically to listing a borehole collar which was surveyed to an accuracy of say 1m, coordinates should never be communicated with decimal places at all, to signal accuracy (or relative inaccuracy). For relative accuracy exceeding 1m, appropriate rounding would need to be applied, e.g. to the nearest 5m.

Extending this to the higher end of the accuracy scale, e.g. mine construction and establishment where millimetric accuracy may be required for engineering infrastructure surveying, instrumentation, measurements and calculation methods must be appropriate for achieving and reporting such accuracy.

Correctly applying the principle of significant figures is a direct indicator of the quality of the source data underlying the number being read or used. If correctly applied, it should also prevent the propagation of error by preventing figures from various sources being erroneously combined into a common database. It is integral to the concept of fit-for-purpose and fit-for-next-purpose.

3.8 Electronic distance measurement

Angle and distance measurement is the most common method of surveying for mining, construction and general engineering projects. By extension, Total Stations are the most commonly used pieces of survey equipment, combining electronic angle and distance measurement into a single unit. Modern Total Stations (c.2015) combine image processing, laser scanning, robotic operation and direct interface to sophisticated processing software. Some models may include an integrated geodetic standard GPS receiver, or north-seeking gyro (for underground and tunnelling orientation checking).

Accuracy specifications for Total Stations are expressed in seconds of arc, mm and ppm (parts per million) of measured distance e.g. 1" (second of arc) and 1mm +1.5ppm, or 5" and 5mm +2ppm. It is therefore important that the instrument selected can deliver fit-for-purpose accuracy, as it is relatively common for instrument accuracy to not match the purpose for which it is used (potentially introducing geospatial deficiency and risk).

Like GPS, electronic distance measurement (EDM) is based on time-of-flight of an emitted signal, in this case a transmitted signal from the instrument to the object being measured and back to the instrument (i.e. double the time). Therefore, distance is determined (automatically) by using half the time-of-flight multiplied by the speed of light.

To measure correct distance, a correction for the density of the atmosphere through which the signal is passing must always be applied. This is typically done by measuring ambient temperature and atmospheric pressure, and using the refractive index for the specific wavelength of the EDM to calculate a correction in ppm (parts per million). This correction is preferably set in the instrument at time of measurement, but can be applied to distance measurement in a post-surveying process.

For high accuracy measurement, the EDM (of the Total Station) must be calibrated on multi-bay baselines, to determine Zero error (independent of distance) and Scale error (proportional to distance). Cyclic error (varies with distance) which relates to phase difference of wavelength, can be (practically) disregarded for modern EDM equipment.

There are numerous designs of reflectors used for EDM measurement, all having what is generally referred to as a “prism constant”, i.e. an offset from the centre of the reflector which can typically range from 0mm to 30mm. This also applies to flat reflective targets (e.g. stickers). Care must be taken not to mix reflectors with different constants, or prisms from different OEMs (original equipment manufacturers), to prevent this relatively common source of measurement error.

3.9 Measurement and error

According to Schofield (1993) “…all measurements, no matter how carefully executed, will contain error, and so the true value of a measurement is never known”.

Therefore, if the true value is not known, the true error cannot be known, which means that the true position of a surveyed point is known only within limits of allowable error. These limits are often prescribed by legislation or standards of practice.

Schofield (1993) continues to describe the classification of errors as follows:

3.9.1 Mistakes or blunders

Sometimes referred to as gross error, although this is a misnomer. These are errors resulting from human factors such as fatigue, inattention or inexperience, therefore great care is required to obviate their occurrence.

3.9.2 Systematic errors

Systematic errors are constant or variable and generally attributable to known circumstances. Systematic errors result from natural conditions such as atmospheric refraction, as well as bias, and can be calculated and applied as a correction to reduce error, although it is unlikely that the correction will fully eliminate error (due to variability in the causal natural conditions). Calibration of all equipment is an essential control for limiting systematic error.

3.9.3 Random errors

Random errors remain after all other sources of error have been removed. The error has a normal distribution, i.e. there is an equal probability of the error being positive or negative. Random errors can be treated by statistical processes, whereas mistakes and systematic error cannot and should not.

3.9.4 Precision and accuracy

To demonstrate the relationship between precision and accuracy, an analogy is that of target shooting.

In the targets shown in Figure 3.7, systematic error is illustrated by the low accuracy/high precision image (centre target).

By reducing the systematic error (e.g. through instrument calibration and/or calculated corrections), a precise cluster of points is shifted to the centre of the target, as illustrated by the high accuracy/high precision image (left target).

Low accuracy/low precision is illustrated by scatter of points in the right target image.

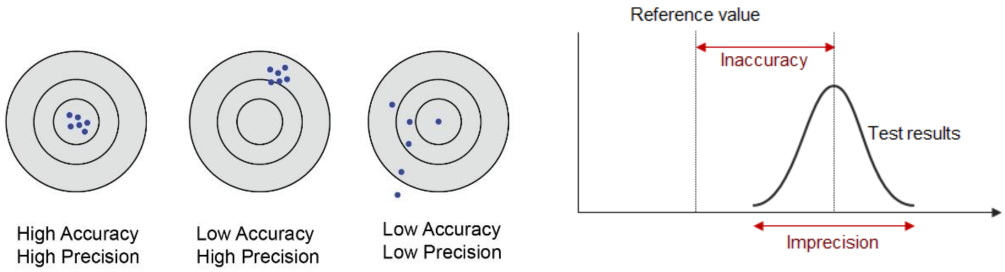

Figure 3.7 Basic concept of errors (source: Pennsylvania State University)

Schofield (1993) draws attention to a number of important facts regarding the target analogy.

- Scatter is an indicator of precision. Wide scatter about the mean (reference value) indicates low reliability (of data), or low precision.
- Precision must not be confused with accuracy. Precision is the relative grouping of points without regard to nearness to the truth, whereas accuracy denotes absolute nearness to the truth.
- Precision may only be regarded as an indicator of accuracy when all sources of error, other than random error, have been eliminated.
- Because true value of a point cannot be practically found, true error cannot be found. Accuracy should therefore be defined within a range.
- Position fixing by means of survey measurements, for point coordinates or for features on a map, is an assessment of the most probable position (statistically, the most probable value) of such point or feature.

3.10 The mining value chain

As mentioned in the introduction to this chapter, the adapted mining chain will form the structure of the central chapters of this dissertation.

Figure 3.8 shows the value chain with examples of activities associated with a core process. Each core process, namely Explore, Evaluate, Establish, Operate and Close, will be addressed in a dedicated chapter. The figure also shows the foundation of geospatial information which spans all processes.

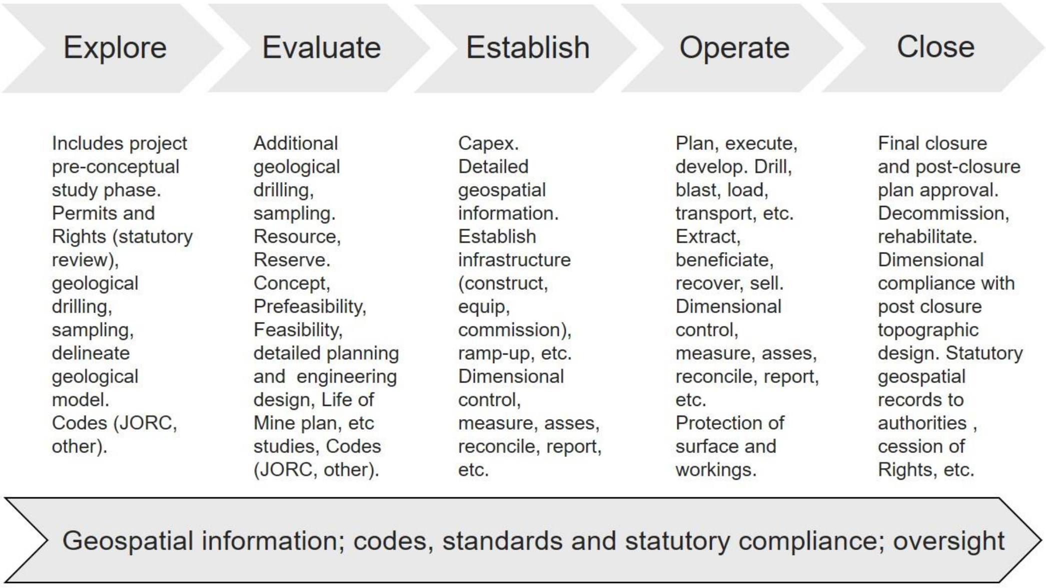

Figure 3.8 The mining value chain

In the chapters to follow, the core process will be linked to principal functions and/or disciplines that are involved at the phase of the life-cycle, to demonstrate functional and process interdependencies which can leverage the value potential of geospatial intelligence to the business of mining.

3.11 Conclusion

This chapter has provided an overview of the fundamental geospatial principles for surveying, an understanding of which is essential to providing geospatial context to guide practice and mitigate associated risk. Furthermore, useful definitions have been provided in Appendix A, to ensure a common understanding of terms used in surveying, and which are essential for understanding numerical and graphical (maps/plans) representation of geospatial information.

The description of datums, projections, coordinate systems and associated corrections which must be applied to measurements, have demonstrated the underlying complexity of the processes required for projecting geodetic measurements onto a plane surface and uniform grid for use in a coordinate reference system, i.e. the format typically encountered by users of coordinates, maps and general geospatial information.

GPS and electronic distance measurement descriptions have addressed general operational theory, drawing attention to sources of measurement error, methods to reduce error, and the practical limitations in accuracy performance of both GPS and terrestrial surveying equipment. In support of this, some theory on measurement and sources of error was provided, to describe precision, scatter and the classification or errors, and the concept of position being defined in relative terms (most probable value).

Consolidation of the information presented in the chapter demonstrated geospatial context in terms of surveying instruments, processing and accuracy which is fit-for-purpose. By extension, it also demonstrated the requirement for significant surveying knowledge, skills and competency, thus highlighting the need to define a suitably qualified person (competent person) in a geospatial context.

Finally, the mining value chain was introduced, to describe core functions to be addressed in the central chapters of this dissertation and how these will relate to different processes/disciplines along the value chain.

Chapter 4 will address the geospatial considerations during the exploration phase of a project – laying the geospatial foundation.

4. EXPLORE

4.1 Introduction

Chapter 3 documented the fundamental geospatial principles of surveying, to provide a foundational understanding, particularly for non-geospatial or non-surveying practitioners, thus providing insight into geospatial competency requirements and the underlying processing required to adequately represent position numerically (coordinates) or graphically (maps/plans).

This chapter, Chapter 4, will describe geospatial considerations during the exploration phase of a mining project in the context of laying the geospatial foundation for all work which may follow. The purpose is to describe essential geospatial considerations, to enable exploration geologists (and surveyors) to apply appropriate (fit-for-purpose and fit-for-next-purpose) surveying and geospatial systems, practice and assurance. In doing so, the chapter will provide a guideline for this stage in a mining project life-cycle. Numerous matters for improved mutual understanding across involved functions and disciplines will be discussed, to demonstrate opportunities for alignment and integration of information.

The scope of exploration activities covered in this chapter will extend to and include a pre-conceptual (or pre-scoping) study. Therefore, the exploration output is a preliminary geological model of a mineral deposit, typically with yet-to-be concluded limits of extent. In other words, this phase is prior to the estimation of a mineral resource and prior to any technical studies. It may be progressing towards public reporting of exploration results, or may be in a Competent Person's report on exploration results at this point of progress.

The focus is mainly on greenfields exploration (remote location, unknown mineral deposits – implying higher risk), however, there is significant relevance for brownfields exploration.

The Australian government House of Representatives Standing Committee on Industry and Resources (2002) describes exploration "…as a series of steps to build or confirm predictions of where minerals deposits might be, and which typically include some or all of the following stages:

- researching, collating and reinterpreting existing geological data and undertaking preliminary conceptual studies;
- acquiring an exploration title, by lodgement or bidding, and obtaining the appropriate Native Title, environmental and cultural heritage clearances;
- undertaking geological, geochemical and geophysical surveying; and
- drilling and logging cores or wells, bulk sampling and quality testing to determine the feasibility of full scale production."

This description, despite its national context, has international relevance.

International codes, standards or guidelines for reporting mineral exploration, resources and reserves refer to the need for a 'Competent Person' to consider geological context when assessing information for public reporting. This chapter will introduce the need to consider geospatial context, together with geological context, and will highlight to the Competent Person signing an exploration public report, the need to consider the material contribution of external surveying and/or geospatial experts in the exploration process. A consequence of this should be reduced risk of deficient geospatial information becoming imbedded in databases and propagated through the geological model into mineral resource and ore reserve models.

Using 'Explore' as a core value chain process, sub-processes will be identified and linked to the principal functions and/or disciplines that are involved at this phase of the life-cycle, to demonstrate cross-functional interdependencies and opportunities for synergies. Furthermore, understanding the value chain provides the opportunity to anticipate and accommodate downstream needs and improve geospatial process intelligence.

An example from the author's personal experience of the impact or potential impact of geospatial errors on geological interpretation, will be presented as a brief case study to demonstrate integrated geospatial risk, consequence and remedial action.

4.2 'Explore' as a core value chain process

An objective of using a mining value chain as a graphical representation of the business, is to enable individual functions or disciplines to view their role in the business, i.e. to go beyond a narrow task or project focus. Depending on the position of the process on the value chain, the view can be both backward (upstream) or forward (downstream). In the case of exploration, the perspective is current (current activities and processes) and downstream (future activities and processes).

Understanding current processes and accommodating downstream requirements through effective work scoping, can introduce efficiencies to a project, avoid re-work and improve overall cost effectiveness. This takes the value chain approach back to Porter's original purpose of creating competitive advantage.

This means, in practice, that all functions or disciplines involved in exploration should have a mutual understanding of their respective roles and contribution to the project. For example, exploration geologists would understand their role, the role of other disciplines or experts, and the future users or uses of the exploration data and information. Alignment of purpose would be improved, and cross-functional foresight introduced into individual activities. This understanding and foresight should guide how work is executed to comply with current and possible future requirements. Obviously, there will be a practical balance of cost, effort and return to be considered.

Figure 4.1 proposes that exploration teams should consider and understand the downstream process of Evaluate when scoping and executing work.

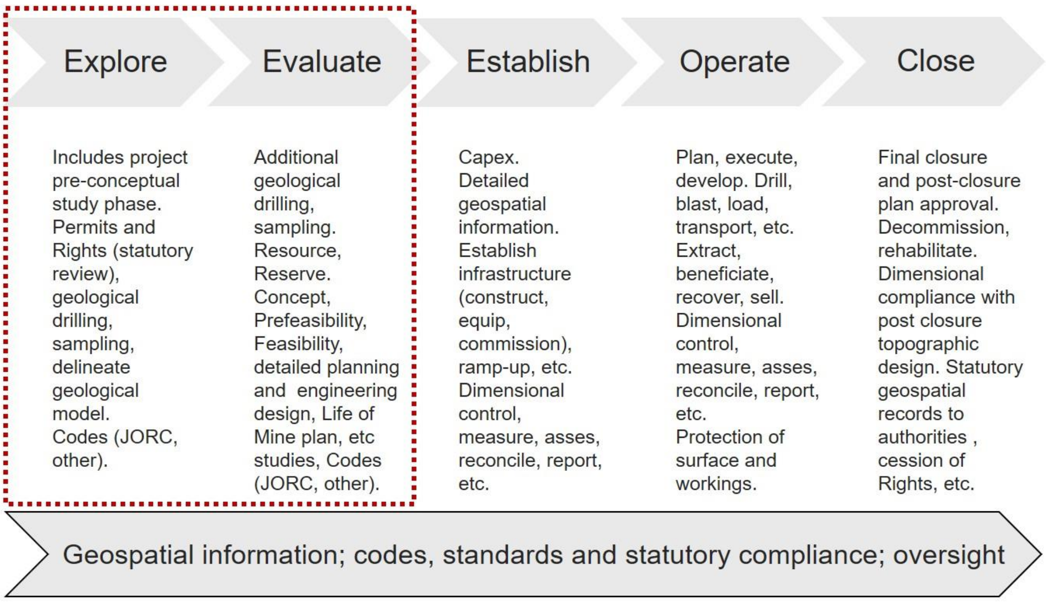

Figure 4.1 Value chain focus area (within red outline)

The functions and individual disciplines involved in Explore would typically be (but not limited to):

- Exploration geology (including geophysics, geochemistry, hydrogeology and activities such as drilling, sampling, trenching);
- Geomatics disciplines (surveying, geographic information science/cartography);
- Legal (mineral and land tenure, access, permits, conditions of tenure) and community consultations;
- Environment (environmental practice, areas of restricted access or activity, site restoration).

4.3 General geospatial considerations for mineral exploration

As stated in Chapter 1, there is a geospatial thread which runs through the minerals business, from exploration to mine closure. Coordinates define the geospatial information on which mines are established and operated. Geological, technical, economic and other attributes are attached to coordinates for multi-dimensional modelling, feeding into numerous other processes including spatial, temporal and quality reconciliation for mining operations. Therefore, while the proportional contribution of surveying and geospatial information to exploration activities is comparatively small, its importance to this and subsequent processes can be regarded as inversely proportional, hence large.

According to Eggert (2010) it may take between 500 to 1 000 grassroots exploration targets to identify 100 targets for advanced exploration, of which 10 may progress through study phases, and of which 1 will become a profitable mine.

It is therefore understandable that there are strictly defined, managed and assured processes which are followed to discover and evaluate minerals, and to establish and operate a mine (hence the existence of reporting codes, legislation, operating standards and codes of practice).

Eggert (2010) further explains that it takes between 5-15 years of exploration, permitting, evaluation, design and construction/development to establish a new mine. During this period, all money expended has been at risk and has yet to yield any return, i.e. all money spent is in the expectation of a future revenue stream and forecast profit.

Now, assuming 5-15 years lead time to mine operation, and a 30-year life of mine followed by a closure period, a project can have a full lifespan of more than 45 years, as demonstrated by numerous past and current mining operations.

Considering this potential lifespan, and that geospatial information is the foundation on which most functions develop discipline-specific information essential to the business of mining, it stands to reason that considerable attention should be paid to the planning, execution and assurance of surveying and geospatial processes from the very outset of exploration activities. This means that geospatial competency and rigour are as important as the geological competency and rigour which underpin minerals projects and investment, and demonstrates a strong cross-functional interdependency.

However, this is often not the case in practice, due to inadequate focus on surveying specifications, systems and practice, thus introducing the risk of the inclusion of materially deficient positional information into foundational spatially referenced datasets or databases. The likely cause is a lack of understanding of the fundamental geospatial principles described in the previous chapter, and an absence of appreciation of cross-functional interdependencies.

This lack of understanding should be recognised as an unintentional form of incompetence and treated accordingly. The Society for Mining, Metallurgy, and Exploration Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves, (hereafter referred to as the SME Guide), under “evaluation criteria”, includes a reporting requirement for reliance on other experts applicable to information in areas where the experience of the Competent Person is insufficient. In the context of surveying, it is reasonable to expect that a competent person (other expert) is suitably qualified and possesses the knowledge, skills and experience to plan, execute, examine, approve, report and sign off on the accuracy, quality and integrity of geospatial information for exploration.

Finally, the results of geological exploration are aggregated into a geological model ahead of potential conversion into mineral resources and ore reserves. The author contends that by considering the geological model to be a geospatial database containing geological attributes, appropriate focus on geospatial importance is achieved, without detracting from the core exploration activities and controls required for public reporting.

It is appropriate at this point to briefly discuss the relationship between geological confidence and geospatial confidence, and that geological and geospatial results contain the sum of all errors of their individual processes.

4.3.1 Geological confidence

Exploration is comprised of a series of steps or processes which are designed to estimate the extent and content of a mineral deposit. While this chapter focuses on pre-conceptual study exploration, should the project progress to the evaluation phase (of concept, pre-feasibility and feasibility studies), advanced exploration and greater density of geological information is required to progress from preliminary geological model, through to mineral resource categories and ultimately, to ore reserve (through the application of modifying factors).

Geological confidence is proportional to the amount of geological knowledge gained from additional exploration, and the quality thereof.

Figure 4.2 shows the relationship of increasing geological confidence, from exploration and through the evaluation phase described above.

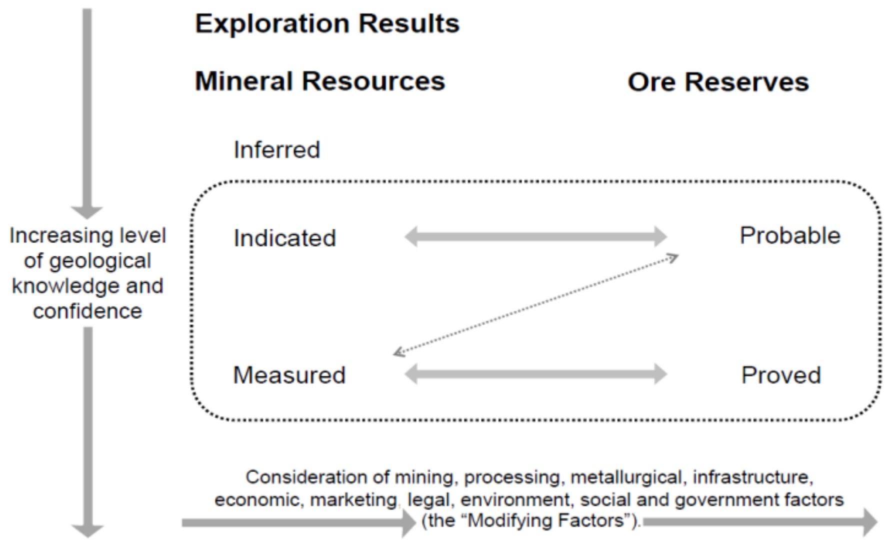

Figure 4.2 **Exploration results, mineral resources and ore reserves** (source: JORC 2012 Edition)

It is interesting to note the similarity in codes by comparing Figure 4.2, which shows the general relationship between mineral exploration, mineral resources and ore reserves described by the Australian Code for Reporting Exploration Results, Mineral Resources and Ore Reserves (JORC), with Figure 4.3 which shows the same relationship as described by the South African Code for Reporting Exploration Results, Mineral Resources and Mineral Reserves (SAMREC).

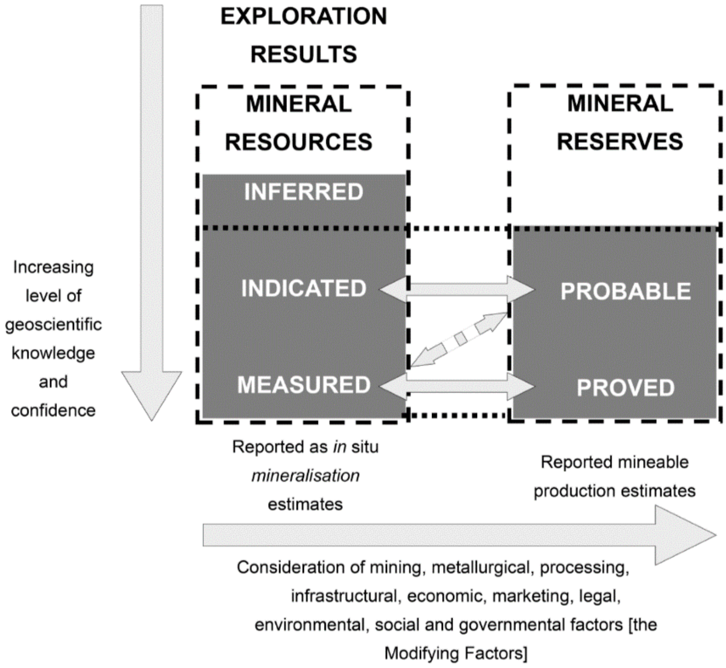

Figure 4.3 Exploration results, mineral resources and mineral reserves (after SAMREC, 2016)

Although JORC and other similar codes provide scant mention of surveying and geospatial requirements, there is a requirement for geological information to be underpinned by appropriately accurate geospatial information. Exactly what this means is not described by the codes, (thereby implying the need for appropriate competencies to guide practice and assurance processes).

4.3.2 Geospatial confidence

Geological confidence increases with the amount of geological knowledge acquired through early and advanced exploration. It is based on the statistical principle that an appropriately large sample population should provide a better estimate, i.e. data density is suited to the required quality of estimate.

Practically, geospatial confidence cannot be increased in the same way as geological confidence. As stated in Chapter 3, point coordinates are the most probable value (of position) once all errors other than random errors have been eliminated from measurement data. Therefore, measurement methods need to provide consistent positional accuracy, within an appropriate range, without further (later) measurements being required.

By extension, geospatial confidence cannot be improved unless resurveyed to a greater precision and accuracy. A resurvey would require that geological drill holes, sample points and trenches which were used to develop the geological model, be preserved, revisited and re-measured.

In the case of downhole surveys this would require that geological drill holes have not collapsed or become obstructed, and that the survey tool can be re-inserted for the full length of each hole for a re-survey. Realistically, this is unlikely and introduces risk associated with this uncertainty.

Unless the original survey can be replicated, for example by referencing the resurvey to the original survey, geospatial integrity cannot be re-assessed. Confirmation would require the use of permanent survey beacons (monuments) which were established and used in the original surveys, or, in the case of GPS, a full record of all settings, measurements and processing to enable the original survey to be reconstructed.

This is of pivotal importance and requires consistent, systematic and standardised survey practice from the outset and throughout exploration.

4.3.3 The sum of all errors

The core process of exploration has numerous associated activities or sub-processes, such as:

- Drilling;
- Drill sample recovery;
- Logging (of core and chip samples);
- Sub-sampling;

- Assaying (to determine mineral content and quality); and
- Density testing.

The results from each of these activities will contain error. Systems and controls are required to ensure that the error falls within an acceptable specified range. The errors, at this point, are independent of geospatial error. All data from the above-mentioned activities will be referenced to coordinates for modelling purposes, thereby becoming geological attributes in a geospatial database.

Downhole surveying of geological drill holes is subject to internal errors that are fully contained within this specific activity, and which have a separate set of controls to achieve geospatial accuracy (within the drill hole) within a specified range. The results of downhole surveys are, at this point, independent of external geospatial error, until attached to 3-dimensional point coordinates which define each drill hole collar position.

For surveying the same principle applies, i.e. that the accuracy of any numerical (coordinates) or graphical (map/plan) geospatial information contains the sum of all inaccuracies and errors accumulated up to that point (including the inherent error of the survey control network, be this a national system or a local survey grid). These inaccuracies and errors are wholly independent of the inaccuracies and errors contained in the above-mentioned geological data.

It is therefore extremely important to appreciate that any geological attribute which is attached to point coordinates carries the sum of errors of the processes for that activity, as well as the sum of errors of the surveying processes required to determine the point coordinates (position).

4.4 Requirements for reporting of exploration results

International codes, standards or guidelines for reporting mineral exploration, resources and reserves are comprehensive in identifying activities requiring assurance processes to enable the Competent Person to sign-off and defend a public report (often referred to as the Competent Person's Report).

JORC will be referred to by default, as it is the original code on which other codes, standards, guidelines or instruments are based (as described in Chapter 2). Where appropriate, other codes, may be referred to for comparative or illustrative purposes.

JORC (2012), Table 1, Checklist of Assessment and Reporting Criteria, provides the following examples (extracted from the checklist) of criteria to be assessed and reported, which relate specifically to reporting of exploration results. Each criterion is accompanied by a concise explanation of what must be considered.

Table 4.1 shows combined extracts from JORC Table 1, sections 1 and 2 which address sampling techniques and data, and reporting of exploration results, respectively. Other included criteria and explanations have indirect geospatial relevance.

Table 4.1 **Extracts from JORC Table 1** (source: JORC 2012)

Criteria	**Explanation**
Section 1 – sampling techniques and data	
Location of data points	• Accuracy and quality of surveys used to locate drill holes (collar and down-hole surveys), trenches, mine workings and other locations used in Mineral Resource estimation. • Specification of the grid system used. • Quality and adequacy of topographic control.
Audits or reviews	• The results of any audits or reviews of sampling techniques and data.
Section 2 – reporting of exploration results	
Mineral tenement and land tenure status	• Type, reference name/number, location and ownership including agreements or material issues with third parties such as joint ventures, partnerships, overriding royalties, native title interests, historical sites, wilderness or national park and environmental settings. • The security of the tenure held at the time of reporting along with any known impediments to obtaining a licence to operate in the area.
Exploration done by other parties	• Acknowledgment and appraisal of exploration by other parties.
Geology	• Deposit type, geological setting and style of mineralisation.
Drill hole Information	• A summary of all information material to the understanding of the exploration results including a tabulation of the following information for all Material drill holes: o easting and northing of the drill hole collar o elevation or RL (Reduced Level – elevation above sea level in metres) of the drill hole collar o dip and azimuth of the hole o down-hole length and interception depth o hole length. • If the exclusion of this information is justified on the basis that the information is not Material and this exclusion does not detract from the understanding of the report, the Competent Person should clearly explain why this is the case.
Diagrams	• Appropriate maps and sections (with scales) and tabulations of intercepts should be included for any significant discovery being reported These should include, but not be limited to a plan view of drill hole collar locations and appropriate sectional views.

From the table, the following geospatial information must be reported (listed in logical sequence, not in tabulated order):

- Quality and adequacy of topographic control;
- Specification of the grid system used;
- Cartesian coordinates (easting and northing) of drill hole collars;
- Elevations above sea level (not above a nominal height datum); and
- Accuracy and quality of surveys used to locate drill holes (collar and down-hole surveys), trenches, mine workings and other (sample) locations.

All other criteria from the table have geospatial relevance, namely:

- Audits and reviews (as applicable to geospatial assurance);
- Mineral tenement and land tenure are described by numerical (coordinate) and other data in respective cadastral registers, together with statutory conditions attached to the associated mineral and land rights;
- Exploration done by other parties will (most likely) contain geospatially referenced data, therefore requiring assessment;
- Deposit type, geological setting and style of mineralisation (geological context) should influence geospatial considerations;
- Maps, sections and diagrams should comply with surveying and mapping standards of accuracy (unless solely for illustrative purposes).

4.5 Geospatial context

The SME Guide (2014), refers to the requirement to represent geological context clearly in maps and diagrams for reporting purposes, i.e. to illustrate the geological setting and how this relates, for example, to local geology and topography.

Geospatial context should be informed by detailed geological context, to enable practice to be adapted to best support the geological characteristics of the deposit (such as mineral type, deposit type, structural indicators, faults and intrusions). Survey specifications should be aligned with the expected and known geological characteristics of a deposit (albeit that these are in the process of being explored) to ensure that the method of survey and accuracy are fit-for-purpose. This alignment of knowledge should guide all geospatial specifications and practice, to provide appropriate confidence for the Competent Person’s Report.

Similarly, other deposit characteristics influence geospatial context, in terms of the data research, areal extent, accuracy and rigour of surveying and geospatial practice, for example:

- Deposit type – Massive (copper porphyry), tabular (coal), narrow tabular (gold, platinum), kimberlite pipe, dyke or sill (diamonds), other;
- Deposit outcropping;
- Deposit dip (horizontal, shallow inclined, steeply inclined?) and/or rolling;
- Deposit depth below surface (potential for drill hole deviation and greater overall positional error);
- Presence of associated gravitational variance (local geoidal variance impact on orthometric height);
- Presence of associated magnetic variance (local impact on magnetic down-hole survey tools);
- Geological structure complexities and discontinuities (faults, dykes, discontinuities, rolling, folding).

Non-geological conditions which influence geospatial context, in terms of the data research, areal extent, accuracy and rigour of surveying and geospatial practice, are for example:

- Areas of restricted activity within and adjacent to the exploration area;
- Potential for, and proximity to, mine workings (current and abandoned) and other voids (man-made or naturally occurring);
- Local, regional or national survey geospatial infrastructure providing for availability, quality and regulation of surveying and geospatial information, including availability of an adequate survey control network and topographical maps; and
- Systematic correction of borehole data when boreholes are drilled at oblique angles through the ore body

4.6 Mineral rights and land rights legislative frameworks

In its checklist of assessment and reporting criteria, JORC (2012) explains the following requirements for mineral tenement and land tenure status:

- Type, reference name/number, location and ownership including agreements or material issues with third parties such as joint ventures, partnerships, overriding royalties, native title interests, historical sites, wilderness or national park and environmental settings.

- The security of the tenure held at the time of reporting along with any known impediments to obtaining a licence to operate in the area.

JORC and other codes are silent on the requirements related to reporting of the geospatial integrity and compatibility of mineral and land rights systems. This is a significant omission that requires inclusion, in some form, in the codes. Risk associated with system incompatibility requires appropriate mitigation and assurance.

It is important to understand that mineral rights and land rights systems can:

- Be independent of one other;
- Be subjects of separate legislation and separate registration processes;
- Fall under the authority of different government departments in the country of operation;
- Contain inherent legacy characteristics in describing the title/right, which may introduce discrepancies between the mineral and land boundary definitions or coordinates.

Where mineral rights are separated from land rights, in other words where the owner of the land does not own the right to minerals on or below such land, there is a potential for boundary disputes caused by independently defined boundary coordinates for minerals and for land, and adjacent owners of minerals and land.

For example, in South Africa, prospecting and mining rights fall under the authority of the Minister of Mineral Resources and are subject to the Mineral and Petroleum Resources Development Act (Act 28 of 2002, as amended) and Regulations, and the Mining Titles Registration Act (Act 19 of 1967, as amended). Mineral rights are registered with the Mineral and Petroleum Titles Registration Office.

By comparison, surface (land) rights fall under the authority of the Minister of Rural Development and Land Reform and are subject to the Land Survey Act (Act 8 of 1997) and Regulations. Numerous other acts may apply, depending on specific circumstances. Title deeds (to the surface right) are registered with the Deeds Office under the Deeds Registries Act, 1937 (Act 47 of 1937).

These legislative instruments are independent but necessarily cross-reference sections of legislation in the above-mentioned acts, or definitions that are mutually applicable to one or more acts. The surveying and geospatial requirements of each are intended to be the same, but are not. The author contends that the geospatial requirements of the Mineral and Petroleum Resources Development Act (MPRDA) have deficiencies or ambiguities regarding boundary coordinate definition when compared with the Land Survey Act.

For example, Form B, Annexure I of the MPRDA Regulations, "Application For Prospecting Right" is designed to accommodate digital entry in a Geographic Information System (GIS). The wording for the land or area over which the right will be registered is such that coordinates of corner points of the area or an SG diagram (defining the surface right, in accordance with the Land Survey Act) are acceptable. Form B provides the following requirement descriptor, "co-ordinates of the corner points of the area/s in degrees, minutes and seconds or decimal degrees or LoX and LoY" (meaning latitude and longitude or Gauss Conform coordinates in the national coordinate reference system). Reference is also made to "Spheroid and Datum" for further clarity. Units of measure are either degree, minutes and seconds, decimals of a degree and international metres. These options have the potential to introduce unintentional and material boundary discrepancies between mineral and land rights (one second of arc is approximately 31m – five decimal places of a second would be required for centimetre resolution). The coordinate entry format applies to all other rights and permits described by the MPRDA.

The system can be classified as a numeric system, as it cannot accommodate descriptive data, nor does it make any reference to accuracy or error. It is therefore inconsistent with the Land Survey Act.

By contrast, the Land Survey Act requires surface rights to be based on a diagram which is submitted to and certified by the office of the Surveyor General, and registered with the Deeds Office. The act defines a diagram as "a document containing geometrical, numerical and verbal representations of a piece of land, line, feature or area forming the basis for registration of a real right…". For example, a boundary feature may be a river or stream and the verbal description of the feature may be "centre line of river". Furthermore, depending on how long ago the land was surveyed and diagram lodged, the coordinates may be in a local coordinate system (legacy of old practice) using units of measure which are no longer in use. The diagram remains valid and does not necessarily require resurvey, as the geometric and descriptive representation support the numerical data (coordinates).

Therefore, unless a mineral right (in this case a prospecting right) falls wholly on an existing surface right as described in a SG diagram, and uses the SG diagram data to register the mineral right, it is extremely unlikely that the mineral and surface right boundaries will be coincident. Consequently, it is prudent for mineral right coordinates to be directly referenced to surface right diagrams, to enable potential boundary disputes to be resolved under the Land Survey Act.

The above example illustrates the geospatial competency required to assess the integrity and compatibility of mineral and surface rights – an activity which is significantly deeper than a legal review of conditions attached to mineral and land tenure. It is unlikely that a person outside of the survey profession would be able to undertake such work and demonstrates the interdependency of the legal and surveying professions when assessing “mineral tenement and land tenure status”, as required by JORC and other codes.

4.7 Exploration done by other parties

Leading from the discussion of mineral and land rights, exploration done by other parties will require similar rigorous geospatial assessment. This will need to include the assessment of any associated mineral and surface rights, and the legal and technical aspects of legislation under which the rights were registered. Additionally, a full technical assessment would be required for the:

- Quality and adequacy of topographic control;
- Coordinate reference system or systems if more than one (e.g. coordinate and grid systems, height datum and units of measure);
- Accuracy and quality of surveys used to locate drill holes (collar and down-hole surveys), trenches, mine workings and other (sample) locations;
- Any other geospatial aspects which may be of material relevance, including legislation, technology used at the time by other parties and associated records;
- Location and assessment of records not provided by other parties, which may be of material relevance.

Depending on the outcome of this assessment, and the number of parties involved in prior exploration, geospatial information may need to be ring-fenced into distinct datasets with clear descriptions of any limitations, inconsistencies or deficiencies which may have been identified. Additional work may be required to verify or improve confidence.

4.8 Survey records and environmental considerations

Ideally, an accurate network of survey beacons (monuments) should be constructed and surveyed prior to the commencement of exploration drilling and sampling activities, to enable consistent quality and adequacy of survey control. This would address the requirements of JORC and other codes, and if planned and executed to the correct specifications, should be capable of being maintained through possible future study phases of the project and mining operations. The relevance is therefore strategic in that it will ensure geospatial consistency well beyond the 5-15 years of exploration, permitting, evaluation and mine establishment described by Eggert (2010).

However, environmental restrictions and physical conditions may impose limits on exploration activity and associated surveying practice.

Physical environmental conditions may prevent the construction of permanent survey reference beacons, due to a lack of stable natural platforms (such as rock outcrops) on which to locate the beacons (this is not uncommon in bog or 'dune sea' areas). Special construction may be required, but may be prohibited by environmental restrictions associated with site restoration (a 'leave no footprint' approach).

The same environmental conditions and restrictions may apply to drill holes and sample positions. It may be physically impossible to preserve drill holes or sample points for future reference.

In such cases it is essential to be able to reconstruct the surveying which established the geospatial foundation for exploration results, for assurance purposes and for possible future exploration. Without providing a detailed description of the exact records to be kept, it is sufficient to advise that every applicable geospatial element described in chapters 3 and 4 must be recorded. Every record of measurements, including where appropriate, instrument settings (particularly for GPS), and every manual or electronic record file. At all times, there must be sufficient data available on record, to enable a relocation and reconstruction of the exploration surveys up to that point in time.

To achieve this this will require a systematic approach to all surveying undertaken on the project. The objective must be the creation of a permanent record. A full description of the system and a detailed report of all material aspects of geospatial information associated with exploration, and its application in the geological model should be compiled and signed off by a suitably qualified and competent person.

While these measures are essential to sites where the above-described environmental conditions and restrictions exist, the capture, preservation and reporting of survey measurements and processing should be standard practice. The records should be sufficient to reconstruct all material aspects for geospatial assurance. The above-mentioned report should be of sufficient detail to adequately inform the Competent Person's report required by JORC or other applicable code.

4.9 Case study

The following case study is summarised from the author's personal experience and one of several excluded examples of geospatial assurance and remediation. The case study has been selected due to the pivotal role played in supporting exploration activities and JORC compliance. The source and extent of the problems encountered, and remedial action taken are described.

It must be noted that the risk of geospatial error during exploration is higher than for an operating mine, i.e. the likelihood of material errors occurring diminish as a project advances. This is typically due the ongoing establishment of systems and controls directly linked to the accuracy of detail required by concept, pre-feasibility and feasibility studies. However, as previously mentioned, these systems and controls should be established at the outset of exploration, to ensure quality, adequacy and consistency of geospatial information throughout the project life-cycle.

4.9.1 Overview

Location: Colombia, South America

Mineral: Coal

Period: 1998 to 2000 (2 years)

Business context: The acquisition and consolidation of a number of adjacent active mining properties into a single entity.

Geological context: The deposit is comprised of multiple coal seams (>30) dipping at approximately 26° from the horizontal. The consolidation of current and historical geological records into a single contiguous geological model was required. Additional exploration was required to improve geological confidence for JORC compliance for mineral resource and ore reserve classification.

Geospatial context: Numerous significant variances were encountered by geologists when attempting to consolidate geospatial information from different sources, i.e. data inconsistency. No local insight or explanation of the inconsistencies was available. Appropriate survey expertise was not locally available to advise, resulting in a request for external assessment and assurance.

4.9.2 Description of surveying intervention and remediation

A geospatial review commenced with research into the national coordinate reference system. Little information existed, particularly in English (Colombia is a Spanish speaking country). Regional surveying control was scant and of low accuracy, having been originally established for medium scale mapping, and was found to be the primary cause of the numerous geospatial inconsistencies encountered in data from adjacent mining properties.

The coordinate system used a Transverse Mercator projection with its origin being the Astronomical Observatory in Bogota. False coordinates of origin were applied to both Eastings and Northings. Precise levelling benchmarks were available along the main arterial road but would require approximately 200km of levelling to transfer consistent height control to the project.

Reprocessing of original geological data (from drill hole log records) available from the mining properties identified positional inconsistencies (up to 12m) and a lack of continuity of geological structure which could not be attributed to known geological faulting in the area. A decision was made to map the surface of the consolidated property using aerial photography to produce large scale topographical mapping as a reference surface, to an accuracy which would support exploration, existing and future mining operations (1:1 000 mapping, 1m contour interval, ≤ 0.25m accuracy).

A single point of planimetric origin was adopted as the project benchmark (a government trigonometric beacon). All other beacons and survey stations were excluded, to ensure that the inaccuracies contained in the national and local coordinate systems could not influence the aerial survey, and current and future survey control.

A single point of height origin was transferred from a precise levelling benchmark on the main arterial road. Further levelling transferred orthometric heights across the project area, for use in GPS and normal terrestrial surveying. The levelling also proved, quantified and nullified significant inclined geoidal separation, a source of variable orthometric height error for precise GPS surveying, the cause of which was a local gravity anomaly caused by the close proximity of a mountain 5 700m above sea level (and approximately 5 600m above the project area), as shown in Figure 4.4.

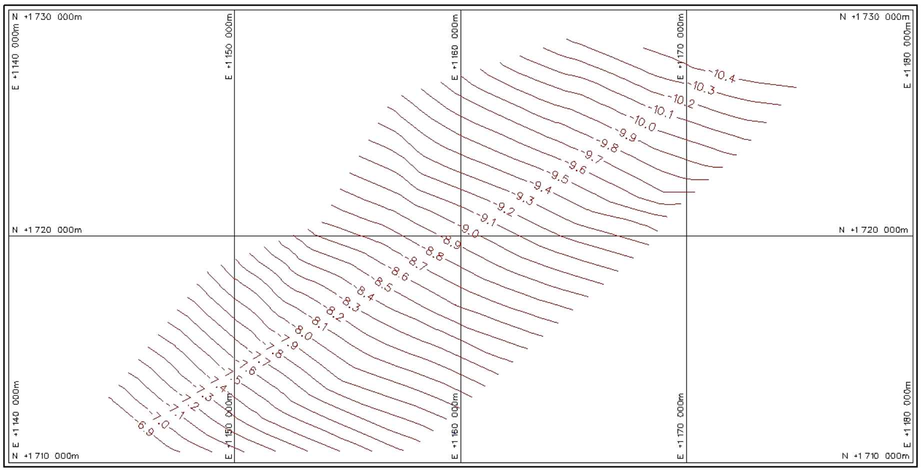

Figure 4.4 Inclined geoidal separation across site (source: Author's collection)

Appendix B shows the quasi-geoidal model for Colombia, as published in 2004 (i.e. after the above-described control survey), showing the localised geoidal tilt caused by the mountain in close proximity to the mine site.

The geospatial assurance processes introduced to the project ensured that a major survey blunder was prevented, the extent of which affected approximately 90% of the new surveying network established by local contractors (professional surveyors). This was achieved by the deliberate introduction of redundancy (surplus measurements) into the new GPS survey and linking this to the new orthometric heights from the above-mentioned levelling. This intervention prevented significant delay to the geological data and exploration consolidation, by avoiding remedial action which would have been required later in the project.

Old exploration drill hole sites (bush clearings) were identified on the aerial photographs. The centre of each clearing was photogrammetrically surveyed to provide new drill hole collar positions and heights for remodelling of geology from old records. Site specific mathematical transformation parameters were calculated, to enable geologists to reliably convert all other old drill hole and sample coordinates to the new survey control system.

An extensive programme of additional exploration was completed over a two-year period, merging old and new drilling results into a contiguous geological model – with the new surveying control network providing the geospatial data consistency and accuracy required for JORC reporting compliance. The quality and adequacy of new topographic control was suitable for geological exploration and modelling, and mining operations.

4.10 Conclusion

This chapter was the first of the central chapters which follow the structure of the mining value chain, describing the geospatial considerations during the exploration phase of a mining project for laying the geospatial foundation for all work which may follow. Its purpose is to guide practice.

The discussion of cross-functional or cross-disciplinary interdependencies, while focusing primarily on surveying and geology activities in exploration, included legal and environmental functions. Cross-functional awareness and mutual understanding of the objectives of the overall exploration process, enables an integrated approach for understanding and mitigating geospatial risk in the exploration and evaluation phases of a mining project. This was reinforced by proposing that geological context should inform geospatial context, to align survey methods and practice with the physical characteristics of the mineral deposit.

Geological confidence, and how this increases with increased geological knowledge was compared to geospatial confidence which cannot be increased in the same way. The purpose of this comparison was to highlight the need to ensure that surveying systems and activities are designed and executed to provide results which ensure fit-for-purpose quality and adequacy of geospatial information without the requirement for re-work and the associated risk of this not being adequately achieved. To ensure appropriate focus on geospatial importance, it was contended that the geological model should be regarded to be a geospatial database containing geological attributes – a significant departure from the norm in industry.

To provide additional context to the content of the chapter, information was aligned with requirements for the reporting of exploration results and how geospatial practice and reporting supports the Competent Person's report. Due to JORC and other codes providing very little detail of geospatial requirements, extracts from the JORC code's criteria for exploration activities were presented and the objectives of specific activities discussed in the context of cross-functional alignment and code compliance – again with reference to geospatial risk in the broader context of reporting requirements. This included mineral and land tenure, exploration done by other parties, environmental conditions and restrictions and the need to keep comprehensive surveying records for assurance purposes.

Finally, a case study was presented, from the author's personal experience, detailing survey intervention and remediation over a two-year period for exploration and mining geology, the outcome of which was a contiguous geological model, mineral resource and ore reserve following the consolidation of a number of adjacent properties.

Chapter 5 will discuss geospatial requirements during project study phases (concept, pre-feasibility and feasibility), in which mineral resources and ore reserves are estimated and reported, inclusive of detailed design and scoping prior to mine establishment.

5. EVALUATE

5.1 Introduction

Chapter 4 documented the geospatial considerations during the exploration phase of a mining project for laying the geospatial foundation for all work which may follow. The scope extended to and included a pre-conceptual (or pre-scoping) study, with exploration output being a preliminary geological model of a mineral deposit. The differences and link between geological confidence and geospatial confidence were described. Consistent reference was made to the requirements of, and compliance with, codes for reporting of exploration results.

This chapter, Chapter 5, will discuss the evaluation or technical studies phase of a mining project, in which Concept, Pre-feasibility and Feasibility studies are concluded (assuming the project progresses through all these stages). The purpose of the chapter is to discuss increasing geospatial accuracy requirements during the studies phase and development of a geospatial strategy and implementation plan to be applied from feasibility study, onwards. A further purpose is to assess the significant increase in process complexity on geospatial information and the contribution of surveying practice to project performance. Geospatial considerations throughout the evaluation phase will be discussed.

During this evaluation phase, the acquisition of increasing geological knowledge is used to improve geological confidence, to enable mineral resource classification in the appropriate category of confidence. The application of techno-economic modifying factors and the consideration of legal, environmental, social and government factors, converts the mineral resource into an ore reserve, once again, into an appropriate category of confidence.

As proposed, in Chapter 4, if the geological model is considered as a geospatial database containing geological attributes, the additional attributes or modifying factors required to achieve appropriate resource and/or reserve classification are an extension of such database. This geospatial foundation therefore remains the basis upon which project knowledge is built, requiring that geospatial confidence is aligned with project requirements. It is appropriate to repeat that deficient geospatial information can have financial, reputational and safety consequences. Geospatial errors, if widespread or of significant magnitude, can be incorrectly interpreted as geological structure with consequent impact on mine design, equipment selection and extraction strategy.

Poos (2003), in discussing the importance of topographic data, explains that topographic deficiencies often begin as simple issues in early exploration, such as acquiring a map which is not sufficiently accurate for the development of a mining project. Due to cost constraints, adequate topographical mapping is not acquired, and the deficient mapping continues to be used into the feasibility study. Poos comments that the impact of topographic data on stripping ratios (surface mining) can be significant, and that feasibility study earthmoving cost estimates for construction can experience significant cost over-runs due to problems with topographic accuracy. Furthermore, topographic error "can affect the length of a shaft or adit required to access the ore body", or result in the underestimation of rock stresses, resulting "in higher ground control costs, or even mine closure".

Evaluation, as a core process, is also the phase during which several functions and disciplines are required to provide critical input into determining the feasibility of a project. Consequently, cross-functional interdependencies are significantly escalated. Identifying and leveraging interdependencies which have geospatial context can reduce geospatial risk and potentially increase project performance through pro-active remediation or management.

Leading from this, the requirement for the concurrent development of integrated geospatial strategy to be concluded by the end of the pre-feasibility stage will be introduced. The strategy will address cross-functional geospatial requirements to guide the development of a detailed execution plan. For this plan to be effective, it must have been subjected to the same rigour as, for example, mine planning or engineering design. It further requires adequate budget, resources and systems for implementation. The strategic objective is for geospatial information and practice to be leveraged during and from the evaluation phase, in support of business performance. This is a significant departure from current practice and will demonstrate the economic potential of applying geospatial intelligence to core processes.

Geospatial context will be aligned with the reporting requirements for mineral resources and reserves. As done in the previous chapter, reference will be made to the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (hereafter to referred to as JORC) and other relevant codes, as and where required.

5.2 Overview of the evaluation phase

It is appropriate to briefly describe each study category, to ensure a common understanding for this chapter – detailed definitions can be found in JORC or other relevant codes. Each of the study categories represents an increase in knowledge, confidence and associated financial, technical and other relevant input. Successful passage through the studies will result in project implementation/mine establishment.

References are made to the Society for Mining, Metallurgy, and Exploration, Inc. 2014 Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves (hereafter referred to as the SME Guide).

- A Concept (conceptual or scoping) study typically requires the development of a mineral resource estimate and is used to assess the development potential of the resource, based on preliminary estimates and historical/benchmark data.
  - Capital cost estimate accuracy ±50% (SME Guide, 2014)
  - Operating cost estimate accuracy ±35% (SME Guide, 2014)
- A Pre-feasibility study requires improved confidence and the application of modifying factors for mineral reserve classification. Typically, several development options (for a mine) will be proposed and assessed, from which a single development option will be selected for progression to Feasibility study.
  - Capital cost estimate accuracy ±25% (SME Guide, 2014)
  - Operating cost estimate accuracy ±35% (SME Guide, 2014)
- A Feasibility study requires the detailed scoping of the single option selected in the pre-feasibility. Detailed geology, geotechnical, metallurgical, mine planning, engineering design and budgeting (which is typically zero-based), at levels higher than those used in the Pre-feasibility study, are applied.
  - Capital cost estimate accuracy ±15% (SME Guide, 2014)
  - Operating cost estimate accuracy ±35% (SME Guide, 2014)
  - Sometimes referred to as a Bankable feasibility study, due to the quality and standard being acceptable for submission to bankers to raise finance (McCarthy, 2016)

By contrast, Eggert (2010), provides the following tables to describe (in summary) activities associated with the development of a mineral project. Eggert's phases of Advanced Exploration and Deposit Development span the activities of 'Evaluate' (concept, pre-feasibility and feasibility studies) and are tabled below. It must be noted that Eggert's inclusion of a scoping study and resources estimates as possible outcomes of advanced exploration, is not in accordance with JORC or other codes' descriptions, but does signal the ongoing acquisition of geological information required for classification of mineral resources. The tables represent a "risk and reward" perspective for mining investment and consequently do not address, in any depth, technical processes. While these tables do not fully align with the above-mentioned brief descriptions of concept, pre-feasibility and feasibility studies, the similarity is clear and the tables useful.

In Table 5.1, Eggert describes the phases of development at which a company could enter the "supply chain", i.e. the point at which investment in a project could be made. Eggert proposes that a company may choose to acquire a mineral asset at any point in the life-cycle and therefore is not required to have exploration capacity and capability, nor does a company need to be subjected to the typical lead time of 5-15 years.

Table 5.1 Where to enter the supply chain (source: Eggert, 2010)

	Grassroots Exploration	Advanced Exploration	Deposit Development	Operating Mine
Lead time until mining	Longer → Shorter (5-15 years of continuous activity from start of grassroots exploration)			
Geologic risks	Higher → Lower			
Land area	Larger → Smaller			
Costs and economic risks	Lower → Higher			
Profit potential	Higher → Lower			
Political risks	Lower → Higher (bargaining power switches to government once mining begins; exploration is 'footloose'			

In Table 5.2 Eggert describes the Advanced Exploration phase, with possible outcomes being a "Scoping study" (conceptual) and "Preliminary feasibility" study (pre-feasibility).

This is post-grassroots exploration which would fall into the activities described in Chapter 4, Explore.

Table 5.2 **Advanced Exploration** (source: Eggert, 2010)

Activities	Detailed target evaluation (geology, geochemistry, geophysics), drilling, trenching, deposit delineation, preliminary metallurgy, collection of environmental and social baseline data, community engagement
Typical expenditures	Up to 100s (million US$) – (2010)
Possible outcomes or studies	- Scoping study: resources estimates, order of magnitude cost estimates, general idea of what a mine might look like - Preliminary feasibility study: more detailed than scoping study and including revised resources estimates, preliminary mine design and engineering, and preliminary cost estimates

In Table 5.3, Eggert describes the "Deposit Development" phase with possible outcomes or studies being the application for required permits and approvals, a feasibility study and a "go/no go decision". The author believes that Eggert's reference to permits and approvals at this late stage requires clarification or further consideration.

Table 5.3 **Deposit Development** (source: Eggert, 2010)

Activities	Detailed drilling, mine planning, metallurgical testing, continued environmental assessment, continued community engagement
Typical expenditures	Varies, can be >US$1 billion – (2010)
Possible outcomes or studies	- Applications for required permits and approvals - Feasibility study: reserve estimates, mine and plant design, detailed engineering and cost estimates, full technical and economic assessment, financing - "Go/no go" decision on mine development

The geospatial considerations for supporting the increasing knowledge, confidence and techno-economic detail required during the project evaluation phase will be described later in this chapter.

5.3 ‘Evaluate’ as a core value chain process

Continuing with the value chain theme, using a mining value chain as a graphical representation of the business enables individual functions or disciplines to view their role in the business, going beyond a narrow task or project focus.

The value chain provides a view both upstream and downstream of the current core-process. In the case of Evaluate, this means that the upstream core process is Explore, and the immediate downstream core process is Establish. Looking further ahead, as will be done during the evaluation phase are Operate and Close, both of which will be considered in detail by the conclusion of the evaluation phase of the project, as part of the feasibility study.

This phase in the project life-cycle is the first in which several technical functions and disciplines become involved, thereby significantly increasing the complexity of work being done. The information and work interdependencies between disciplines and functions are similarly increased. Information provided by one sub-process may form the basis of one or more other sub-processes. An example of this would be the geological model being upgraded to an applicable mineral resource category and then used as the basis for techno-economic assumptions, design and planning for conversion into an ore reserve. The foundation of all this information remains geospatial, which should be at an appropriate level of accuracy and confidence.

The objective of using the value chain as a common reference is that all functions or disciplines involved in the evaluation/technical studies phase have a mutual understanding of their respective roles and contribution to the project, thereby enabling alignment of purpose.

Figure 5.1 below shows the core-process of Evaluate and its adjacent core-processes. Typical activities are listed below the core-process, to provide an indication of work required and the involvement of numerous functions, disciplines and other fields of expertise.

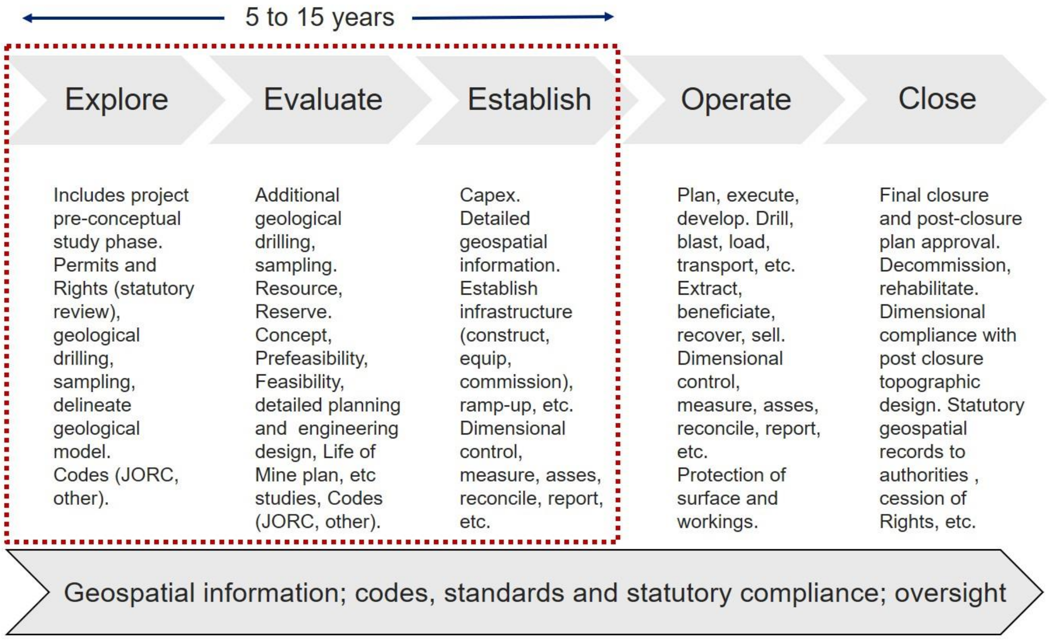

Figure 5.1 Value chain focus area (within red outline)

The functions and individual disciplines involved in Evaluate would typically be (but not limited to):

- Exploration geology (including geophysics, geochemistry, hydrogeology and activities such as drilling, sampling, trenching);
- Mining geology and mineral resource management;
- Mining, Geotechnical, *Processing (Metallurgy)*, Civil, *Electrical, Mechanical*, Structural and Environmental, engineering;
- Geomatics disciplines (surveying, geographic information science/cartography);
- *Information Technology*;
- Ventilation and Occupational Hygiene engineering;
- Legal (mineral and land tenure, access, permits, conditions of tenure);
- Project Management;
- *Finance*;
- *Social/community professions*; and
- External stakeholders, including government.

The functions or disciplines appearing in italics in the above list are unlikely to make direct use of geospatial information. The balance (greater than 70% – estimated) are either reliant on, or make significant use of, accurate geospatial or spatially referenced information.

Also from the above list of functions and/or disciplines, it is unlikely that mutual understanding of all roles is probable. The author therefore proposes that there should be:

- Mutual understanding where there are close interdependencies of processes or activities; and
- Mutual awareness where interdependencies are lower or absent.

What is important is the mutual awareness of the role of each in the evaluation phase, and how each influences business risk and performance.

5.4 Geospatial accuracy and confidence

Throughout the evaluation phase, the accuracy of and confidence in information is continually being improved, irrespective of the information's application, e.g. this can be geological, mining, engineering and financial information. The level of detail is higher, and the estimation ranges are lower and tighter. This improvement is required as a project passes through the successive evaluation stages of concept, pre-feasibility and feasibility studies and is directly linked to increasing categories of classification of mineral resources and ore reserves.

Chapter 4 described and compared geological and geospatial confidence. The key differentiator between these was that geological confidence increases with the acquisition of geological knowledge (more information), whereas geospatial confidence cannot be increased in the same way – it is a function of the quality of the survey control network and the measurements taken to calculate the position of surveyed points.

Geospatial confidence and accuracy require separate assessment. This can be achieved by the application of one or more methods of assessment, the results of which should be comprehensively documented, and summarised for evaluation and inclusion in the Competent Persons report (required by JORC or other applicable code).

Assessment examples are described briefly below. Both methods, or derivations thereof, can be used.

5.4.1 Survey accuracy assessment

Survey accuracy can be directly assessed against prescribed limits of error that are either legislated or contained in an applicable standard. Knowledge of applicable legislation and standards is essential where statutory compliance is required.

At this stage of a mining project, it is appropriate to quote legislation that is applicable prior to a mine being established and operated.

For example, in South Africa, Regulations to the Land Survey Act (Act 8 of 1997), section 5 prescribes the following accuracy for cadastral surveying (for registering a right). The assessment criteria below are well suited to general application, not just to cadastral surveying:

"Class C refers to all surveys not included in Class A or B, and shall include surveys for mining titles in respect of base minerals-

"when the position of a point is determined by polars, traverse, triangulation, trilateration, GPS or a combination of these methods, the displacement between any observed ray, measured distance or GPS vector and the equivalent quantity derived from the final co-ordinates of the point fixed shall not exceed-

for Class A : A metres;

for Class B : 1,5A metres;

for Class C : 3A metres;

where A is equal to-

$$0{,}04 + \frac{S}{30\,000}$$

"and S is the distance between the known and the unknown point: Provided that in the case of a GPS vector the comparison is made between the vector derived from the final co-ordinates and the measured vector after the datum transformation has been applied: Provided further that in the case of a traverse the comparison is made to the misclosure of the traverse, where S is the total length of the traverse in metres;…

"when the vertical position of a point is determined, the difference between any determination thereof and the finally adopted height shall not exceed 0,10 metres:".

As a project advances through the evaluation phase, other legislation or standards may become applicable, requiring different formulae for assessment of accuracy, such as mining legislation upon commencement of mining. Knowledge and foresight is required to ensure the ability to adapt or prepare geospatial information for compliance with present and future legislation and standards.

5.4.2 Mapping accuracy assessment

The American Society for Photogrammetry and Remote Sensing (ASPRS) standards assess mapping accuracy in prescribed classes of accuracy (Class 1, 2 and 3). The accuracy or "limiting error" is directly linked to the mapping scale for which the map was prepared (there are numerous similar standards) – as described in Chapter 2 of this dissertation. Planimetric and height accuracy are assessed separately. To support the standards, guidance is provided on survey control network standards, check surveys and assessing map accuracy.

The methods prescribed for planimetric and height assessment are the same. A representative sample of well-defined points (minimum 20 per map sheet) covering the area of the survey are re-surveyed to higher accuracy than the original. The difference between the original value (position or height) and the new re-surveyed value (position or height) at each point is calculated. The RMSE (root mean square error) of the differences, for planimetric position and for height, are compared with the limit of error (required accuracy prescribed by the standard). 90% of all points assessed must fall within the limit of error. Confidence can be expressed statistically (e.g. at 68% or 90% confidence).

5.4.3 Down-hole survey accuracy assessment

Down-hole surveys can be a significant source of error, depending on the mineral deposit type and setting. It is important to situationally assess the potential impact of geospatial error and the degree to which this could translate into geological risk.

Sindle *et al* (2006), in investigating and explaining frequent and common sources of error in down-hole trajectory surveys, noted that "The value of any information gleaned from exploration boreholes is increased enormously when this information can be accurately placed within the three-dimensional model of the mine site. It is not uncommon to find trajectory data to be out by tens of degrees causing compounding errors at the end of long holes. This misinformation can end up being extremely costly when mine plans and resource estimates are based upon it.”

The findings of numerous controlled tests of down-hole surveying tools conducted at the De Beers Voorspoed Mine were presented at an Institute of Mine Surveyors of South(ern) Africa Borehole Surveying Colloquium in 2005.

To create a benchmark drill path (trajectory), a PVC pipe of appropriate diameter was laid down an access ramp and then over the pit crest into the (then) disused open pit, to replicate a geological drill hole of ~400m (389.6m) in length. The pipe was secured by means of plinths and brackets, to ensure its stability. Sufficient horizontal and vertical deviations were included in the design to replicate a typical down-hole survey trajectory. More than one magnetic source was present.

The drill path (PVC pipe) was accurately surveyed (by mine surveyors) using conventional ground survey methods, to provide a geospatial benchmark against which various down-hole survey tools were evaluated. Such tools included optical, magnetic and north-seeking sensors. A total of nine different instruments were tested; 7 magnetic sensors (Electronic Multi-Shot); 2 non-magnetic sensors (1 Optical and 1 gyro).

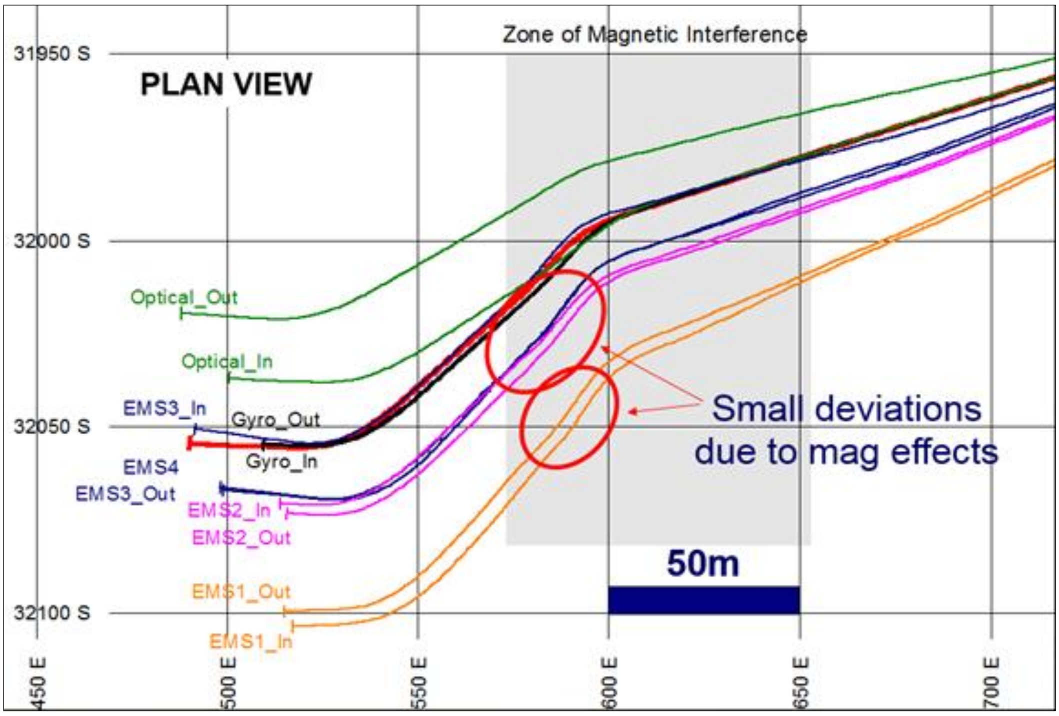

Figure 5.2 Benchmark study results: Azimuth (source: Wolmarans, 2005)

Down-hole survey errors (vs. benchmark) were used to assess the impact on geological modelling. According to Nordin (2005) the impact of a 10% deviation in down-hole survey on the volume of the geological solid model of the kimberlite pipe, ranged between 29.1% (“10% Shrunk”) and -33.1% (“10% Expanded”). At 4% deviation, the change in volume already exceeded 10%.

In discussion of the controlled test results, Wolmarans (2005) stated that “Resource classification can be downgraded if uncertainty in location of contacts and volume are too big”. He reported on controlled tests where linear displacement (vs. benchmark), expressed as a percentage of hole length ranged from 0.2% to 19.7%, presenting these as “spheres of [geospatial] uncertainty”. He questioned where individual responsibility and accountability for borehole orientation surveys should lie, with direct reference to the mine surveyor.

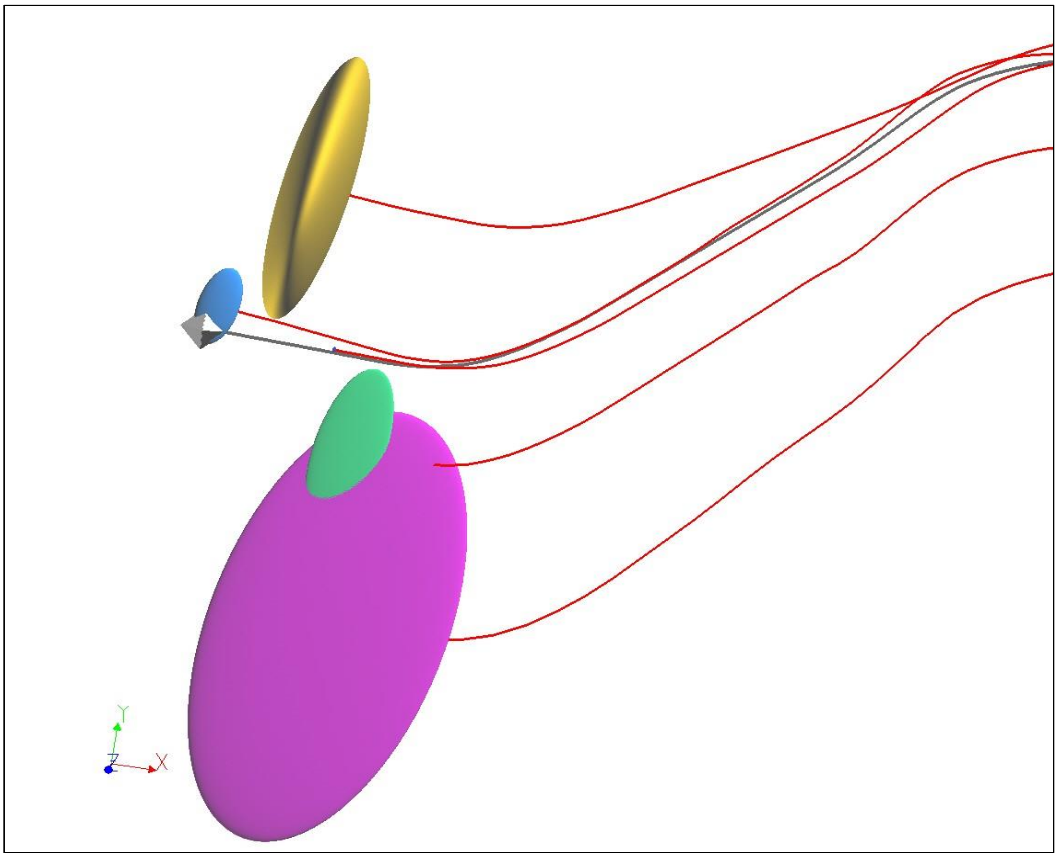

Figure 5.3 Spheres of [geospatial] uncertainty (source: Wolmarans, 2005)

The author contends that down-hole survey accuracy assessment is a joint responsibility of the surveyor and the geologist. This interdependency must be understood to ensure that effective assurance measures are in place to mitigate risk associated with this source of potential error. The surveyor should be responsible for assessing either all records related to a down-hole survey, or the actual re-survey of a drill hole. In both cases, there are two separate activities and results, namely the:

- Assessment of the accuracy of the drill hole collar position and alignment (direction and dip) – responsibility of the surveyor; and
- Assessment of the down-hole survey data and resultant drill string trajectory – responsibility of the geologist.

Depending on the down-hole survey tool used, e.g. magnetic or non-magnetic, the following would require assessment:

- Instrument "laboratory" calibration, to confirm performance within design specifications;
- Site calibration, to determine whether alignment direction and dip is within site-prescribed tolerance. This would require;
  - assessment against a known (surveyed) orientation/direction,
  - assessment against a known (surveyed) dip,
  - assessment of the need to compensate for meridian convergence, and
  - assessment of the need to compensate for local magnetic declination and/or anomalies.

Sindle, Nordin and Wolmarans described errors which would be defined as being "material" in terms of JORC or other applicable code, with consequent impact on geological confidence. The above-described assessments of geospatial accuracy and confidence are therefore extremely important to consider during the evaluation phase of a project.

5.5 Technical studies geospatial requirements

The technical studies phase is when mineral resources and reserves are developed into appropriate categories of confidence. It is concerning to note that JORC and other applicable codes are silent on geospatial requirements for technical studies. There appears to be an assumption in the codes that the assurance processes which have been applied to geological data and information have adequately addressed geospatial accuracy. Common across the codes are reporting criteria during exploration related to data location, quality and adequacy of topographic data, down-hole surveys, and details of coordinate systems.

By using Eggert's illustrative tables (tables 5.2 and 5.3) to link the code requirements for exploration, mineral resources and reserves to conceptual/scoping, pre-feasibility and feasibility studies, the following evaluation criteria for topography are quoted in the SME Guide (2014):

Table 5.4 SME Guide topographic requirements

Exploration	Resources	Reserves
General topographic map is sufficient.	Topographic map in sufficient detail to support mine planning and conceptual infrastructure layout.	Detailed topographic map. Aerial surveys must be checked with ground controls and surveys, particularly in areas of rugged terrain, dense vegetation or high altitude.

The above criteria are insufficient, unless engineering and survey expertise guides the technical requirements for subsequent Competent Person reporting.

As a further example of the silence on geospatial accuracy and confidence in the codes, Table 5.5 shows an extract from SAMREC (the South African Code for Reporting of Exploration Results, Mineral Resources and Mineral Reserves), which has no reference at all to geospatial information. References are to resource and reserve categories. It appears to be either assumed or implied that geospatial assurance has been adequately applied to geological data and information.

Table 5.5 SAMREC Table 2 for technical studies

Scoping Studies, Pre-Feasibility Studies (and ongoing life-of-mine studies) analyse and assess the same geological, engineering and economic factors with increasing detail and precision. Therefore, the same criteria may be used as a framework for reporting the results of all three studies.

The criteria for a Pre-Feasibility Study are considered the minimum requirements for a Life of Mine Plan.

Scoping Studies cannot convert inferred Mineral Resources to Mineral Reserves.

Technical Studies may not include Exploration Targets or Mineralisation.

SAMREC TABLE 2			
General	**Scoping Study**	**Pre-Feasibility Study**	**Feasibility Study**
Resource Categories	Mostly inferred.	Mostly Indicated.	Measured and Indicated.
Reserve Categories	None.	Mostly Probable.	Proved and Probable.
Mining Method and Geotechnical Constraints	Conceptual	Preliminary options	Detailed and optimised
Mine Design	None or high-level conceptual.	Preliminary Mine Plan and schedule.	Detailed Mine Plan and schedule.
Scheduling	Annual approximation.	Quarterly to annual.	Monthly for much of payback period.
Mineral Processing	Metallurgical test work.	Preliminary options.	Detailed and optimised.
Permitting – (Water, Power, Mining, Prospecting and Environmental)	Required permitting listed.	Preliminary applications submitted.	Authorities engaged and applications submitted
Social Licence to operate	Initial contact with local communities.	Formal communication structures and engagement models in place.	Contract/agreements in place with local communities and municipalities (local government).
Risk Tolerance	High.	Medium.	Low.

Moving on from the reporting codes, and resources and reserves which are outputs of the technical studies, to a mining company/in-house asset development standard, geospatial requirements are addressed more specifically but have very low proportional visibility due the large body of content in the standard. The following extracts refer to “Site Information”, “Mineral Resources and Geology” and “Engineering Design and Infrastructure”. It is instructive to note that “Mining” (not shown in Table 5.6) does not stipulate any geospatial accuracy requirement for mine planning and design.

The references to geospatial requirements (shown in Table 5.6) represent less than 1% (estimated) of the content of the in-house standard. However, the dependency on accurate geospatial information for tenure (land and mineral rights), mine and engineering design (inclusive design safety in the case of residue disposal) and cost estimating far exceeds the low representation (of less than 1%). The author contends that for this reason geospatial risk and the role of geospatial information has been significantly underestimated in technical studies. It is therefore fundamentally important to ensure adequate representation of professional surveyors on project study teams.

What is also apparent from the table are the conflicting references to topographic map requirements for different activities at the same stage of study, which imply a possible lack of understanding of mapping accuracy standards, or preferences in map scale not accuracy requirements. Furthermore, the combination of contour intervals and map scales (called for by the in-house standard) do not comply with ASPRS and other mapping accuracy standards.

To illustrate the link between codes for reporting of mineral resources and ore reserves and technical study phases, the author has added an overarching “bar” across the in-house[1] table (Table 5.6).

It should be noted that following a feasibility study would be a stage to validate engineering, management, procurement, construction and commissioning information for project implementation (as required by the in-house standard).

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[1] Mineral resources estimates are developed during a conceptual study, whereas reserve estimates are developed during pre-feasibility and feasibility studies.

Table 5.6 In-house asset development standard extracts

Element	Mineral Resources Conceptual Study	Mineral Reserves Pre-feasibility Study	Feasibility Study
Site Information	Obtain basic large scale maps defining regional topography c/w preliminary property lease/claims boundaries.	Update topographical maps by conducting a preliminary, site specific, topographical survey at >3m contour interval.	Detail the site specific topographical survey maps by conducting a detailed topographical survey (+/- 1m contour intervals). Where required, (for verification) conduct ground controls and surveys.
Mineral Resources and Geology	Establish robust survey control network. Establish elevation using orthometric heights and levelling programme. Minimum 6 pillar beacons and orthometric height calibration.	Maintain survey network.	Need for accurate and precise geographical framework for infrastructure planning and building. Establish rigorous and accurate and highly precise survey control network.
Engineering Design and Infrastructure	Conduct a preliminary assessment of the large scale regional topographic maps, aerial photographs and public domain information.	Update topographic maps by conducting preliminary site specific topographical survey (+/-3m contour intervals) with existing infrastructure and final locations for the plant, major infrastructure, utility and access (road and rail) routes c/w indicative sizes, confirmed lease/claim boundaries, geotechnical outcomes and legislative limits (e.g. flood and blast lines)… For preliminary definition of key access requirements: "Preliminary routes and contour plans at > 1m contours and >1:2500.	Detail the site specific topographical survey maps (+/- 1m contour intervals) with existing infrastructure, final locations for total mine solution c/w final sizes and incl. final utility and access routes, final acquired lease boundaries, geotechnical outcomes and legislative limits (e.g. flood and blast lines). Where required (for verification) conduct ground controls and surveys… For residue disposal strategy: "Final location and design at approximately 1m contour intervals and 1:10 000 scale. For detailed design of key access requirements: "Detailed site specific topographical survey (as above) at +/- 1m contour intervals and 1:200 scale.

The ASPRS and other mapping accuracy standards provide a clear link between map scale, accuracy and contour interval. In other words, a required planimetric or height accuracy can be translated into a map scale and contour interval, as can a required contour interval into required planimetric (X, Y) or height (Z) accuracy. It is not recommended that a convenient map scale is nominated without considering the associated accuracy – particularly if specifying aerial surveys for mapping. It should also be noted that the ASPRS states that a 1:500 scale map is "the practical limit for aerial methods", i.e. a larger scale such as 1:200 would require terrestrial-based surveying methods.

Table 5.7 shows the above-described relationship and proposes associated typical applications (in mining projects).

Table 5.7 ASPRS large scale mapping accuracy (source: Author's collection)

X, Y Accuracy (m)	Z Accuracy (m)	Contour Interval (m)	Contour Accuracy (m)	Typical Map Scale	Typical application for required accuracy, contour interval or map scale
0.05	0.03	0.2	±0.07	1:200	Detailed Engineering and Design
0.125	0.08	0.5	±0.17	1:500	Detailed Engineering and Design
0.25	0.17	1	±0.33	1:1000	Feasibility / Gen. Design / Operation
0.62	0.42	1.5	±0.50	1:2500	Pre-feasibility / Closure
1.25	0.84	2.5	±0.83	1:5000	Pre-feasibility / Closure
2.5	1.68	5	±1.67	1:10000	Conceptual / Pre-feasibility / Closure
5.0	3.22	10	±3.33	1:20000	Conceptual
12.5	8.40	20	±6.67	1:50000	Pre-conceptual / Conceptual

5.6 Building Information Modelling (BIM)

Before introducing Building Information Modelling (hereafter referred to as BIM) to the discussion on geospatial strategy in the next section of this chapter, some explanation of BIM and its potential are required. In the context of this research, 'Building' should be replaced by the word 'Asset' – as advised below.

In mining, BIM should be thought of in an asset development and operation context, and as a means to manage an asset through its life-cycle. The author contends that by adopting BIM for the Feasibility stage of evaluation, there is significant advantage to cross-functional collaboration, information management and information sharing, with benefits to be realised by earlier adoption in the pre-feasibility stage onwards. BIM can play a pivotal role in realising project efficiencies during the construction and development of mining infrastructure and a mine, and if continued, could provide opportunities for mining asset management performance efficiencies. Importantly, BIM can be used to define and execute an integrated geospatial strategy which is fully aligned with technical business performance – as explained below.

The Royal Institution for Chartered Surveyors (RICS, 2014a) proposes that "Adopting a BIM approach can bring predictability to a project, not just around capital delivery but operation too.", adding that "key BIM words to remember are: people, information, processes, technology…A word to forget is 'Building'.".

Azhar, *et al* (2008) cited Bazjanac (2006) with the following statement, "A building information model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule. This model can be used to demonstrate the entire building life-cycle."

Eadie, *et al* (2013) cited Vanlande, *et al* (2008) describing BIM as a process of "generating storing, managing, exchanging and sharing building information in an interoperable way".

Eadie, *et al* (2013) quoted Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM, indicated benefits such as (CIFE, 2007):

- "Up to 40% elimination of unbudgeted change;
- "Cost estimation accuracy within 3%;
- "Up to 80% reduction in time taken to generate a cost estimate;
- "A saving of up to 10% of the contract value through clash detections; and
- "Up to 7% reduction in project time."

According to Bernstein (2014), quoted in an article in New Civil Engineer, a construction industry survey conducted by McGraw Hill Construction on the benefits of BIM showed "…contractors reporting shorter schedules by 9%, project cost decreases of 10% and increases in project ROI of 2%".

Crossrail, a GBP 14.8bn project to extend the underground rail system below London, is regarded as a showcase for the use of BIM (due its project control and efficiency advantages, the use of BIM for the project was made mandatory by the UK government). Crossrail describes BIM as "the process of generating, building and managing data through the life of the project by using model-based technologies linked to a database of project information. BIM incorporates data – physical, environmental, commercial – on every element designed…". Crossrail states its key benefits to using BIM are:

- "**Reduction of risks** from greater visibility into design and construction interfaces and activity;
- "**Improved safety** through increased construction awareness from easy review of complex details or processes on site;
- "**Reduced errors** from using a trusted "single source of truth" approach to data management, for example ensuring only the most appropriate version of models, drawings and documentation is used;
- "**Improved collaboration** through linked data sets and integrated 3D models that create a "virtual" Crossrail before the physical Crossrail is constructed, allowing design and construction refinement;
- "**Reduced information loss** between project phases, ensuring we capture and hand over full asset information into the Operations and Maintenance phases; and
- "**Improved project delivery** leveraging technology advances including data interoperability and mobility".

The key benefits clearly address information interdependencies, cross-functional collaboration, risk mitigation and value creation as described in this research.

Considering that the project cost of developing a mine typically exceeds US$ 1bn, the potential benefits of BIM are significant (e.g. the De Beers Venetia Mine Underground Project, an extension of an operating mine, is currently being developed at a cost of US$ 2.1bn, for commencement of production in 2022 following nine years of construction, development, equipping and commissioning).

5.7 Geospatial strategy

Considering that a typical mining project may take 5-15 years before a mine becomes operational (Eggert, 2010) it is reasonable to assume that an enormous amount of information has been generated by the conclusion of technical studies and that effective information control and management systems are in place. What cannot be assumed is that the information has been used to its full potential.

As previously mentioned, this phase in the project life-cycle is the first in which several technical functions and disciplines become involved, thereby significantly increasing the complexity of work being done. The information and work interdependencies between disciplines and functions has similarly increased.

Considering that references to geospatial or survey requirements in the in-house asset development standard (which is typical of industry practice) was <1% of total content (section 5.5), but that cross-functional use of geospatial information is greater than 70% during technical studies (section 5.3), the involvement of an appropriately resourced survey team in the pre-feasibility and feasibility stages of evaluation is imperative. (From experience, the inclusion of survey professionals in the technical studies phase is normally overlooked, or included too late to enable leveraging full value from geospatial information and associated survey practice.)

There is a definite inflection point during the evaluation phase at which geospatial information requirements shift from being the foundation of mineral resource and ore reserve models, to being the geospatial foundation for engineering functions for mine design and construction. At the commencement of construction (to be discussed in the next chapter) geospatial accuracy requirements will be millimetres, not centimetres, decimetres or metres, requiring a step change in geospatial practice which must be fully scoped, planned and resourced by the conclusion of the evaluation phase.

To enable geospatial information and practice to be leveraged during and from the evaluation phase in support of business performance, a dedicated and integrated strategy which is aligned with business objectives is required.

As mentioned above (section 5.6), a BIM approach can be used to define and execute a geospatial strategy which fully supports a feasibility study and project implementation, and is fully aligned with technical business performance. The project efficiency and performance potential is significant. It is worth repeating the benefits reported by CIFE (2007):

- “Up to 40% elimination of unbudgeted change;
- “Cost estimation accuracy within 3%;
- “Up to 80% reduction in time taken to generate a cost estimate;
- “A saving of up to 10% of the contract value through clash detections; and
- “Up to 7% reduction in project time.”

For BIM to be feasibly considered, the author proposes that the technical studies teams, inclusive of the survey team, develop a joint and fundamental understanding of BIM (and, as advised, that the word ‘Building’ is dropped and replaced by ‘Asset’). This should be concluded during the pre-feasibility study to enable the benefits to be realised during the feasibility study and beyond.

A framework for the strategy can be made by adapting Bazjanac’s statement to apply to a mining project, e.g. “*Implement a model and systems which effectively manage asset* geometry, spatial relationships, geographic information, quantities and properties of *asset* elements, cost estimates, material inventories and project schedule. This model can be used to demonstrate the entire *asset* life-cycle.” – (author’s changes appear in italics). The framework would then be used to ensure alignment for a dedicated strategy at functional or sub-process level. Key to the strategy would be to effectively address and align the requirements of “people, information, processes, technology” (RICS, 2014a).

With the integrated strategy, systems and implementation plan in place, planning at the sub-process level can be completed, again with the focus on people, information, processes and technology, to ensure appropriate capacity and capability availability aligned with the project’s schedule and needs.

With specific reference to the outcome of strategy and implementation planning for the surveying discipline, the objective would be to have the above-mentioned capacity and capability operationally ready by commencement of mine construction and development, i.e. by the conclusion of the evaluation phase. Roles, responsibility and authority within a defined reporting structure must be approved and in place, including operating standards aligned with project technical specifications.

All project KPIs (Key Performance Indicators) which require survey involvement, measurement and reporting, which are materially important for project control, must have been defined. From this point onwards, through the life-cycle (Establish, Operate, Close), the survey discipline must possess the people, processes and technology to measure and present geospatial information in a manner which supports business effectiveness, i.e. measuring, analysing, reconciling and reporting on the right KPIs at a frequency which supports effective asset management.

Achievement of these objectives would be a key enabler for geospatial information to be used to its full potential in support of project performance.

5.8 Conclusion

This chapter was the second of the central chapters which follow the structure of the mining value chain. It described the requirement for increasing geospatial accuracy during the progression of a project through the evaluation phase / technical studies stages, ending with project implementation.

The evaluation phase is the first in a project life-cycle in which several technical functions and disciplines become involved, thereby significantly increasing the complexity of work being done. Information and work interdependencies between disciplines and functions similarly increase – demonstrated by the estimation of cross-functional use of geospatial information during technical studies being greater than 70% (of the total functions or disciplines listed).

Methods of assessing accuracy were presented as examples of how to apply geospatial assurance, inclusive of considerations for down-hole surveys. Limits of error for surveying and for mapping were discussed with examples of applicable legislation and standards. Attention was drawn to the requirement for knowledge and foresight to adapt or prepare geospatial information for compliance with other legislation or standards which may become applicable as a project advances through the evaluation phase.

Information from a number of sources, including industry professionals, mineral reporting codes and a mining company's in-house standard were presented to demonstrate the changing requirements in geospatial accuracy during evaluation, describing the shift of geospatial focus from mineral resources and ore reserves, to supporting engineering and design requirements for mine establishment. The inflection point at which geospatial information requirements shift from being the foundation of mineral resource and ore reserve models, to being the geospatial foundation for engineering functions for mine design and construction was noted.

Due to the apparent significant underestimation of geospatial risk and the role of geospatial information in technical studies, the fundamental importance to ensure adequate representation of professional surveyors on project study teams was proposed as being imperative.

The need for the development of a comprehensive cross-functional geospatial strategy to enable geospatial information and practice to be leveraged during and from the evaluation phase, in support of business performance, was discussed.

To realise the full value-additive potential of geospatial information, BIM or 'Asset' Information Modelling, was proposed as the means to develop and implement the strategy, ultimately rolling down to sub-process or discipline-activity-level planning and implementation. Key to this would be the effective scoping of "People, Information, Processes and Technology".

Examples of the realised benefits of BIM from the construction industry were quoted to illustrate the value potential of geospatial information when "quantities and properties of asset elements, cost estimates, material inventories and project schedule" are combined into a single information system for cross-functional sharing.

Finally, the outcome of strategy and implementation planning for the surveying discipline was presented for the provision of appropriate capacity, capability and operational readiness by the conclusion of the evaluation phase.

Chapter 6 will discuss geospatial control, positioning, monitoring and reporting during the construction and development of a mine, and the alignment thereof with the project's schedule and needs.

6. ESTABLISH

6.1 Introduction

Chapter 5 discussed the evaluation or technical studies phase of a mining project, in which concept, pre-feasibility and feasibility studies were concluded, culminating in a final validation of engineering, management, procurement, construction and commissioning information for project implementation. It was noted that during the evaluation phase, geospatial information requirements shifted from being the foundation of mineral resource and ore reserve models, to being the geospatial foundation for engineering designs, mine design and construction.

This chapter, Establish, will discuss geospatial aspects of the project implementation and mine establishment, i.e. during the construction and development phase of a mine. The purpose is to describe geospatial control, positioning, monitoring and reporting during mine establishment, and effective surveying practice and management of geospatial information.

Construction would typically involve the coordination of several discrete disciplines, such as civil, structural, architectural, mechanical and electrical engineering. A number of these disciplines, including mining engineering, would be involved in the development of the mine workings (whether underground or on surface). All would be coordinated by a project management function.

During this phase, there are high levels of cross-disciplinary interdependencies, many of which involve spatially referenced designs, plans or 3-dimensional models. With geospatial information as the foundation for mine design and construction, dependence on such information is high. Effective control, sharing and use of this information is essential to construction and development efficiency. Failure to do this effectively can result in escalated financial (cost) and safety risks, and reputational risk should consequences be significant.

This is also the phase during which engineering designs are established in physical space. The role of the surveyor in this process is critical, requiring appropriate competencies, systems, controls and technology to ensure correct positioning and dimensional control, and effective communication with project engineers. Surveying capacity and capability must therefore be operationally ready and available at the outset of project implementation.

In the process of establishing engineering designs in physical space, dimensional control can require a very high order of accuracy with tolerances of millimetres, particularly for structural alignment or positioning of pre-fabricated structural elements/components. This requires a departure from general survey practice, to ensure that exact dimensions from designs are replicated on the ground. No projection corrections may be applied. The means to achieve this will be described, starting with the survey control network.

In considering the above-mentioned accuracy requirements, it should be noted that limits of error which were adequate for exploration, mineral and land rights, and project evaluation are no longer adequate (or applicable). The project has reached a point of transition. Engineering surveying and appropriate construction limits of error apply, requiring documented construction surveying standards, which if necessary must be contractually specified.

However, development of mine workings will be taking place concurrently, requiring the application of the above-mentioned accuracy standards within a mining legislation framework. Both must be considered, and as mentioned in Chapter 5, knowledge and foresight is required to adapt or prepare geospatial information for compliance with the construction accuracy standard and legislated accuracy standards for a (future) operating mine. In countries such as South Africa and Australia, this would require the legal appointment of a surveyor with specific qualifications and competencies to be responsible for all surveying activities on the mine. Other countries, such as Canada, assign this responsibility to the engineer.

To address the potential risk of deficiencies in geospatial information or surveying practice having significantly adverse consequences for project efficiency, key surveying requirements and practice which support geospatial assurance and the project schedule will be discussed. Examples of adverse consequences of such deficiencies are project standing time, re-work or over/under statement of quantities, with consequent potential dispute. Mitigation of geospatial risk will focus on dimensional control, with associated temporal and quality (accuracy) compliance.

6.2 'Establish' as a core value chain process

The objective of using the value chain as a common reference is that all functions or disciplines involved in mine establishment (the construction and development of a mine) develop a high-level, mutual understanding of their respective roles and contribution to the project, thereby enabling alignment of purpose.

As graphically represented by the value chain, Establish is the progression from the Evaluate phase and therefore the second in which several technical functions and disciplines are involved, resulting in significantly increased complexity of work and cross-functional interdependencies.

However, mine establishment will be highly internally focused on a project execution plan, integrated schedules, cost, safety and quality key performance indicators (KPIs), all of which support effective project execution and contractual compliance. This requires a level of organisational control and sub-processes which cannot be adequately represented in the value chain in Figure 6.1. It is therefore reasonable to assume that the Engineering, Procurement and Construction Management (EPCM) contractor (appointed by the mine owner) is focused on construction and commissioning, with limited need for understanding the value chain. However, as proposed in the previous chapter, awareness (vs. understanding) is required.

By contrast, the functions and disciplines required to develop and operate the mine, and which were involved during the evaluation phase, will play an increasingly active role by the end of mine establishment. They will need to be operationally ready for the next downstream process, i.e. Operate (the mine). The focus returns to the business of mining. In this context, the value chain retains its significance as an enabler for mutual understanding of respective roles, contribution to the business and alignment of purpose (despite providing limited construction and development detail).

Figure 6.1 shows the core-process of Establish and its adjacent core-processes. Typical activities are listed below the core-process, to provide an indication of work required and the involvement of numerous functions, disciplines and other fields of expertise.

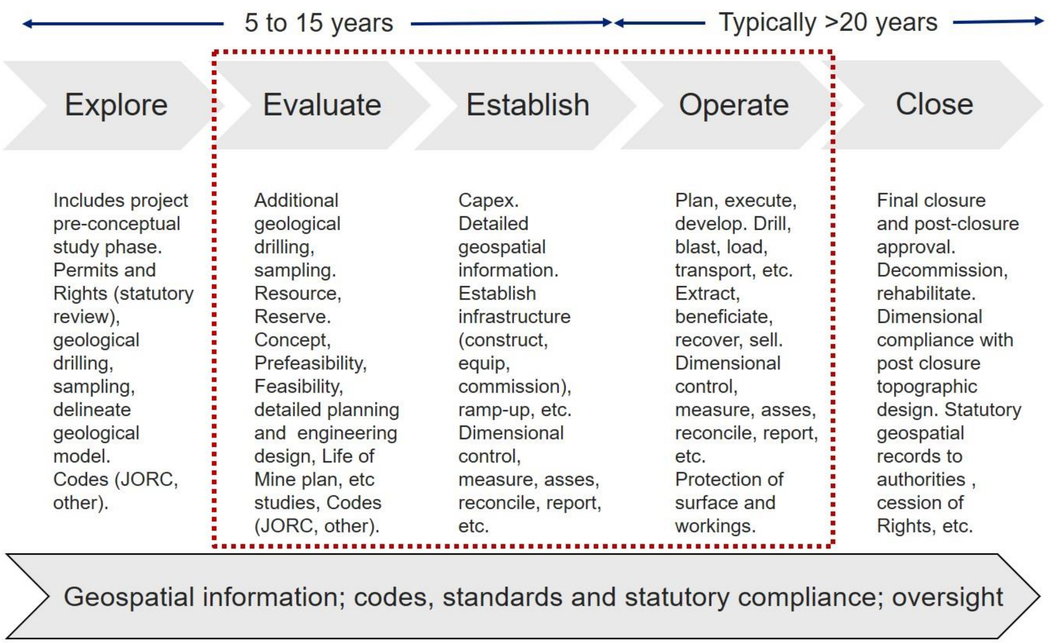

Figure 6.1 Value chain focus area (within red outline)

The functions and individual disciplines involved in Establish would typically be (but not limited to):

- Project Management (owner's team);
- EPCM contractor and associated engineering disciplines e.g. Civil, *Electrical, Control and Instrumentation, Mechanical*, and Structural engineering;
- Shaft sinking;
- Mining geology and mineral resource management;
- Mining, Geotechnical, Processing (Metallurgy) engineering;
- Geomatics disciplines (surveying, geographic information science, drafting);
- *Information Technology*;
- Ventilation and Occupational Hygiene engineering;
- Legal (mineral and land tenure, access, permits, conditions of tenure);
- Security;
- *Finance*;
- *Social/community professions*; and
- External stakeholders, including government.

The functions or disciplines appearing in italics in the above list are unlikely to make direct use of geospatial information. The balance (greater than 70% – estimated) are either reliant on, or make significant use of, accurate geospatial or spatially referenced information.

6.3 Geospatial accuracy for engineering and construction

As previously mentioned, establishing engineering designs in physical space requires that surveying be to a high accuracy, often with tolerances of millimetres for structural alignment or the positioning of pre-fabricated structural elements or components. To a lesser accuracy, but of equal importance for contractual design and execution, is a topographic map or model for earth works, buildings, roads, and general infrastructure dimensional control. Accuracy requirements are therefore variable, meaning that the surveying rigour, methods and equipment used may differ, depending on the purpose of the work being executed.

Understanding this variability is essential to ensure that fit-for-purpose processes and technology are used. It also requires a fundamental understanding of the engineering design, to enable informed decision making on what defines fit-for-purpose. However, what is common to all accuracies, is that there must be an accurate survey network established on which to base all surveying and dimensional control. The design and accuracy of this network, which will be the geospatial foundation for mine construction, development and future operation, requires highly skilled planning and execution.

To achieve tolerances of millimetres for dimensional control, the survey network would need to be to a higher accuracy than the dimensional control established from the network.

Based on experience of mine construction and establishment, the author proposes the following as adequate to accommodate typical engineering construction accuracy requirements for mine establishment:

- Horizontal (X, Y) accuracy of 2mm ±3mm (which translates into a total error margin of 5mm), where 2mm is the accuracy of the survey control;
- Height accuracy (Z) of $2\sqrt{k}$ (answer in mm), where k is the distance levelled in kilometres;
- Appropriate methods of surveying and assessment of accuracy must form part of routine geospatial assurance; and

- Lower accuracy dimensional control or general setting-out accuracy requirements would be by agreement or written instruction, and recorded. Appropriate accuracy or limits of error would be specified (for X, Y and Z).

The author contends that these accuracy standards remain valid for current and future mine establishment projects.

It should be noted that both the survey control accuracy (2mm) and the height accuracy formula, without intention, compare well with Royal Institution of Chartered Surveyors (RICS) guidance for "Measured surveys of land, buildings and utilities", for Secondary or 2nd Order control.

6.3.1 RICS survey accuracy guidance

RICS (2014b) addresses variable accuracy requirements by applying a formula for "accuracy bands", i.e. ranges of variable accuracy for different applications as determined by the client or engineer. Extracts (first four bands of more than 10) from the guidance document accuracy table appear in Table 6.1 for further discussion, however some key requirements from the guidance document require consideration.

- "The surveyor is required to eliminate all systematic errors (biases) and gross errors (mistakes) from his/her work and survey outputs.
- "Where possible the surveyor should ensure there is sufficient redundancy in his/her survey observations (control and/or survey detail) to enable survey accuracy to be proven by measurement and analysis of the distribution and size of random errors.
- "For survey accuracy to be quantified there must be sufficient measurements to create redundancy in the observations (i.e. repeat or spare observations which allow an average to be generated and residuals to be calculated). Where there are no redundant or repeated observations survey accuracy cannot be verified.
- "All accuracies quoted within the accuracy band table are taken as the accuracy of individual survey points relative to the survey control points. Verification of the survey detail accuracy by site checks must include measurement to or from survey control".

The first three bullet points regarding elimination or errors, accuracy and redundancy are common requirements for all surveying activities and would be specified in relevant surveying standards for a project or an operating mine.

Table 6.1 Survey accuracy band table (after RICS, 2014b)

Plan accuracy (X, Y)			**Height accuracy (Z)**			
Band	1 sigma	2 sigma	Band	Accuracy hard detail	Accuracy soft detail	Example survey types/uses (not exhaustive list, nor fixed to a band)
A	±2mm	±4mm	A	±2mm	N/A	Monitoring, high accuracy engineering setting out and fabrication surveys
B	±4mm	±8mm	B	±4mm	N/A	Monitoring, high accuracy engineering and measured building surveys and setting out
C	±5mm	±10mm	C	±5mm	N/A	Engineering surveying and setting out, high accuracy measured building surveying, heritage recording
D	±10mm	±20mm	D	±10mm	±25mm	Engineering surveying and setting out, measured building surveys, high accuracy topographic surveys, determined boundaries, area registration

RICS explains how to determine the relative accuracy of a survey point from the tables as follows:

- "Relative accuracy between survey detail points shall be subject to the accuracy of each detail point's banding combined, plus the control parts per million (PPM) multiplied by the distance in excess of 100m between the points. This can be calculated by squaring the standard deviation of each survey detail point's relevant band accuracy, adding them together and then taking the square root of the total to establish the relative accuracy, i.e. $\sqrt{(\sigma 1^2+\sigma 2^2)}$ plus the distance minus 100m multiplied by the specified control PPM.
- "For example, the relative plan positional accuracy between a band B point and a band D point, located 200m apart and surveyed from survey control specified with 20 PPM will be: $[\sqrt{(4^2+10^2)}]+[((200m-100m)*1/50000)]=[11]+[2]=13mm$."
  - (Author's note) – where positional accuracy between the band B and band D points is calculated at 1 sigma, and where 20ppm = 1/50 000.

6.4 Calibration, checking and adjustment

It follows from reviewing the above-mentioned accuracy requirements, that instrument calibration is extremely important, as is the selection of the correct equipment that is capable of measuring to the accuracies required by the project.

Martin (2007) observed that "… the rapidity and simplicity of modern survey instruments result in a tendency to assume measurements are exempt from error…This is… simply not true. Instrument verification, testing and calibration are every bit as important today as they were in the past". This observation remains relevant.

The purpose of the calibration is to confirm that each piece of surveying equipment and its ancillary equipment are performing to the manufacturer's specification. Ancillary equipment would include thermometers and barometers used for determining atmospheric corrections to be applied to distance measurement, prisms/reflectors, and possibly GPS antennae.

It should be mandatory for all survey equipment used on site to be calibrated to pre-defined standards, which are aligned with international or national norms and that are defensible should surveying inaccuracy or error become the subject of dispute. Aside from this technical and legal reasoning for calibration, it should be noted that it is simply good, professional practice.

To place this into a business contribution context for mine establishment, it should be viewed as one essential constituent of geospatial efficiency and assurance. Calibrated and adjusted surveying equipment reduce the risk of geospatial error and hence the potential time and cost consequences of construction or development standing time or re-work. Preventing standing time contributes to operational and cost efficiency. The author contends that the role of geospatial efficiency is one of prevention of value destruction and is consequently not recognised, or if recognised, underestimated.

There are principally two types of calibration that must be addressed. The first can be regarded as a laboratory bench test, in which the manufacturer or certified test facility tests and certifies the accuracy of the equipment under controlled conditions. Each piece of survey equipment used for precision work should have a calibration certificate.

The second test is one which must be conducted by the surveyor “in the field”, i.e. in conditions under which the equipment is typically used. This may require the establishment of calibration or checking facilities on site, e.g. a multi-bay EDM (electronic distance meter) baseline, or similar for other equipment such as levels. Each piece of survey equipment used for any survey work on site should have a certificate of calibration, checking or adjustment (whichever is applicable), determined on site. A compliance register should be kept. Records should include the numerical information from the calibration, testing or adjustment processes.

The test processes should be repeated at an interval which effectively mitigates geospatial risk associated with instrument error. “The surveyor is responsible for ensuring all equipment is calibrated/verified and checked prior to use and maintained as such throughout the period of survey works, as well as ensuring it is fit for the survey purpose required.” (RICS, 2014b).

The author will not describe calibration, checking or adjustment methods in this research, as this would be too lengthy. Numerous calibration, checking and adjustment procedures are available for reference from manufacturers, professional practice guidelines and books on surveying.

6.5 Survey Control Network

Schofield (1993) states that the “setting-out engineer [surveyor] should establish such a system of work on site that ensures the accurate setting out of the works well in advance of commencement of construction”.

In the context of establishing the survey control network, this would require a complete understanding of the project’s accuracy tolerances and the physical layout of the site. Schofield also advises that the establishment of a survey control system is of prime importance and located such that control points or beacons “survive the construction processes”.

In other words, the control network must be planned in such a way that a permanent reference framework of beacons, from which additional surveying control or surveys can be expanded, must be established prior to construction and must remain intact and stable for the duration of construction. This control network will typically be incorporated into the control network of the mine during development, and where required, subjected to mine surveying statutory requirements.

The author contends that it is imperative that the value of survey control network is understood by all parties working on the project. It is the geospatial foundation for all dimensional control and other surveying activities throughout mine establishment, to the commencement of operations. It will be expanded and maintained throughout the operating life of the mine, through to mine closure. Post-closure, it will constitute a vital geospatial record of mine workings (voids) for possible future development or as a hazard reference.

Considering the accuracy requirements of a survey control network for engineering construction purposes, high levels of skill, planning and measurement competencies are required – coupled with the use of appropriate equipment to achieve the specified accuracy.

RICS (2014b) provides the following guidance:

- “The surveyor shall establish survey control points that shall be linked together by a network of observations to realise the survey grid on the ground. This network shall include all types of observations required to establish plan and height control and provide sufficient redundancy in observations to allow proof of accuracy.
- “All survey control point network observations, regardless of observation method, shall be computed and adjusted rigorously using the most appropriate technique to ensure that the survey control accuracy is achieved, and supports the detail accuracy as defined in the accuracy band table and survey detail specification.

As with the elimination or errors, accuracy and redundancy being common requirements for all surveying activities, the above two points regarding the survey control network are equally important and would be specified in relevant surveying standards.

In accordance with the above RICS guidance, measurement methods and adjustment techniques should not be prescribed. These should be selected based on site-specific conditions and requirements. For this reason, the author will not provide detail on surveying and processing for control networks. Required rigour, accuracy and assurance must guide practice.

6.5.1 Control network beacons

Establishing the network is a joint effort between construction contractors (e.g. the EPCM contractor), project engineers and surveyors, to enable the planning, locating and constructing of permanent control beacons. The selected positions of the beacons must ensure long-term inter-visibility (as structures are erected), and adequate measurement geometry, stability and survival. In the event of a beacon being damaged, destroyed or rendered useless, there must be sufficient redundancy of beacon numbers within the control network, for the geospatial integrity to be restored and/or assured. There should not be a situation where the ability to execute dimensional control and other surveying activities is materially compromised, nor should any associated consequences negatively impact on project schedule or geospatial quality.

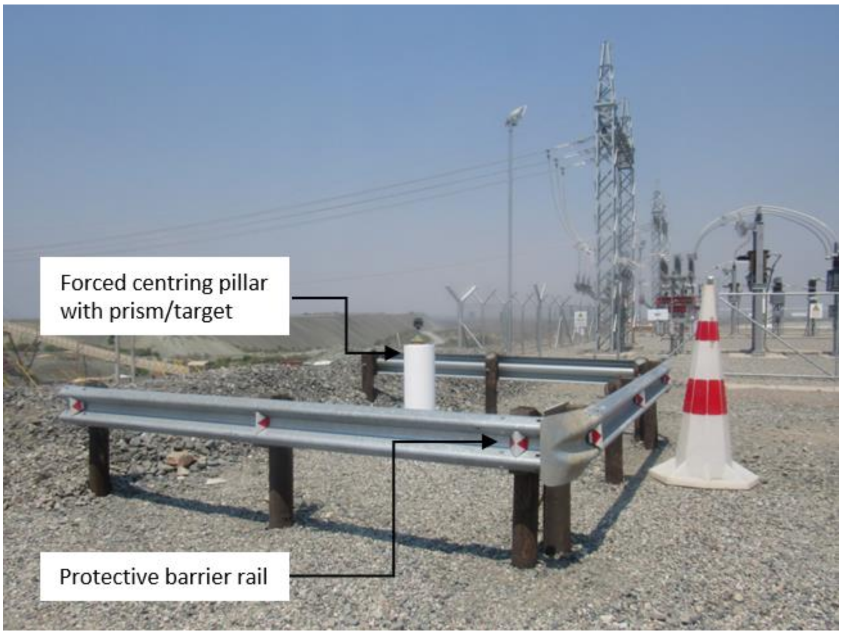

Figure 6.2 Pillar beacon with protection barrier (source: Author's collection)

Forced centring concrete pillar beacons are recommended, to remove any error associated with centring error of survey equipment on a beacon. Typically, this requires that a suitable beacon plate is set into the top of the beacon upon construction. At the centre of the beacon plate is a 5/8-inch Whitworth thread which corresponds with the universal thread common to most survey instruments. Survey equipment is simply screwed onto the beacon plate, to ensure repeatable forced centring for angular, distance or GPS measurement.

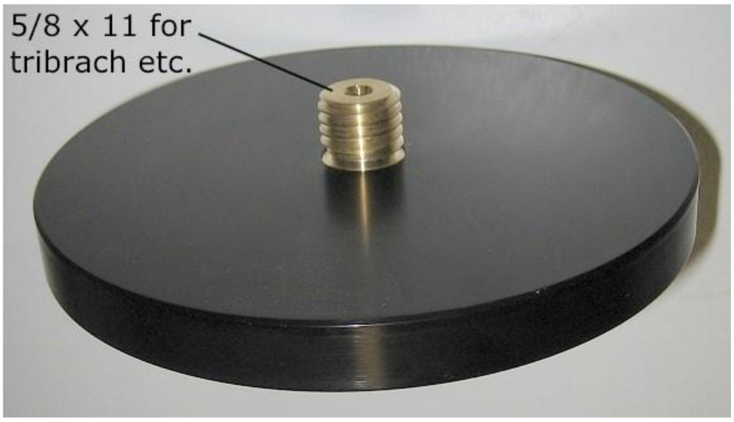

Figure 6.3 **Forced centring plate** (source: www.swisstek.com)

A suitable benchmark point (e.g. stud) should be imbedded at a convenient point into the beacon, to serve as an accurate height reference point for levelling.

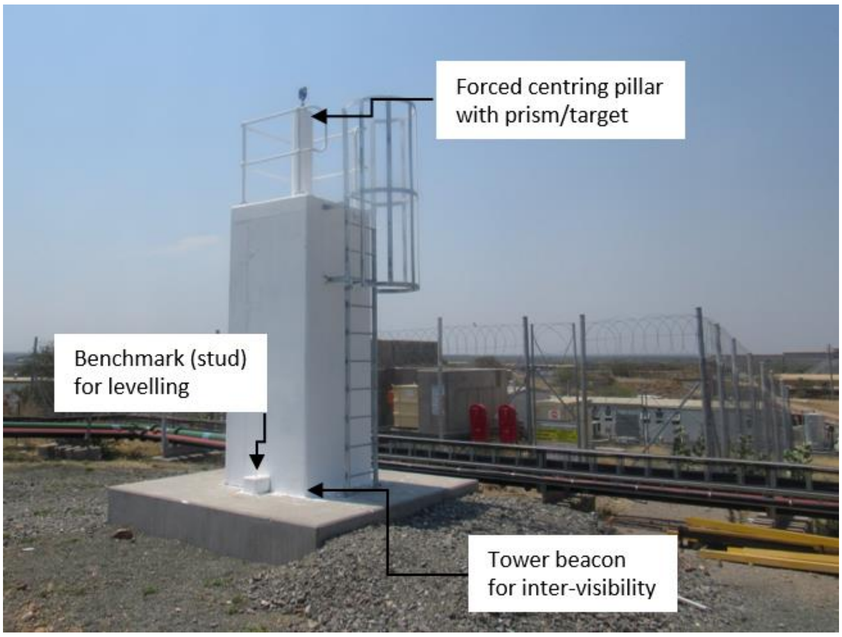

Figure 6.4 **Tower beacon** (source: Author's collection)

6.6 Establishing underground survey control

In the discussion of the survey control network in 6.5. above, it was mentioned that the network would typically be incorporated into the control network of the mine during development, and subjected to mine surveying statutory requirements. Knowledge of and compliance with these statutory requirements is therefore mandatory – this will be discussed further in Chapter 7.

There are a number of geospatial considerations to transferring survey control from the surface to underground. The purpose remains the same as for development of surface infrastructure, i.e. to enable the design of the underground mine to be established in physical space and to guide mine development and future underground mining operations.

According to Schofield (1993), “The essential problem in underground surveying is that of orientating the underground surveys to the surface surveys, the procedure involved being termed correlation”.

It is fundamentally important to consider that the geospatial foundation of the project (including the mineral resource, reserve and mine design) was established from surface survey control. It is therefore imperative that underground survey control and surface survey control be accurately correlated.

Another key consideration is that underground surveying requires completely different methods of survey and accuracy assessment – the measurement redundancy provided by linking to multiple control points within a survey network is not available. Rigorous methods of survey measurement, processing and assurance must be consistently applied. Appropriately regular confirmation of bearing by means of gyro-theodolite must be a mandatory component of the survey assurance process.

Detail of surveying processes will not be provided here and can be found in other publications. However, depending on the physical attributes and location of the orebody, underground access can be either by vertical shaft or by a decline (tunnel), or both. Transferring surface survey control underground via a decline is significantly less challenging (technically and physically) than by vertical shaft. In fact, vertical shaft surveying can be regarded as a highly specialised area of practice (with associated scarcity of skills, as noted by Bennett and Livingstone-Blevins, 2015).

The principal difference between vertical shaft and decline surveying is that survey control and orientation in a vertical shaft are typically transferred by means of plumb wires (of known position and height on surface) which are regularly stabilised down the shaft by passing through steady-brackets. Orientation distance is limited by the distance between the plumb wires, as dictated by the shaft diameter. Checking of bearing by gyro-theodolite can only occur once shaft break-away tunnels have advanced enough to provide adequate distance between traverse points. However, for a decline, orientation can be extended directly from the surface control network, down the decline. Orientation distances are significantly longer than for shaft surveying and regularly checking of bearing by gyro-theodolite is immediately possible.

To provide an indication of the extent of underground control requirements, Bennett and Livingstone-Blevins (2015) provided the following information on shaft, decline and access development metres in Table 6.2 for the Venetia Underground Project.

Table 6.2 Development metres (after Venetia Underground Project, 2015)

Description	**Start**	**Finish**	**Development metres** (rounded off)
Decline	04-Mar-14	17-Jul-17	4 511
Production shaft (vertical)	20-Oct-14	14-May-18	1 070
Decline ramp 500 to 900	04-Jul-17	11-Feb-21	4 708
Service shaft (vertical)	16-Feb-15	29-Aug-19	1 065
Common access	10-Apr-16	03-Jul-20	5 920
Maintenance facilities	12-Feb-18	01-Jun-21	1 870
Common water handling	25-Jul-18	29-May-21	2 999
Common ventilation	04-Mar-17	12-May-21	4 075
Common ground handling	10-Jun-17	21-Sep-20	3 940
K01 mining method	07-Aug-18	13-Aug-22	23 290
K02 mining method	03-Sep-18	03-Mar-22	15 155
Total	**04-Mar-14**	**13-Aug-22**	**68 601**

Figure 6.5 shows an isometric view of the mine design, to demonstrate the geometric complexity for establishment in physical space.

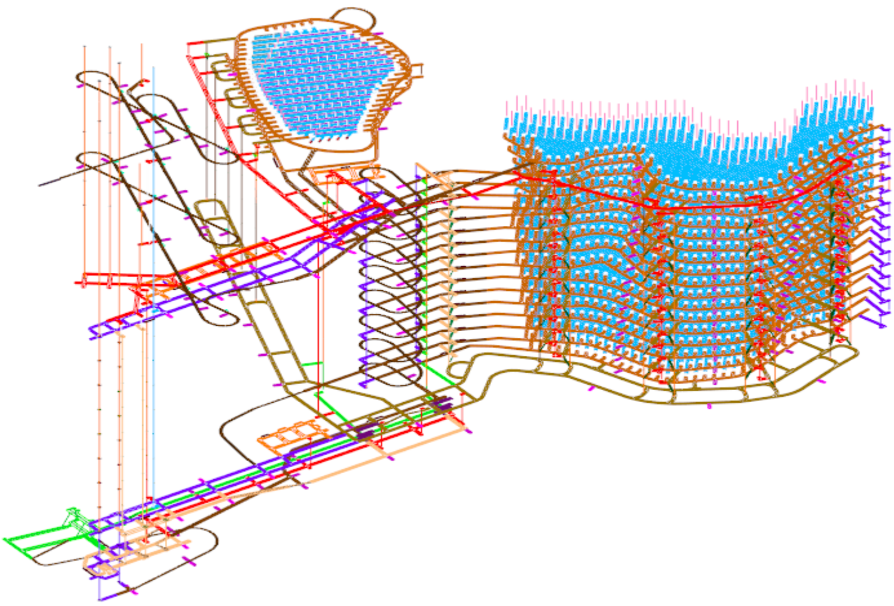

Figure 6.5 Venetia underground design (source: De Beers Consolidated Mines)

6.7 Local coordinate system for engineering and construction

As mentioned in the introduction to this chapter, construction requires that engineering designs are established in physical space, accurately. Key to their establishment is the requirement that dimensions established on the ground, from plan (design), are the same as the design dimensions (within a specified tolerance or accuracy). In other words, 1 metre from plan is exactly 1 metre on the ground.

This requires that the corrections for a specific map projection (to project from the curved surface/reference ellipsoid to a plane/flat map surface) must not be applied. Conversely, should engineering design be superimposed or referenced to a topographic map, the projection corrections associated must be reversed – an easy process when using digital mapping (e.g. in a CADD system).

The practical aspects of this will now be discussed, with specific reference to a South African example.

6.7.1 The South African Coordinate Reference System

As described in Chapter 3, the South African Coordinate Reference System is a South oriented Transverse Mercator projection (therefore, projection factors or corrections have been applied), where North = 180°.

2° wide belts running north to south cover the country, with central meridians on every odd degree of longitude, starting in the west at 15° and ending in the east at 33° cover the country (Survey Handbook, 1991). Hence the nomenclature of Lo15, Lo17…Lo33 to describe each belt.

Y-coordinates are positive west of the central meridian and negative east of the central meridian. X-coordinates are positive, measured from a zero origin on the Equator (Survey Handbook, 1991).

Angles are measured in a clockwise direction.

Figure 6.6 shows the above-described system attributes for Lo 29 (Survey Handbook, 1991), and the local engineering system project area (Thomas, 2014) to be described in 6.7.2.

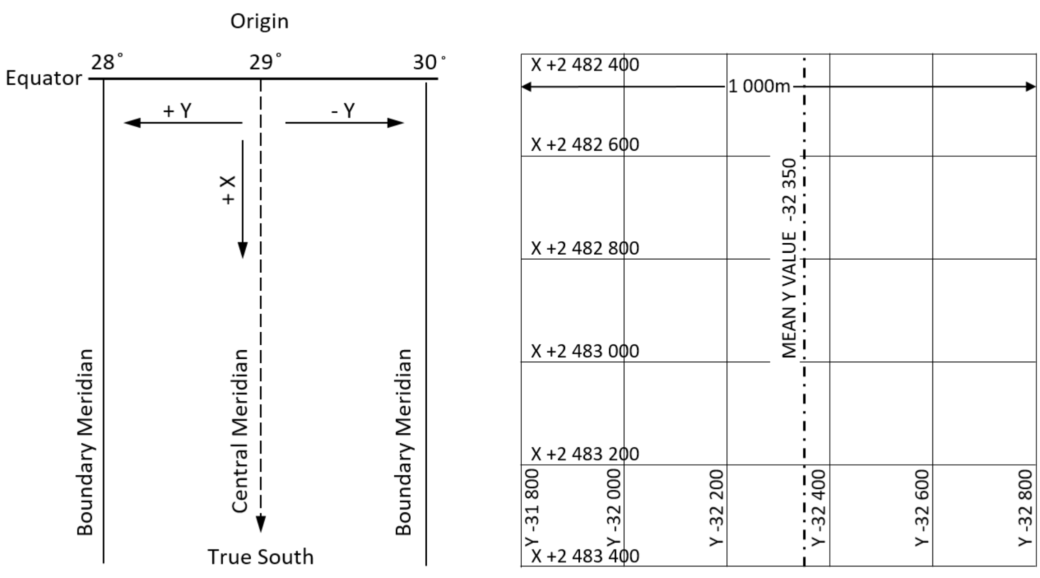

Figure 6.6 Lo system and local engineering system (after Survey Handbook, 1991 and Thomas, 2014)

For example, on Lo 29 (Cape), coordinates of Y = -32414.933m X = 2482569.503m mean:

- A central meridian of 29° E;
- 32414.933m east of the central meridian;
- 2482569.503m south of the Equator; and
- Cape Datum (using a modified Clarke 1880 ellipsoid, i.e. coordinates established prior to the 1st January 1999 change in the coordinate reference system).

These coordinates would require transformation to a local engineering coordinate system, free of projection corrections, for dimensional control of construction where dimensions established on the ground from plan (design), must be exactly the same as the design dimensions.

6.7.2 Local engineering system

In the example under discussion, the South African Coordinate Reference system described above is the basis of topographical mapping and information for the mine being established and to which engineering designs are referenced. In this example, the project is using Lo 29, a 2° wide band, which equates to approximately 222 500m in width, or 111 250m on either side of the central meridian. However, a project construction site (where the highest accuracy is required) is significantly smaller in extent, say 1 000m x 1 000m. This would exclude the overall project footprint covering features such as access roads, powerlines and pipelines.

According to Poos (2003), if a local mine coordinate grid system is required, there should be a significant difference in easting (Y) and northing (X) coordinates between the original and new/local systems. Poos also recommends the calculation of a coordinate conversion (transformation) between the two systems, for ease of transfer of coordinates. However, what is still required is that the projection corrections for sea level and for scale enlargement must be reversed. Due to the limited areal extent of a typical project, other projection corrections may be ignored. This process is described below.

There are two typical approaches to establishing a local engineering system of coordinates, namely:

- Rigorous processing of surveying measurements for the control to establish plan and height control "ensuring sufficient redundancy in observations to allow proof of accuracy" (RICS, 2014b), linked to a nominal project origin and without applying any corrections for scale enlargement and height above sea level; or
- The above-mentioned rigorous processing, linked to the national coordinate reference system and applying corrections for scale enlargement and height above sea level. A post-process coordinate transformation would then be determined to link to a nominal project origin and reverse the corrections for corrections for scale enlargement and height above sea level.

The latter is described briefly (in first-principles) below:

- Subtract constants from the Y and X coordinates which are large enough to significantly differentiate the local engineering system (from the original);
- Nominate a new central meridian for the project which would typically run through the centre of the construction site. In this case, in a north/south direction, as no rotation of axes is required;
- Determine the average height above sea level of the project site and determine the sea level correction (as described in Chapter 3). The inverse of this correction will be used as a transformation factor;
- Determine the average Y coordinate (distance from central meridian) of the site and determine the scale enlargement correction (as described in Chapter 3). The inverse of this correction will be used as a transformation factor;
- Combine the inverse sea level correction and inverse scale enlargement correction into a single transformation scale factor; and
- Convert the coordinates of the original network to the local engineering by subtracting the coordinate constants (to shift to the nominal project origin) and applying a rotation (in this case, zero) and scale factor to inter-beacon distances and directions.

The following example from the author's collection shows the result of the above-described process when the factors are used to determine a Helmert transformation for a project site. The original inputs to the transformation were (Thomas, 2014):

- Coordinate constants of Y +30 000m and X -2 480 000m (note signs);
- Average height above sea level 718m;
- Average distance from central meridian (Y coordinate) of 32 350m.

HELMERT (1st Order) CO-ORDINATE TRANSFORMATION BY PARAMETRIC ADJUSTMENT

COMMON CONTROL POINTS

	PROJECT CONTROL Lo29			PROJECT CONTROL ENG	
Name	y	x	NAME	Y	X
BCN1	-32414.933	2482569.503	BCN1	-2414.933	2569.503
BCN2	-32177.456	2482941.175	BCN2	-2177.432	2941.212
BCN3	-31992.296	2483219.246	BCN3	-1992.254	3219.310
BCN4	-32239.557	2483317.250	BCN4	-2239.539	3317.324
BCN5	-32619.397	2483252.967	BCN5	-2619.417	3253.035
BCN6	-32578.666	2482931.624	BCN6	-2578.682	2931.660

TRANSFORMED CONTROL POINTS

NAME	TY	TX	DY	DX
BCN1	-2414.933	2569.503	±0.0000	±0.0000
BCN2	-2177.432	2941.212	+0.0002	+0.0002
BCN3	-1992.254	3219.310	-0.0003	-0.0002
BCN4	-2239.539	3317.324	+0.0002	±0.0000
BCN5	-2619.417	3253.035	-0.0002	+0.0001
BCN6	-2578.682	2931.660	±0.0000	±0.0000

TRANSFORMATION PARAMETERS

CY =	30001.7778
CX =	-2480245.9585
A =	1.0000990666
B =	0.0000005774
Scale =	1.0000990666
Swing =	+0.00.00.1
Std. Devn =	0.0002
Mean Y-Shift =	30000.0080
Mean X-Shift =	-2479999.9535

Figure 6.7 Transformation Lo29 to local engineering system (source: Thomas, 2014)

Due to the calculation process, Thomas reported that variances of 0.25mm were noted. Thomas concluded; “The transformed control points between the preliminary and final transformation for both BCN1 and BCN5 do not change and the final standard deviation is 0.0002m. Even though the scale factors do change it is negligible and therefore does not affect the transformation of co-ordinates between the two systems for the project”.

The original elevations above sea level of the beacons continue to be used throughout the project, i.e. mean sea level will be retained as the project height datum.

6.8 Requirements for project surveying effectiveness

Schofield (1993) recommends that a system of work be established on site to ensure accurate dimensional control, before commencement of construction. In this context, the terms “setting-out” and “dimensional control” should be regarded as synonymous.

This system of work should consider the following factors:

- “A complete and thorough understanding of the plans, working drawings, setting-out data, tolerances involved and the time scale of operations…;
- “A complete and thorough knowledge of the site, plant and relevant personnel. Communications between all individuals is vitally important. Field checks on survey control already established on site… should be carried out at the first opportunity;
- “A complete and thorough knowledge of the survey instrumentation on site, including the effect of instrumental errors on setting-out observations…;
- “A complete and thorough knowledge of the stores available, to ensure adequate and continuing supply…;
- “Office procedure should be so organised as to ensure easy access to all necessary information. Plans… amended or superseded should be withdrawn from use…All setting-out computations and procedures used should be clearly presented, referenced and filed; and
- “Wherever possible, independent checks of the computation, abstraction, extrapolation of the setting-out data and the actual setting-out procedures should be made”.

Schofield cautions that the above-described work should never be delegated without effective supervision to junior or inexperienced members of the site team, thereby inferring the requirement for effective and technically competent process management.

6.8.1 Contemporary challenges to effectiveness

It is useful to relate contemporary challenges to geospatial effectiveness on a current mine establishment project, as shared by the (mine) owner’s survey principals. Interestingly, the issues raised appear to be typical of construction projects, as encountered in research sources such as text books, professional publications and guidance notes. The issues are also typical of the author’s experience and show a high level of alignment with Schofield’s recommended system of work.

In relating their joint experience, Mafoko and Zitha (2017) believe that the following summarised issues are typical of the project environment:

- Contractual specifications for surveying accuracy and how the quality thereof is to be assessed are absent, ambiguous, or deficient;
- Scarcity of key technical and management skills impacts on project efficiency. Similarly, sub-optimal capacity and capability affects leadership and work execution;
- There is a significant shortage of suitably skilled and competent surveyors for the complexity of the project;
- The role of the surveyor in the project is not defined or is typically overlooked, leading to challenges and conflicts in surveying service delivery;
- The reporting hierarchy and authority of the surveying discipline within the project is not optimally aligned for it to deliver on its mandate, particularly in the context of statutory authority, unbiased reporting and geospatial assurance;
- The value of the survey control network and its importance are not respected;
- Deficient document version control management results in incorrect plans or designs being issued, i.e. no single version of the truth, resulting is significant cost overruns for affected work packages (up to 260% reported for earthworks);
- Integration of contractor's and owner's team surveyors should require common systems and technology, access to a central database of geospatial and design information, and if possible, shared facilities;
- Ownership of the survey function of the project should rest with the (mine) owner's team, to ensure clear lines of reporting and rapid response to any geospatial anomalies or deviation from specification;
- Selecting the right surveying equipment and technology is imperative and must consider the environmental conditions of operations (up to 46° C ambient temperature); and
- Contractual tolerances for bills of quantity must be clearly defined, to ensure quality-based payment and to minimise the potential for contractual dispute.

As mentioned in the previous chapter, an effective integrated geospatial strategy and execution plan, finalised during project evaluation, would have addressed the above-mentioned challenges through a structured and collaborative cross-functional process. It would have addressed requirements of:

- Human resources – people, to ensure appropriate capacity and capability availability aligned with the project's schedule and needs;
- Hierarchy and authority – roles, responsibility and authority within a defined organisational and communication hierarchy, including operating standards aligned with project technical specifications;
- Integration – of information, processes and technology, through shared systems and facilities;
- Quality – a precise survey control network established before the commencement of mine construction and development; and
- Service delivery – operationally ready surveying capacity and capability established before the commencement of mine construction and development.

6.9 The surveyor's role as auditor of geospatial compliance

During mine establishment, there can be numerous contractors executing work packages which require dimensional control, some in construction and others in the development of mine workings. It is reasonable to assume that these contractors provide their own surveying capacity, which may or may not fall under the general management of the EPCM contractor (principal contractor). Construction or development work packages typically have discrete measures of quantity, quality and cost in terms of a master contract or sub-contracts. Overall project management would typically be the responsibility of the mine/project owner's team.

To provide the owner's team project manager with effective geospatial assurance, it is strongly recommended that the overall coordination of surveying activities is conducted by an owner's team survey function. As mentioned by Mafoko and Zitha (2017), contractor's and owner's team surveyors should be integrated and have common systems, technology, access to a central database of geospatial and design information, and if possible, share facilities.

The value additive role of surveying and geospatial information in risk mitigation during mine establishment should be directed at:

- Dimensional control and assurance;
- Measuring analysing and reporting of actual vs. planned performance against design and schedule for bills of quantity:

- Geospatial analysis for clash detection;
- Ensuring availability and execution of surveying functions in support of the project schedule; and
- Correlating surface and underground survey control for underground mines.

However, the principal role of the owner's team surveyors should be that of independent auditor of all work packages which have measures of quantity, quality and cost for contractual compliance, which are directly linked to geospatial information and establishment of designs in physical space. Agreed contractual tolerances should determine what is within specification for payment and what falls beyond tolerance with associated penalties. Some examples of such work packages are:

- General earthworks;
- Structural dimensional control;
- Excavation dimensional control;
- Ground support; and
- Volumetric measurement of concrete and shotcrete.

Ongoing review of designs by surveyors for clash detection and early design remediation should prevent standing time and re-work, both of which impact on schedule and cost efficiency.

From the author's experience, surveying is regarded as a basic service, as opposed to being core to project control. Consequently, the assurance role of surveyors in geospatial risk mitigation, and supporting the project schedule and cost efficiency is often overlooked. This opinion is supported by the "system of work" recommended by Schofield (1993) and the contemporary challenges related by Mafoko and Zitha (2017).

For optimal influence on the project, survey measurement and assurance processes must be undertaken at a frequency which supports operational control and project management objectives. This frequency will need to be guided by contractual, work package and schedule requirements. In addressing this, Mafoko and Zitha, adopted the practice of "short-term-interval-control" or high frequency of measurement, to ensure that, as far as reasonably possible, survey reporting provides leading indicators or early detection of deviation from dimensional tolerances.

Appendices C and D show examples of reporting and assessment of compliance for geospatial assurance and contractual compliance.

6.10 Conclusion

This chapter, Establish, was the third of the central chapters which follow the structure of the mining value chain, following from Explore and Evaluate. Its purpose was to describe geospatial control, positioning, monitoring and reporting during mine establishment, and effective surveying practice and management of geospatial information.

The establishment, or construction and development phase of a mine is when engineering and mine design are established in physical space. Cross-functional dependency on geospatial information remains high (greater than 70% - estimated), but its role and that of the surveyor has moved from passive to active, directly enabling construction and development progress. Failure to effectively integrate control, share and use this information can result in escalated financial (cost) and safety risks, and possible reputational risk should consequences be severe.

Construction, infrastructure development and mine development require surveying and dimensional control processes to adhere to high levels of accuracy, with tolerances measured in millimetres. To achieve the required accuracies requires high levels of survey skill, competency and technical rigour.

To address the above-mentioned accuracy, information from a number of sources was presented to describe the key requirements for establishing a suitable survey control network, with reference to network attributes, equipment calibration responsibilities, accuracy standards and accuracy assessment. A method to establish a local engineering coordinate system (grid) was presented, with reference to actual mine establishment records. Construction accuracy requirements of 2mm ± 3mm from the author's experience were validated against guidance accuracies presented by the Royal Institution for Chartered Surveyors (UK). Similarly, the means to combine variable accuracy requirements for different applications was presented.

Challenges to surveying effectiveness shared by survey principals on a current mine establishment project were presented, aligning exceptionally well the author's experience and the assessment of information referenced from different sources. The following key criteria for geospatial effectiveness were identified:

- The fundamental importance of geospatial information as the foundation for mine design, construction and development;
- The requirement for a highly accurate survey control network, established prior to construction – remaining intact, stable and functional for the duration of construction;
- The requirement for adequate capacity and capability (people, information, processes and technology), aligned with the project's schedule and needs;
- The requirement to have a complete and thorough knowledge of plans, designs, specifications, tolerances, roles and the project schedule; and
- The requirement for appropriate hierarchy and authority, describing roles, responsibility and authority within a defined organisational and communication structure, including operating standards aligned with project technical specifications.

Finally, the potential value contribution of surveying to a project was presented. The author contends that the principal role of the owner's team surveyors should be that of independent auditor of all work packages which have measures of quantity, quality and cost for contractual compliance, which are directly linked to geospatial information and establishment of designs in physical space. This assurance role of surveyors in geospatial risk mitigation, and supporting the project schedule and cost efficiency, is often overlooked, consequently the true value of potential is not realised.

Chapter 7 will discuss measurement, monitoring, reconciling and reporting in the operational phase of a mine, and how these can support operational value drivers (the business of mining).

7. OPERATE

7.1 Introduction

Chapter 6 discussed geospatial aspects of project implementation and mine establishment, during which construction of mining infrastructure and development of mine workings commenced, and which concluded with the commissioning and handover of a mine ready to commence operation. The purpose of the chapter was to describe geospatial control, positioning, monitoring and reporting during mine establishment, and the assurance role of surveyors in geospatial risk mitigation, supporting the project schedule and cost efficiency.

The purpose of this chapter, Operate, is to describe the role of geospatial information and the surveyor as key enablers and contributors to safe, efficient and profitable mining.

The commencement of mining operations represents a break from the upstream value chain core processes of Explore, Evaluate and Establish during which significant capital was committed, at risk, for a yet-to-be realised return on capital employed (ROCE). Operate is the point at which a project begins to generate a cashflow in accordance with the mine's business and operational plans.

Cross-functional interdependencies will have shifted in accordance with operational processes (such as mineral resource management, mining, processing and environmental protection), however, geospatial information remains the foundation of mineral resources and reserves, grade control, mine designs and planning, mineral accounting, reconciliation and reporting. Effective control, sharing and use of this information is essential. The potential consequences of failing to do this effectively can be significant, escalating financial (cost), safety and legal risks. Therefore, the assurance role of surveyors or the surveying function is similar to that described in the previous chapter – it remains directed at geospatial risk mitigation and supporting operational efficiency.

This chapter will discuss the role of surveying in the context of measuring, monitoring, reconciling and reporting of mining operations in a manner which supports compliance (operational and statutory) and provides value through the provision of geospatial foresight to influence operational management decisions and control. It will describe how, by understanding business value drivers, surveyors can contribute significantly to business performance by aligning measurement frequency and output to provide operational geospatial intelligence, rather than focusing on traditional dimensional control, production reporting and statutory duties.

However, the statutory responsibility of the surveyor (or the engineer, depending on legislation in the country of operation) will remain unchanged – that is to provide accurate geospatial information, maps and plans of the workings to support the safe operation of the mine. Unlike preceding phases in the project, geospatial deficiencies in mine plans or related records escalate potential risk, the consequences of which could be single or multiple fatalities, or significant environmental impact – with associated ramifications for the business. Examples of significant incidents will be discussed in this chapter.

Dimensional control activities during mining are directed at establishing the mine design in physical space and measuring geometric, temporal and quality compliance with planned objectives, as well as guiding operations through or past physical hazards and stopping mining activities at prescribed limits of extent.

For optimal contribution by the surveying function, the geospatial strategy and plan discussed in Chapter 5 will need to have comprehensively addressed the operational, business and statutory requirements for mine operations and provided for appropriate survey resources at commencement of mining. This assigns the same level of importance to the surveying function as placed on other operational functions or disciplines in term of operational readiness planning.

It is not intended that this chapter describes methods of measurement, monitoring, reconciling and reporting – the objective is to describe how doing this can contribute materially to operational and business effectiveness. It is a prerequisite for success that the surveying function possesses a fundamental understanding of operational processes and activities to enable a shift to 'reporting what will happen vs. what has happened'. To demonstrate potential contribution, an example of an open pit production cycle of 'drill, blast, load and haul' is used, in which the optimal use of quality geospatial information for blast design and drilling can improve productivity, by enabling an increase in the rate and the efficiency of work.

7.2 ‘Operate’ as a core value chain process

As described in previous chapters, the objective of using the value chain as a common reference for all functions or disciplines involved during a particular phase of a mining project’s life-cycle, is to develop a mutual understanding of respective roles and contribution, thereby enabling alignment of purpose.

As graphically represented by the value chain, Operate, is the third phase in which several mining technical functions and disciplines are involved. Cross-functional interdependencies fit into a general production cycle, which includes mineral processing/extraction and transport of product (for sale, further beneficiation or industrial consumption).

According to Lane and Wylie (2014), “Mining companies are traditionally managed in silos, with each discipline owner or department head focusing on and managing key performance indicators (KPIs) very specific to their area of control. For example, the individual responsible for the ‘drilling and blasting activity’ focuses on KPIs relating to improving that activity, often without understanding the impact on downstream activities such as loading, hauling, and processing”. This observation supports the purpose of the value chain to identify cross-functional interdependencies, develop mutual understanding to enable effective collaboration and improve collective contribution to operational performance. It also suggests that KPIs can drive behaviour which is not supportive of cross-functional purpose.

Regarding alignment of purpose, the author proposes that it is of fundamental importance to understand that a mine is a business. Every employee is part of the business and every task or activity has both a technical (or practice-area) and business purpose. Understanding the upstream process or activity which feeds a current process or activity, and the contribution of current work on downstream processes or activities, can significantly improve outcomes. It follows that this understanding of work and of the points of transfer of information will lead to successful collaboration and improved efficiencies.

Figure 7.1 shows the core-process of Operate and its adjacent core-processes. Typical activities are listed below the core-process, to provide an indication of work required and the involvement of numerous functions, disciplines and other fields of expertise.

To represent the clear break from mine establishment processes, the upstream core process of Establish has not been included within the red block – see Figure 7.1. However, the link to Evaluate has strong upstream relevance, particularly the feasibility study, as it represents the techno-business evaluation on which the mine was established. Mineral resources and reserves, the business plan, life-of-mine plan, organisational structure, resourcing and equipping all relate back to feasibility study and implementation decisions.

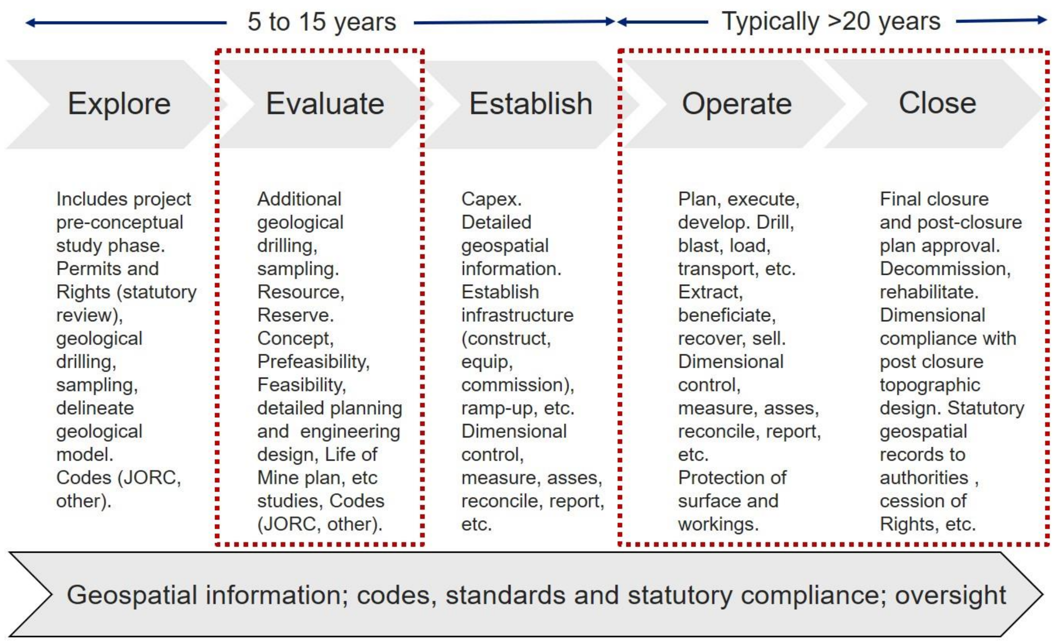

Figure 7.1 Value chain focus area (within red outline)

The functions and individual disciplines involved in Operate would typically be (but not limited to):

- Mining geology and mineral resource management;
- Mining, Geotechnical, Processing (Metallurgy) engineering;
- Geomatics disciplines (surveying, geographic information science, drafting);
- Ventilation and Occupational Hygiene engineering;
- Engineering (e.g. electrical, mechanical);
- Safety and Environment (impact monitoring, protection);
- *Information Technology*;
- Security;

- *Finance and Administration*;
- *Social/community professions*;
- External stakeholders, including government; and
- Legal (mineral and land tenure, access, permits, conditions of tenure)[2].

The functions or disciplines appearing in italics in the above list are unlikely to make direct use of geospatial information. The balance (greater than 80% estimated – up from the estimated 70% in Evaluate and Establish) are either reliant on, or make significant use of, accurate geospatial or spatially referenced information. Surveying is key to the provision of this information.

In commenting on cross-functional interdependencies within a legal context, Bennett (2011) noted the numerous interfaces of mine surveying "with several other mining departments, legal structures and possible international codes", which he used to develop a broad framework for practice and legal compliance.

7.3 Geospatial context

Due to the direct relationship of geospatial information to mine safety, mine surveying or the keeping of accurate mine maps/plans and records are highly regulated in several countries. This is principally to address protection of the surface and workings and extends beyond mine closure, i.e. there is a need for accurate records on location relative to features which may require protection from mining, and to proximity to hazards while mining and after cessation of mining.

Depending on country of operation, legislation may prescribe responsibility for the keeping of accurate mine maps/plans and associated records to the surveyor or to the engineer. Where legislation is absent, or not specific on this responsibility, guidance is provided by International Labour Organisation or other codes of practice (Bennett, 2011), or internal company standards. Irrespective of the controlling instrument, the responsibility for the keeping of accurate geospatial records, for mining and post-mining safety, rests with the mine owner.

[2] Inclusive of the surveyor's role in mining estate management activities, such as negotiation with land owners/farmers for access to or lease of land; compensation for impact of mining operations; mineral and land rights acquisition and/or renewal; quantifying royalty payments; and relocation of graves affected by mining.

For this chapter, the author has assigned the responsibility to the surveyor, as prescribed by legislation in countries such as South Africa, Australia and Ireland. However, in countries such as Canada, this responsibility rests with the appointed engineer/mine manager, as described by statutes of that country.

A common requirement of South African, Australian (legislation varies per State) and Irish mining regulations, is the appointment of a suitably qualified and competent surveyor to be in general charge of surveying and all associated activities on a mine. The surveyor is responsible for assessing and certifying as accurate and correct, keeping and preserving, prescribed geospatial information and records which have a bearing on safety or risk.

Irish legislation is specific in extending this responsibility to geospatial information from other sources, i.e. not from general mine survey records. Statutory Instrument S.I. No. 78_1970 – Mines (Surveyors and Plans) Regulations, 1970, S7. (2) states that "It shall be the duty of the surveyor for a mine to establish the accuracy as regards any matters which may involve substantial error or danger, of any such plans, drawings and sections of the mine *which have not been prepared by him* or to ensure that such accuracy is established by a person who is qualified to be appointed the surveyor for that mine." – Author's italics.

However, the role of the mine surveyor is also to measure, monitor, reconcile and report on mining operational activities. This involves routine activities, in support of the mining production cycle, for example:

- Dimensional and directional control, (such as setting out of mining blocks and blast patterns, and providing line and grades);
- Dimensional control for and measurement of mine residue deposits;
- Dimensional and directional control for infrastructure extension as mining advances;
- Volumetric measurement (ore, waste, stockpiles – in-situ and broken material);
- Extension of the survey control network, as required by mining activity;
- Mineral accounting;
- Mine production reporting;
- Reconciliation of mining vs. plan (quantity, quality, content, location, temporal/schedule); and
- Mining statistics reporting for statutory return/declaration to mining authorities.

From this, it clear that the mine surveying is a core function of mining operational execution and control.

7.4 Mine surveying and mine safety

Phillips, H, Emeritus Professor at the School of Mining Engineering of the University of the Witwatersrand, often used the adapted quote "Eternal vigilance is the price of safety" when speaking of mine safety.

As mentioned in the introduction to this chapter, deficiencies in mine plans or related records carry escalated potential risk, the consequences of which could be single or multiple fatalities, or significant environmental impact. The assurance role of the mine surveyor in the provision of accurate and correct geospatial information must always be viewed in this context. The surveyor must be "eternally vigilant" in this fundamental role, whether legislated, or not.

Examples of surveying activities associated with mine safety and protection of the surface and workings of a mine, are:

- Accurately establishing the mine design in physical space;
- Guiding/directing mining through or past hazards;
- Stopping mining at prescribed limits or boundaries;
- Monitoring of ground movement resulting from mining (e.g. surface subsidence or slope instability);
- Monitoring of mine residue deposits (design compliance and stability);
- Potential surface and/or underground flooding risk assessment;
- Showing on mine maps, plans or sections –
    - all known physical hazards, including voids, which may contain dangerous accumulations of noxious or flammable gas, or water;
    - all objects or areas which require protection from mining;
    - the full measured extent of all excavations (for future reference for mining or surface development);
- For underground mines, the preparation of mine rescue and ventilation plans; and
- The certification as accurate and correct of all information represented on such maps/plans.

Cawood and Richards (2007) discussed the specific duties of mine surveyors as prescribed by the South African Mine Health and Safety Act (Act 29 of 1996). Chapter 14 (of the Act) addresses protection of the surface and workings, citing examples such as "ingress of water or other fluid material into workings…rock falls, subsidence, cavities and collapse of surface structures at mines." Chapter 17 (of the Act) addresses duties of the legally responsible mine surveyor ("Competent Person"), and of the employer, regarding surveying, mapping and mine plans.

Importantly, Chapter 17 regulations include the requirement to keep plans "showing mine residue deposits containing fluid material" and "geological features that could affect mining". The inclusion of these plans in Chapter 17 places responsibility for the accuracy of detail depicted on these plans on the mine surveyor, despite content of the plans being provided by other functional areas.

The above-mentioned examples require effective communication from and to the mine surveyor of the risks associated with each activity, to ensure that risk exposure is anticipated and mutually understood. This communication should trigger appropriate responses, for example, mining towards geotechnically hazardous ground, voids, or other physical hazard would require specific precautions to be implemented, with associated assessment of risk severity. Similarly, mining towards an area which requires protection from mining may be associated with environmental restrictions, not safety risk. Again, effective communication of the mining advance should trigger a specific response and assessment of risk. This process of triggering action is generally referred to as a TARP (Triggered Action Response Plan), forming part of an operational control hierarchy.

The author contends that as a consequence of this operational focus on safety related compliance, the potential contribution of quality geospatial information to the performance of the business is typically overlooked or underestimated.

7.4.1 Significant incidents involving deficient geospatial information

It is appropriate to briefly describe two of the four mine accidents described in Chapter 2, to reinforce the role of mine surveying and mine plans in mine safety. It must be noted that mine plans and surveying records remain critically important in-perpetuity, to be referenced for possible future mining operations or for development of infrastructure on land affected by past mining operations, thus shifting geospatial application from mine safety to public safety. Hence, custodianship of plans and surveying records transfers from the mine owner to the State after mine closure. For example, Powell, *et al* (2010), discussed the need in the United Kingdom to examine and determine the accuracy of mine plans as old 150 years to address the hazards associated with abandoned mine workings.

- Gretley Colliery – New South Wales, Australia (1996). Nature of the incident: multiple fatalities caused by inrush of water from adjacent abandoned and flooded mine workings (Young Wallsend Colliery). Errors in the plans of adjacent abandoned mine workings, *provided by the state mining authority*, resulted in Gretley miners breaking through into the old flooded mine workings. Despite legislation at the time being silent on the responsibility of the mine surveyor regarding external geospatial records, the mine surveyor was found guilty of not verifying beyond doubt the accuracy of the old mine plans provided by the state mining authority (as would have been required under Irish mine surveying legislation), thereby setting a legal precedent in what is deemed as reasonable duty of care.
- Quecreek underground coal mine – Pennsylvania, USA (2002). Nature of the incident: non-fatal entrapment caused by inundation of the mine due to mining breaking through into adjacent abandoned and flooded mine workings (Harrison No. 2 mine). Accurate mine plans of Quecreek mine enabled the trapped miners to be located and extracted through a rescue drill-hole drilled to the position of entrapment. According to the Department of Labor Mine Safety and Health Administration (2003), "The primary cause of the water inundation was the use of an undated and uncertified mine map of the Harrison No. 2 mine that did not show the complete and final mine workings...The root cause of the accident was the unavailability of a certified final mine map for Harrison No. 2 mine in the State of Pennsylvania's mine map repository."

7.4.1 Drill-hole risk

"If you drill a hole, you leave a hazard" (Author, c. 2001).

It is necessary to draw attention to the risk associated with drill-holes and the need to know the position of such holes, accurately – a risk which is often overlooked at the time of drilling.

Whether drilled during exploration, as ongoing information gathering to improve geological knowledge, or for whatever reason, the author contends that every drill-hole becomes “legacy” hazard for future by mining operations. For example, such drill-holes may:

- Contain dangerous accumulations of water, noxious or flammable gas;
- For horizontal, in-seam or cover drilling, provide a path for material or rock particles to be ejected under force from blasting or blast concussion; and
- Contain metal casing, lost drill rods or drill bits, which when intersected by mining have the potential to cause a ‘hot spark’ capable of igniting flammable gas.

Similarly, the activity of drilling needs to consider the risk of intersecting active or abandoned underground mine workings and voids, thus causing potential harm. The planning and location of drilling activities should be done in consultation with the mine surveyor, to ensure that the proximity of mine workings or known voids are considered and appropriate action taken to avoid an unwanted and unsafe event. Examples of unwanted and unsafe events are:

- Drilling from surface or underground into active mine workings; and
- Drilling from underground into abandoned mine workings or voids with potential to cause inundation of the workings.

Maintaining adequate records of drill-holes and the effective awareness and communication thereof, is an essential risk mitigation measure.

7.5 Mine planning and resourcing to plan

Mine planning is typically an iterative process, starting with a Life of Mine (LOM) plan and progressing through various stages of increased granularity/detail over shorter periods/planning horizons. From the author’s experience, the planning hierarchy can be briefly described as:

- A Life of Mine plan – initially signed off during the project evaluation as the agreed plan for exploitation of the mineral asset and periodically updated as required by mining and market conditions (e.g. changes to modifying factors);
- A medium-term plan – typically covering a planning horizon of 3 to 5 years, providing more detail than the LOM plan, for capital budgeting and business planning purposes;

- A short-term plan – typically covering a planning horizon of 12 to 18 months. The level of detail is adequate for detailed budgeting and can also be referred to as the annual plan; and
- An operational plan – typically covering a 3-month operational control horizon.

The planning progression from LOM plan should be such that each following planning horizon is a sub-set of the preceding level of planning, to ensure alignment with the original plan on which the mine was established. This practice also enables current vs. previous plan and current vs. original plan reconciliation.

From this planning progression, the full capital expenditure, operational expenses and resourcing requirements for the mine are determined, budgeted and procured, to ensure that the right people, information, processes, technology and equipment are in place to deliver on the business and short-term plans, *at commencement of the plan's execution horizon*.

It is therefore reasonable to conclude that the following are known, at a granular level, agreed and appropriately resourced for effectiveness:

- Business value drivers and KPIs;
- Reporting and reconciliation requirements, formats and frequency; and
- Roles, responsibilities and accountability.

By extension, the role of the mine surveying function in "…measuring, analysing, reconciling and reporting on *the right KPIs* at a frequency which supports effective asset management" as described in Chapter 5, will be understood within the business, and within the survey function. This function must also be adequately resourced, as described above, to contribute to achieving the mine plan and business objectives.

In this context, the role has shifted from protecting value to identifying and supporting value creation.

7.6 Mine surveying as a contributor to value

The wrong KPIs can drive the wrong behaviours, for example achieving a tonnage mined target without reference to compliance with plan or other production quality metrics. It is therefore imperative that rigorous consideration be applied to defining what is to be measured and at what frequency.

The author contends that a survey function which is correctly resourced to measure, reconcile and report the right KPIs at the right frequency, shifts its contribution to providing leading indicators of actual performance, thus enabling improved operational control and management. Survey reporting becomes geospatial intelligence capable of influencing operational effectiveness and efficiency. It moves from reporting what happened, to what will happen.

In addition to its role of production auditor, a prerequisite would be that the survey function has a thorough understanding of the KPIs being measured and the interdependencies between KPIs or information and processes which feed into or influence a KPI, supported by value chain alignment of purpose. Also required is an understanding of the business value drivers to which the KPIs are aligned.

What has just been described is the MRM (mineral resource management) role of the mine surveyor, which includes mineral accounting and reconciliation, as typically practiced on South African precious metals and diamond mines. This is not the case globally, nor is it necessarily the case across and within mining companies. However, South African tertiary minerals surveying education and government examinations for assessing competency for legal appointment and responsibility, are purposely aligned with this MRM function.

Critical to the success of the above-described function is that what is being measured, and the frequency of measurement, have been rigorously reviewed and validated across functions as being totally relevant to supporting the business. The means to do this is beyond the scope of this topic, however, it is reasonable to assume that some form of asset optimisation process to identify key value drivers and associated KPIs will provide the validation required.

KPI validation, as opposed to replicating typical practice, should avoid the situation described by Drucker, in which he states that “there is nothing quite so useless, as doing with great efficiency, something that should not be done at all”, i.e. efficient reporting on the performance of processes which have little or no impact on operational and business performance.

The right KPIs, measured at the right frequency, drive the right performance.

7.7 The production cycle – identifying opportunity

Lane and Wylie (2014) described the production cycle of an open pit mine as "… a set of interconnected activities in a mining value chain", for example, drill, blast, load, haul, crush, process and sell.

For an underground mine, this could be adapted to drill, blast, load, scale, support, transport, crush, process and sell.

The EM Model[3] (Figure 7.2) simplifies the mining cycle to an absolute minimum, "Break Rock and Remove Rock", (followed by processes for beneficiation and sale).

The above descriptions have numerous sub-processes which describe individual activities that must take place within the production cycle and that are interconnected. This interconnectivity means that excellence in one activity does not necessarily mean improved productivity if a production constraint exists in a downstream activity (Lane and Wylie, 2014). This explains the failure of some activity-based KPIs within organisational silos to influence overall performance and business value. Therefore, a prerequisite for effectiveness is that all activity leaders must understand the interconnectivity of KPIs and the contribution thereof to business effectiveness.

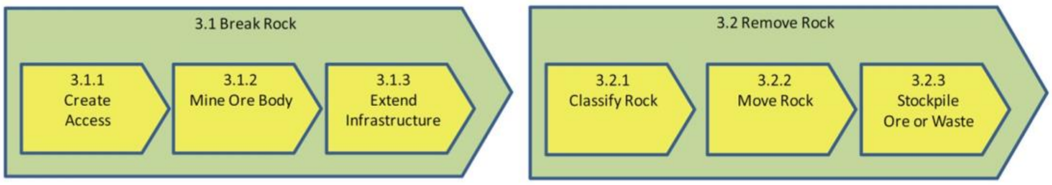

Figure 7.2 Production cycle and sub-processes (source: EM Model)

Furthermore, interconnectivity and cross-functional interdependencies (as referred to throughout this dissertation) are describing the same condition of the links between processes and activities on a value chain, and the requirement for mutual understanding of such processes and activities to enable effective alignment of objectives. Understanding and alignment have the value additive potential to fundamentally improve productivity.

[3] The Exploration and Mining Business Reference Model (2010)

A common formula for expressing production is:

Production = Rate x Time (Cambitsis, 2012),

i.e. the work rate of an activity and the time spent on that activity determines the quantity produced. This cannot be contested; however, the limitation of this formula is that it does not accommodate *quality* or the *interconnectivity* of processes. Further work would be required to assess the influence of all activities comprising a process, e.g. all the activities which contribute to effective hauling productivity. This is where the opportunity lies for driving performance by measurement and reporting KPIs that contribute to effectiveness.

7.8 Contributing value to drill, blast, load and haul

Unless cutting rock, production starts with drill and blast.

Returning to the generic formula for production and adapting this to express value, the focus moves from a measure of quantity to that of quantity and quality:

Quality production = Rate (of quality work per unit of time) x Time (to execute quality work).

The measure of quality would be defined by the activity and its optimal effectiveness. For example, drill and blast quality could be linked to the following:

- Geometric compliance with blast design (breaking rock in the right place);
- Technical compliance with blast design (correct position, alignment and depth of blast holes);
- Fragmentation and moisture content (of broken rock); and
- Confinement of fragmentation and geotechnical impact (limited damage to adjacent in-situ rock – slope or hanging wall/roof, footwall/floor).

To use an open pit example of the benefits of effective drilling and blasting, the following value contribution should be considered:

- Blast limits are achieved, ensuring geometric compliance with plan, and if applicable, to final cut limits;
- Pit slopes are undamaged by blasting activity, resulting in improved slope stability (subject to the geological and geotechnical characteristics of the rock);

- Compliance with blast design (e.g. heave or cast) contributes to loading and grade control effectiveness;
- Fragmentation benefits the rate of loading (productivity), crushing and processing (if ore); and
- An even bench floor benefits the rate of hauling and reduces mechanical wear on the loading and hauling fleet, improves fuel consumption (reduced rolling resistance) and increases tyre life.

The contribution of geospatial information and the survey function to this process begins with providing topographic detail of appropriate quality to enable optimal drill and blast design. This quality and detail may differ from the topographic information used for general volumetric measurement, particularly on bench free-faces, therefore it is reasonable to assume that additional surveying will be required, with associated resourcing. This also requires an understanding of the level of detail required by the blast design process and the interconnectivity of activities, and effective communication with drill and blast activity leaders.

Linking the above-mentioned quality attributes and effective rock breaking to multiple downstream benefits, it is reasonable to conclude that accurate and effective surveying and assurance for drilling and blasting is the first point in the production cycle at which the survey function can materially contribute to operational effectiveness and business performance – therefore, effort, resources and understanding must enable this contribution. Survey measurement processes and reporting must be directed at providing geospatial intelligence in support of production processes – and must be fully integrated (into production processes) and understood to be a key enabler of effectiveness and efficiency, not merely a positioning requirement.

7.9 Contributing value by providing geospatial intelligence

To reinforce the importance of geospatial intelligence and to ensure common understanding of the concept, further discussion is appropriate.

The objective of measuring, monitoring, reconciling and reporting the right KPIs at the right frequency is to enable or influence improved operational control and management. Survey reporting becomes geospatial intelligence, capable of influencing operational effectiveness and efficiency, when done proactively rather than reactively and includes appropriate opinion or insights, thus providing leading indicators for the effectiveness of the process or activity being reported.

Additionally, by addressing the interconnectivity of activities and associated KPIs, reporting can move from an approach of what happened, to what will happen if a reported trend continues. Leading indicators provide the foresight to anticipate an outcome and, if required, to institute measures to mitigate a potentially negative outcome. Similarly, leading indicators can be positive and reinforce the continuance of current practice.

An example of the potential contribution of providing geospatial intelligence is reporting on the consequence of failing to remediate a deviation from plan, such as the future impact of not mining a bench back to design limit. Typical reporting would indicate actual position of mining vs. the planned position (limit) and perhaps a compliance-to-plan metric. However, the inclusion of an assessment of the consequences (of not mining to limit) on subsequent mining, e.g. potentially compromised slope design, the impact on planned production, possible geometric constraints to mining, and the potential risk and revenue impact of the deviation, provides leading indicators and transforms geospatial information into geospatial intelligence for operational response.

This approach can be applied to numerous other activities, such as deviation from planned waste stripping or underground development on the ability to access the orebody for future mining, or the failure to expand residue deposit containment facilities in alignment with current and future mineral processing rates.

The author contends that by adopting this practice consistently to the relevant processes and activities, mine surveying can make a material and positive contribution to the business of mining.

7.10 Reconciliation

Reconciliation is a critical management tool. Its purpose is to report operational performance against targets (or modelled estimates), thereby contributing to operational and business effectiveness.

Fouet, *et al* (2009) described reconciliation as the measurement of variance between two like measures at different points along the mining sequence, noting that mining companies use reconciliation factors as key performance indices for operational assessment.

Hargreaves and Morley (2014) expanded on this and proposed the practice of "multidisciplinary… universal reconciliation… across the entire mining value chain to strengthen the interplay between the technical disciplines and to identify opportunities and loss of value in order to maximise operational performance". They identified "insufficient feedback between technical discipline silos" as a frequent disconnect between actual production processes and the models on which operations were planned, and proposed universal reconciliation as "an opportunity… to reassess how the operation should be run and how operational effectiveness should be measured."

Fouet, *et al*, Hargreaves and Morley were addressing the same issues raised in this chapter, namely cross-functional interconnectivity and the requirement to measure, monitor, reconcile and report the right KPIs to improve operational control and management.

According to Riske, *et al* (2010) there are three types of reconciliation, namely spatial, temporal and physical.

- Spatial reconciliation addresses the three-dimensional location of mining activities to measure "absolute performance between predictive models and the actual results determined by mapping and survey measurement."
- Temporal reconciliation "compares performance across the mining sequence on time based ranges (such as shifts, days, weeks, months, years etc.)", i.e. tracking data over time. It may or may not be spatially referenced.
- Physical reconciliation focuses on "attributes such as contained metal, various quality parameters and volumes. Typically, physical reconciliation is combined with temporal data and is generally reported…quarterly or annually".

From the descriptions of the purpose and different types of reconciliation, survey measurement is a significant contributor to the reconciliation process, inclusive of mineral accounting for physical reconciliation as typically practiced on South African precious metals and diamond mines. However, to enable optimal contribution to reconciliation processes, the survey function must fundamentally understand the cross-functional interdependencies (the interconnectivity of processes) and provide data and information to support each reconciliation process.

Figure 7.3 shows typical reconciliation relationships across the mining value chain, encompassing spatial, temporal and physical elements.

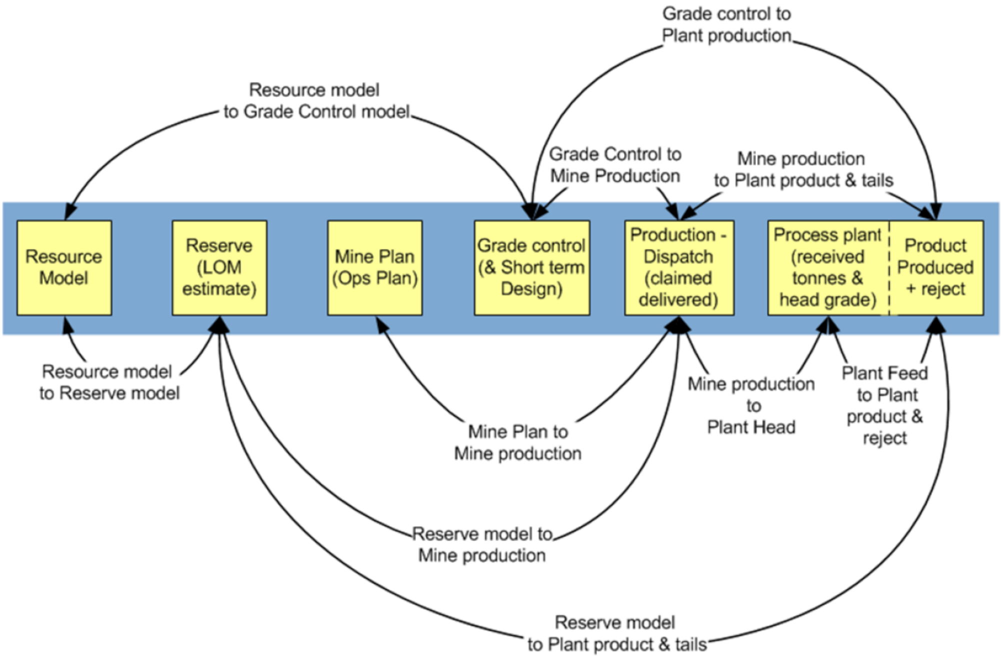

Figure 7.3 **Reconciliation relationship across the mining value** (source: Morley, 2014)

Figure 7.3 is indicative of typical reconciliation comparisons, however, depending on operational and business control needs there can be any number of elements identified for reconciliation, to measure performance against targets (actual vs. planned).

7.11 Conclusion

This chapter, Operate, was the fourth of the central chapters to follow the mining value chain. Its purpose was to describe the role of geospatial information and the mine surveyor as key enablers and contributors to safe, efficient and profitable mining.

The author proposed that it is of fundamental importance to understand that a mine is a business, that every employee is part of the business and that every task or activity has both a technical (or practice-area) and business purpose. Understanding cross-functional interdependencies and the interconnectivity of operational activities supports collaboration and can significantly improve operational performance effectiveness by monitoring and responding to the right KPIs.

Geospatial intelligence was described as the means to provide foresight to influence operational management decisions and control by shifting to reporting leading indicators, i.e. what will happen vs. what has happened. The foresight provided enables an outcome to be anticipated and, if required, measures to mitigate a potentially negative outcome to be instituted.

To demonstrate the role of geospatial information and the survey function as key enablers and contributors to safe, efficient and profitable mining, two principal responsibilities of the mine surveyor (or engineer) were discussed, in technical and value contribution terms, namely:

- Protection of value – the requirement for keeping accurate plans and records of the surface and workings of a mine – typically prescribed by regulation or other statutory instruments; and
- Enabling value creation – the requirement to measure, monitor, reconcile and report on operational processes, i.e. production auditing and reconciliation to improve operational effectiveness and efficiency.

Separating value contribution into the above-mentioned categories (of value protector and value enabler) allowed each to be reviewed comprehensively in isolation, thus providing clarity regarding the purpose of the mine surveying function on an operating mine, for mine surveyors and other mining functions and disciplines.

The contribution of mine surveying to mine safety and the protection of value, i.e. the principal purpose of protecting the surface and the workings of a mine, was described together with legal and operational context. To enable understanding of the value of accurate survey records, maps and plans, and the destructive potential of deficient geospatial information, two significant mine incidents were described which involved incorrect or incomplete plans of the position and extent of old mine workings. Both incidents demonstrated the significant consequences associated with geospatial risk and the requirement for accurate records, maps and plans to be kept in-perpetuity, hence the custodianship of such to transfer from the mine owner to the State. Importantly, it was noted that these geospatial records carry dual relevance, i.e. for both mine and public safety – an aspect for further mention in the following chapter on mine closure.

The contribution of mine surveying to value creation focused on opportunities to improve operational effectiveness and efficiency, by measuring, reconciling and reporting of KPIs that are aligned with operational value drivers. Detail on surveying methods and practice was intentionally excluded – with the preference being to describe the means to consistently identify opportunity for value contribution, by developing a fundamental understanding of operational processes and activities and integrating practice to optimally support operational activities. This approach addressed the cross-functional interdependencies, interconnectivity of activities and limitations of discipline-silo KPI measurement, the value potential of which was demonstrated by using an example of drill, blast, load haul effectiveness as a contributor to business performance.

Despite two distinctly different principal responsibilities, the role of geospatial information and the mine surveyor as key enablers and contributors to safe, efficient and profitable mining, was demonstrated as being core to operational effectiveness.

Chapter 8 will discuss geospatial considerations for mine closure and the contribution of geospatial information in mitigating risk and achieving closure objectives.

8. CLOSE

8.1 Introduction

Chapter 7 discussed mine surveying in the context of measuring, monitoring, reconciling and reporting of mining operations in a manner which supported operational and statutory compliance, and provided value through the provision of geospatial foresight to influence operational management decisions and control.

To demonstrate the role of geospatial information and the survey function as key enablers and contributors to safe, efficient and profitable mining, two principal responsibilities of the mine surveyor were discussed in technical and value contribution terms, namely value protection (statutory responsibilities typically directed at safety and health) and value creation (geospatial intelligence for operational effectiveness and efficiency).

The purpose of this chapter, 'Close', is to describe geospatial considerations for mine closure.

These considerations and the potential value additive contribution of mine surveying to this process, will draw significantly on the practices described in Chapter 7 regarding the provision of geospatial foresight to influence closure management decisions and control. Additionally, geospatial considerations for mine closure will build on content and practice described in chapters 5 and 6 (Evaluate and Establish). In doing so, the cross-functional interconnectivity of geospatial information throughout the life-cycle of a project will be demonstrated.

The objectives of mine closure are broadly understood to mean the decommissioning and rehabilitation of a mine (and mining property) in a manner which ensures future safety and environmental stability, while mitigating the impact (of closure) on affected communities.

Operationally, mine closure is typically understood to be the restoration of land to an agreed form, standard and purpose, as a condition of being awarded a license to operate, e.g. a prospecting or mining right. Furthermore, the issuing of such a right is linked to financial guarantees that the holder of the right has made adequate financial provision for this purpose.

However, the International Council on Mine and Metals (ICMM, 2008) considers mine closure as a core part of the business of mining, across the full mining project life-cycle, thus spanning decades. Leading from this, Anglo American (2013) emphasised that the creation of sustainable value requires designing, planning and operating with closure in mind.

Both the ICMM and Anglo American are describing the requirements of leading practice to guide mining companies, with a vision to leave a positive legacy beyond mine closure.

This expanded approach is pivotal to defining the geospatial context and the scope of mine closure planning and execution. Consequently, an understanding of mine closure objectives is required from commencement of exploration, as opposed to regarding closure as a process to be considered at some time in the future (and therefore having little bearing on current operational activities).

Within this context, geospatial data and information which may have material relevance to closure activities, and which may be required for future reference in core value chain processes for closure integration into operational planning and engineering design, need to be identified and preserved. Where these records could have a bearing on future mine or public safety[4], or significant environmental risk[5], such records may be required to be preserved in-perpetuity, thereby influencing information management strategy and systems.

Due to the complexity of mine closure as a core business process, it is not intended to describe the numerous activities and functions involved in achieving effective and sustainable mine closure, unless these have a direct geospatial context or influence.

Finally, until mine closure is legally effected, the responsibility for the keeping of accurate geospatial records, and the requirement for a person to be legally responsible for making, keeping and certifying as accurate such records, remain in effect. Consequently, the survey function is integral to effective closure.

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[4] Safety risk associated with discontinued mine workings and voids for possible future mining or infrastructure development on or below the surface.

[5] Environmental risks such as contamination of surface and/or ground water, mine residue deposit containment and chemical, hazardous waste or other sources of potential contamination.

8.2 'Close' as a core value chain process

As described in previous chapters, the objective of using the value chain as a common reference for all functions or disciplines involved during a particular phase of a mining project's life-cycle, is to develop a mutual understanding of respective roles and contribution, thereby enabling alignment of purpose.

Under typical, rather than leading practice circumstances, Close (mine closure) would be viewed as a discreet core process immediately downstream of Operate. There would be no further downstream core processes, although post-closure liabilities may constitute business risk (safety, financial and reputational risk) requiring ongoing monitoring. Cross-functional interdependencies would be associated with closure and rehabilitation activities that are concurrent with mining operations or following the cessation of mining and dedicated to effective closure as prescribed by legislation or legally binding agreements.

The EM Model (2010) uses this simplified approach to closure, with "Rehabilitate" being the sixth and final core process of its value chain. Sub-processes to this are "Initiate Rehabilitation", "Design Rehabilitation" and "Execute Rehabilitation" (Figure 8.1) and are "focused on marshalling all necessary resources in order to follow through on previous rehabilitation commitments (e.g. Environmental Impact Assessment) as well as on decisions regarding the final state of the rehabilitated site".

The EM Model (2010), is a product of a collaborative industry forum (The Open Group), therefore it is reasonable to assume that its definition of Rehabilitate processes represents consensus (at that time) on mine closure. From the author's experience, this assumption is representative of the operational understanding of mine closure as a process of rehabilitation to a standard and form as committed to when applying for a mining right (mining permit).

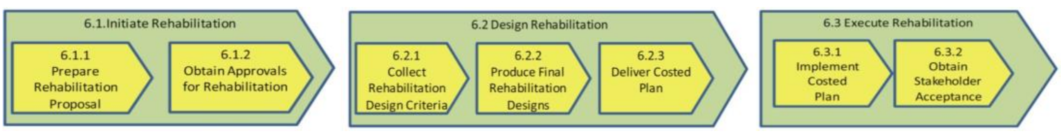

Figure 8.1 EM Model Rehabilitation sub-processes and activities

Leading practice however, as advocated by the ICMM and developed by other organisations from the ICMM Planning for Integrated Mine Closure: Toolkit (2008), differentiates between continuous closure planning in increasing detail along the mine life-cycle, and mine closure rehabilitation (as described by the EM Model) which may be a concurrent or final closure process. The Anglo American (2013) concept of “designing, planning and operating with closure in mind” was developed from the ICMM toolkit (2008).

This research will accommodate both definitions of mine closure, by adapting the value chain to show ‘Close’ as the terminal core process of the value chain which is to be considered throughout the life cycle. These definitions (or approaches) are not mutually exclusive. Figure 8.2 shows this integration across the full life-cycle.

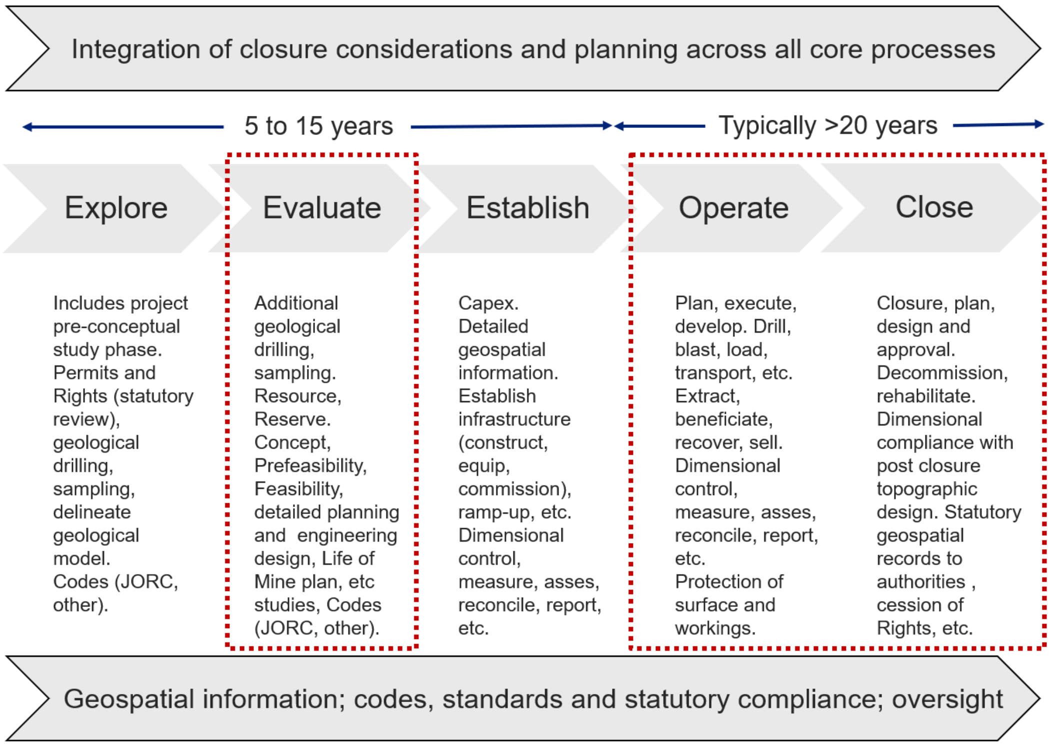

Figure 8.2 Value chain focus area (within red outline)

Consistent with the previous chapter, Operate, the value chain upstream core process of Evaluate has relevance, due to the leading practice approach advocated by the ICMM (2008) and Anglo American (2013) respectively, namely;

- To develop and integrate closure planning across the project life-cycle; and
- To design, plan and operate with closure in mind.

Irrespective of the approach taken to mine closure, whether integrated across the core processes over the full life-cycle, or as a detailed focus area at or towards the cessation of operations, a fundamental understanding across functions and disciplines is required to enable alignment of purpose for effective closure.

Common to both approaches and assuming closure activities that are concurrent with mining operations, the functions and individual disciplines involved in Close would typically be (but not limited to):

- Mining geology and mineral resource management;
- Mining, Geotechnical, Processing (Metallurgy) engineering;
- Geomatics disciplines (surveying, geographic information science, drafting);
- Ventilation and Occupational Hygiene engineering;
- Engineering (e.g. electrical, mechanical);
- Safety and Environment (impact monitoring, protection);
- *Information Technology*;
- Security;
- *Finance and Administration*;
- *Social/community professions*;
- External stakeholders, including government; and
- Legal (mineral and land tenure, access, permits, conditions of tenure).

Additional specialist involvement to address closure-specific activities, such as:

- Hydrology;
- Hydrogeology;
- Geochemistry;
- Water quality;
- Air quality;
- Bio-diversity; and
- Land use.

The functions or disciplines appearing in italics in the above list are unlikely to make direct use of geospatial information. The balance (greater than 85% estimated – the highest in the life-cycle) are either reliant on, or make significant use of, accurate geospatial or spatially referenced information.

However, the number of functions and disciplines involved will drop significantly following cessation of operations when activities are limited to decommissioning, site restoration, rehabilitation and closure. Geospatial information and geospatial referencing of closure related information will remain a key requirement during and beyond mine closure.

8.3 Mine rehabilitation and closure

The objectives of mine closure are typically understood to mean the decommissioning and rehabilitation of a mine (and mining property) in a manner which ensures future safety and environmental stability, and mitigates the impact (of closure) on affected communities.

Operationally, mine closure is typically understood to be the restoration of land to an agreed form, standard and purpose, as a condition of being awarded a license or permit to mine and as a condition of formal closure/relinquishment.

The Government of Western Australia (2015) through two regulatory bodies, namely the Department of Mines and Petroleum (DMP) and the Environmental Protection Agency (EPA), provides guidance for mine closure objectives, namely:

- "…for rehabilitated mines to be (physically) safe to humans and animals, (geo-technically) stable, (geo-chemically) non-polluting/non-contaminating, and capable of sustaining an agreed post-mining land use." (DMP);
- "…Rehabilitation and Decommissioning is to ensure that premises are decommissioned and rehabilitated in an ecologically sustainable manner." (EPA); and
- "…Any residual liabilities relating to the agreed land use should be identified and agreed to by the key stakeholders".

The simplicity of these stated objectives enables broad understanding, without the distraction of describing the complexity of the processes required to achieve successful closure, and the potential safety, financial and reputational risks associated with failure to meet prescribed standards or societal expectations.

8.3.1 Closure context

Adequate mine closure is complex, challenging and often not achieved, as demonstrated by very many known cases of unsuccessful closure or abandonment which contribute significantly to anti-mining sentiment internationally.

Recognising this, Anglo American (2013) commented that the mining industry worldwide can learn from the negative legacy left by mines which have been abandoned (unclosed) or poorly closed, and committed to a process to close mines in a manner which would leave "… a lasting positive legacy".

Funding of mine closure is from financial guarantees and provisions made by the mine owner as a condition of receipt of a license or permit to operate. Assuming a typical period to evaluate, establish and operate a mine (Figure 8.2), decades may have passed since such provisions were initially scoped, estimated and agreed to.

According to the ICMM (2008), planning for mine closure "… is as complex as the project feasibility process that culminates in a constructed operation. The planning horizon is measured in decades, not months or years. Planners must deal with social, economic and environmental parameters that over a generation are bound to change".

According to Anglo American (2013), there is typically "an under-provision for most of the operating life of a mine with a rapid increase in the accepted cost of closure in the last 3-5 years of a facility's life. However, at this late stage of a mine there is also an increasing inability to fund the cash flow required to close a facility adequately. This in turn could lead to a consideration of ways in which costs can be reduced, resulting in a compliance-only mindset, and limited consideration of what can be done to promote lasting post-closure social and environmental benefits".

Citing Brown (2007), and Nzimande and Chauke (2012) regarding unsuccessful mine closures in South Africa, van Druten and Bekker (2017), stated that there are "… approximately 5700 derelict and ownerless mines… which will require 800 years [collectively] to rehabilitate at a cost of R100 billion". Furthermore, "Formal mine closure remains an elusive undertaking presenting various risks and significant liabilities affecting investor confidence, and threatening the viability of the mining industry in South Africa".

In pursuit of leading practice for mine closure, the ICMM and Anglo American have proposed the integration of mine closure planning (into sub-processes), to optimally address closure risks and achieve successful mine closure. Similarly, van Druten and Bekker (2017) proposed an inclusive model to counter unsuccessful mine closure.

8.3.2 Integrated mine closure planning

Integrated closure planning involves the development, in increasing detail through a project life-cycle, of a closure vision and plan (Figure 8.3).

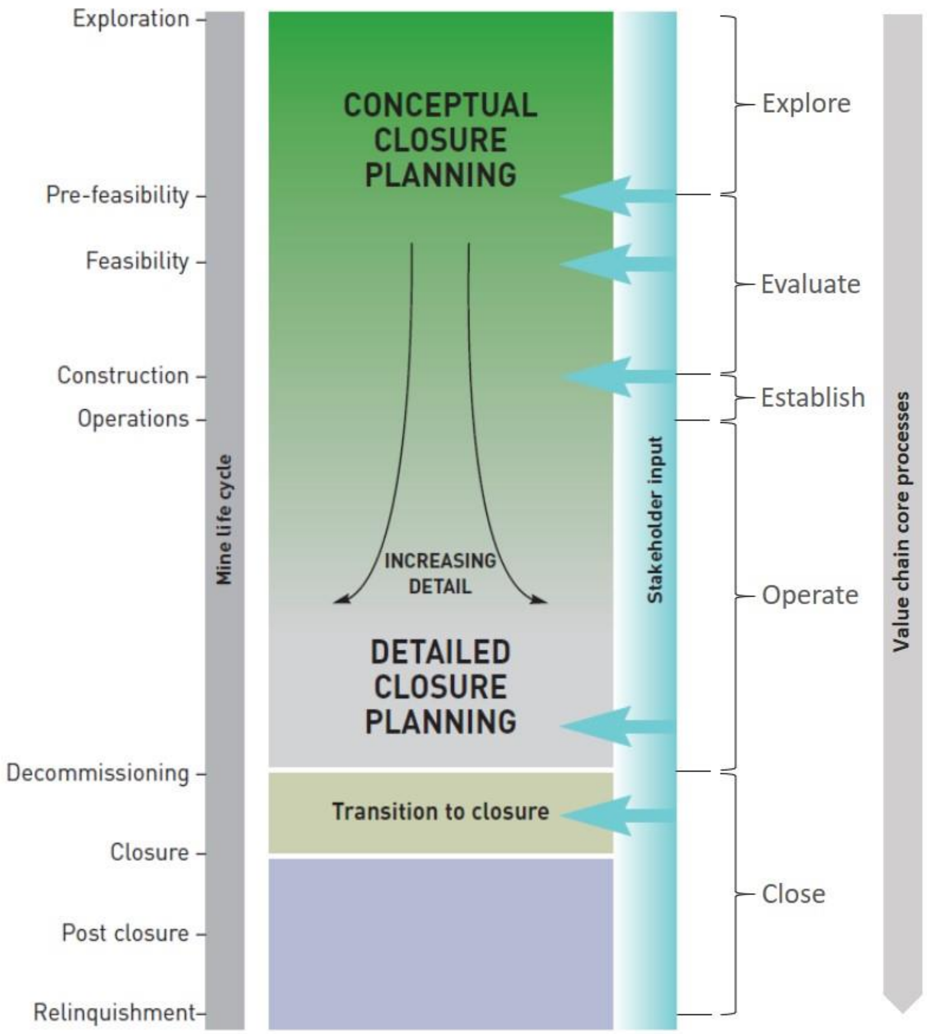

Figure 8.3 Adapted ICMM closure planning with value chain core processes (right hand column)

From Figure 8.3, the earliest stage at which closure planning can begin is during exploration, when the planning would be conceptualised, despite there being no assurance that the exploration will result in a project advancing through to mine establishment.

Arguably, mine closure during exploration is difficult to conceive, however, the engagement with authorities, communities and other stakeholders, and the location and environmental setting of the exploration region or site, will provide information with which to begin forming a concept of closure conditions.

An objective of integrated closure planning is to ensure that similar rigour is applied to mine closure as is applied to project evaluation in the conceptual, pre-feasibility and feasibility studies, to ensure that closure cost estimates, design and engineering are adequate to achieve the closure vision and plan. It is therefore reasonable to conclude that on completion of a feasibility study, in addition to environmental and social impact assessments and management plans, controls and permits, a mine closure plan is available that is:

- Of comparable adequacy in design, engineering and resourcing detail as the Life of Mine plan;
- Of comparable adequacy in cost estimate accuracy;
- Aligned with the Life of Mine plan and planning review cycle; and
- Integrated with planning and geospatial information strategy and systems.

For closure activities which are concurrent with operations, such activities should be incorporated into short-term and operational plans for execution, to enable effective control and management.

Consistent with mine planning objectives, integrated mine closure planning should ensure the provision and availability of people, information, processes, technology and equipment at commencement of the plan’s execution horizon, with clearly defined roles, responsibilities, accountabilities, budgets, KPIs and reporting.

Furthermore, by incorporating mine closure planning with the planning hierarchy and review cycle, mine closure plans should:

- Be updated using the latest relevant information and assumptions;
- Maintain cost estimates within current accepted accuracy ranges;

- Improve the visibility, knowledge and understanding of mine closure objectives; and
- Enable closure activity auditing, i.e. measuring, monitoring, reconciling and reporting of closure activities to support planned and statutory compliance.

Notwithstanding the life-cycle span of integrated closure planning, the core-processes of exploration and mine establishment (construction and development) will be subjected to their own environmental management, stakeholder engagement, closure and site restoration plans, i.e. exploration and mine establishment must achieve their respective closure and restoration objectives.

An important consideration for mine closure environmental planning described by the International Institute for Environment and Development (2002), is that it is typical to design for a 100-year precipitation event risk, due to the relatively short life-cycle of a mining project. However, due to climate change, it may be appropriate to consider a 10 000-year (or longer) precipitation event risk when designing for long-term stability of closure facilities such as surface water diversion works.

Finally, closure planning should make provision for unexpected premature closure and/or temporary suspension of operations ("mothballing").

The author contends that with the appropriate level of rigour and detail applied to mine closure planning, and improved visibility and understanding of the closure plan, broad awareness and understanding of closure objectives will be achieved, thereby improving operational effectiveness in support of mine closure – "designing, planning and operating with closure in mind" (Anglo American, 2013).

8.4 Geospatial context

As described in the previous chapter, there is a direct relationship between geospatial information and mine safety regarding the protection of the surface and the workings of a mine. Consequently, mine surveying and the keeping of accurate mine maps, plans and records are highly regulated in several countries. In the absence of legislation, other controlling instruments may provide guidance on appropriate and defensible standards of practice and accuracy.

The surveyor is responsible for keeping, preserving, assessing and certifying as accurate and correct, prescribed geospatial information and records which have a bearing on safety or risk. In some countries, legislation is specific in extending the surveyor's responsibility to geospatial information from other sources which are shown on the surveyor's plans, drawings and sections (despite this information not having been prepared by the surveyor).

Such survey records and geospatial information have a bearing on both mining and public safety. The concept of post-closure public safety is contained in the objective expressed by the Government of Western Australia (2015), "…for rehabilitated mines to be (physically) safe to humans and animals, (geo-technically) stable, (geo-chemically) non-polluting/non-contaminating, and capable of sustaining an agreed post-mining land use".

It is therefore of fundamental importance to consider that:

- Irrespective of the controlling instrument, the responsibility for the keeping of accurate geospatial records, for mining and post-mining safety, rests with the mine owner;
- Accurate records of the position and extent of mine workings and all features which may have a present or future bearing on safety or risk, must be kept permanently in a useable format, i.e. preserved and available in-perpetuity; and
- Such records and geospatial information must be prepared and/or certified as accurate and correct by a person who is recognised as qualified and competent to do so.

Furthermore, until mine closure is legally effected, a mining property is technically still a mine, albeit one in the process of closing. Legal responsibilities, and where appropriate, legal appointments addressing competency and responsibility, remain a statutory requirement for the owner of the mine.

Therefore, unless there is a compelling reason for exemption from legislation or other controlling instruments which prescribe requirements for surveying and the keeping of accurate plans and geospatial records, compliance is mandatory until closure is legally effected and ownership of the mining property relinquished. This applies equally to geospatial information and products prepared by other functions or disciplines for mine closure. Consequently, there is a need for mine closure practitioners to possess an understanding of the survey function, its geospatial context and its regulation.

Upon successful mine closure and relinquishment, all relevant maps, plans and geospatial records will transfer (typically) to the custodianship of the State in a permanent archive.

8.5 Integrated mine closure support activities

Earlier in this chapter, an objective of integrated mine closure planning was described as applying similar rigour to mine closure as to techno-economic project evaluation, to ensure that closure cost estimates, design and engineering are adequate to achieve the closure vision and plan.

Operationally, the mine closure plan would be aligned with the mine's planning hierarchy, be of appropriate detail and accuracy of design, engineering, resourcing, and cost, and would be regularly reviewed at the same frequency as Life of Mine, or as situationally necessary, the medium-term, short-term and operational plans.

This level of integration would provide a consistent approach to updating closure planning, and reporting and managing closure liabilities throughout the life of a mine. Furthermore, applying consistent techno-economic, planning and design rigour to closure options at a frequency aligned with operational planning and execution, should result in improved visibility and understanding of the closure plan and vision.

Consequently, appropriate resources (people, processes and technology), monitoring and reconciling of appropriate KPIs would be integrated with production cycle activity reporting and support.

Geospatial considerations and the role of mine surveying within the core-processes of Explore, Evaluate, Establish and Operate, were discussed in preceding chapters describing technical aspects of practice to mitigate risk and enable value creation for the business. The integration of geospatial and surveying practice with mine closure will provide a similar contribution potential to mine closure activities. Key to effective support, is a fundamental understanding of the closure vision, plan and objectives.

8.5.1 Geospatial strategy and closure planning considerations

Geospatial strategy as described in Chapter 5, must include mine closure provisions to enable effective integration and alignment with business objectives (of which successful mine closure is the terminal objective). This requires that mine closure strategy, as formulated during the evaluation phase of a project, must be visible and understood to enable appropriate integration with geospatial strategy.

Successful integration of strategy should lead to effective planning and resource allocation. It should also provide an appropriate level of awareness of geospatial information or records which may have a bearing on closure design, liability assessment and risk mitigation, and which should be preserved for future reference (in an information management system).

Cross-functional alignment is therefore a key consideration for defining resource requirements for specific planning horizons, i.e. the closure vision, plan and objectives must be known and understood at a fundamental level.

The author contends that the closure definitions provided by the Government of Western Australia (2015) could be used to formulate strategic planning, by questioning what geospatial information would be relevant to support mine closure which:

- Is physically safe (to humans and animals);
- Is geotechnically stable;
- Is non-polluting/non-contaminating;
- Can sustain an agreed post-mining land use;
- Is decommissioned and rehabilitated in an ecologically sustainable manner; and
- Has reasonably and effectively mitigated any residual liabilities?

It is reasonable to assume that a significant percentage of mine closure information is geospatially referenced in terms of general positioning (e.g. coordinates and height), and specifically relative to features or structures created by mining. Therefore, the features and detail which are required to be accurately shown on mine plans are of high relevance to the above-mentioned geospatial closure attributes, for example:

- The position and extent of mine workings, voids, dumps and mine residue deposits;
- Geological features and geotechnical risk zones;

- Ground movement resulting from mining (e.g. surface subsidence or slope instability);
- Surface and sub-surface drainage features; and
- Post-restoration topography.

To provide effective geospatial support to mine closure, the survey function must possess the capacity and capability to measure, analyse, reconcile and report on the right closure KPIs at a frequency which supports effective process management.

8.6 Mine surveying as a contributor to closure effectiveness

The specific roles, responsibilities and activities involving geospatial information and the function of surveying do not require repeating here in detail, however, the assumption is made that established, information systems, processes and technology are adequate and effective for integration with, and in support of, mine closure. It is further assumed that such integration will exploit synergies for planning and execution, to the benefit of process efficiency and the business.

To provide examples of the role of the survey function in supporting mine closure, Table 8.1 provides brief details of typical surveying and geospatial activities which address efficiency, effectiveness and risk mitigation.

Of the tabulated examples, three require further discussion due to not having been mentioned in previous chapters. Each of the three examples can be accommodated using a mine's existing geospatial information systems, processes and technology.

Table 8.1 Examples of surveying and geospatial activities supporting mine closure

Activity	Closure purpose	Examples
Systematic capture of relevant geospatial records.	Procure and preserve records which may have a bearing on safety, environmental or closure risk.	- Aerial photography; - Satellite imagery (optical, hyperspectral[6] and thermal[7]); and - InSAR[8] (subsidence, movement or change monitoring).
Oversight and custodianship of accurate geospatial information and records.	Integrated information management system linking mine closure, survey and operational planning technologies (includes geospatial accuracy and quality control).	- Integration with BIM or GIS systems (geospatial strategy); - Statutory or other controlling instrument compliance; and - Accurate plans showing all relevant features of the surface and workings of a mine.
Optimisation of rehabilitation designs (fit-for-purpose).	Geospatial and rehabilitation sustainability design effectiveness. Execution efficiency and effectiveness.	- Restore drainage effectiveness; - 3D modelling for design input, engineering and assessment; - Cut and fill volumes; and - Earthmoving optimisation.
Establish closure designs in physical space.	Dimensional control, achieving planned physical composition and form.	- Geometric/dimensional control; - Hazard and areal limit proximity referencing; and - Integration of designs into machine guidance systems.
Measure, analyse, reconcile and report on closure KPIs.	Control and management of efficiency and effectiveness.	- Activity reporting; - Spatial, temporal and physical reconciliation; and - Provision of geospatial intelligence (forward looking).
Soil resource management accounting (can be extended to other environmental resources).	Treating topsoil and sub-soil as a resource to ensure adequate controls and monitoring of effective preservation for planned future use.	- Applying mineral accounting principles and systems to account for in-situ and stockpiled soil inventories; - Measure and reconcile at appropriate frequency; - Soil resource availability forecasting.

[6] Enables electromagnetic signatures to be identified for different rocks, soils, plants and chemistry and pollution sources and extent.
[7] Enables thermal differences to be identified for detection of surface and sub-surface combustion (hot spots), pipeline leaks, water ingress and decant points, and ground and water pollution thermal plumes.
[8] Spaceborne Interferometric Synthetic Aperture Radar capable of detecting millimetres of movement of the ground surface or objects and structures thereon.

8.6.1 Soil resource management

A mine is evaluated, designed and established based on the economic value of the mineral resource and ore reserve. To monitor the extraction and movement of mineral content, mine planning and operations typically have mature and effective accounting systems to monitor and reconcile such extraction and movement.

Soil, particularly top-soil, should be treated with similar rigour, as it is a resource that has a significant economic and ecological value for mine closure. Ineffective soil resource management or inadequate soil quantity can compromise sustainable post-rehabilitation land use.

For optimal effectiveness, soil resource management should be integrated into mine planning and initiated prior to the commencement of mine development, using existing or adapted mineral resource management and mineral accounting systems and capabilities, to address:

- Estimates at an appropriate level of confidence for quantity, quality, location and other relevant attributes should be captured in geospatial database, similar if not the same as the mineral resource and ore reserve;
- In-situ depletion, stockpiling and stockpile depletion should be planned and controlled, and aligned with the mine planning hierarchy;
- Authorised access to soil stockpiles and the depletion thereof; and
- Appropriate accounting, reporting, reconciliation and forecasting measures.

The author proposes that soil resource management is a critical activity supporting future closure, which as a minimum should be practiced throughout operational and closure phases of a project. However, depending on a mine’s surface infrastructure footprint, inclusive of residue deposits, it may be necessary to introduce soil resource management during construction and development of a mine.

8.6.2 Systematic capture of geospatial records

Throughout the life-cycle of a mining project, data is being collected from which a closure vision and plan is developed, in increasing detail, culminating in a final closure plan.

During this period which typically spans decades, an awareness is required of what geospatial records could have a bearing on mine closure planning and risk mitigation.

The surveyor is ideally placed throughout the mining value chain, to recognise, capture and store such records, and/or to advise on geospatial processes or products which support closure planning and assessment. A prerequisite for effective practice is that the surveyor has a fundamental understanding of mine closure objectives and risk.

Images, for example, provide a visual record at an instant in time, which is then available for examination and interpretation at any time in the future. A series of images taken throughout a project's life-cycle can provide valuable information on physical developments which could impact on surface and sub-surface effects of mining operations, population growth and density, environmental changes (whether resulting from mining, or not) and other pertinent change events. The images can also be of significant value potential in enabling early intervention (if required) if a negative-impact trend is detected, or to disprove or mitigate liability for damages or negative-impact conditions for which the mine owner is not responsible.

8.6.3 3D modelling

The creation of 3D models is standard practice for surveying, mining and engineering and often the principal method for volume calculations of mine production and general earthmoving activities.

Less frequent during operations and closure is the use of detailed 3D models for:

- General design, engineering and assessment;
- Drainage modelling and design;
- Dozer-push productivity and cost optimisation for re-shaping dumps, residue deposits, or other surface features;
- Cut and fill volume optimisation;
- Modelling of void capacities (underground and surface) for determining storage capacity, assessing decant (of stored water or fluid material) risk, or calculating back-fill requirements; and

- Calculating surface area of re-contoured topography for capping, sub-soil and topsoil quantity requirements (for depletion from the soil resource management system), prior to re-vegetation.

Effective use of 3D modelling for applications such as described above, has the potential to significantly improve design, planning, assessment and execution. When linked to optimisation processes, material cost and productivity efficiencies can be achieved.

8.7 Mine closure regulatory requirements (surveying, maps, plans and geospatial records) – South Africa

In South Africa, the departments of Mineral Resources (DMR) and Water and Sanitation (DWS – previously named the Department of Water Affairs and Forestry; DWAF) – are the issuers of certificates or approvals for mine closure. Of importance is that the DMR cannot issue a mine closure certificate, without first receiving closure approval from the DWS (thus implying compliance with the requirements of the National Water Act, Act 36 of 1998 and regulations thereto). Van Druten and Bekker (2017) noted that the "overlapping and contradictory regulatory mandates" are regarded as a key reason for failure to achieve mine closure.

It is beyond the scope of this chapter to discuss the South African regulatory framework in detail – this subject has been adequately addressed by other authors and by numerous statutory instruments. However, it is instructive to extract from the requirements of the Mine Health and Safety Act (MHSA) and Regulations, and the Mineral and Petroleum Resources Development Act (MPRDA) and Regulations, the geospatial considerations for mine closure. In the case of the MPRDA and Regulations thereto, some interpretation is required to determine geospatial requirements and adequacy – a similar situation to that presented by the minimal detail on geospatial adequacy contained in various codes for reporting on exploration results, mineral resources and reserves.

In terms of the Chapter 17 of the Mine Health and Safety Act (MHSA), the regulations relating to surveying, mapping and mine plans are clear on the obligations for updating and submitting mine plans and records upon a mine being abandoned, closed or rendered inaccessible, thereby addressing the requirement for geospatial records to be kept in-perpetuity for future mine and public safety.

Regulation 17(29) (a) requires that all plans and copies prescribed in Chapter 17 (of the MHSA) are updated by the “competent person” (legally appointed surveyor for a mine) and that the Director: Mine Surveying (of the DMR) is notified in order to inspect such plans.

Regulation 17(29) (b) calls for a surface rehabilitation plan to be drawn, where the surface has been disturbed by mining, “showing the final contours and established water courses”, and that the Director: Mine Surveying (of the DMR) is notified to inspect and approve such plan.

Regulation 17(30) requires that updated hard copies (on durable material) of the above-mentioned plans, copies referred to in regulation 17(26), and inventories thereof together with a register of survey stations (survey control points) be “handed in to the office of the Director: Mine Surveying following the inspection and approval of the plans contemplated in 17(29)”.

Regulation 17(31) requires that “where rehabilitation is completed after cessation of mining, that the surface and rehabilitation plans… are updated upon such completion”.

Finally, regulation 17(32) requires that the “Director: Mine Surveying must issue a certificate of compliance with the requirements of regulations 17(29) to 17(31)… within 60 (sixty) calendar days of compliance…”.

Therefore, in addition to the closure approval required from the DWS, Chapter 17 of the MHSA prescribes a certificate of mine surveying ‘geospatial compliance’ be issued by the DMR as a condition of mine closure.

However, the MPRDA and Regulations contain requirements for geospatial information and records for submission upon application for mine closure, as well as geospatial conditions and restrictions during mining operations and concurrent (“progressive”) rehabilitation. These requirements typically do not directly address geospatial adequacy, assessment and compliance which require mine surveying competency. Consequently, the requirements of the MPRDA and Regulations must be understood and addressed by the surveyor legally appointed and responsible for surveying on a mine, prior to mine closure being approved. As previously stated, if closure is not approved, the legal responsibility for surveying, mapping and mine plans will remain a statutory requirement.

Furthermore, this legal responsibility for the preparation (and certification as accurate and correct) of these prescribed geospatial conditions, restrictions and records, imposes cross-functional interdependencies for which awareness and understanding are required.

For example:

Regulation 56 (of the MPRDA) describes the principles for mine closure (which are well aligned to the integrated mine closure principles described earlier in this chapter).

Regulation 56 (e) requires that “land is rehabilitated as a far practicable to its natural state, or to a predetermined standard or land use…”. This means rehabilitation to a topographical form and design, which by extension require surveying processes to establish the design in physical space to specific design criteria. These activities are an extension of the surveying processes required in the construction, development and operation of a mine, and therefore linked to the regulatory requirements of Chapter 17 of the MHSA.

Further indirect geospatial conditions and restrictions appear in regulation 69 regarding the disposal of waste material at specified locations or sites, e.g.:

Regulation 69. (6) states that “coal debris shall not be allowed on any ground where there exist, or where there are likely to occur, surface fissures or cavities and a result of underground operations”.

Regulation 73. addresses management of residue stockpiles and deposits regarding physical, chemical, mineral, environmental, geotechnical and groundwater characteristics and risks, and associated design, operation and decommissioning.

Regulation 73. (3) (e) addresses environmental classification of residue stockpiles and deposits, with specific reference to “the location and dimensions of the deposit (height, surface area);… the spatial extent, duration and intensity of potential impacts”.

A number of MPRDA regulations not quoted here include design and monitoring requirements, all of which are likely to include geospatial aspects for construction, operation, decommissioning or rehabilitation and closure.

In assessing geospatial adequacy, the mine surveyor must consider the regulatory framework which defines the geospatial context of mine closure processes and guides practice, thus requiring appropriate legal and technical competency.

8.8 Conclusion

This chapter, Close, was the fifth and final of the central chapters to follow the mining value chain. Its purpose was to describe the geospatial considerations for mine closure, while drawing on collective knowledge and practice described in the previous chapters.

The objectives of mine closure are broadly understood to mean the decommissioning and rehabilitation of a mine (and mining property) in a manner which ensures future safety and environmental stability, while mitigating the impact (of closure) on affected communities.

In operational terms this objective is understood to mean the restoration of land to an agreed form, standard and purpose (as a condition of being awarded a license to operate), and linked to guarantees of adequate financial provision for this purpose. In this case, closure and rehabilitation activities would typically be concurrent with mining operations or following the cessation of as required by a final closure plan, legislation or legally binding agreements.

In contrast to the above-mentioned understanding of mine closure, the concept of integrated mine closure (ICMM, 2008), or mining with closure in mind (Anglo American, 2013) was introduced and described in some detail, as representing leading practice and as the aspiration of achieving a lasting positive post-closure legacy.

The key differentiator between the broadly understood objective of mine closure and integrated mine closure is that the latter requires the development, in increasing detail through a project life-cycle, of a closure vision and plan, with the commencement of conceptual closure beginning during exploration. The purpose of the early introduction to developing a closure vision and plan is to prepare for and apply similar evaluation rigour to mine closure as is applied to project evaluation for conceptual, pre-feasibility and feasibility studies, to ensure that closure cost estimates, design and engineering are adequate to achieve effective closure. This results in the extension of cross-functional engagement and collaboration across the value chain, as opposed to being typically prevalent during the core-processes of Operate and Close.

This integrated approach was further developed to include alignment of closure planning with the mine planning hierarchy and cycle, to ensure appropriate integration, detail and confidence as required for Life of Mine planning, in increasing detail, through to operational level planning. Consequently, this aligned approach should ensure the provision and availability of people, information, processes, technology and equipment at commencement of the plan's execution horizon, with clearly defined roles, responsibilities, accountabilities, budgets, KPIs and reporting.

The purpose of the extended discussion of integrated mine closure was to enable a fundamental understanding of the closure vision, plan and objectives, and the risks associated with unsuccessful closure. From this, geospatial context was formulated to enable the contribution of geospatial information and practice that best support mine closure and mitigate closure risks to be described.

Key considerations of geospatial context for mine closure were noted as:

- The responsibility for keeping, preserving, assessing and certifying as accurate and correct, prescribed geospatial information and records which have a bearing on safety or risk, rests with the mine owner;
- Accurate records of the position and extent of mine workings and all features which may have a present or future bearing on safety or risk, must be kept permanently in a useable format, i.e. preserved and available in-perpetuity;
- Such records and geospatial information must be prepared and/or certified as accurate and correct by a person who is recognised as qualified and competent to do so; and
- Until mine closure is legally effected, a mining property is technically still a mine, therefore, legal responsibilities, and where appropriate, legal appointments addressing competency and responsibility (e.g. the mine surveyor), remain a statutory requirement for the owner of the mine.

Within this context, the Western Australian Government (2015) definition of mine closure, with reference to safety, stability and ecological sustainability, was used to provide further guidance for geospatial considerations, by questioning what geospatial information would be relevant to support mine closure which:

- Is physically safe (to humans and animals);
- Is geotechnically stable;
- Is non-polluting/non-contaminating;
- Can sustain an agreed post-mining land use;
- Is decommissioned and rehabilitated in an ecologically sustainable manner; and
- Has reasonably and effectively mitigated any residual liabilities?

Mine closure in a South African legislative context was discussed, to demonstrate the principal compliance and approval processes required, in addition to the specific closure requirements of the MPRDA for the issuing of a mine closure certificate. The discussion further demonstrated that the regulatory framework defines geospatial context for mine closure processes, which consequently guides practice.

In a departure from descriptive practice in previous chapters, the risk mitigation and value contribution of the geospatial information and the survey function were assumed to continue throughout closure processes and activities. Value protecting and value enabling contributions are similar or unchanged, however their application is adapted to support different KPIs and objectives. Hence, the two principal applications and responsibilities of geospatial information and the mine surveyor respectively, continue as key enablers and contributors to safe, efficient and profitable mining, and are core to mine closure effectiveness.

Chapter 9 will summarise the research findings to answer the principal question *"Can a cross-functional Value Chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?"* and the secondary questions presented as consequence thereof. Recommendations and a conclusion will be provided.

9. SUMMARY OF RESEARCH FINDINGS

9.1 Introduction

The preceding chapters, three to eight, discussed geospatial principles, considerations and requirements for effective practice and support, spanning the full life-cycle of a mining project. Throughout the chapters, consistent reference was made to cross-functional or cross-discipline interdependencies, interconnectivity of processes, risk mitigation and value creation potential in the business of mining, and to statutory or other controlling instruments where relevant. Integral to these chapters was the development of the concept of geospatial context to inform and guide practice.

The purpose of this chapter, Chapter 9, is to summarise major research findings as presented in chapters three to eight and to answer the principal question, *"Can a cross-functional Value Chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?"*

This will be followed by discussion of the secondary questions presented in the introductory chapter to this research, which led from the above-mentioned principal question.

It is appropriate to briefly re-state the individual purposes of chapters three to eight:

Chapter 3 discussed fundamental geospatial principles and an introduction to the mining value chain, which are essential requirements for understanding this body of work.

Chapter 4, Explore, discussed geospatial considerations during the exploration phase of a mining project in the context of laying the geospatial foundation for all work which may follow.

Chapter 5, Evaluate, discussed increasing geospatial accuracy requirements and geospatial strategy development through the evaluation phase of a project (conceptual, pre-feasibility and feasibility studies).

Chapter 6, Establish, discussed geospatial control, positioning, monitoring and reporting during the construction and development of a mine in the context of supporting the project schedule and budget.

Chapter 7, Operate, discussed the activities of measuring, monitoring, reconciling and reporting of mining operations in the context of regulatory compliance, operational foresight and value contribution.

Chapter 8, Close, discussed geospatial considerations for mine closure, with reference to typical and leading closure practice, while drawing on collective knowledge and practice described in the previous chapters.

Discussion of the principal question and the secondary questions leading therefrom will follow the major findings (per chapter) presented below.

9.2 The mining value chain

Introduced in Chapter 3, the mining value chain was used consistently throughout all central chapters of this research, to graphically represent the core-processes of a mining project life-cycle, namely: Explore, Evaluate, Establish, Operate and Close.

Findings related to the use of the value chain are presented separately under 9.2.1, rather than included with the discussion of fundamental geospatial principles which formed the principal content of chapter three – see Chapter 3.

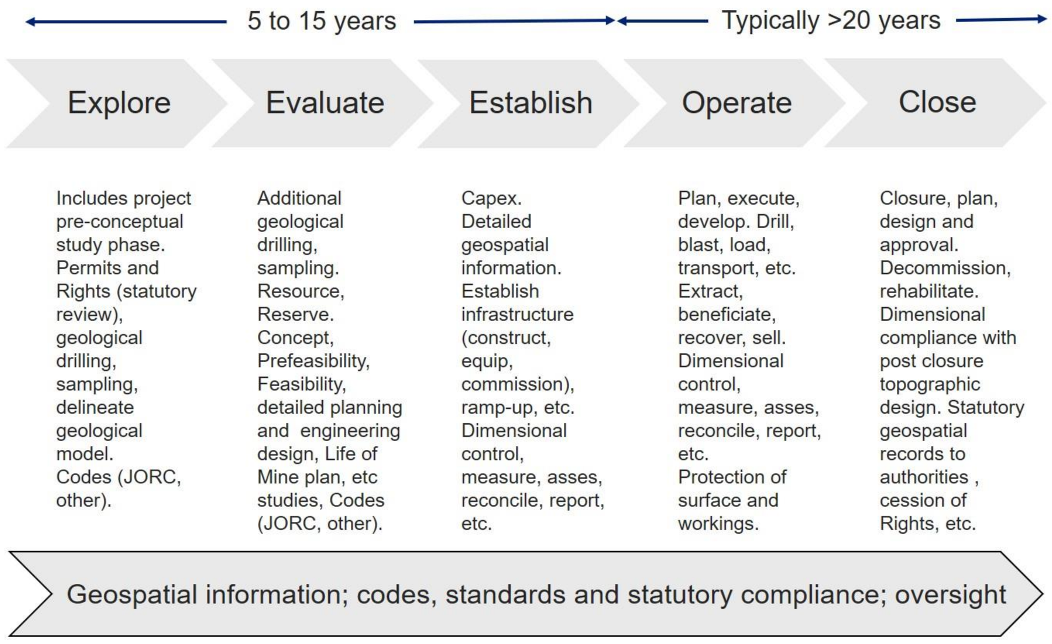

Figure 9.1 The mining value chain showing core-processes of the life-cycle

Under each core-process of the value chain, typical activities are listed to provide ease of reference and focus on a specific area of practice or activity. As indicated at the base of Figure 9.1, geospatial information spans the full value chain, from exploration to mine closure.

9.2.1 Major findings (the mining value chain)

The consistent referencing to the value chain, achieved the purpose of:

a. Providing a graphical representation of business to enable individual functions or disciplines to view their respective roles in the business, thereby moving beyond narrow task or project focus.
b. Identifying upstream and downstream value chain processes, to enable an understanding and accommodation of cross-functional or cross-disciplinary interdependencies, and provide insight into defining information which is fit-for-purpose and/or fit-for-next-purpose.
c. Enabling alignment of purpose, understanding and mitigation of risk, and introducing cross-functional foresight into individual activities.
d. Creating context and perspective for effectively scoping work to introduce efficiencies to a project, avoid re-work, and improve effectiveness in support of the business of mining.

By achieving this collective purpose, the use of the value chain was consistent with its original purpose as proposed by Porter (1985), by providing focus and understanding of strategically relevant activities (alignment of purpose) and enabling strategy (and the execution thereof) for creation of competitive advantage.

9.3 Fundamental geospatial principles

Chapter 3 provided an overview of the fundamental geospatial principles for surveying, an understanding of which is essential to providing geospatial context to guide practice and mitigate associated risk – see chapter three.

Useful definitions were provided in Appendix A, to ensure a common understanding of terms used in surveying, and which are essential for understanding numerical and graphical (maps/plans) representation of geospatial information.

9.3.1 Major findings (fundamental geospatial principles)

a. Consolidation of the information presented in the chapter described geospatial principles in terms of surveying measurement, processing and accuracy which is fit-for-purpose, (e.g. accuracy requirements vary, depending on purpose).

b. The description of datums, projections, coordinate systems and associated corrections which must be applied to measurements, demonstrated the underlying complexity of the processes required for projecting geodetic measurements onto a plane surface and uniform grid for use in a coordinate reference system, i.e. the format typically encountered by users of coordinates, maps and general geospatial information in the minerals industry.

c. The requirement for significant surveying knowledge, skills and competency was demonstrated, thus highlighting the need to define a suitably qualified person (competent person) in a geospatial context, to be involved in every core-process of the mining value chain.

9.4 Explore – the exploration phase

Figure 9.2 Simplified mining value chain – exploration

Chapter 4, Explore, was the first of the central chapters to follow the structure of the mining value chain and described geospatial considerations during the exploration phase of a mining project, and the laying of the geospatial foundation for all work which may follow – see Chapter 4.

9.4.1 Major findings (Explore)

a. Cross-functional or cross-disciplinary interdependencies, while focusing primarily on surveying and geology activities in exploration, included legal and environmental functions.

b. Geospatial information forms the foundation for exploration information and all subsequent phases of a project, and is integral to geological confidence. It is therefore of strategic importance, that surveying and geospatial information management are planned and executed to the correct specifications, and capable of being maintained through the full project life-cycle to ensure geospatial consistency.
c. The geological model is a geospatial database containing geological attributes, not the converse. Geospatial quality assessment, controls and assurance are essential, and require appropriate geospatial/surveying competency.
d. Geological setting or context should inform geospatial context, to align survey methods and practice with the physical characteristics of the mineral deposit, and should guide all geospatial specifications and practice, to provide appropriate confidence for the Competent Person's report (on exploration).
e. Complete and adequate survey records must be kept, to enable a replication of the original surveys should this be required for practical or assurance purposes.
f. International codes, standards or guidelines for reporting mineral exploration, resources and reserves (Codes) are silent on the general requirements for geospatial adequacy (with a probable consequence of underestimation of the importance thereof) and the requirement for survey competency to advise on such. The absence of a definition of a competent person in the geospatial context carries significant risk potential which should be addressed, in some form, in the Codes.
g. Geospatial risk must be considered in the broader context for the reporting of exploration results, to include mineral and land cadastre compatibility, exploration done by other parties, environmental conditions and restrictions and the need to keep comprehensive surveying records for assurance purposes.

9.5 Evaluate – the technical studies phase

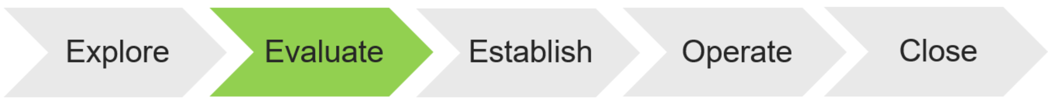

Figure 9.3 Simplified mining value chain – project evaluation

Chapter 5, Evaluate, discussed increasing geospatial accuracy requirements during the evaluation or studies phase of a mining project, and the development of an integrated geospatial strategy and implementation plan to be applied from feasibility study onwards. A further purpose of the chapter was to assess the significant increase in process complexity on geospatial information and the contribution of surveying practice to project performance – see Chapter 5.

9.5.1 Major findings (Evaluate)

a. Cross-functional interdependencies are significantly escalated, due to the involvement of several additional functions and disciplines in providing critical input into determining the feasibility of a project.
b. International codes, standards or guidelines for reporting mineral exploration, resources and reserves are typically silent on geospatial assurance requirements during technical studies (project evaluation).
c. Mineral resources and ore reserves are derived from the geological model, and are therefore, by extension, geospatial databases. Geospatial quality assessment, controls and assurance are essential.
d. During project evaluation, geospatial information shifts from being the foundation of mineral resource and ore reserve models, to the geospatial foundation for engineering functions, for mine design and construction.
e. Information and work interdependencies, demonstrated by the cross-functional use of geospatial information during project evaluation, exceed 70% (of the total functions or disciplines involved – estimated).
f. References to geospatial and surveying requirements represent less than 1% (estimated from the content of a mining company's asset development standard), indicating an underestimation of geospatial risk and the role of geospatial information, and inadequate representation of professional surveyors on project study teams.
g. Integrated cross-functional geospatial strategy should be developed and executed during project evaluation, to enable geospatial information and practice to be leveraged in support of project and business performance (as demonstrated by safety, cost, collaboration, resourcing and operational efficiency benefits reported in case studies on BIM).

9.6 Establish – the construction and development phase

Figure 9.4 Simplified mining value chain – construction and development

Chapter 6, Establish, discussed geospatial aspects of project implementation and mine establishment, i.e. during the construction and development phase of a mine. The purpose was to describe geospatial control, positioning, monitoring and reporting during mine establishment, and effective surveying practice and management of geospatial information – see Chapter 6.

9.6.1 Major findings (Establish)

a. Cross-functional dependency on geospatial information remains high (greater than 70% – estimated). Failure to effectively integrate, control, share and use this information can result in escalated financial, safety, and reputational risk.
b. Construction, infrastructure development and mine development require surveying and dimensional control processes to adhere to high levels of accuracy, typically with tolerances of millimetres. To achieve such accuracy requires high levels of survey skill, competency and technical rigour.
c. Surveying equipment must be capable of measuring to the accuracies required by the project and must be calibrated and adjusted to reduce the risk of geospatial error and hence the potential time and cost consequences of construction or development standing time or re-work.
d. For optimal influence on project efficiency, survey measurement and assurance processes must be undertaken at a frequency which supports operational control and project management objectives. This frequency will need to be guided by contractual, work package and schedule requirements.
e. The following key criteria for project surveying effectiveness were identified:
    - The fundamental importance of geospatial information as the foundation for mine design, construction and development;

- The requirement for a highly accurate survey control network, established prior to construction – remaining intact, stable and functional for the duration of construction;
- The requirement for adequate capacity and capability (people, information, processes and technology), aligned with the project's schedule and needs;
- The requirement to have a complete and thorough knowledge of plans, designs, specifications, tolerances, roles and the project schedule; and
- The requirement for appropriate hierarchy and authority, describing roles, responsibility and authority within a defined organisational and communication structure, including operating standards aligned with project technical specifications.

f. The principal role of the project/mine owner's team surveyors should be that of independent auditor of all work packages which have measures of quantity, quality and cost for contractual compliance, and which are directly linked to geospatial information and establishment of designs in physical space. This assurance role of surveyors in geospatial risk mitigation, and in support of the project schedule and cost efficiency, is often overlooked. Consequently, the true value of potential is not realised.

9.7 Operate – the mining operations phase

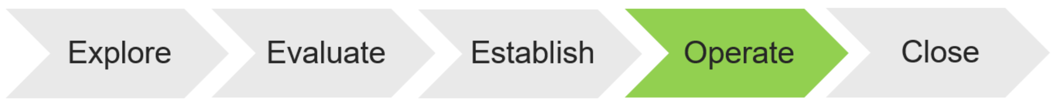

Figure 9.5 Simplified mining value chain – mining operations

Chapter 7, Operate, discussed the role of geospatial information and the mine surveyor as key enablers and contributors to safe, efficient and profitable mining. Specific reference was made to measuring, monitoring, reconciling and reporting of mining operations in a manner and at a frequency which supports operational and statutory compliance, and provides value through the provision of geospatial foresight to influence operational management decisions and control – see Chapter 7.

9.7.1 Major findings (Operate)

a. Understanding cross-functional interdependencies and the interconnectivity of operational activities, supports collaboration and can significantly improve operational performance effectiveness by monitoring and responding to KPIs which drive value.

b. Errors in maps, plans and other pertinent geospatial information pose risk which can have severe safety, financial and reputational consequences, including single or multiple fatalities, and significant environmental and socio-economic impacts.

c. Mine plans and surveying records remain critically important in-perpetuity, to be referenced for possible future mining operations or for development of infrastructure on land affected by past mining operations, thus shifting geospatial application from mine safety to public safety.

d. The mine surveyor has two broad principal responsibilities, namely:
   - Protecting value – the requirement for keeping accurate plans and records of the surface and workings of a mine – typically prescribed by regulation or other controlling instruments – and directed at mine safety and protection of the surface and workings of a mine; and
   - Enabling value creation – the requirement to measure, monitor, reconcile and report on operational processes, i.e. applying geospatial intelligence to production auditing and reconciliation to improve operational effectiveness.

e. Survey reporting becomes geospatial intelligence capable of influencing operational effectiveness and efficiency, when done proactively rather than reactively, with appropriate opinion or insights, thus providing leading indicators for the effectiveness of the process or activity being reported.

9.8 Close – mine closure

Figure 9.6 Simplified mining value chain – mine closure

Chapter 8, Close, discussed the geospatial considerations for mine closure both as a terminal process on cessation of mining, and as an integrated process spanning the full project cycle, beginning during exploration. In both instances, closure activities that are concurrent with mine operations are common.

Risk mitigation and value contribution of geospatial information and the survey function continue throughout closure processes and activities. Value protecting and value enabling contributions are similar or unchanged, however the application thereof is adapted to support different KPIs and objectives – see Chapter 8.

9.8.1 Major findings (Close)

a. Geospatial strategy, people, information, processes, technology and practice (as described in the central chapters), all contribute to and support mine closure effectiveness.
b. Integrated mine closure requires the development of a closure vision and plan, to ensure that similar rigour is applied to mine closure evaluation as is applied to project evaluation, to ensure that closure cost estimates, design and engineering are adequate to achieve effective closure.
c. Alignment of closure planning with the mine planning hierarchy and cycle, ensures appropriate integration, detail and confidence as required for Life of Mine planning, in increasing detail, through to operational level planning.
d. Effective integration and alignment results in the extension of cross-functional engagement and collaboration across the value chain for mine closure, as opposed to being typically prevalent during the core-processes of Operate and Close.
e. Accurate records of the position and extent of mine workings and all features which may have a present or future bearing on safety or risk, must be kept, preserved and accessible in-perpetuity.
f. Until mine closure is legally effected, a mining property is technically still a mine, therefore, legal responsibilities, and where appropriate, legal appointments addressing competency and responsibility (e.g. the mine surveyor), remain a statutory requirement for the owner of the mine.

9.9 Answering the principal research question

The principal question asked at commencement of this research was, "*Can a cross-functional value chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?".*

In addressing this question, the mining value chain was used throughout all central research chapters, to represent the core-processes of a mining project life-cycle, namely: Explore, Evaluate, Establish, Operate and Close and to provide process and geospatial context.

Consistent reference was made to the consequences of deficient geospatial information and/or practice, to safety, financial and reputational risk, and where appropriate, included environmental and socio-economic consequences. Examples were used to demonstrate the role of geospatial error as a significant or root cause of mine accidents. Conversely, accurate geospatial information, is an enabler of successful mine rescue, thus preventing multiple fatalities. Discussion included statutory considerations, with reference to pertinent regulations from numerous countries or jurisdictions, or in the absence thereof, to standards or other controlling instruments.

Regarding the early development of an integrated geospatial strategy during project evaluation (conceptual, pre-feasibility and feasibility studies phase) and the appropriate representation of professional surveyors in the evaluation process, the use of a BIM approach was discussed as the optimal means for geospatial strategy development and implementation.

Notwithstanding the significant advantages of using BIM, the independent development of a geospatial strategy was discussed, to address the value enabling role of people, information, processes, technology and practice integration for each of the core-processes of the mining value chain.

Further discussion identified the dual roles of the survey function in risk and value contribution terms, namely: protector of value (typically directed at mine safety and post-closure public safety), and enabler of value creation (providing geospatial intelligence to improve operational effectiveness).

Thus, the value chain enabled understanding of cross-functional interdependencies and the interconnectivity of processes and activities, leading to improved collaboration, strategy and systems integration, and opportunities to significantly improve operational performance. Furthermore, the graphical representation of the business of mining as a value chain provided clarity and alignment of business purpose, by showing that every task or activity has both a technical (or practice-area) and business purpose, i.e. an understanding of what must be done, and why it is must be done.

The major findings and discussion presented above, demonstrate and support the positive contribution of the value chain in risk mitigation and as a value enabler.

Therefore, *this research confirms that a cross-functional value chain approach to minerals surveying and geospatial information defines geospatial context, mitigates risk and enables value creation in the business of mining.*

9.10 Answering secondary research questions.

Leading from the principal question, were secondary questions which were considered throughout the central chapters of this research. Consequently, the major findings presented in the preceding sections of this chapter apply to the principal question and the secondary questions leading therefrom.

Secondary questions (in italics below) as introduced in chapter one, are not in order of importance, nor do they necessarily lead from one another

SQ1. What should surveyors, managers and users of geospatial information know in order to understand geospatial risk?

Of fundamental importance is the requirement for a common understanding that geospatial information runs through the minerals business, from exploration to mine closure. Position, defined by coordinates, is used to define mineral and surface rights, and as the foundation for deposit delineation, resources and reserves, mine establishment, operation and closure.

Therefore, geospatial information and associated strategy, systems, controls and practice are a primary consideration, not a secondary consideration.

The role of the surveyor and of geospatial information is integral to all core-processes of the value chain and typically regulated by numerous statutory instruments or standards, thus demonstrating that the risk of deficient geospatial information is commonly accepted, (for example in the registration of mineral and surface rights, mine design, and mine and public safety).

In addition to this fundamentally important common understanding:

- Understanding geospatial risk requires an understanding of the core-processes of the mining value chain, the interconnectivity of activities and the primary objectives of each core-process, i.e. a high-level cross-functional understanding of a mining project.
- From this understanding, geospatial risk can be determined by assessing the likelihood of occurrence and consequence of deficient geospatial information on current and downstream processes.
- Key to this would be an activity-based understanding of the purpose to which the geospatial information is put, understanding the limitations of geospatial information received/used and the understanding of the next use. For example;
  - An exploration geologist would require an understanding of the risks to geological confidence of geospatial inaccuracy or inconsistency.
  - Similarly, a surveyor involved in exploration would need to understand geological and geospatial context, and the inherent qualities of geospatial records or information required by that core process.

SQ2. Is there adequate understanding of geospatial accuracy requirements for processes across the business?

This research indicates that the answer to this question is no, geospatial accuracy requirements are not understood across the business.

- International codes, standards or guidelines for reporting mineral exploration, resources and reserves (Codes) are silent on the general requirements for geospatial adequacy and accuracy, both during exploration and during the technical studies (project evaluation) in which mineral resources and reserves are developed and declared.
- For project evaluation, a mining company asset development standard, while calling for a "… rigorous and accurate and highly precise survey control network" for a feasibility study, contains conflicting references to topographic map requirements for different activities at the same stage of study. This implies

a probable lack of understanding of mapping accuracy standards, or preferences in map scale not accuracy requirements.

- Geospatial accuracy requirements for mine establishment (construction and development) activities are typically specified to tolerances of millimetres, with a survey control network accuracy of ±2mm.
- Geospatial accuracy requirements for an operating mine are regulated and are not as stringent as for construction activities, with some exceptions. Generally, accuracy is prescribed by legislation or other controlling instrument, which continues to apply until mine closure is legally effected.
- Geospatial context is essential for defining purpose. Geospatial accuracy is variable, subject to context and regulation, and requires knowledge and surveying competency to assess, certify or achieve.

SQ3. Is there adequate understanding of the risks of deficient geospatial accuracy across the business?

This research indicates that the answer to this question is no, the risks of deficient geospatial accuracy across the business are typically not understood.

- The above-mentioned points on understanding geospatial accuracy requirements (previous question) are all relevant to understanding geospatial risk.
- The absence of understanding of geospatial accuracy (see previous question) implies an absence of understanding of geospatial risk, i.e. deficient accuracy is likely to introduce safety, financial, and reputational risk, depending on context and severity of consequence.
- To mitigate these risks, geospatial information must be appropriately accurate, defensible (if legally challenged or subjected to external scrutiny), and supportive of operational and business process risk. Therefore, an understanding is required of the objectives of core-processes, functions and activities wherever use is made of geospatial information.

SQ4. Are the cross-functional links and points of information transfer between functions understood?

This research indicates that cross-functional links and points of information transfer are apparent, but not necessarily understood.

- Nowhere in the information researched was clarity of understanding mentioned or demonstrated, regarding a comprehensive understanding of the interconnectivity of activities spanning the full value chain from exploration to mine closure. In some cases, research showed awareness or understanding for portions of the value chain, or functions or activities within a core-process, but not spanning all core-processes.
- As stated in chapter one, extensive review of available literature did not yield any published work that addressed geospatial context linked to functional and process interdependencies.

SQ5. What level of understanding of surveying principles is required to assess the accuracy, quality and integrity of geospatial information?

The level of understanding is variable, depending on the process or activity to which the geospatial information relates. At the very least, the fundamental geospatial principles described in chapter three would need to be comprehensively understood.

Assessing accuracy, quality and integrity of information is more complex than capturing and processing the information. In addition to a comprehensive understanding of fundamental geospatial principles, contextual expertise and understanding may be needed to assess aspects of the information which may not be immediately patent, or which are implied by its composition, purpose, or the technical and legal framework of operation.

The required understanding of surveying principles to assess accuracy, quality and integrity, typically exceeds the level required for executing the work.

SQ6. What qualities, knowledge and skills would constitute a person to be suitably qualified or competent to examine, approve and sign off on the accuracy, quality and integrity of geospatial information?

- As stated above, the knowledge and skills should be at a level which exceeds that required for executing the work. Therefore, it is reasonable to state that a level of expertise and competency is required which exceeds an appropriate/recognised academic qualification in surveying.

- From the author's notes, a competent and suitably qualified person would mean "a person recognised as competent to establish the accuracy of any map, plan, drawing, section or physical position… [meaning] a qualified surveyor who possesses the relevant knowledge, skills and experience to establish and certify the accuracy of a map and survey records".
- The qualities of deduction and critical judgement would be required where assessment calls for significant investigation into geospatial context, associated records, legislation, historical systems and practice, and other information of relevance.

SQ7. What systems and controls would be required to mitigate geospatial risk, ensure defensibility of practice and support operational efficiency?

This question was not intended to prompt the development of a comprehensive description of systems and controls to mitigate geospatial risk. As with the over-arching approach to this dissertation, the intention was to provoke thought, in this instance on what constitutes geospatial risk and what reasonable measures should be taken in this regard. Defensibility of practice is therefore a result of taking such reasonable measures.

The examples provided below, should prompt thought and provide guidance:

- For every core-process (of the value chain) functions and activities which use, or have as a foundation, geospatial information or point coordinates must be identified and documented.
- Similarly, cross-functional awareness and the points of transfer of geospatial information would need to be identified, documented and understood.
- For each such function or activity, the consequence of geospatial deficiency would require systematic assessment of the likelihood of occurrence of an unwanted event, its severity and consequences (e.g. safety, financial, reputational and other), from which risk mitigation and management measures would be taken.

With specific reference to surveying and geospatial records and practice:

- Develop and maintain cross-functional awareness and understanding of the contribution of processes and activities to achieving technical and business objectives – aligning geospatial context;

- A suitably competent and suitably qualified person must be responsible for all surveying and geospatial information for every phase of a project life-cycle, from exploration to mine closure. Responsibilities must include:
  - Ensuring that all surveys are scoped, specified and executed, to conform with an accuracy which considers geospatial risk and consistency, is fit-for-purpose, and fit-for-next-purpose (should such next-purpose require a higher accuracy);
  - Assessing and certifying as accurate and correct, keeping and preserving, prescribed geospatial information and records which have a bearing on safety or risk;
  - Identifying and complying with relevant legislation, standards or controlling instruments which have a bearing on surveying and/or geospatial practice and information;
  - Identifying geospatial information and records for which the accuracy cannot be verified, or which are deficient for the intended use;
  - Establishing and maintaining integrated systems, processes and controls for sharing of geospatial information, document or map/plan version control and access thereto, and recording and communicating the accuracy and limitations of such information;
  - Measuring, monitoring, reconciling and reporting the right KPIs at the right frequency to enable or influence improved operational control and management of processes and activities.

9.11 Surveying qualifications and competency

Numerous references were made to surveying knowledge, skills and competencies, which varied according to application along the value chain, commencing in chapter three following discussion of fundamental geospatial principles.

In this context, a suitably qualified person should possess a strong and comprehensive surveying qualification, such as a higher degree in surveying, as the foundation for such knowledge, skills and competency.

In the case of a mine surveying qualification, a significant portion of the curriculum should include geodetic surveying, map projections, cadastral systems and precise engineering surveying techniques and practice, i.e. there would be strong commonality with a typical land surveying degree, together with relevant legal knowledge.

With this strong foundation of surveying knowledge, competency should be developed in specific areas of practice or specialisation, for example surveying competencies required for exploration or mine establishment.

The development of skills and demonstration of competency should be a post-graduation process (similar to that required in other professions), with appropriate standards, oversight and recognition provided by a suitable professional body, and where appropriate, regulation.

The demonstration of competency would entitle registration in the appropriate category or categories of practice, thus communicating professional standing to the public, the minerals industry and professional peers. In so doing, the definition of a 'competent person' in the geospatial context would be defined for reference in or by mineral codes, and differently for other activities requiring specialisation along the mining value chain, thus addressing a critical aspect of geospatial risk mitigation and management.

9.12 Conclusion

The purpose of this chapter, Chapter 9, was to summarise major research findings and to answer the principal research question and secondary questions leading therefrom.

For logical progression, each of the central chapters of this research (chapters three to eight) were addressed separately. In the case of Chapter 3, this was addressed in two sections to enable respective focus on the mining value chain, and on fundamental geospatial principles. These were followed by sections on the core-functions of the value chain, Explore, Evaluate, Establish, Operate and Close.

Major findings for each of the above-described sections, were presented in the relevant section – drawn from the content and conclusions of the central chapters to which the findings relate. Consequently, the major findings required no further discussion and provided the basis of the answers to the principal and secondary research questions.

Following from these major findings, the principal research question was presented – "*Can a cross-functional value chain approach to minerals surveying and geospatial information define geospatial context, mitigate risk and enable value creation in the business of mining?".*

To answer this question, succinct discussion of the value chain, geospatial context, risk and value creation to the business of mining, following the progression of findings of the central chapters, was required. Leading to the answer, summary conclusions extracted from each chapter, combined with major findings were presented, the conclusion of which supported a positive answer to the principal question, namely that:

This research confirms that a cross-functional value chain approach to minerals surveying and geospatial information defines geospatial context, mitigates risk and enables value creation in the business of mining.

In answering the secondary questions (of which there are seven), a similar approach was adopted, namely that summary conclusions extracted from each chapter, combined with major findings, were presented.

Not all secondary questions were structured to enable definitive positive or negative answers, i.e. some secondary questions were requests for information. For this reason, all secondary questions will not be discussed here, and it is recommended that each is revisited in section 9.10, above.

It is important to note that to answer secondary questions one and seven (SQ1. and SQ7.) requires the development of potentially lengthy responses which are beyond the intended scope of this chapter, and which could be included in further work resulting from this research. Each could be considered for development of independent guides to practice. Consequently, the detail of the answers provided was limited to essential considerations without further development or discussion. These questions were:

SQ1. What should surveyors, managers and users of geospatial information know in order to understand geospatial risk? and

SQ7. What systems and controls would be required to mitigate geospatial risk, ensure defensibility of practice and support operational efficiency?

Surveying qualifications and the development of competencies and specialisation aligned with value chain core-processes and activities were described thus addressing a critical aspect of geospatial risk mitigation and management. Furthermore, demonstration of competency would entitle registration in the appropriate category or categories of practice, thus communicating professional standing to the public, the minerals industry and professional peers.

Finally, it is worth repeating that due to geospatial information running through the full life-cycle of a mining project, geospatial information and associated strategy, systems, controls and practice are a primary consideration, not a secondary consideration within all core-processes.

Chapter 10 will discuss conclusions to and recommendations from this research.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

As suggested by the title *"A Cross-Functional Value Chain Approach to Geospatial Information: A Guide to Practice for the Minerals Industry"*, this dissertation is intended to serve as an industry-wide guideline to be referenced by all disciplines involved in the business of mining, at all levels of mining organisations, and in any country of operation. It acknowledges different legislative and regulatory frameworks, and where appropriate cites country-specific examples to demonstrate relevant points or to provide appropriate context.

The structure of the dissertation is intended to present sufficient information and knowledge in each of its central chapters, to enable appropriate practice to be formulated. Each central chapter has been written as a guide to practice and a foundation on which to build further work. Furthermore, the introduction and conclusion of each central chapter provide summaries of the chapter content to enable 'quick referencing' by the reader.

The purpose is to prompt thought, while deliberately avoiding a 'check-list' approach, which the author contends encourages a 'compliance mind-set', i.e. thought should lead to contextual understanding, which should lead to practice which is suited to a specific context, site, activity or group of activities. In doing so, the overarching issue of understanding the geospatial interdependencies across the mining value chain are addressed, to enable cross-functional integration to mitigate risk and improve business performance.

Consistent throughout the research is the use of a mining value chain which represents the core-processes of a mining project life-cycle, namely: Explore, Evaluate, Establish, Operate and Close.

Chapter 9 discussed the major findings of this research and answered the principal and secondary questions, thereby achieving the objectives stated in Chapter 1, Introduction.

In answering these questions, each of the central chapters (three to eight) was revisited and discussed separately. Consequently, it is not necessary to summarise each chapter in this final chapter, thereby devoting chapters nine and ten to the findings, conclusions and recommendations of this research, rather than having a single concluding chapter. This was necessary due to breadth of the topic spanning the full cycle of a mining project, and to the number of secondary questions which were answered.

References to geospatial risk should be understood as risk in which geospatial deficiency or error is a principal component, but which may not be classified as such due to being associated with an event or activity (e.g. without apparent geospatial relevance).

Discussion of risk and risk consequence fell into three categories, namely safety, financial and reputational. Where appropriate, each risk category and its potential severity were discussed in relation to geospatial deficiencies. For example, geospatial deficiencies introduced during exploration could be transferred through a geological model into mineral resource and reserve models, and mine planning and design, resulting principally in financial and reputational risk. Regarding safety risk, geospatial deficiencies or errors in mine surveying, mine plans and other geospatial records could result in single or multiple fatalities, hence the discussion of mine accidents or incidents to demonstrate risk consequence.

This chapter, Chapter 10, will discuss common themes identified in the research findings which span more than one chapter or core-processes of the value chain, leading to recommendations to enable the value potential of this research to be realised. In so doing, there will be minimal direct reference to previous chapters.

The point of departure for the conclusions to follow, as described in Chapter 9, is that this research has confirmed that *“a cross-functional value chain approach to minerals surveying and geospatial information defines geospatial context, mitigates risk and enables value creation in the business of mining”.*

10.2 Conclusions

The requirement for a common understanding that geospatial information runs through the business, from exploration to mine closure, is of fundamental importance.

Geospatial information is the foundation of all mining projects. It is used by several functions and in several processes throughout a project life-cycle. Physical, geological, geotechnical, economic and environmental attributes are attached to coordinate points which form the basis upon which investments are made, and mines established and operated. Geospatial information and associated strategy, systems, controls and practice are therefore a primary consideration not a secondary consideration, within all core-processes of the value chain and have significant relevance to the business of mining. Therefore, comprehensive knowledge of fundamental geospatial principles, typically high levels of surveying competency and mutual cross-functional understanding of the value chain are required.

Throughout this dissertation, reference was made to relevant legislation or other controlling instruments, and to the legal responsibilities of the surveyor, or in some jurisdictions the engineer, regarding the keeping of adequate geospatial records, maps and plans. However, reference was also made to defensibility of practice and to duty of care, to guide practice irrespective of the existence of legislation or standards which define the duties and responsibilities of the surveyor (or engineer). Importantly, the absence of a statutory of other controlling instrument does not mean that there is an absence of responsibility or duty of care.

This research indicates that the risk of deficient geospatial information to the business is typically not understood, and that it is reasonable to conclude that this applies to all disciplines involved in core-processes of the value chain (Explore, Evaluate, Establish, Operate and Close) to a greater or lesser extent, inclusive of the surveying discipline. This conclusion is supported by evidence of a typical lack of understanding of geospatial accuracy requirements for relevant processes and activities across the business.

Another significant contributing factor to this conclusion, is the lack of evidence in this research of a broad and adequate understanding of the interdependencies and interconnectivity of activities of value chain core-processes which enable high-level cross-functional understanding of a mining project. Furthermore, evidence could not be found that demonstrated assessment of geospatial risk across the full life-cycle of project, nor the expression of such risk consequences in safety, financial, and reputational terms, and similarly for potential environmental and socio-economic impacts.

When considered in a risk context for mitigation and management, it is appropriate to refer to the combination of requisite accuracy and geospatial deficiency as geospatial ‘adequacy’, thus establishing a link to terminology used in international codes, standards or guidelines for reporting mineral exploration, resources and reserves (Codes). In doing so, a link is also established to the first core-process, Explore and the geospatial foundation of a project, i.e. the first cross-functional bridge to the next core-process.

Central to geospatial adequacy, is the concept of accuracy which is fit for purpose, i.e. accuracy standards can vary according to intended application, ranging from possibly metres for exploration, to millimetres for mine establishment and operation. Therefore, geospatial context should be defined to guide practice and ensure that appropriate accuracy standards and specifications are applied which consider fit-for-purpose, and where appropriate, fit-for-next-purpose.

Further support of the finding of deficient understanding of geospatial risk consequences was the silence or limited reference to geospatial adequacy in the Codes, and to the competency required to assess such adequacy. As an example of the impact of geospatial error in geological modelling, Wolmarans (2005) commented on the risk of a mineral resource classification being downgraded, as a result of material error in geospatial information, indicating a potentially significant risk to project viability.

As a probable consequence of this silence or limited reference to geospatial adequacy in the Codes, there is an under-representation of the surveying profession during the technical studies phase of a project (project evaluation), despite the broad dependence of the project on geospatial information. There is an inflection point during this project phase, at which geospatial information shifts from being the foundation of mineral resource and ore reserve models, to being the geospatial foundation for engineering functions for mine design and construction. However, the research indicated that less than 1% of the content of a mineral asset development standard made reference to geospatial and surveying requirements, despite more than 70% of functions described in the standard using geospatial information – a substantial anomaly requiring further assessment. Consequently, geospatial strategy, standards, capacity and capability are not adequately addressed before commencement of mine establishment (construction and development), resulting in potential escalated risk and related geospatial assurance in mitigation thereof.

During mine development, operation and closure there is typically a greater awareness of geospatial risk, due to the direct relationship of geospatial information to mine safety. Mine surveying or the keeping of accurate mine maps/plans, and the certification as accurate and correct of all information represented on such maps/plans, is typically regulated in several countries, principally to address "protection of the surface and workings". This demonstrates that the risk of deficient geospatial information is commonly accepted. However, as a consequence of operational focus on safety related compliance, the potential contribution of quality geospatial information to the performance of the business is typically overlooked or underestimated. The role of surveying in supporting safe mining and mitigating geospatial risk is not an unnecessary statutory imposition and should be recognised as protecting value, thus contributing (indirectly) to the business.

To demonstrate the potential of surveying and geospatial information as an enabler of value, the concept of geospatial intelligence was introduced. The objective of measuring, monitoring, reconciling and reporting the right KPIs at the right frequency, is to enable or influence improved operational control and management, whether this be in support of a project schedule during mine establishment, or in support of mining operations and ultimately, mine closure.

Survey reporting becomes geospatial intelligence, capable of influencing operational effectiveness and efficiency, when done proactively rather than reactively and includes appropriate opinion or insights, thus providing leading indicators for the effectiveness of the process or activity being reported.

Additionally, by addressing the interconnectivity of activities and associated KPIs which drive value, reporting can move from an approach of what happened, to what will happen if a reported trend continues. Leading indicators provide the foresight to anticipate an outcome and, if required, to institute measures to mitigate a potentially negative outcome. Similarly, leading indicators can be positive and reinforce the continuance of current practice.

During mining operations, although relevant across the value chain, it is typical for activities to be executed without adequate consideration of cross-functional interdependencies, resulting in sub-optimal effectiveness of linked processes. Recognising this impediment to operational effectiveness and value contribution, Lane and Wylie (2014), observed that *"Mining companies are traditionally* *managed in silos, with each discipline owner or department head focusing on... their area of control… often without understanding the impact on downstream activities…"*. Similarly, Hargreaves and Morley (2014) proposed the practice of "*multidisciplinary… universal reconciliation… across the entire mining value chain to strengthen the interplay between the technical disciplines and to identify opportunities and loss of value in order to maximise operational performance*". These observations support the purpose of the value chain to identify cross-functional interdependencies, develop mutual understanding to enable effective collaboration and improve collective contribution to operational performance.

Geospatial strategy, people, information, processes, technology and practice support the core-processes of the mining chain, inclusive of mine closure. Upon closure, the responsibility remains for the keeping of accurate geospatial records, maps and plans, as these typically have a bearing on future mine or public safety, or environmental risk. Such records may be required to be preserved in-perpetuity, thereby influencing information management strategy and systems.

Further to mine closure, it was noted that until mine closure is legally effected, resulting in the relinquishment of the right to mine, a mining property is technically still a mine, therefore, legal responsibilities, and where appropriate, legal appointments addressing competency and responsibility (e.g. the mine surveyor), remain a statutory requirement for the owner of the mine, as does duty of care.

The issue of competency was discussed in each of the central chapters of this dissertation, firstly related to fundamental geospatial principles, followed by discussion under each of the core-process of the mining value chain, from exploration to mine closure. Importantly, the competencies differ depending on the application or core-process, thus highlighting the need to situationally define a suitably qualified and competent person, recognising the requirement for specific expertise. Suitable qualifications and competencies require careful consideration – again the concept of defensibility and duty of care should provide guidance.

In addition to the above-mentioned competencies, it is important to consider that the knowledge, skills and competency required to examine, approve and sign off on the accuracy, quality and integrity of geospatial information exceeds those required to execute work. This has relevance to the Codes, (e.g. reliance on "other experts" applicable to geospatial information in areas where the experience of the

“Competent Person” is insufficient), and for every core process described in the value chain.

From the above-mentioned summary conclusions, the critical role of geospatial information in risk mitigation and business performance monitoring has been demonstrated, with specific reference to the interdependencies between functions such as exploration, mining, processing, environmental protection and mine closure. The value potential is significant.

10.3 Recommendations

The recommendations to follow consider actions to be taken in order to realise the full value potential and contribution of geospatial information and the surveying function to the business of mining, spanning the full project life-cycle.

Key to achieving this is the effective promotion of awareness and understanding of the principles and findings of this research which confirmed that a cross-functional value chain approach to minerals surveying and geospatial information defines geospatial context, mitigates risk and enables value creation in the business of mining.

For the purpose of these recommendations, South African professional bodies and organisations are used as examples. These can be substituted to accommodate local context in any country of operation. Where appropriate, similar international organisations and bodies can be included.

10.3.1 Communication and awareness

Effective communication of this topic to the correct audience is key to promoting awareness and understanding.

The target audience can be selected from the lists of disciplines which appear under the value chain figure in each of the core-process chapters, namely, Explore, Evaluate, Establish, Operate and Close. Although not an exhaustive list, it should be sufficiently complete to include the majority of technical disciplines involved in mining projects and operations, including legal, environmental and social/community professions and practitioners.

It is recommended that:

a. Based on the principles and findings of this research, papers are written and published in prominent journals and other publications targeting professional bodies or learned societies, and presented at appropriate industry forums and conferences.

b. Content is developed to cover the full mining value chain, a core-process (e.g. Explore or Operate), or a focus area within a core-process.

c. Ideally, papers should cover all core-processes, from Explore to Close, after which focus area papers can address specific value or practice areas.

d. Where possible, joint authorship should represent more than one discipline, to reinforce cross-functional collaboration.

e. This process of authorship and publication is coordinated, and driven by an appropriate professional body or institution of higher learning.

10.3.2 Development of a code of practice

It is recommended that a geospatial and surveying code of practice (CoP) is developed for the minerals industry, based on the structure and content of this dissertation, to become a reference document or guide to practice.

a. It is proposed that this task is assigned to the Institute of Mine Surveyors of Southern Africa (IMSSA).

b. Appropriate resources, inclusive of professional editing, are assigned, to enable publication in the shortest reasonable period. If necessary, sponsorship should be secured.

c. Where appropriate, this should be a collaborative process involving other mining disciplines in either contributing to content development or to reviewing and commenting on content, i.e. cross-functional approach. This would require IMSSA to collaborate with associate industry bodies, such as the Southern African Institute for Mining and Metallurgy and the Geological Society of South Africa.

d. Based on the fundamental geospatial risk principles described in this research, the CoP should include a geospatial risk matrix which addresses the event type (risk), likelihood of occurrence, severity, consequence and classification of consequence, to manage such risk. Again, this should be a collaborative process involving other disciplines which are exposed to or affected by the assessed risks.

e. To ensure broad exposure, the CoP should be made available through IMSSA and other industry and professional bodies, such as the;

- Southern African Institute of Mining and Metallurgy;
- Geological Society of South Africa;
- South African Council for Geomatics Professions;
- Engineering Council of South Africa; and
- South African Council for Natural Scientific Professions.

f. As an alternative to the above-described approach, mining companies or operations could use the fundamental principles described in this work to develop company or site-specific codes of practice.

10.3.3 Further work

Each central chapter of this dissertation was written as a guide to practice and a foundation on which to build further work. Consequently, there is significant scope for further work and post-graduate research, either at masters or doctoral degree level (depending on the scope and depth of research).

a. The research agenda should be driven by an institution of higher learning to address topical needs of the minerals industry.

b. Research topics could address a core-process (e.g. Explore or Operate), or a focus area within a core-process.

c. It is strongly recommended that BIM, or as proposed in Chapter 6 “Asset Information Management” is addressed as a research topic, for application in mining evaluation, establishment, operation and closure, or as a guide to geospatial strategy development. The value potential is significant and is a natural progression of this research.

10.3.4 Revision of curricula to include the content and findings of this research

Exposure to the principles of cross-functional and cross-disciplinary interdependencies, and the understanding of geospatial information throughout the value chain, should form part of tertiary minerals education. This would require that curricula are revised to include the content and findings of this research.

a. The process for revising curricula is not known to the author and would require support from an institution of higher learning, such as the School of Mining Engineering at the University of the Witwatersrand, to support and initiate the process.

b. As a first step to identifying the disciplines which fall within the scope of a revision of a curriculum, the disciplines and universities supported by the Minerals Education Trust Fund[9] (METF) can provide the nucleus for change.

c. Expanding the scope of relevant disciplines (and hence institutions and qualifications) can be guided by the lists of disciplines which appear under the value chain figure in each of the core-process chapters, namely, Explore, Evaluate, Establish, Operate and Close.

d. As a parallel or alternate process, short courses on the subject (of this research) can be presented, similar the short courses and post-graduate courses currently presented at the University of the Witwatersrand, or as an introduction to mining (which would include minerals industry management in its target audience).

10.4 Conclusion

This research has demonstrated the critical role of geospatial information in risk mitigation and business performance monitoring, with specific reference to the interdependencies between functions such as exploration, mining, processing, environmental protection and mine closure. The value potential is significant, as is the potential for further work resulting from this research.

[9] The purpose of the METF is to support, promote and advance the interest of minerals education in South Africa, in the disciplines of Mining (including, geotechnical and ventilation engineering and mine surveying), Metallurgy/Chemical Engineering and Geology. The METF is comprised of approximately 30 companies in the minerals industry supporting academic programmes at nine universities.

Key to achieving the value is to adapt minerals industry education accordingly, and to consistently communicate the principles of this work to industry through broad publication of suitable material and through engagement with professional bodies.

Numerous recommendations have described how this could be achieved. The challenge now is to put this work to effect.

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Appendix A – Useful surveying and mapping definitions

Accuracy	The difference between the most probable value and the true value. In a mapping context, the degree to which objects on a map or in a database match their true positions on the ground, as numerically defined by a coordinate system. Not to be confused with Precision. • Accuracy requirements are variable, depending on purpose. • Cost of data acquisition and processing increases with increasing accuracy. • Map accuracy is directly related to map scale. • Data of known ground-scale accuracy can be related to the appropriate map scale.
Ellipsoid	A mathematical figure which represents a uniform shape of the earth, formed by revolving an ellipse about its minor axis.
Ellipsoidal Height	The height of a point on the Earth measured from and perpendicular to the Ellipsoid. Not to be confused with height above sea level (Orthometric Height).
Fit-for-purpose (accuracy)	The accuracy suited to the purpose for which the geospatial information is being prepared. Fit-for-purpose is therefore variable and contextual, and may range from metres to millimetres in accuracy, depending on application.
Geoid	A non-uniform model of the shape of the earth which best fits mean sea level, i.e. the closest mathematically definable figure of the Earth. It is an equipotential surface (i.e. the surface on which the gravity potential is constant).
Geoidal Height	The height separation at a point between the surface of the Geoid and the surface of the Ellipsoid. Not to be confused with height above sea level (Orthometric Height).
Geospatial	The geographic location and characteristics of natural, described or constructed features above, or below the Earth's surface, i.e. data which is geographical and spatial in nature.
GNSS (GPS)	Global Navigation Satellite System, the standard generic term for satellite positioning systems such as Navstar GPS

	(USA), Glonass (Russia), Galileo (European Union) and Beidou (China) and other systems under development.
Height Datum (or Vertical Datum)	The origin to which heights are referenced on the Earth's surface, which is commonly Mean Sea Level (MSL). • Typically prescribed by national statutes or conventions. • Local height datums do occur (nominal or prescribed). • Gravitational variation influences MSL (see Geoid).
Horizontal Datum	The point of origin on the ellipsoid that provides a reference frame for coordinates (on the Earth), typically prescribed by national statutes or conventions. Due to the non-uniform shape of the Earth, localised datums provide improved positional accuracy, consequently hundreds of datums exist worldwide.
(Map) Projection	The mathematical system of projecting points from the ellipsoid (curved surface) onto a plane (flat surface) for representation on a map. Often referred to as a grid, survey grid or grid system.
Map / Plan	Any map, plan, drawing or section, whether printed or in digital format, which is a visual representation of objects above or below the surface of the Earth. • Map and Plan can be used interchangeably (based on context). • Mining legislation typically uses the word plan.
Mean Sea Level (MSL)	Corresponds to the geoid, which is 'a best approximation' of Mean Sea Level. When used as a height datum (for surveying and mapping purposes), it is customary for it to be referenced to tide gauge measurements at a specific geographical location.
Meridian Convergence	Is the difference between Grid North (GN) and True North (TN) at a point, where; all lines of meridian are true north-south lines which converge towards the poles; whereas grid lines are all parallel to the central meridian of a coordinate system and therefore do not converge towards the poles.

	• Meridian convergence = TN - GN. • Is zero on the central meridian. • Increases with distance from the central meridian. • Increases with distance from the equator. • Is of opposite signs on opposite sides of the central meridian.
Orthometric Height	The height of a point on the Earth above the Geoid, i.e. height above MSL. Due to the Geoid approximating MSL, local adjustments to orthometric height may be required to correspond with the height datum.
Precision	Is the relative grouping or closeness of points (of measurement), without any reference to true positions on the ground. Not to be confused with Accuracy (e.g. geospatially precise data may be inaccurate).
Project, Mine or Local Datum	A nominal height and/or horizontal datum adopted, normally for convenience, that does not comply with prescribed national or regional datums.
Scale	The relationship between a distance measured on a map and the corresponding distance on Earth.
Competent Person	For surveying, this means a person qualified and recognised as a surveyor and possessing the relevant knowledge, skills and experience to undertake surveying work, and to assess and certify the accuracy of a map and surveying records.
Survey Control System	The Cartesian system for representing point coordinates or positions on a map, typically prescribed by national statutes or conventions.
WGS84	World Geodetic System (1984) is the geocentric (Earth centred), Earth-fixed terrestrial reference system and geodetic datum used by GPS, and which has its own reference ellipsoid.

Sources:

Allan, A L., Hollwey, J R., Maynes, J H B. (1975) Practical field surveying and computations, London, UK: Heinemann.

Author's collection. (no date) Notes, images and information gathered over years.

City Services Unit. (1991) Survey Handbook (Sixth Edition), Durban, South Africa: Durban Corporation.

RICS (Royal Institution of Chartered Surveyors). (2003) Guidelines for the Use of GPS in Surveying and Mapping, Coventry, UK; RICS Books

Schofield, W. (1993) Engineering Surveying (Fourth Edition), Oxford, UK: Butterworth-Heinemann Ltd.

Appendix B – Quasi-geoidal model for Colombia (2004)

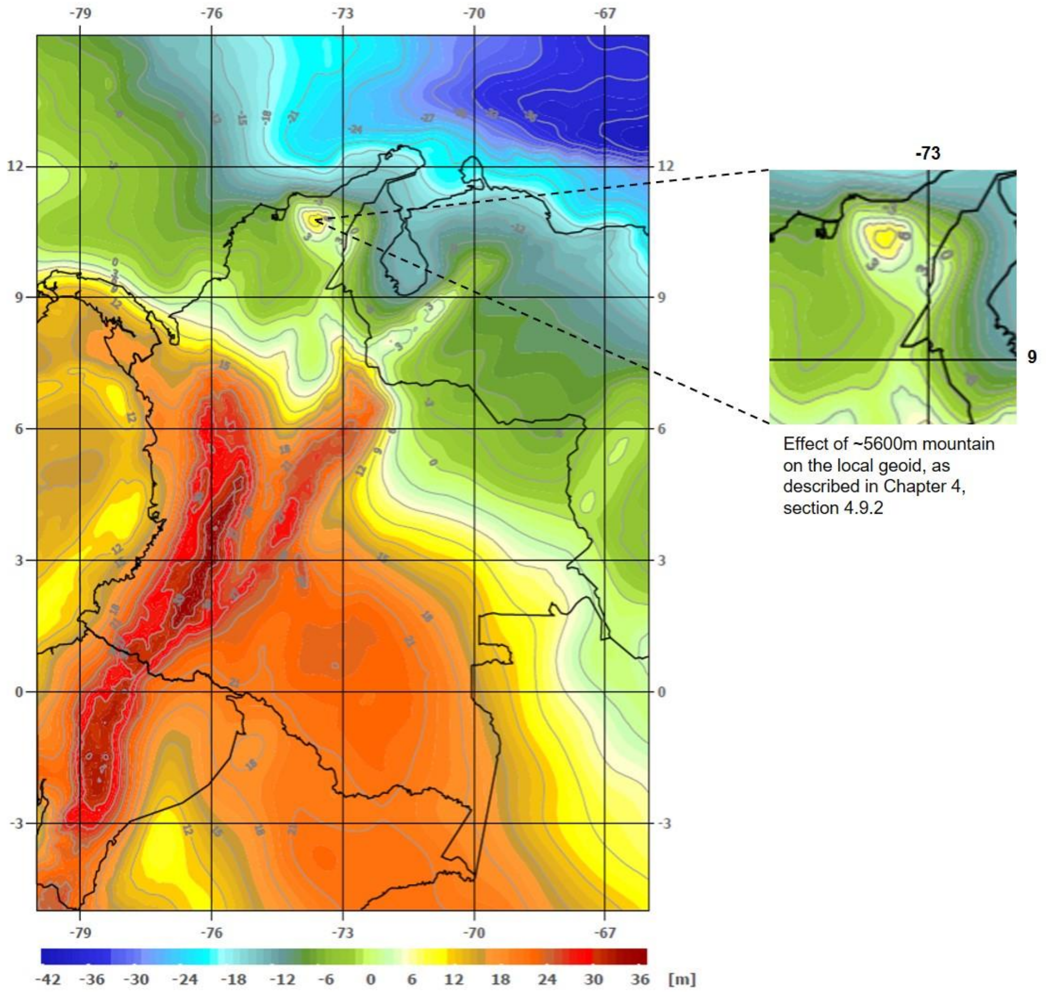


Figura 2.7 Modelo geoidal (cuasi-geoidal) para Colombia (GEOCOL2004)

Source:

Instituto Geográfico Agustín Codazzi, October 2004 (Author’s collection)

Appendix C – Shaft profile design compliance report

VUP Production Shaft Profile Report (Prelum)

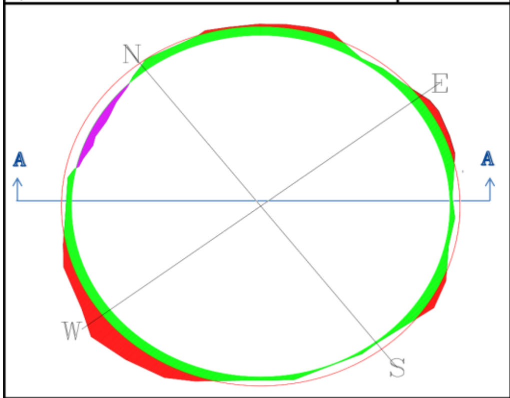
Scan date		04 May 2017	Thursday
TOP OF COLLAR	717.946		
TOP OF COLLAR	TO	Shaft Bottom	472.0
Tape Bracket 11	TO	Top of Ring 76 A	28.2
Top of Ring 76 A	258.034		
Bottom of Ring	TO	Shaft Bottom	11.4
Tape Bracket 11	TO	Shaft Bottom	40.3
Tape Bracket 11	286.234	#Bottom AMSL Elevation	245.9
Previous			467.0
Advance for the blast =	Min Depth		5.0
Advance for the Month =			5.0
Cover Elevation no 13	237.0	P# Bottom to next cover	8.9

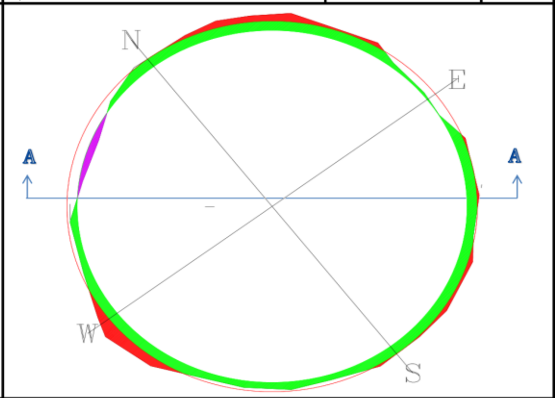
Comments: Scan on clean bottom

	Underbreak	Shaft Spec	45.365
	Overbreak allowable	Incl allowable Overbreak	50.265
	Overbreak non allowable	Allowable Overbreak	4.901
	Overbreak unavoidable		

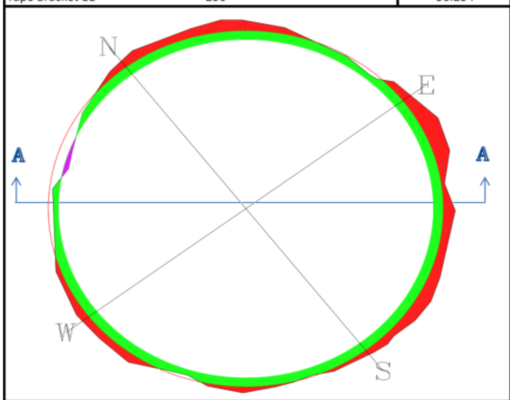
	252	251	250		Ave	m³	Persentage	Max
Underbreak	0.252	0.172	0.054		0.212	1.070	0.4%	
Overbreak allowable	3.287	3.669	4.337		3.478	17.550	6.9%	9.75%
Overbreak non allowable	1.601	0.952	2.689		1.277	6.441	2.5%	
Overbreak unavoidable	0.000	0.000	0.000		0.000	0.000	0.0%	
Total Area	50.001	49.814	52.337		49.907	251.831	109.0%	

Tape Bracket 11	252	34.234	Tape Bracket 11	251	35.234

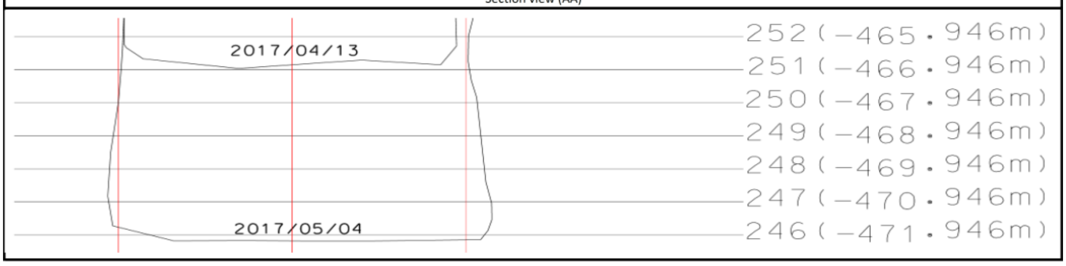




Tape Bracket 11	250	36.234



Section view (AA)



MRC Surveyor	VUP Surveyor	Geotech
Chief Surveyor	Master Sinker	MRC Production Manager

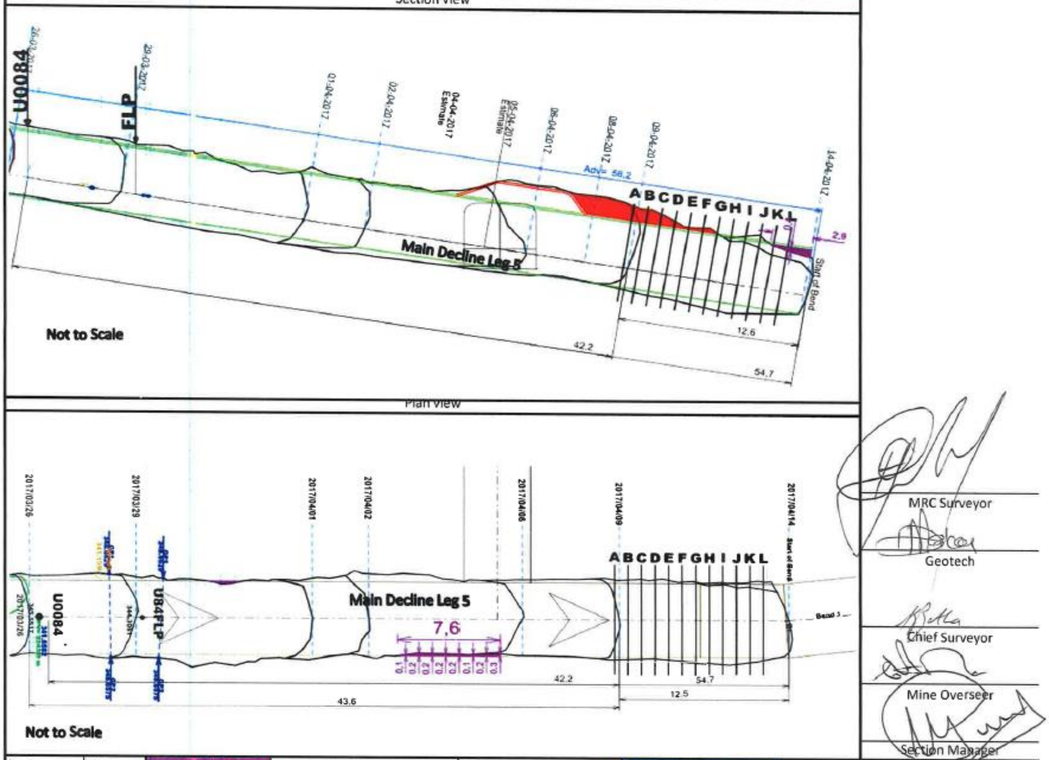
Source:

Mafoko, D. (2017) Venetia Underground Project

Appendix D – Decline profile design compliance report

Main Decline Leg 5					Time of scan			Decline	
Blast Week	from	10 April 2017	to	14 April 2017	15:00		Underbreak	Tunnel specification m2	33.100
Peg no	U0084	Peg to face =		54.7			Overbreak allowable	Including allowed overbreak	35.199
Peg value	2243.9	Total distance=		2298.6			Overbreak non allowable	Allowable overbreak	2.099
Previous month total distance in =				2242.5			Overbreak unavoidable		
Advance for the week DECLINE =				12.5			Water		
Advance for the month Ancillary meters=				8.4					
Advance for the Month =				64.5	Cover Value	2515.5	Dist to next cover	206.9	

Section view



Section	Cut no	Underbreak	Overbreak Allowable	Overbreak non allowable	Overbreak unavoidable	Total Area	O/BREAK	%
A	2270	0.043	2.088	8.373	0.000	40.754	37.96	%
B	2271	0.000	2.215	7.135	0.000	40.544	37.11	%
C	2272	0.000	2.177	6.169	0.000	40.180	35.88	%
D	2273	0.000	2.244	3.448	0.000	37.770	27.73	%
E	2274	0.000	2.210	2.413	0.000	37.235	25.92	%
F	2275	0.000	1.859	2.733	0.000	37.636	27.27	%
G	2276	0.208	1.613	2.448	0.000	37.213	26.55	%
H	2277	0.374	1.404	2.604	0.000	37.368	27.63	%
I	2278	0.404	1.577	3.595	0.000	38.338	14.94	%
J	2279	0.503	1.334	2.051	0.000	35.284	-3.81	%
K	2280	0.358	0.930	0.743	0.000	33.007	-14.76	%
L	2281	1.021	1.039	0.995	0.000	32.313	-14.84	%
Average		**0.261**	**1.691**	**3.121**	**0.000**	**37.304**	**-24.86**	**%**
m^3		3.259	21.139	39.016	0.000	466.294		
Percentage		0.79%	5.11%	9.43%	0.00%	113.49%		
Target			6.0%			100.0%		

Comments:

Survey: Overbreak/Underbreak (excessive) will be declared defect.

Geotech: Reduce overbreaks and mine as per layout

Geology

Mining:

Blast Profile Decline 20170410 -20170414.xlsx

Source:

Mafoko, D. (2017) Venetia Underground Project