REDUCING COSTS ON BULK MATERIAL HANDLING PROJECTS

Author: Marthinus Johannes Schmidt, Pr. Eng. (Student 502264)

Supervisor: Prof. T.J. Sheer

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ABSTRACT

The objective of this study is to provide a framework for reducing bulk materials handling project costs in a systematic way by considering key cost drivers and potential saving opportunities without compromising the functionality of systems. The impact that these possible savings may have on the overall project viability and cost is explored by predominantly focussing on coal projects. Typical project specifications are considered in order to understand to what extent they influence project costs. The need to align project specifications with the business vision and requirements is argued while recognising how the upfront project scope definition remains key towards avoiding unnecessary capital expenditure. A case is made to justify strict project specifications for long term projects. High level selection guidelines are provided on costly storage and land transportation systems. The merits of utilising used plants, systems and equipment are investigated. Case studies are presented to caution against unintended consequences of under-investment. The financial impact of engineering decisions is a central theme throughout. A high level framework showing how different aspects of bulk materials handling costs are interrelated is provided to enable project teams to maintain a balanced view throughout project studies and implementation.

DECLARATION

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

MJ Schmidt
502264
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NOMENCLATURE

AA	Anglo American PLC, A global mining company
BMH	Bulk materials handling
BOQ	Bill of Quantities
CBS	Cost breakdown structure
Capex	Capital expenditure
CPS	Corrosion protection system
DMR	Department of Mineral Resources
HDG	Hot dipped galvanizing
IRR	Internal rate of return
OEM	Original equipment manufacturer
Opex	Operational expenditure
P&G’s	Preliminary and General charges
SHE	Safety, Health and Environmental
VIP’s	Value improvement practices
WBS	Work Breakdown Structure

1 INTRODUCTION

1.1 Background

The unprecedented demand for minerals from around 2005 until 2013 has enabled mining companies to make good profits due to high commodity prices. Unfortunately the sudden downturn in the world economy has led to the end of the so called super-cycle to the extent that many commodity prices dropped more than 50 % while capital and operational costs have been rising all along. Consequently the return on investment on many large mining projects has been disappointing, calling for large financial write-downs. Against this backdrop, it is imperative that new mining projects are carried out in the most efficient manner to demonstrate viable investment cases. Whilst it is anticipated that the supply and demand of commodities such as iron ore and metallurgical coal will probably take many years to stabilise, it is nevertheless inevitable that various mineral projects will proceed in order to honour contractual supply commitments.

In an inflated commodity price cycle, project capital expenditure is much less sensitive when compared to a low price environment. During prosperous times company specifications are often expanded while the affordability of these additional design requirements is not necessarily evaluated carefully. Ironically, when the cycle turns, newly developed specifications and best practice documents are often perceived as restrictive to achieve investment hurdle rates. The hurdle rate is the minimum rate of return required by a company when making an investment. It must be understood that the business model of large mining companies is usually very different from that of junior miners. Traditionally mining giants would obtain the best mining reserves and establish infrastructure in view of long term operations. Junior miners, on the contrary, generally target shorter operational horizons on a lesser cost basis. When visiting typical operations from these two groupings, the difference in infrastructure expenditure is usually obvious. Junior miners often get along with the bare minimum while larger mining companies have a tendency to invest more heavily in higher quality roads, office complexes, perimeter fencing etc. When tough financial cycles prevail, specifications of large mining companies come under criticism when the viability of projects is in the balance. The need to evaluate current project design practice and requirements dictated by company and industry specifications is unavoidable.

This study aims to establish a framework by which sound cost savings can be achieved in bulk material handling (BMH) projects while still delivering fit-for-purpose systems and components. This study furthermore aims to challenge perceptions that mining projects can be carried out much cheaper by merely applying less onerous company specifications. Understanding the design life is vital to evaluating this notion. It seems logical that a case can be made to have less stringent engineering requirements for short term, low return types of projects to ensure financial viability whilst satisfying national regulations and standards. On the contrary, when approaching the design of long term projects, it would seem logical to recognize where upfront investment can provide future benefits to reduce operational and maintenance expenditure.

An operating mine may consist of either underground or open cast operations or a combination of these. Beneficiation facilities, utilised to produce a higher grade product, are often encountered while discard systems will be required to handle the waste material. The BMH systems associated with typical underground operations would include a series of section, trunk and shaft conveyors and most likely some surge and crushing facilities which may be located underground or on surface. Section conveyors are regularly moved to access a new mining location while main trunk conveyors are usually fixed installations catering for the entire life of mine. Although various mining equipment and techniques are used underground, continuous miners and flexible conveyor trains are often utilised. Battery haulers or shuttle cars are utilised to discharge raw coal onto the section conveyors via feeder breakers. Raw material brought to surface may be transported by road, rail or conveyor systems for beneficiation or perhaps to an inland client after passing through crushing and screening operations. Raw material extracted at open cast operations will generally be road hauled to a tip where crushing and screening activities will take place before transporting the raw product for further beneficiation or point of sale.

A pictorial view of BMH systems and infrastructure commonly associated with beneficiation and export facilities are shown below in Figure 1.1.

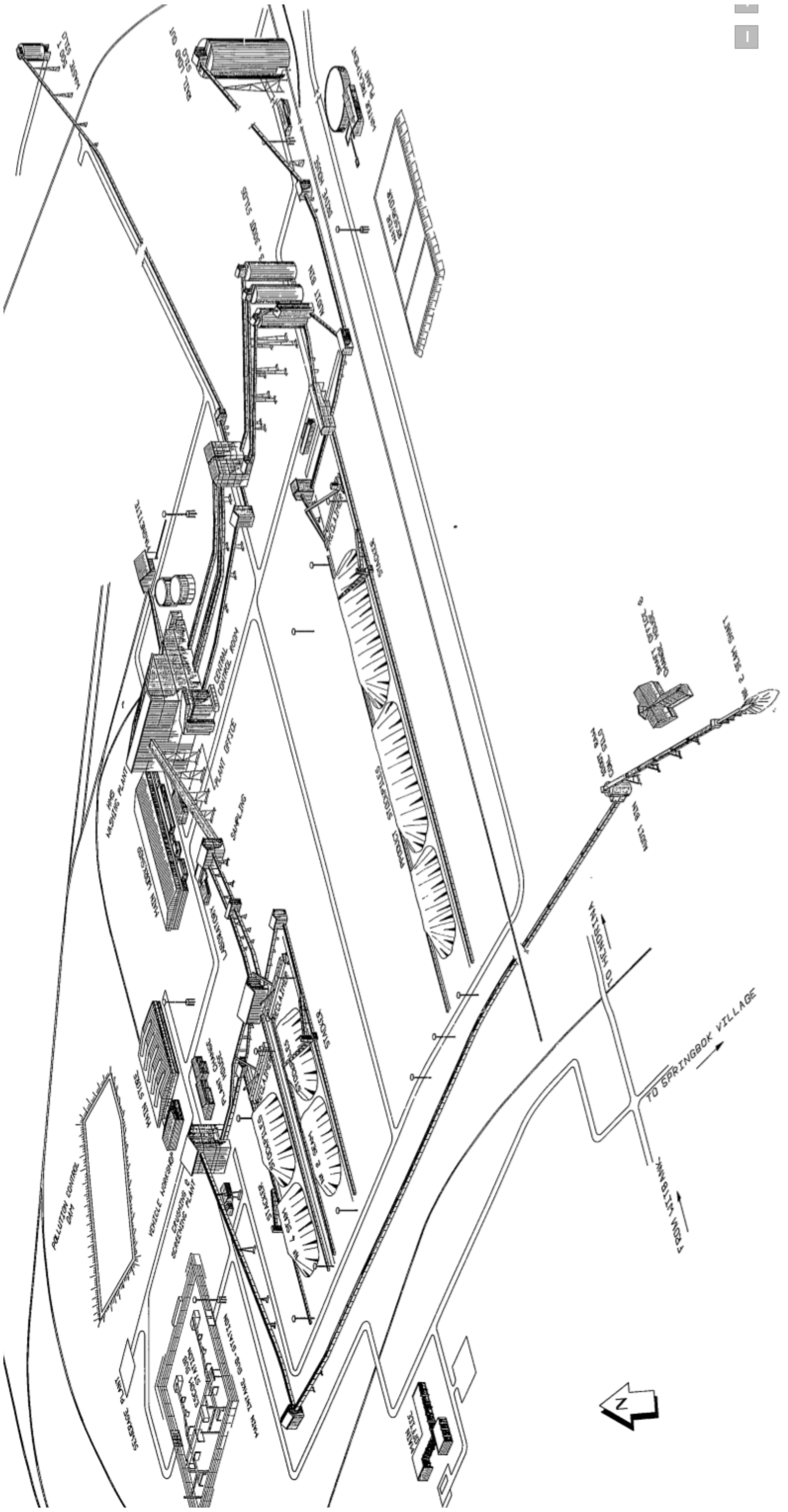


Figure 1.1: BMH Systems and infrastructure of a typical export colliery.[1]

Deep level gold or platinum mines are however very different from the operations described above. Sophisticated vertical shafts with associated hoisting systems, refrigeration plants and pumping systems are central to these operations. Although the research report will largely focus on the coal mining industry, the principles and proposed framework for understanding and reducing costs on BMH projects are considered generic.

It is anticipated that this study will assist project teams to make informed upfront decisions and provide insight not only regarding capital expenditure on BMH systems but also to facilitate a balanced perspective on longer term implications of investment decisions.

1.2 Research Motivation

The motivation for this study originates predominantly from the impact of severe pressure on commodity prices and subsequent difficulty to achieve acceptable return on investment for mining projects. Engineering teams are sometimes severely criticized for designs and specifications which are deemed to be overly conservative and unaffordable. The need to drive down the project capital cost in order to demonstrate viable business cases during study phases is fully supported but cost reductions must be done in a sensible and systematic manner whilst ensuring sustainability for the anticipated life of the operation. To achieve this, a clear understanding of cost drivers are pertinent. Lucrative short term savings may result in expensive fixes and additional maintenance due to inadequate design. The efficient use of capital remains key.

1.3 Problem Statement

The capital costs associated with BMH systems in relation to the overall project costs are often misunderstood by project teams. With a short term outlook, savings may be realised on BMH systems which could prove to be expensive in the long run if underinvestment is made on infrastructure. Although savings may be realised on BMH systems, it arguably seldom makes significant difference to the bottom line of the business case.

BMH design and investment is often done based on legacy corporate specifications which were traditionally, for large mining houses, based on substantial mining reserves where infrastructure would be used for no less than a few decades. The hypothesis is therefore that the design and investment approach for smaller short term projects needs to be fit for purpose to ensure the efficient use of capital and a positive return on the investment. When considering long term projects, it is subsequently postulated that a greater upfront investment can be justified.

1.4 Scope Restrictions

Although the principles covered in this study can be generically applied to BMH projects, they are presented with the coal industry in mind. The study will be focused on company-specific specifications and requirements based on a long term investment approach. Considerations for shorter term projects will be inferred.

1.5 Research Question

The central research question to be answered by this study is:
How can the industry reduce costs on BMH projects in a systematic way while still satisfying the business requirement?

1.6 Research Objective

The key objective of this study is to provide a framework for reducing BMH project costs in a systematic way by considering key cost drivers and potential saving opportunities without compromising the functionality of systems.

1.7 Methodology

A literature review will be conducted to establish what learnings can be taken from previous research work, implementation project experiences and industry best practice. It is deemed key to understand typical BMH project cost in relation to the overall project expenditure. Typical BMH project costs will be quantified as a percentage of overall project costs by means of researching available information captured in the project archives of a leading mining house. Representative BMH project specifications will be reviewed to understand the impact thereof on overall project costs. The design life of a project is considered to be a key consideration when evaluating these specifications. Expert opinion will furthermore be sought from industry by means of interviews and informal discussions to evaluate guidelines and learnings obtained from literature studies. A framework for evaluating and reducing BMH project costs will subsequently be developed. Figure 2.3 from Chapter 2 provides an overview of how the different study sections fit together. Representative case studies will be identified to test the validity of this framework. The study will be concluded with comments on the applicability of the framework and suggestions for reducing BMH project costs.

1.8 General

Throughout the text a project with a time horizon of less than 10 years is referred to as short term project i.e. a long term project would have an operational life of more than 10 years.

Project specifications are documents defining the goals, functionality and specific details required to satisfy the vision of the owner or company. Large mining houses typically develop generic project specifications on an ongoing basis and then adopt these documents when embarking on a new implementation project or study. These company specific but generic project specifications are referred to as company or corporate specifications. In this text, project engineering specifications and project specifications are interchangeable.

A standard, as referred to in the text is a set of guidelines, definitions and instructions which serves as common language while establishing safety criteria or defining quality. ISO and SANS standards are typical examples.
In this text, the business need or requirement can be defined as critical activities or functions that must be performed to meet the organisational objectives without dictating a specific solution.

Project expenditure details are not only confidential but may also be misleading since the basis and time of implementation from one project to another could be vastly different. Costs are therefore expressed throughout this report as a percentage of a suitable baseline value.

1.9 Report Overview

The outline of chapters is as follows:

Chapter 1 – Introduction

Chapter 2 – Literature review

Chapter 3 – Project specifications and costing elements

Chapter 4 – BMH capital expenditure in perspective

Chapter 5 – Stringent project specifications in perspective

Chapter 6 – Re-using plants, systems, equipment and major structural steel components

Chapter 7 – Financial implications of underinvestment

Chapter 8 – Surge and storage system selection

Chapter 9 – BMH transportation systems

Chapter 10 – Conclusion and recommendations

Appendix A – Examples of surge bunkers and silos

Appendix B – Extract from EMS study (1975) on silos and bunkers.

2 LITERATURE REVIEW

2.1 Mining projects as an investment

According to PricewaterhouseCoopers (PWC)[2], the mining sector has been caught up in the over-investment of infrastructure which has delivered poor returns for investors. Although mining is generally recognised as a cyclical industry, mining companies have become un-favoured in recent years because of low commodity prices whilst having incurred substantial debt on financial balance sheets. Investments in the mining sector have underperformed relative to other industries (PWC)[2]. In previous years, where high profit margins were common, the life of the asset or project infrastructure was perhaps not considered critically enough which may have resulted in overinvestment on infrastructure and inflated disposal cost. (PWC)[2] furthermore found that global mining production remained flat between 2007 and 2009 despite the investment of approximately $200bn. Govreau[4] nevertheless draws attention to the fact that some greenfield project activity will continue since companies have to replace capacity lost from depleting reserves and declining ore grades. Although most engineers take pride in designing systems to the best of their ability, it must be kept in mind that without a profit motive the business cannot be successful. Whilst safety, health and environmental (SHE) matters have become a major focus in recent years, profit is arguably maximised by spending only as much as required (and no more) on aspects which do not contribute to the bottom line revenue of the business.

2.2 Project scope definition

Reduced capital costs are ultimately achieved by the correct upfront project scope definition which is informed by the thorough understanding of the business need. The “functional thinking” concept from value engineering principles as described by Huber et al [3] can be applied to provide only what is dictated by the business need and nothing more hence ensuring the efficient employment of capital. Although terminology is not consistently used in industry, the concept or scoping phase is where the greatest value can be realised for the project. Value influence curves aim to illustrate that the ability to reduce costs becomes more difficult as the project time line progresses. The value influence and expenditure curves for a typical mining project are shown in Figure 2.1 below.

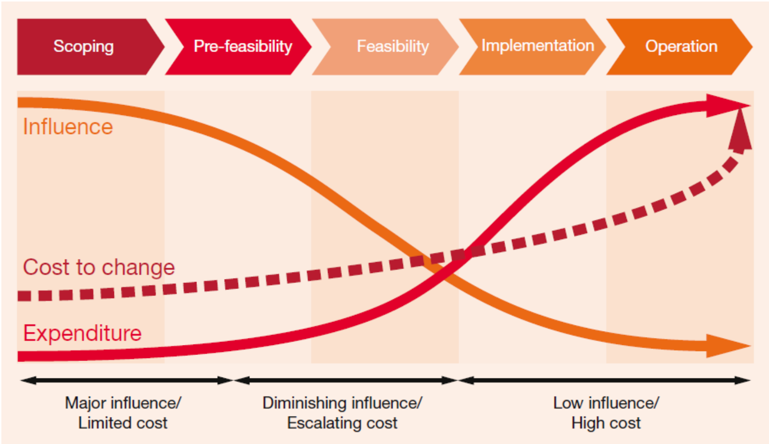


Figure 2.1: Value influence vs. expenditure curves.[2]

Managing the demand for capital is therefore predominantly achieved during the early phases of the project lifecycle.

Considering that this study specifically focuses on BMH projects, it is worthwhile to note that, for large coal mining projects, the contribution of BMH systems as a percentage of the overall project capital expenditure may be well below 20 %. This figure is expected to be even less for hard rock, deep mining types of projects. This matter is discussed further in Chapter 4.

2.3 Project specifications

The requirement for stringent project engineering specifications is nowadays constantly challenged in board rooms in anticipation that compromised specifications may result in project go-aheads because of reduced capital requirements. It would appear that the fundamentals of the life cycle costing approach covered in detail by Blanchard and Fabrycky[5] are overlooked in the current market conditions where the life of the assets as well as operating and maintenance costs are overshadowed by an overemphasis on initial capital costs. It is pertinent that all fundamentals of the life cycle cost approach must be applied to understand the business requirement for project specifications.

Lane and Dickie[6] caution how the approach to detail designs may have a substantial influence on overall plant costs. The upfront approval and specification of adequate design criteria is vital prior to embarking on the detail design. According to Deloitte[7] stringent project specifications indeed attract cost but it is a secondary matter for consideration once a rigorous financial justification for the project has been achieved. Lane and Dickie[6] however elaborate on this matter and draw attention to varying levels of capital sensitivity between different projects. Junior mining companies may have limited funding options and generally place a high priority on capital savings as opposed to life-of-mine optimisation. There is usually a trade-off between capital and operational expenditure. A higher upfront investment may therefore result in lower long term operational costs. Sidus[8] confirmed that junior miners tend to spend as little as possible on projects and accepts higher operational expenditure which is funded from earnings. The requirement for “fit for purpose” designs on projects especially those with a time horizon of less than 10 years therefore makes sense. Reverting back to value engineering principles, McCuish[9] advocates customised standards and specifications to ensure that the actual project requirements are not exceeded so that unnecessary costs are not incurred. Nevertheless, when considering value improvement practices (VIP’s), it is clear that standards and specifications have a high potential to impact value. This is graphically depicted in Figure 2.2 below.

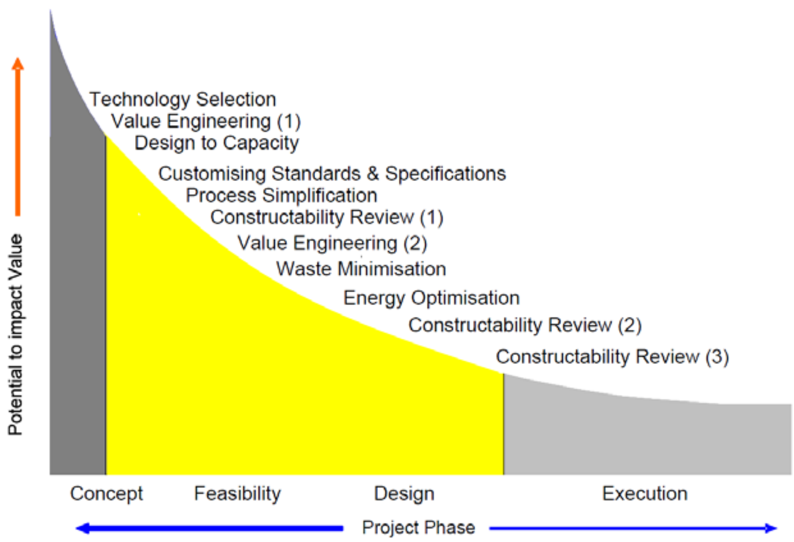


Figure 2.2: Value improving practices – potential to impact value.[3]

Stringent project specifications, where they can be justified, are deemed a long term investment. It can in most cases be argued that the owner has only one chance to get it right i.e. during the establishment of the infrastructure. If the window of opportunity is not used during the project design and construction phase, production pressures may be such that the desired improved specification can never be implemented at a later stage. This could potentially lead to premature failure or more frequent breakdowns of a system.

2.4 Capital cost reduction

So what can be done to reduce capital cost? Deloitte[7] suggest a phased modular construction approach to preserve capital. When commodity prices rise, upscaling can be done. Ernst & Young[10] make a case for standardised designs, replication and the leveraging of existing engineering designs and practices while enforcing tried and tested company design specifications. Connelly[11] endorses both the concepts of modularisation and using standard designs while highlighting how these principles lead to shorter construction times and ultimately capital cost savings. Connelly[11] advises that the reduction of design cost needs to be done with caution while a quality design may ultimately save on capital expenditure and unexpected future costs. The need to innovate while analysing opex/capex trade-offs is advocated by PWC[2]. The methods and concepts used a decade ago may not be the most economical today. Further development of technologies which might have been problematic on previous projects may now be mature enough that new projects can benefit from it.

Brown and Singh[12] promote the development of comprehensive design option lists early on in the project and argue that this will assist in creating a strong economic focus. Brown and Singh[12] furthermore claim that when leaders uphold this economic focus, capital cost reductions of 5-10 % can be achieved. It is furthermore stated that scope changes can be limited to account for less than 1 % of the total capital expenditure.

McGregor[13] advocates the application of the cost to worth ratio concept borrowed from value engineering. The use of these value engineering principles will provide guidance on where efforts to save capital should be focused. It is senseless to pay a huge premium on a certain feature or facility which provides insignificant benefits. This aspect is closely linked to the “functional thinking” approach already mentioned. Much cost could potentially be saved by avoiding expenditure which does not contribute to the core functional requirement of a system. Mackenzie and Cusworth[14] furthermore point out that key cost drivers may vary across different industries. In the coal mining business, energy cost is a major driver. Fuel price levels adversely affect open cast operations while the cost of electricity has a significant influence on the operational cost of an underground operation and beneficiation plant.

Lane and Dickie[6] endorse most of the matters already discussed but also highlight additional key factors that impact on project capital costs. These include the need to right-size equipment, minimising plant and project footprint, simplification of the flow sheet, clear definition of battery limits and designs which match the anticipated project life.

Learnings from Dukhedin-Lalla’s[15] guidelines on the development of pilot plants with specific reference to the anticipated lifespan of the infrastructure is arguably universal and can be applied to the development of mining projects.

Although mining projects traditionally had a long term investment horizon of a number of decades, short term small projects with life of mine less than 5 years are nowadays not uncommon. Dukhedin-Lalla[15] discourages the use of commercial-plant specifications for the development of pilot plants. These installations are generally associated with a short lifespan. It is advised that cost and implementation time can be saved by applying basic industry-accepted codes, standards and practices as opposed to using the more stringent “commercial” specifications throughout. Specification shortcomings can be supplemented with specific requirements by the owner. The compounding effect in cost escalation by the application of onerous commercial-plant specifications is demonstrated by means of a number of examples relevant to pilot plant development. This principle is very relevant to the study topic and highlights the fit for purpose design approach. The cost benefits of allowing creativity, flexibility and innovation in the design approach are highlighted.

Connelly[11] points out that overly aggressive capital reductions may result in inefficient operations which could reduce the overall availability of the plant and result in loss of revenue in the long run.

2.5 BMH surge and storage facilities

Surge and storage facilities require a considerable investment. It may constitute a substantial portion of capital assigned to the establishment of BMH systems especially where the overall BMH scope is fairly small but there is a business need for a large storage facility such as a bunker. Connelly[11] notes that a number of mining projects have failed due to aggressive capital cost cutting on surge facilities resulting in design throughputs not being achieved while certain plants were not operable because of the omissions. The merits of decoupling units, which are known for low availability, by introducing surge capacity before or after these units are discussed. It is therefore appropriate to evaluate merits of various storage facilities and relative costs compared to one another. A comprehensive trade-off study by EMS[16] comparing costing expressed in Rand per cubic metre of storage for conventional circular silos and various bunker alternatives was done in 1975. The outcome of the investigation demonstrates that the selection of an economical storage system is driven by the storage volume requirement and various project specific requirements. Chapter 8 explores this topic in greater detail where guidelines for the selection of appropriate storage systems based on recent mining projects are provided.

2.6 BMH transportation systems

The selection of the appropriate material transportation system for mining projects has direct bearing on the scoping function as alluded to by PWC[2] and discussed in the beginning of this section. Detailed trade-off evaluations for road, rail and belt conveying options were conducted by Lawrie et al[17] based on an Australian context. Key factors driving the transportation system selection include the life of the operation, the tonnage to be moved on an annual basis and the transportation distance. The selection of an appropriate transportation system is vital for successful mining projects. It is included in this study for completeness as transportation systems often require a substantial portion of the overall project capital cost. Pipeline and waterway transportation systems were specifically excluded because they are not considered relevant in a South African context.

2.7 Used plants, systems, equipment and major structural steel components

Connelly[11] advises that considerable savings can potentially be made by using second hand systems and equipment but cautions that the cost may outweigh the savings. Dismantling, reconditioning, transportation and reassembly costs need to be carefully considered. Other factors to be considered include evaluating the suitability for process requirements, availability of spare parts and the condition of the equipment.

2.8 Culture

Cavender[18] argues that the continuous reduction of costs should become a priority throughout organisations and not merely during periods of low commodity prices. He states that companies which are most successful in cost reductions tend to avoid cyclicality of the market by remaining cost sensitive. Through strong leadership, a cost reduction mind set can be established which can bring about a culture of continuous improvement endorsed throughout the organisation. This is an ongoing proactive approach in developing cost management expertise within the organisation instead of reacting to negative changes within the business environment when it occurs. By implication a cost sensitive culture requires buy in from all employees to bring about continuous improvement within their sphere of influence, believing that they can control costs, regardless of market conditions.

2.9 Project Specifications

The discussion of corporate project specifications relevant to the study topic forms part of the literature review but is covered in Chapter 3 for ease of reference and to enhance the flow of the overall document. Although some company specifications may seem overly conservative to an outsider, more often than not stringent requirements were introduced subsequent to failures or incidents within the industry. The mining industry presents unusual accidental and special loading conditions which are not adequately catered for by national design standards. In some cases severely corrosive environments need to be catered for which preclude certain fabrication practices, while minimum material thickness are prescribed.

2.10 Conclusion

According to PWC[2] the mining sector has in recent years become less attractive as an investment destination due to poor returns as a consequence of over-investment in times of high commodity prices. Although project approvals are invariably subjected to the ability of a project team to demonstrate a viable business case, a culture of being cost sensitive goes a long way towards remaining competitive regardless of prevailing market conditions. The most significant impact towards the reduction or avoidance of capital expenditure can be made during the scope definition phase of the project as demonstrated by the value versus expenditure curve diagram shown in Figure 2.1. Focussing only on specifications to bring about cost reductions when tough market conditions prevail is rather inappropriate. Stringent project specifications indeed attract cost but it would appear that this is a secondary matter for consideration once a rigorous financial justification for the project has been achieved. Standards and specifications nevertheless have a high potential to impact value on a project. Stringent project specifications may be justified as a long term investment. Whilst over-investment on project specifications is certainly not desired from a business point of view, it must be kept in mind that under-investment could be far worse for a long term project. The costs associated with subsequent upgrades and remedial works will undoubtedly far outweigh the initial cost savings while production pressures, access restrictions etc. may never allow remedial works.

For short term projects, the justification for stringent specifications will most likely not be possible. In some instances, the funding models of junior miners, who are smaller players in the market, require the absolute minimum capital expenditure to obtain a project go-ahead.

Various value improving practices and strategies are available to facilitate cost reductions. The appropriate selection of high value items, systems or technology remains key. Likewise capital expenditure decisions cannot be separated from understanding the ongoing operational expenditure of any system. Savings may be achieved by re-using equipment and systems but the associated risks must be understood. The merits of re-using systems, major components or equipment must be evaluated on a case by case basis. Although some mining company specifications may seem overly conservative, justification therefore can often be found as explained by Schmidt [23] in the recognition that certain special conditions unique to the industry need to be catered for which are not adequately addressed in national standards.

The conclusion from the literature survey was incorporated into a diagram that represents a framework for understanding key cost drivers, influences and considerations for BMH projects with respect to capital expenditure. The details will be explored in later chapters. The diagram maps the study sections and attempts to demonstrate how various different cost aspects of BMH projects relate to one another. Understanding the influence of these key elements on the overall project cost is of the essence for this study since it will demonstrate where the focus areas for potential cost reductions should be. Figure 2.3 below consequently outlines the framework for understanding and reducing costs of BMH projects. The same diagram will be re-worked in the concluding chapter to reflect the study outcome.

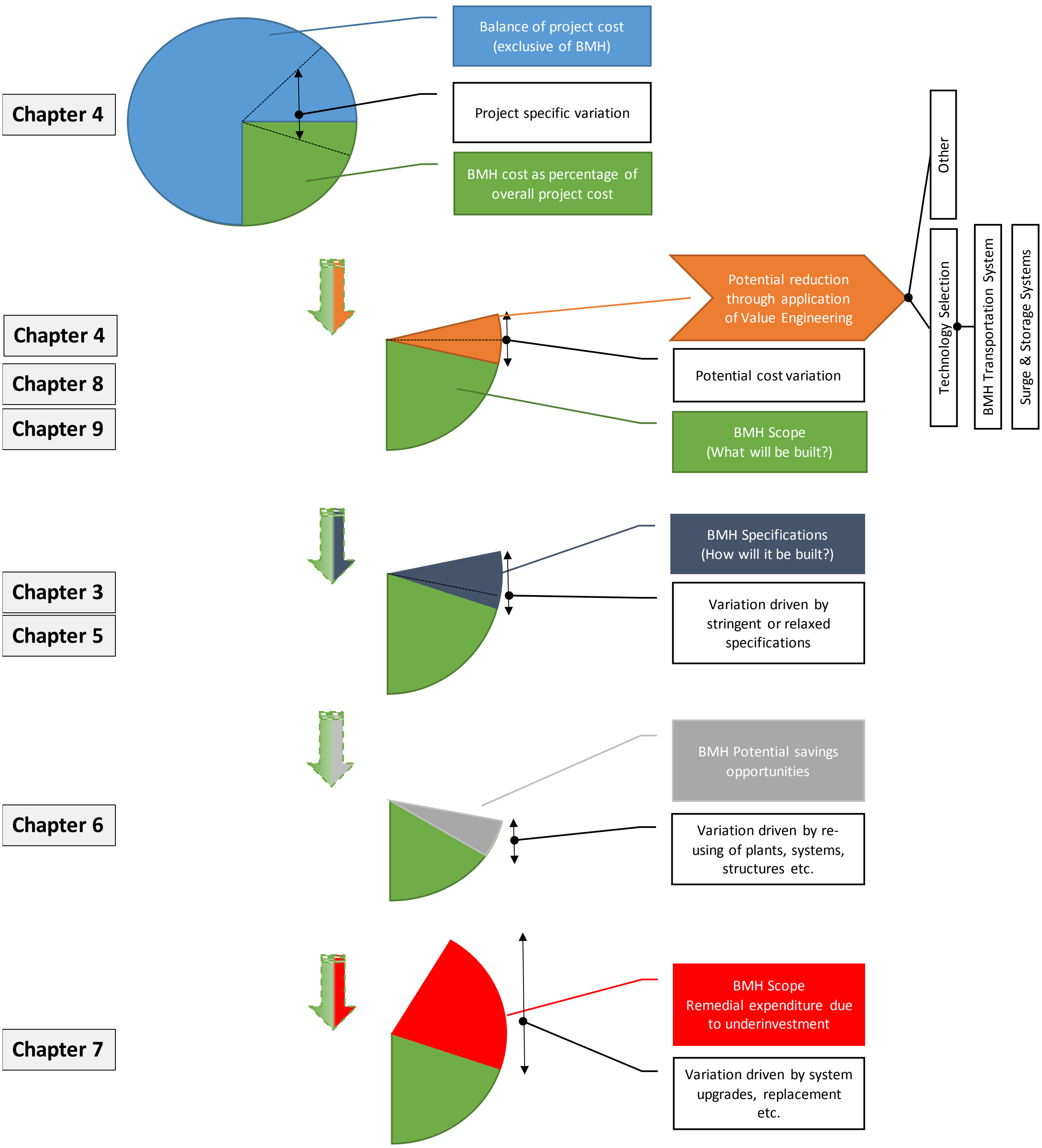


Figure 2.3: Study map for key cost drivers on BMH projects

3 PROJECT SPECIFICATIONS AND COSTING ELEMENTS

This chapter forms part of the literature review presented in the previous chapter but is covered separately for ease of reference and to enhance the flow of the overall document. An overview of selected national and company specific standards or specifications currently available for the design of materials handling systems and structures is presented. The discussion focuses mainly on stipulations which influence project costs to provide background to aspects and elements which will be discussed in later chapters. Parts of selected standards and specifications which do not contribute to the emphasis of this study are therefore omitted.

The documents presented in this chapter are deemed representative of typical corporate specifications. Various specifications from parastatals and mining companies were considered during the study. In spite of some differences, the same fundamental requirements are essentially prescribed in diverse formats. It was consequently decided that the inclusion of variations on the same theme in this report would not add much value in addition to documents already covered below. Mandatory requirements and regulations dictated by the Department of Mineral Resources (DMR) which result in increased project costs are not covered in this study since compliance with these is not negotiable.

3.1 Project Specifications

The following documents are presented in summary form in this chapter, for later reference.

1. AA 114/1 (2007) Design of steel structures – Anglo American Company Specification[19].
2. AATC 859 (2013) AATC Design criteria and guidelines for surface infrastructure, Mechanical and Structural – Anglo American Coal Company Specification[20].
3. AATC 169 (2013) Fire protection standard for conveyors and coal transfer - Anglo American Coal Company Specification[22].

Specific clauses and requirements from the above documents are discussed in this chapter to provide background for trade-off and case studies which are covered in following chapters.

Anglo American Specification AA 114/1

AA 114/1 (2007) Design of Steel Structures, is an Anglo American Company Specification[18] and is discussed in this section. It must be noted that Anglo American recognises that the mining industry presents unusual accidental and special loading conditions which are not adequately catered for by national design standards. Learnings from past incidents and failures have been incorporated into the AA114/1 specification over a few decades.

Overview of AA114/1[23]

This specification details the requirements for the design of steel structures, and for steel components in structures framed in other materials, for underground and surface applications in mine shafts and plants. SANS 10160-1 (1989)[24] and SANS 10162-1 (2005)[25], form the basis of the specification. The limit states design approach is mandatory while allowable stress methods are precluded. Specific rules and requirements pertaining to the following items are spelled out:

- Design standards, specifications and related publications
- Design responsibility
- Quality management of design process
- Design calculations
- Design drawings and approval
- Materials
- Load factors and load combinations
- Design requirements and procedures
- Serviceability requirements
- Construction details.

Loads

Nominal permanent and imposed loads are determined in accordance with SANS 10160-1 (1989), but additional clauses are stipulated to cater for mining-specific conditions. The following loading conditions will be covered in this study:

Imposed floor loads – It is required to assess these loads taking into account the intended use or occupancy of the structure. Specific minimum uniformly distributed floor design loads are dictated. Of particular interest is the live load value of 2,5 kPa specified for conveyor gantries, which is an attempt to cater for unintended spillage loads. Floor and platforms are to be designed to sustain 5 kPa loading. Figure 3.1 below shows a typical example of the spillage which is often encountered on conveyor gantries due to belt wander, overloaded belts or the sliding of wet material down a steeply inclined belt. Manual unloading of belts onto walkways following an electric trip of the drive, which cannot start with a loaded belt, is not unusual. Although poor housekeeping can never serve as justification for over designing structures, the mining industry has learned from numerous conveyor gantry collapses over several decades that the design value of 1,5 kPa as prescribed in SANS10160-1 (1989) is insufficient where spillage may occur.

Figure 3.1: Conveyor walkway spillage.[1]

Wind loads – It is required that the relevant terrain category is assessed in consultation with, and is approved by, the client and the owner. The terrain category adopted for inland terrains is not to be less severe than a category that falls midway between Category 2 and Category 3 as specified in SANS 10160-1 (1989). It is required to design conveyor and pipe gantries assuming a force coefficient C_f of 1.6 and the effective area A_e as the solid projected area. Past failures have occurred where conveyor gantries were sheeted to suit the business requirement many years after the establishment of the mining infrastructure.

Abnormal loads or conditions – Formal risk assessment is mandatory to establish whether abnormal loads or conditions should be considered in the design.

Amongst several other items listed for consideration is the impact of vehicles and other moving objects. This does not imply that conveyor structures, as shown in Figure 3.2 below, need be designed for dozer impact loads, but rather that the need for an operating procedure to manage such a risk should have been a documented action item following on from the compulsory risk assessment.

Figure 3.2: Dozer activity on an over-filled stock pile.[1]

A collapsed cable suspension bridge is shown in Figure 3.3 below. Severe corrosion due to the entrapment of moisture around the rope anchors caused the failure after a relatively short service life.

Figure 3.3: Suspension bridge failure due to corroded rope anchors.[1]

Erection rigging load – The assessment of nominal loads acting on structures or structural elements specifically designed for erection rigging is to be done with the incorporation of an impact factor of 3,5. Rigging loads are non-routine lifts and are classified as safety critical. The impact factor caters for the dynamic effects associated with rigging operations. Figure 3.4 shows an example of lifting points specifically designed for a major construction activity.

Figure 3.4: Rigging points designed for an 80 ton lift.[1]

Construction Details

The following items are of interest for the purposes of the study:

Minimum metal thickness – Table 2.1 below shows the minimum material thickness which may be selected as dictated by the level of exposure. The designers' selection of steel sections is therefore limited and often results in heavier structures where an alternative member with a lighter mass per unit length cannot be chosen.

Table 3.1: Corrosion category classification – AA 114/1, Table 2.[19]

EXPOSURE	WEBS OF I-, H- AND [- SECTIONS	SEALED HOLLOW SECTIONS	COLD-FORMED PURLINS AND GIRTS	PLATES	ALL OTHER SECTIONS
Steel exposed to severe corrosive environments	6,5 mm	6,0 mm	Not allowed	8,0 mm	8,0 mm
Steel in underground construction					
Steel exposed to the weather	5,5 mm	5,0 mm	Not allowed	6,0 mm	7,0 mm
Steel not exposed to severe corrosive environments	5,0 mm	4,5 mm	3,0 mm [use only if specifically agreed to by the owner]	5,0 mm	6,0 mm
Steel not exposed to the weather					

Back-to-back construction – This method is prohibited in underground applications as well as where steel is exposed to weather or severely corrosive environments.

Anglo American Thermal Coal Specification AATC 859

The Anglo American Thermal Coal Specification AATC 859 covers mechanical and structural design guidelines for surface infrastructure. The content is deemed representative of corporate specifications typically published by various parastatals and mining houses. It covers general and specific requirements often not prescribed in national standards and specifications. References to British and German standards are often called, especially where local standards are not available or deemed insufficient. Some clauses may be unique to the company since it emerged from past incidents or failures which have been incorporated in an attempt to prevent repeats.

Overview of AATC 859

AATC 859 (2013) AATC Design Criteria and Guidelines for Surface Infrastructure, Mechanical and Structural is an Anglo American Coal Company Specification which details the specific design requirements not covered in other company specific or national standards. It aims to define best practice within a coal business unit context and highlights considerations during project development. It provides designers latitude to decide what's best for the specific project within established guidelines. This document is a design guideline and not a specification as such. National and Company specific specifications and standards are widely referenced while addressing design considerations under the following main sections:

- Process design criteria
- Mechanical design criteria
- Structural design criteria
- Design interfaces

Specific requirements related to the areas of interest of this study are discussed below. These elements are highlighted since compliance therewith arguably adds additional costs to BMH projects.

1. Standardisation - Specific attention is drawn to economical designs whilst rationalising components for optimum spares holding and interchangeability. Right-sizing, a term used for ensuring that excessive installed drive power is avoided, also needs to be considered during the standardisation phase of design. Besides aspects already mentioned, standardisation is a balancing act between reduced spares holding and efficient power usage.

2. Conveyor inclination - The maximum permissible angle of inclination is capped at 13° except where large spherical lumps are to be handled in which case a 10° inclination will apply. Conveyor inclination limits attempt to improve safe access and working conditions but the footprint of infrastructure inevitably increases. Elevated conveyors are much more expensive than ground mounted conveyors. A lower permissible inclination implies that a larger portion of conveyors will be elevated.

3. Conveyor belt speeds - Upper limits for belts speed are dictated depending on specific application. This requirement may result in the selection of wider belts although concessions are generally granted where the design will become uneconomical especially on overland conveyors. Limitations on conveyor belt speeds aims to balance maintenance costs with capital expenditure. High belt speeds are associated with increased load cycles on conveyor idlers.

4. Conveyor artificial friction factor – Guideline friction factors are provided. For overland conveyors, design values provided are conservative based on publications by Nordell[26] in this specialist field. Reduced load factors can nevertheless be used when selecting installed motor power when the conveyor was designed with conservative artificial friction factors. The risk of not being able to start up an overloaded belt under extreme climatic

conditions or when a replacement belt has less favourable rolling resistance characteristics drives the business requirement for somewhat conservative design factors.

5. Platework – A minimum thickness of 6 mm is specified for general platework while materials handling chutes must be fabricated from no less than 8 mm plate thickness. Learnings from corrosion challenges encountered on older mines as well as local impact damage influenced the rationale for specifying minimum material thickness. Some coal reserves have exceptionally high sulphur content which cause acidic conditions resulting in rapid corrosion of platework.

6. Conveyor head frames - These must be designed to withstand forces imposed by the conveyor under all operating conditions and may not transmit any forces into conveyor gantries. This requirement came about subsequent to a series of gantry collapses in the industry. It requires that structures supporting head frames must be designed to withstand belt pulling forces.

7. Conveyor walkways – Conveyors up to and including 900 mm wide belts must be equipped with 900 mm wide walkways while an additional walkway, 750 mm wide, must be provided on belts wider than 900 mm. This requirement is to provide safe access for the changing out of conveyor idlers.

8. Conveyor walkway construction – open grid grating must be used. Lightweight expanded metal options have proven to be unsuccessful on past projects due to fabrication issues which led to tripping hazards.

9. Cat ladders - only permitted by concession where a low frequency of access is required. This requirement is safety related.

10. Cladding of structures – side sheeting is required from above first floor to allow for ease of access. 0.8 mm roof sheeting is required on all structures

except for conveyors where 0.6 mm is acceptable. This requirement is driven by aesthetics and ease of maintenance during times of inclement weather.

11. Elevation of floor level to 200 mm above ground. - This requirement is to facilitate drainage in order to provide safe and clean working areas.

12. Column bases and trestle plinths – elevation of concrete by up to 2 m. This requirement attempts to minimise impact damage by vehicles.

13. Hand railing – The use of an angle type of construction is mandatory. Tubular hand railing is prohibited. The latter system is much easier to install and cheaper since various suppliers offer modular types of constructions. Angle-type hand railing is cumbersome to fabricate and install. Expensive re-work on site is often encountered.

14. Corrosion protection – New structural steel is to be hot dipped galvanised to SANS 121[27] Table e unless the design life of the operation exceeds 30 years in which case a heavier duty coating is to be considered.

    CPS 132[28] is a heavy duty painting system which was developed for structures situated in a general heavy mining or industrial environment. This system is also used for non-specialised plate work applications and may be used as an alternative to hot dipped galvanising for the protection of structural steel subject to concession. CPS 122[29] is a normal duty painting system for general mining or industrial environment.

AATC 169 Fire protection standard for conveyors and coal transfer

The Anglo American Thermal Coal Specification AATC 169 was developed in conjunction with a fire consultant in collaboration with the company's insurer. Insurance premiums can be reduced when a reduced risk of fire damage and hence production losses can be demonstrated. The expense of fire protection systems is therefore to some extent offset by reduced ongoing business running costs. Once again, this document may be quite unique when compared to equivalent documents developed by parastatals, rivals and other industries but it is deemed representative for the purposes of this study.

Overview of AATC 169

The AATC 169 standard is essentially an extract from a very comprehensive company specific fire protection standard, ACSA Fire protection standard 1/2009 - Anglo American Coal[21], which was compiled by a specialist fire consulting company which covers the entire range of surface and underground areas of a typical colliery. The standard specifically covers overland, elevated conveyors on surface, surface tunnel, bunker and silo feed conveyors and surface plant conveyors.

It is important to note that the level of fire protection required is often informed by a risk assessment performed by the project team with representation from affected parties from the relevant operation.

It is worthwhile to mention that the need for deluge systems generally accounts for a substantial portion of fire protection systems. Deluge systems are usually associated with high volumes of water which implies that large reservoirs, pumping and piping systems are required. Besides capital expenditure, fire protection systems require ongoing maintenance and testing which adds to operational expenditure.

3.2 Costing elements

The cost engineering aspect associated with capital projects is a major exercise in itself and vital to control project expenditure within approved budgets. Quantity surveyors play a major role throughout the project studies, detail engineering and implementation to assist the owner in successful project delivery. For the purposes of this study a few basic elements need to be discussed to provide a basis for work presented in later chapters.

Preliminary and General charges

Preliminary and General charges (P&G's) are expenses incurred before work in producing the project deliverables commence, together with costs which are not specifically part of a bill item.

Cost Breakdown Structure

The cost breakdown structure (CBS) commonly known as the project capital estimate may be compiled in accordance with the project Work Breakdown Structure (WBS) or based on company specific structures and codes according to Rooza[30].

The CBS is populated with detailed costing data as derived from the various Project Bills of Quantities. The CBS enables a quick overview of individual cost elements such that high expenses can easily be identified without studying the details. Within the cost engineering fraternity, typical expense ratios are used to evaluate and interrogate the integrity of the CBS. Shown below in Table 3.2 is a typical CBS where the overall cost as derived from each respective estimate number is tabulated against a high level description.

Table 3.2: Typical project cost breakdown structure – BMH elements highlighted.[1]

ESTIMATE NUMBER	DESCRIPTION	COST
110	Site Establishment	5 038 924
140	Mining Access - Opencast	200 298 277
211	Mining Equipment - Overburden removal	1 651 481 675
212	Mining Equipment - Coal loading & hauling	451 916 305
213	Mining Equipment - Rehabilitation Equipment	52 956 681
214	Mining Equipment - Ancillary Equipment	614 413 205
215	Mining Equipment - Pumping and dewatering	6 713 141
216	Mining Equipment - Pit Construction Equipment	89 221 990
217	Mining Equipment - Surface equipment (Off road)	-
218	Mining Equipment - Surface equipment (On road)	-
219	Mining Equipment - Phola overland conveyor	-
220	Arterial Transport	160 026 263
290	Bulk Storage and Allied Transport	245 151 589
320	Crushing, Washing and Screening	228 536 918
380	Water Treatment Plant	7 179 360
390	Waste Rock, Residue and Effluent Disposal	37 579 512
560	Fuel Handling and Storage	25 736 034
570	Pollution Control	219 034 075
620	Permanent Road and Terraces	489 889 904
622	Provincial Road Deviation R545	209 711 197
640	Stormwater Drainage	79 220 212
650	Water Supply	48 860 789
660	Sewerage	4 245 319
740	Stores, Offices and Amenity Buildings	307 207 483
741	Explosive magazine	18 881 280
750	Recreational Facilities	6 491 246
760	Landscaping and Gardens	27 159 986
770	Security	28 895 000
780	Medical Facilities	11 861 110
840	Workshops	235 472 012
850	Electric Power Reticulation (Medium Voltage)	290 687 346
851	Electrical Power Reticulation (High Voltage)	289 216 992
860	Instrumentation and Control Systems	25 624 433
861	Networks and Information Management	66 145 926
880	Pumping and Dewatering	4 626 057
890	Surface Transport	55 267 594
891	Surface Transport: Off-road	20 130 866
920	Contractor Preliminary and General Cost	667 982 129
	Sub-Total : R	**6 882 860 830**
910	Outside Consultants	356 293 849
952	Pre-Production Technical Investigations	232 019 993
954	Lease Area and Property Rights	543 790 853
956	Spares	184 972 311
960	Company Operating Costs	374 186 007
970	Operational Readiness	288 240 433
9983	Mine & Regional Project Management Costs	18 000 000
9982	Reimbursables	49 921 079
9981	Purchasing Commission	172 071 521
	Sub-Total : R	**9 102 356 876**
9990	Contingencies	1 046 597 899
9991	Contingencies on Escalation	258 073 922
	Total : R	**10 407 028 697**
9980	Escalation	4 059 952 026
953	Foreign Exchange Variations	695 677 520
	Total : R	**15 162 658 243**

Bill of Quantities

A clear understanding of the Bill of Quantities (BOQ) associated with BMH projects is vital for the purposes of this study. The cost impact of stringent project specifications will ultimately be evaluated based on the effect it has on the overall project cost estimate. Excluding P&G charges associated with construction, the total cost incurred for having a steel structure installed on site can be broken up into the various cost elements as shown below in Table 3.3. The figures are expressed in percentage terms and as obtained from industry rates.

Table 3.3: Cost elements of structural steel.[31]

Cost element	(% of Total)	Increase (% of cost element)	Increase (% of cost element)
Raw steel	40%	**10%**	
Shop detailing	7%		
Fabrication	21%		
Corrosion protection	11%		**25%**
Transportation	3%		
Erection	18%		
Total	**100%**	**104%**	**103%**

Cost components directly influenced by the project specification includes the amount of raw steel required and the type of corrosion protection system applied. All costs components listed above are nevertheless directly linked to the total mass of steel. Industry rates are expressed in Rand per ton. If the total mass of steel therefore changes, it impacts proportionally on each cost component. It is however shown that a 10 % rise in the price of raw steel will bring about an increase of only 4 % in the overall cost of a steel structure. Likewise if the cost of the corrosion protection system increases by say 25 % in order to comply with stringent specifications, the effect on the bottom line total cost will be about 3 %. The BOQ provides a cost breakdown such that the cost structure of each component or system is transparent. It therefore augments the tender adjudication process. An example of a typical BOQ for conveyor steel work is provided below in Table 3.4.

Table 3.4: Typical project bill of quantities.[1]

Item No.	Payment Refers	Short Description	Unit	Quantity	Fabrication/Supply Rate	Fabrication/Supply Amount	Transportation Rate	Transportation Amount	Erection/Install Rate	Erection/Install Amount	Total
	PSST	**SCHEDULE NO. 4.2 - STEELWORK IN CONVEYORS**									
		Hot Dip Galvanised Steelwork									
4.2.1	8.3.1(c)	Conveyor Overland Modules	t	30,860	30 850,00	952 031,00	1 000,00	30 860,00	6 850,00	211 391,00	1 194 282,00
4.2.2	8.3.1(j)	Tail Frame Structure	t	2,200	35 150,00	77 330,00	1 000,00	2 200,00	6 850,00	15 070,00	94 600,00
4.2.3	8.3.1(k)	Take-up Structure	t	23,560	35 150,00	828 134,00	1 000,00	23 560,00	6 850,00	161 386,00	1 013 080,00
4.2.4	8.3.1(l)	Transfer Tower Structure	t	17,020	35 150,00	598 253,00	1 000,00	17 020,00	6 850,00	116 587,00	731 860,00
		Trestles									
4.2.5	8.3.1(n)	Trestles	t	0,940	35 150,00	33 041,00	1 000,00	940,00	6 850,00	6 439,00	40 420,00
		Gantries									
4.2.6	8.3.1(o)	Gantries	t	32,050	35 150,00	1 126 557,50	1 000,00	32 050,00	6 850,00	219 542,50	1 378 150,00
		Steelwork									
4.2.7	8.3.1(e)	Handrails	t	3,230	35 150,00	113 534,50	1 000,00	3 230,00	6 850,00	22 125,50	138 890,00
4.2.8	8.3.2	Hot dipped galvanised bolts grade 8.8 **1.5% x 109.860t**	t	1,650	55 000,00	90 750,00	0,00	Included	0,00	Included	90 750,00
		Sundries									
4.2.9	8.3.1(m)	Machined Wheel Assembly complete as per drawing 5478-0101-MED-0123	no.	20	8 000,00	160 000,00	80,00	1 600,00	950,00	19 000,00	180 600,00
4.2.10	8.3.1(m)	Machined Wheel Assembly complete as per drawing 5478-0101-MED-0125	no.	4	20 500,00	82 000,00	250,00	1 000,00	1 200,00	4 800,00	87 800,00
4.2.11	8.3.1(m)	Wire rope	m	55	132,25	7 273,75	5,00	275,00	20,00	1 100,00	8 648,75
4.2.12	8.3.1(m)	Chain link	m	27	120,00	3 240,00	5,00	135,00	20,00	540,00	3 915,00
		To Collection :	R			4 072 144,75		112 870,00		777 981,00	4 962 995,75

Financial Model

According to McPherson[32] the project financial model is a set of assumptions about future business conditions that drive projections of a company's revenue, earnings, cash flows and balance sheet accounts. Without a viable business case it makes no sense to invest in the development of a project. Financial modelling is a science in itself and will not be discussed in any detail in this study. It is nevertheless important to note that financial modelling is used to provide a basis on which financial justification can be provided to develop a project within given parameters. Although evaluation criteria differ amongst companies, internal rate of return (IRR), net present value (NPV) and NPV to capex ratio are commonly used evaluation metrics. If the financial model predicts a positive NPV for a certain project, it may not be lucrative enough as an investment case. Given that capital is a scarce resource, a company would only want to invest in the projects which will deliver the best return.

Although the viability of a project is sensitive to the capital requirement, it is one of various important input parameters in the project financial model. According to Heidgen[8], for an export product, the most important revenue variables are the sale price and exchange rate. The cost of labour is of utmost importance since a real increase i.e. an increase above inflation rate could be incurred over time. For open cast operations, the cost of fuel is most important while the cost of electricity is a major driver for underground operations and projects where large beneficiation plants need to be operated. Although operational cost has a very severe influence on the viability of a project, long term projects are most sensitive to this parameter. Operational expenditure is usually traded off against the capital expenditure hence for a lower capital investment, a higher operational cost is to be expected. For a short term project, the least amount of capital outlay will be desirable to maximise return. When a longer term project is developed, a higher capital investment, which will in turn reduce the operational expenditure, would be financially beneficial up to the cross-over point. The NPV sensitivity analysis of a typical South African mining project demonstrating the interaction between export sales price, domestic sales price, capex and opex is shown below in Figure 3.5. The domestic sale price is indicated as "Eskom Price".

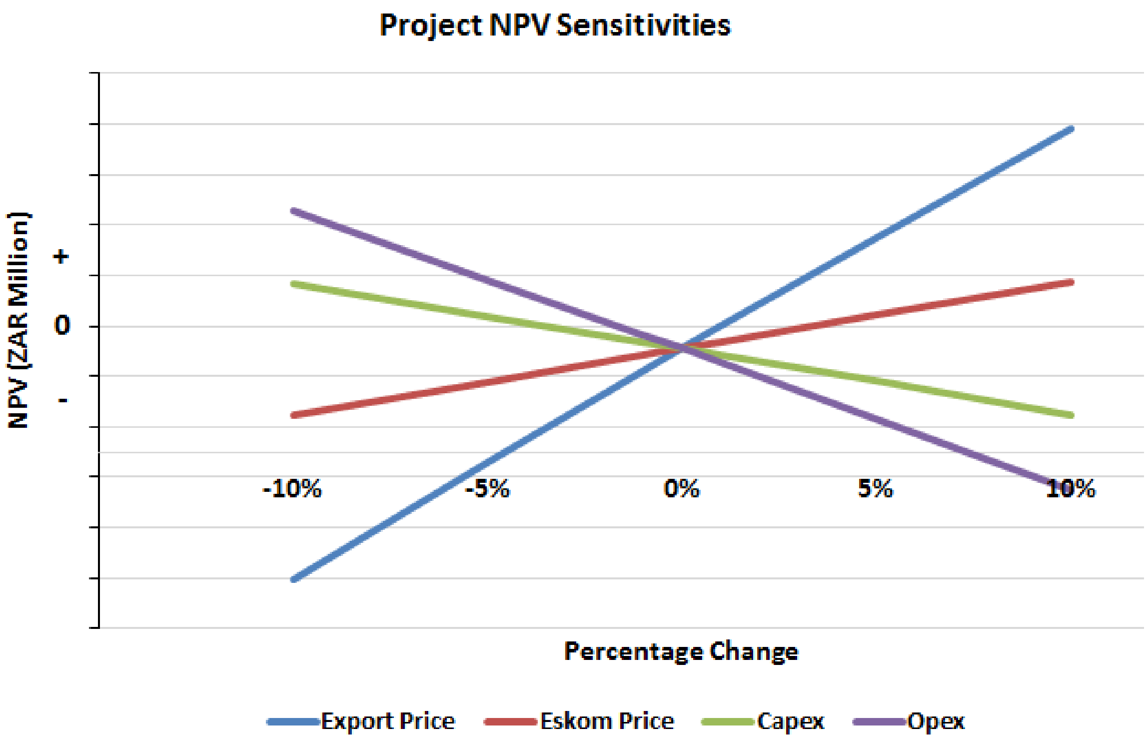


Figure 3.5: Typical project NPV sensitivity.[8]

The above graph is an output from the project financial model which facilitates investment decision making by senior management. The slope of the capex curve is relatively flat in comparison with that of opex and export sales price which implies that a change in capex has a lesser influence on the project NPV. Also important to highlight is that the project NPV is more sensitive to changes in the opex cost.

The time value of money is another key financial concept to consider. In simple terms it is beneficial from a financial point of view to delay capital expenditure as long as possible. Within the context of this study it implies that it is desirable to establish an operation with the least possible capital even if future expansions or expenditure will be required. On the other hand, a project or option selection which can ensure cash generation early on in the project life is extremely beneficial from a business perspective.

3.3 Summary

This chapter forms part of the literature review presented in the previous chapter. Selected cost inflating requirements from corporate specifications used in the design of BMH projects are presented. Specifications used by parastatals and mining companies are similar although special requirements are occasionally dictated. The documents selected for discussion are deemed representative of industry standards. Some clauses from corporate specifications may be unique to the specific company since they may have emerged from past incidents or failures which have been incorporated in an attempt to prevent repeats. Several special requirements emerged from the acknowledgement that the South African mining industry presents unusual accidental and special loading conditions which are not adequately catered for by national design standards.

The WBS and BOQ extensively used by quantity surveyors are vital building blocks for cost trade-offs presented in later chapters.

Some insights into the project financial model were provided to have a basis from which additional costs due to the compliance with stringent specifications that may or may not be justified are discussed in later chapters. The sensitivity analysis of capital expenditure on the viability of the project ultimately determines to what extent marginally higher costs can be tolerated. Although every project is unique, it is nevertheless worthwhile to note that the sensitivity of capital expenditure is only one of many metrics analysed by means of the financial model. It could nevertheless be a determining factor for some project go-aheads.

This chapter provides a basis for the understanding of trade-off studies and cost analysis which is presented in later chapters.

4 BMH EXPENDITURE IN PERSPECTIVE

Mining projects are complex and invariably of a multi-disciplinary nature. Specialist skills from a very wide range of professions are consequently required. Although this report focusses on BMH engineering and costing aspects, it is nevertheless essential to provide some insight into the overall cost of large mining projects. This is required to gain an appreciation for the impact that reduced BMH expenditure will have on the overall project value. Once the typical expenditure within the BMH scope is better understood within the context of the overall project cost, the effect of relatively small additional expenses incurred for compliance with stringent specifications can be appreciated. The figures presented in this chapter were taken from a combination of implemented projects and legitimate feasibility studies. Due to the confidentiality considerations, figures are expressed in percentage terms while specific project names and details are withheld. It must nevertheless be understood that every mining project is unique and figures may vary substantially depending on the details of the specific project.

4.1 Cost analysis of typical mining projects

It is logical that greenfields projects will generally involve a wider range of professional skills than for brownfields where land ownership, services, logistics and licensing may already be in place for an existing operation which will merely be expanded for an increased output or the extension of the current production profile. The cost analysis of greenfields and brownfields projects may therefore differ dramatically. Subsequently, for the latter type of project, the percentage of BMH expenditure in relation to the overall project cost, could be much higher which implies that cost reductions in this regard will have a greater impact on the overall project cost. The contribution of BMH expenditure of recent greenfields coal projects is provided below in Table 4.1 as a percentage of the overall project cost. Costing figures quoted were obtained from various confidential project reports. Also refer to Table 3.2 of the preceding chapter where BMH cost elements were highlighted on the CBS.

Table 4.1: BMH expenditure in relation to overall project costs – coal projects.[33]

Project Decription	BMH as % of Total
Project 1 - Long overland conveyors	14%
Project 2 - Establishment of opencast mine	5%
Project 3 - Expansion project with DMS plant	5%
Project 4 - Life extension at open cast mine	11%
Project 5 - New coal processing facility	16%
Project 6 - Establishment of U/G mine & long overland cvr	14%
Average value	11%
All projects exceed ZAR 4bn (2016 money values)	

The contributions of BMH expenditure of two hard rock mining projects are provided below in Table 4.2 as a percentage of the overall project cost.

Table 4.2: BMH expenditure in relation to overall project costs – deep level mines.[1]

Project Description	Total Capital	BMH as % of Total
Project 1 - Diamond deep level, brownfields project	100%	9%
Project 2 - Copper, greenfields opencast mine	100%	9%
Average value		9%
All projects exceed ZAR 4bn (2016 money values)		

From Table 4.1 above it is clear that the BMH scope, of the various coal projects considered, contributed on average just above 11 % of the total project expenditure. When considering hard rock, deep mining projects this figure reduces somewhat i.e. 9 % for the projects considered in Table 4.2

The cost of mining equipment and underground development can be a very substantial portion of the overall project cost. On the contrary, the overall cost contribution of BMH systems may often be a relatively insignificant percentage of the overall project cost. For a multi-billion Rand project, this may nevertheless amount to a large sum of money which needs to be optimally utilised.

For certain brownfields projects, the cost of BMH systems may occasionally amount to a substantial portion of the total project expenditure. Typical examples include projects[32] where reserves need to be accessed by means of constructing a new tip and long overland conveyors while using the current mining fleet, beneficiation plant and office complex. BMH systems may in these cases contribute close to 50 % of the overall project cost.

By analysing the CBS further, the percentage contribution of conveyor steel and the total BMH steel were found (on average) to be 5 % and 6 % respectively, of the total expenditure for projects considered. This is shown below in Table 4.3.

Table 4.3: Structural steel and BMH as percentage of direct costs.[33]

Project Decription	Total Capital	Total Direct Cost	BMH as % of Total	CVY Steel	BMH as % of Direct Cost	Steel as % of Direct Cost
Project 1 - Long overland conveyors	100%	74%	14%	8%	19%	11%
Project 2 - Establishment of opencast mine	100%	56%	5%	1%	9%	2%
Project 3 - Expansion project with DMS plant	100%	42%	5%	1%	12%	3%
Project 4 - Life extension at open cast mine	100%	69%	11%	6%	15%	8%
Project 5 - New coal processing facility	100%	71%	16%	9%	16%	9%
Project 6 - Establishment of U/G mine	100%	67%	14%	6%	14%	6%
Average value		63%	11%	5%	14%	6%
All projects exceed ZAR 4bn (2016 money values)						

It is nevertheless important to note however that the overall cost contribution associated with the establishment of steel structures is roughly 50 % of the total BMH expenditure component. The variation in cost for establishment of the total tonnage of steel will thus have a noteworthy impact on the overall BMH expenditure but a far lesser effect on the overall project value. It is indeed an important outcome for the purposes of this study since it implies that the viability of a project business case may not be all that sensitive to the incorporation of stringent specifications. The matter is explored more fully in the next section by means of running a sensitivity analysis on a project financial model.

4.2 Sensitivity analysis utilising a project financial model

An overview of the project financial model was provided in Chapter 3. For purposes of demonstrating the sensitivity of additional expenses incurred in order to comply with stringent specifications, a 20 year project life was selected where the BMH scope amounts to 18 % of the total project value and 21 % of the total direct costs. This is roughly double the average percentage value determined for projects analysed above. The impact of expenses incurred towards compliance with stringent project specifications will therefore be amplified when considered against the projects analysed above. It is shown in Chapter 5 that stringent specifications may add up to 20 % additional costs. The impact of saving half of this figure was subsequently analysed. It was calculated by means of a comprehensive financial model by Heidgen[8] specifically developed for a real project that a hypothetical reduction of 10 % in the BMH capital expenditure due to applying less stringent specifications would bring about a 4 % reduction in the overall project value. A 9 % improvement would be realised on the project NPV while increasing the NPV to capex ratio by approximately 2 %. This analysis did not consider the implied increased operational costs associated with lower capital investment which will wipe out some of the benefits stated above. It nevertheless provides some insight towards understanding the significance of reduced expenditure. A 1 to 2 % improvement on the NPV to capex ratio will not be significant for a highly profitable project but will certainly assist towards getting a marginal project, in the sense of financial evaluation, approved.

The example above is deemed representative of a typical mining project and shows that capital reduction is undoubtedly desirable from a revenue point of view although the net effect could be rather insignificant. Capital savings nevertheless need to be pursued at every cost element in the project capital estimate without singling out the BMH scope.

4.3 Conclusion

By analysis of the cost breakdown structures of nine representative projects, each having a total value in excess of ZAR 4bn, it was demonstrated that BMH expenditure in relation to the overall project expenditure was on average below 11 %. This figure is slightly higher when considering the BMH scope as a proportion of the direct cost incurred.

For certain brownfields projects however, the cost of BMH systems may occasionally be higher. For a certain project where the BMH scope totalled 21 % of the total direct cost, it was found that an improvement of between 1 and 2 % could be achieved on the NPV to capex ratio when hypothetically saving 10 % on the BMH expenditure. Capital expenditure and operational expenditure are usually a trade-off provided that the scope definition was done correctly. For long term projects the reduction of opex has a major influence on the viability of the project where short term projects tend to be more capital sensitive.

It can ultimately be concluded that the effect of project savings achieved through the reduction of the BMH expenditure will contribute somewhat towards the viability of a marginal project whilst having an insignificant effect on the lucrative investment case.

5 STRINGENT PROJECT SPECIFICATIONS IN PERSPECTIVE

5.1 Introduction

The literature survey covered in Chapter 2 suggests that the most significant way of reducing overall mining project expenditure is arguably by proper upfront scope definition. It can therefore be stated that “what” we build has a greater bearing on project costs compared to “how” we build i.e. the specification. Stringent project specifications may nevertheless attract significant costs and must be critically evaluated. In Chapter 3 certain elements of stringent corporate specifications were discussed. The aim of this chapter is to focus on some of the most significant elements of these requirements in order to put the added expense into perspective, without a detailed analysis on a micro level. Case studies extracted from actual projects will be used to quantify in percentage terms what added expense is really incurred by imposing strict project specifications.

When evaluating the suitability of onerous project specifications, it is important to keep in mind what the intended design life of the project is. By constantly weighing the consequences of a compromised specification, a fit for purpose design approach can be tailored for the specific project. As highlighted in the literature review, short term projects have to be approached with less conservatism in specifications while additional cost may be absorbed on long term projects. The sensitivity analysis of BMH expenditure by means of a financial model was discussed in Chapter 4. For a long term project life, strict project specifications may prove to be advantageous to avoid or reduce future maintenance expenses, which may not be applicable at all to a short term project. There are nevertheless opportunities to reduce capital expenditure.

The evaluation of a stringent project specification cannot be done without a thorough understanding of the BOQ already discussed on Chapter 3. The overall cost of any particular project item is interdependent with various aspects such as the supply rate, transportation, installation rates and P&G costs driven by economy of scales. An unbalanced focus on the cost of supply, viewed in isolation, may prove to be unwise in the long term if remedial work or maintenance needs to be done as a consequence of a short sighted decision taken during the establishment of the project. Once production has commenced, re-work and remedial work to infrastructure usually becomes exponentially more expensive, especially where this work can only be done during scheduled maintenance windows. Where remedial work causes business interruption, the perceived initial cost saving by the selection of an inferior specification is rapidly wiped out whilst the return on investment for the project may be adversely impacted. Ironically this matter is seldom evaluated critically after project completion. This aspect is linked to financial implications of underinvestment covered in Chapter 7.

A workshop was conducted with a leading project design house[34] specialising in small mineral projects. A series of mini case studies is subsequently presented in this chapter to demonstrate the cost premium associated with stringent design specifications while attempting to provide a balanced view by highlighting some longer term benefits thereof. The case studies were selected in collaboration with industry specialists[34] to highlight typical elements encountered on BMH projects which have the most profound impact on costs. The selection of case studies is deemed representative since the costing basis of the individual elements discussed is generic for any BMH project.

5.2 Case studies

Minimum material thickness – structural steel

In Chapter 3 it was shown that the requirement for the selection of structural sections with a specified minimum material thickness was largely driven by corrosion considerations. While this criterion is considered very relevant for long term projects, it may be completely irrelevant for short term projects or environments where corrosion poses little threat to structural integrity. Project specifications demanding a specified minimum material thickness limit the designers' range of selection by about 30 % [34]. Whilst this may in some cases lead to the selection of an alternative section with an equal or better structural efficiency, in general, compliance with this clause leads to heavier structures. A trade-off design exercise was done by a foremost design consultant[35] to determine the premium payable on a large BMH transfer house when complying with the most severe corrosion category stated in the Anglo American specification AA 114/1 Table 2. It was demonstrated that compliance with this specification clause increased the total steel mass from 109 tons to 124 tons i.e. an increase of approximately 14 %. Figure 5.1 below shows the arrangement of this structure.

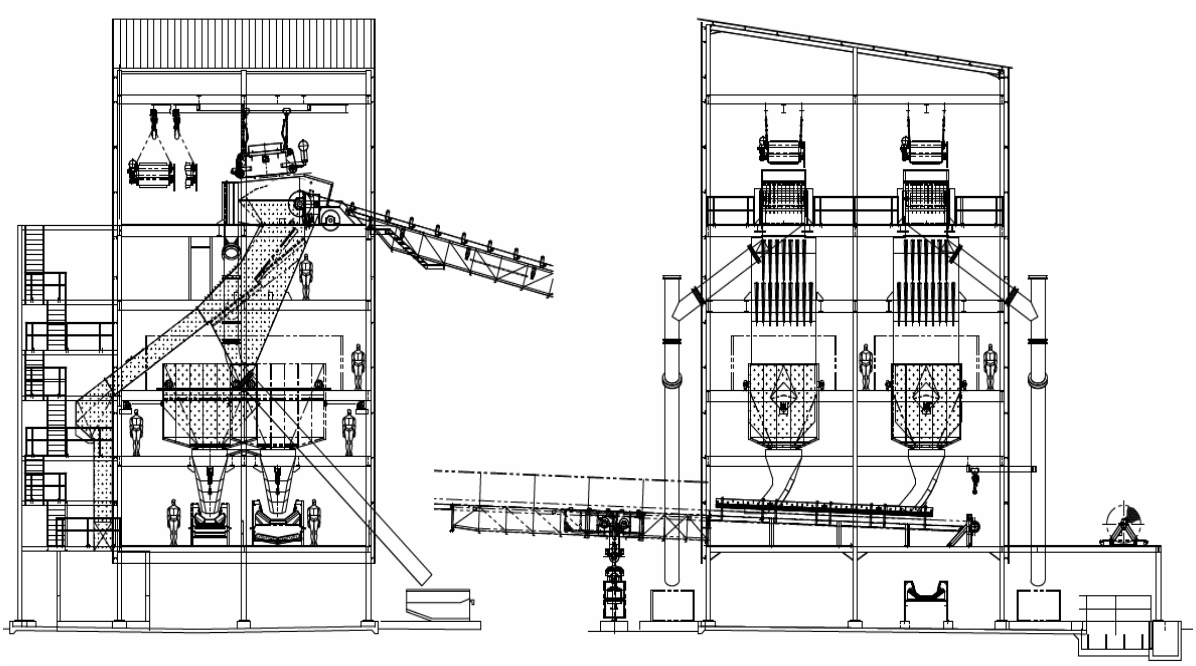


Figure 5.1: Material transfer house.[35]

For a short term project it may be deemed unacceptable to incur costs which are higher than necessary to satisfy national design code requirements. In reality there are many operations where extremely corrosive environments are encountered. Leachate studies[36] for acid mine drainage prediction were conducted to determine acid leaching from the coal samples. Mine drainage quality parameters such as pH, acidity, alkalinity, sulphate and Fe (II) were monitored over the two-week period. The 4-seam coal samples were found to significantly leach out acid (1750-8550 mg/L CaCO3 equivalent), sulphate (1650-7200 mg/L), Fe (II) (28-445 mg/L) and zero alkalinity upon contact with water. These results show that a highly corrosive environment is to be expected when the raw coal becomes wet. These conditions need to be considered when establishing BMH systems and beneficiation plants. According to Mc Millan[37], a metallurgist, it is not uncommon to encounter pH levels as low as 2 at certain coal processing operations. Figure 5.2 below shows severe corrosion of the structure of an apron feeder which was replaced after 20 years of service according to Mouton[38].

Figure 5.2: Apron feeder structure.[1]

Significant capital expenditure had to be incurred only 4 years before the end of the life of this operation. Had the conditions been properly understood at the time of detail design, this structure could have lasted the required lifespan of 25 years. In the light of this example, the upfront cost premium on the supply of steel of say 14 % would have been a good long term investment. Obtaining a return on investment on significant capital expenditure near the end of the life of a mine, when ore grades are generally very poor, may prove to be problematic. The risk of running unsafe operations or facing early closure of the operation must not be underestimated. The degradation of structures may well be blamed on a poor maintenance strategy, however, production pressures seldom allow considerable downtime to address these types of situations until such a time where operations have to be shut down because the structure is unsafe or no longer functional. The cost of remedial work may be so overwhelming that work is delayed until it becomes uneconomical to repair. Replacement cost and the implementation duration required may be detrimental to the operation. Figure 5.3 below shows a severely corroded column of an underground structure at another operation.

Figure 5.3: Corroded column of an underground structure.[1]

The need for complying with a specified minimum material thickness is arguably closely connected with the selection of an appropriate corrosion protection system which is discussed in the next section.

Corrosion Protection Systems – structural steel

The selection of an appropriate corrosion protection system, (CPS) during the detail engineering phase of a BMH project is deemed of utmost importance. Whilst a significant percentage saving may be achieved on corrosion protection expenses in the short term by merely applying a high quality primer, this approach is only deemed viable for short term projects.

A hot dipped galvanizing (HDG) system is often perceived to be very expensive compared to painting. The reality is however that a quality paint CPS system is more expensive than HDG whilst the total cost of ownership of the latter is far less. Shown below in Table 5.1 is a summary of comparative initial costs of HDG versus a heavy duty 3 coat paint system, CPS 132[28] compiled for three BMH brownfields projects by Hennop.[31]

Table 5.1: Comparative pricing between CPS systems.[31]

CPS	Project 1	Project 2	Project 3
HDG	Unity	Unity	Unity
CPS 132	2,1	1,90	2,20
Where: CPS is Corrosion protection system HDG is Hot Dipped Galvanizing CPS 132[27]			

The data provided above in Table 5.1 is consistent with the research findings of Goodwin and Weyers[39] who demonstrated that the total life cycle cost of a paint system is up to 5.6 times that of the most expensive HDG coating system when considered over a 75 year design life. This design life may seem rather extreme but recent studies conducted for BMH infrastructure for the coal supply to a major power station in Mpumalanga were based on a 60 year design life. A heavy duty HDG system was selected according to Cotter.[40]

A renowned corrosion specialist, Perham[41] however cautions that HDG may not always be suitable for certain acidic conditions, in which case a HDG system may be used in conjunction with a duplex paint system. This is an extremely costly but durable system especially designed for dense medium separation plants, (DMS) where acidic conditions are prevalent. The DMS plant of a well-known export colliery in Mpumalanga is a prime example of the success of this system. After approximately 4 decades the system is still serving its purpose.

The analysis of three medium sized projects showed that an approximate saving of 33 % could be achieved on the total CPS expenditure by only applying a primer subsequent to sand blasting preparation. This practice may be considered for short term projects that will be established in moderately corrosive environments. It would however be unwise to utilise an inferior CPS for long term projects.

Cost saving opportunity - Structural steel

Considering the case studies covered under minimum material thickness and corrosion protection systems above, a case can be made for the requirement of a trade-off study between the selections of a superior CPS versus compliance with the minimum material thickness clause. Costing done by Hennop[31] shows that HDG is approximately 14 % of the total steel supply rate for the medium weight structure category. Six BMH projects established over the past decade were analysed. The HDG structural steel at these site showed no noticeable degradation after approximately 10 years of service. It can be concluded that the requirement for a minimum material thickness specified in conjunction with a superior CPS i.e. HDG was over conservative given the absence of acidic conditions.

Minimum material thickness – platework

Similar to structural steel discussed above, due to corrosion considerations the AATC 859[20] specification prohibits the use of plate work of a lesser thickness than 8 mm. Detailed measurement done by Cotter[40] for a complex material transfer chute where it was shown that the 8 mm thickness resulted in a construction which was 28 % heavier than the same chute fabricated from 6 mm plate. Although an 8 mm plate weighs approximately 33 % more than a 6 mm plate of the same area, less stiffening is required. This explains the 5 % discrepancy in mass. Shown below in Figure 5.4 is the transfer chute under discussion.

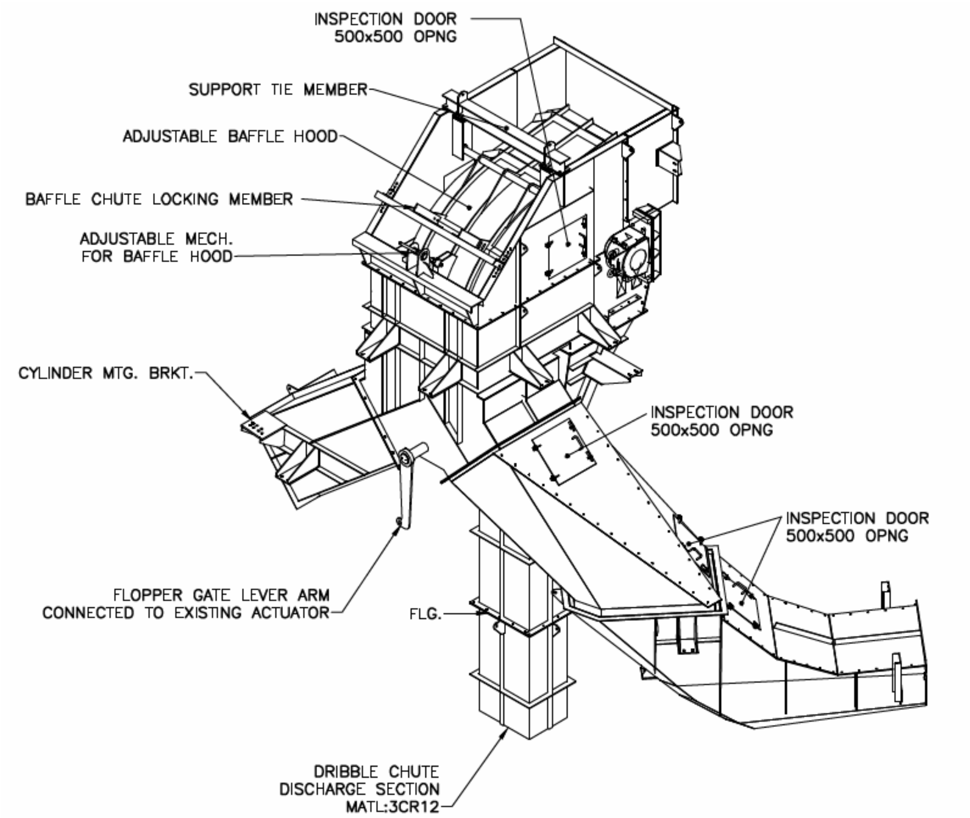


Figure 5.4: Material transfer chute.[1]

Whilst 6 mm thick plate work is deemed satisfactory for short term projects, after a few decades of usage, complete replacement is to be expected. The initial capital outlay associated with 8 mm thick plate work may just ensure that the original chute installations will outlast the life of the mine. The level of corrosion and top lump size of the bulk material handled will be determining factors. The impact energy exerted on chute work increases in proportion to the mass of the lumps handled. A 350 mm lump will exert double the impact energy of a 280 mm lump since the volume of a particle is determined by a cubed function.

Structural steel – design loading

Although design loading is applicable to all types of BMH structures, conveyor gantries are specifically considered here because of their relatively high cost contribution. According to a leading project design house,[34] gantries designed in compliance with stringent corporate specifications can be more than 50 % heavier than their standard offering for small projects. An elevated section of a conveyor is the most expensive part due to the higher steel mass required per unit length. For a typical 1050 mm wide conveyor, a 28 m long gallery type of gantry with double walkways has a unit weight of approximately 500 kg/m. This amounts to approximately 14 tons of steel which is roughly equivalent to the steel mass required for a basic transfer house. From discussions in Chapter 3, wind loading and live loading, which includes spillage loads, are the most significant loading to be accounted for in the design of a gantry. Although gantry design criteria could arguably be relaxed somewhat to reduce the overall weight, mining companies have recorded numerous collapses over the past few decades. Though various combinations of factors have contributed to these failures, according to Krige and Van Schalkwyk[42] spillage loads often exacerbated the situation and led to failures. Shown below in Figure 5.5 is a collapsed gantry where spillage loads contributed to the failure.

Figure 5.5: Collapsed conveyor gantry.[1]

The corporate specification requirement that all gantries are to be fully cladded is nevertheless deemed overly conservative especially for short term projects. The requirement was adopted into specifications subsequent to a wind related failure on a gantry which was cladded although it was originally designed as a un-cladded structure. Structures need to be designed for their intended purpose. Most gantries encountered at junior mining company sites are of the un-cladded, open type.

Structural steel - Hand railing

A trade-off study conducted by a leading BMH consultancy[34] for a short term project demonstrates that the angular type of hand railing construction, commonly used by large mining houses, comes at a premium of approximately 43 % albeit it is a relatively small cost compared to the overall project cost. For a short term project where low corrosion is expected, modular HDG tubular construction is considered adequate.

Structural steel - flooring

A trade-off study conducted by a leading project design house [34] for a short term project demonstrates that a saving of approximately 56 % can be made on conveyor gantry flooring by using expanded metal flooring instead of open grid grating. According to Du Plessis[43] the use of expanded metal flooring on conveyors was problematic on past projects since tripping hazards were introduced at joints between flooring panels. This matter is not really unsurmountable and can be addressed through proper training and quality assurance. For short term projects, expanded metal flooring is deemed a viable alternative on conveyors to realise cost savings. The cost of conveyor flooring in relation to the total cost of the gantry, not to mention the overall BMH cost, is nevertheless insignificant. According the same project design house [34] stringent dynamic design requirements imposed by mining companies may result in 10 to 15 % additional steel mass where large vibrating equipment must be catered for.

Fire protection

By analysing the project estimate of a major capital project[33], it was found that the cost of fire protection systems amounted to approximately 5 % of the total BMH scope. Although this may be a substantial expense, company insurance premiums are directly affected by the level of fire protection provided according to Smart.[44] Although the incidence of fires on BMH systems is fairly low, the consequence may be severe. Fire incidents, directly related to BMH systems, were analysed for a large mining business unit consisting of 12 operations. It was found that five major events occurred over the past decade of which two events resulted in severe revenue loss. The most extreme case resulted in the loss of export revenue equivalent to a period of 4 months while the business interruption lasted for a period of 8 months, during which the export conveyor was rebuilt. The root cause of both these events can be traced back to poor maintenance or housekeeping practices. Ironically fire systems were installed but only due for commissioning the week after the fire occurred. Figure 5.6 below shows how an export conveyor is destroyed by fire.

Figure 5.6: Conveyor system destroyed by fire.[1]

Not only is the capital outlay for proper fire protection systems high, but ensuring that systems are maintained and fully functional is an ongoing operational cost. The decision to install specialised fire protections systems is deemed part of the owners' philosophy and appetite for risk. For short term projects, it is unlikely that specialised high value deluge systems can be justified.

Cladding of buildings

Whilst it is not uncommon, at junior mining sites, to encounter BMH systems without any sheeting whatsoever, cladded buildings and transfer houses certainly provide some protection against harsh weather conditions. Maintenance work can usually commence regardless of inclement conditions. Cladding of buildings has some aesthetical value but maintenance facilities must specifically be catered for. Open buildings allow a maintenance philosophy where all work can be carried out with mobile cranes. The sheeting cost of a major BMH project was analysed to understand the contribution of sheeting in relation to the overall BMH scope. Table 5.2 below shows that cladding cost amounts to roughly 0.4 to 0.8 % of the total BMH scope depending on the system selected.

Table 5.2: Cladding alternatives as a percentage of overall BMH cost.[32]

Description	Roof	Side	Conveyor	Total
Area (m^2)	24760	15888	42103	82751
	Installed cost as percentage of Total BMH scope (%)			
0.6 mm Chromadek Option	0,13	0,08	0,22	**0,43**
0.8 mm Chromadek Option	0,18	0,12	0,31	**0,61**
0.6 mm Alubond Option	0,17	0,11	0,28	**0,56**
0.8 mm Alubond Option	0,25	0,16	0,43	**0,85**
0.6 mm ZincAL Colourplus AZ150 G550	0,15	0,10	0,25	**0,50**
0.8 mm ZincAL Colourplus AZ150 G550	0,20	0,13	0,33	**0,66**

It is very important to select a cladding option that will last the life of the operation. Sheeting replacement is not only a costly and onerous task, but also poses a safety risk if it needs to be done at an operational mine. Conveyor sheeting is often omitted on short term projects. The need for sheeting is often driven by environmental considerations.

Conveyor belt width

A detailed trade-off study[45] on a series of 5 overland conveyors covering a transportation distance of approximately 25 km showed that an all-inclusive cost premium of roughly 17 % was to be paid for the selection of step up in belt width up. i.e. 1050 mm belt width selected where 900 mm width was satisfactory. A premium of 17 % is higher than the industry norm. Another detailed study[45] on a 7 km overland conveyor showed that a cost premium of roughly 12 % was to be paid for the selection of a 1200 mm belt width instead of 1050 mm. It is important to understand that the maximum belt speed specified in a project is a starting point only. If a maximum overland belt speed is specified at e.g. 4.5 m/s, it is not sensible to increase the belt width merely because the specified maximum speed is marginally exceeded by the initial design proposal. This issue highlights the need for sensible discussion to ensure that project specifications are correctly interpreted to satisfy the intent and perhaps not always the letter thereof albeit with a request for concession. The optimisation of conveyor structural steel modules can bring about some project savings, especially on long conveyors. It is however just as important to ensure that the design is simple and that the modules can be easily installed. If complications are encountered on a very long overland conveyor it could have an adverse impact on the construction schedule and project costs.

5.3 Summary of potential BMH cost reduction

The outcomes of the studies presented above are from real projects of which most were implemented. The results are therefore representative but it must be kept in mind that the exact numbers will vary between projects. Table 5.3 below shows a summary of savings which could potentially be realised when a short term project view is applied.

Table 5.3: Summary BMH savings possibilities with less stringent specifications.[32]

Item or aspect	Omission possible (Yes / No)	Saving potential Compared with long term spec (%)	Saving potential Percentage of BMH (%)	Significance (High / Low)
Structural steel - minimum thickness	No	15	7,5	H
Corrosion protection - primer only	No	33	1,7	L
Mechanical (drives, pulleys, belting, idlers etc.)	No	12	3,6	H
Sheeting	Yes	100	0,5	L
Handrailing - tubular vs angle	No	40	2,0	L
Fire protection	Yes	100	5,0	H
Potential reduction of BMH expenditure (ignoring belt width selection)			**20,3**	
*Conveyor belt speeds / belt width**	*No*	*12*	*5,4*	*H*
Potential reduction of BMH expenditure (including belt width selection)			**25,7**	
* Mechanicals subtracted to avoid double accounting All figures provided are representative but project scope dependent				

For discussion it will be assumed that 10 % of savings on the BMH project scope could be achieved quite comfortably when establishing a short term operation. If a high figure of 20 % is used hypothetically, it can be shown that the impact of these savings on the overall project cost through the implementation of fit- for-purpose specifications, may be as low as about 5 % according to Heidgen.[8] This is deemed an optimistic savings scenario. When considering that the average BMH scope contributed on average about 10 % of the overall project cost for the analysis done in Chapter 4, this number reduces dramatically. As already mentioned, a lower capital investment implies that greater operational expenditure will be incurred. The sensitivity analysis on capital required as already discussed in Chapter 4 implies that the NPV benefit as a consequence of BMH cost reductions may be of little consequence towards ultimately obtaining project approval.

5.4 Business vision

The impact that the anticipated project life has on the selection of project specifications has already been covered. An aspect which is different but related in a sense is that of the business vision of the current owner. The imminent sell-off of operational assets would logically influence the owners' appetite not to invest with a long term approach. It is to be expected that the reduction of capital expenditure on current business ventures will enjoy a greater focus than ensuring a long term hassle free operation.

5.5 Conclusion

The compilation of project specifications is tied in closely with the life expectancy and duty requirement of a project as well as the long term business vision of the owners. Stringent project specifications are a worthwhile investment for long term projects and may ensure that significant capital and maintenance expenditure is avoided towards the end of the project life. It would seem logical that engineers developing new projects, under constant pressure of cost reduction, will be inclined towards a short term, capital savings approach. On the contrary, engineers who have battled to get maintenance and remedial work done on 30 year old plants will tend to take a longer term view when it comes to project specification decisions. It is arguably a balance between these opposing methodologies which can bring about the achievement of sound cost-savings on BMH projects. The mere short term avoidance of minimising capital expenditure may result in significant future expenses when the business cannot afford it. Likewise, high upfront expenditure in the wrong areas may prove to be an overinvestment bringing no long term benefits whatsoever. Large mining companies have traditionally only ventured into long term project investments. Project specifications were subsequently developed with a long term view in mind. With declining ore grades the development of many short term projects is now a reality for all mining companies. A mind shift is consequently required to adapt project specifications in line with the life expectancy and duty requirement of the specific project. It must be emphasised that the most significant cost savings will be realised through accurate scope definition. It was demonstrated that stringent project specifications contributes to less than 25 % of the overall BMH expenditure. This could be a considerable amount of money but when viewed in relation to the overall project expenditure it translates into a figure of 3 to 6 % depending on the scope. The significance of these numbers depends on the sensitivity of capital expenditure in the project financial model but according to Heidgen[8] it will seldom be a determining factor for project go-ahead.

5.6 Recommendations

Project specifications need to be aligned with the business vision and requirements. Project managers need to understand how sensitive the project viability is to capital expenditure so that informed decisions can be made in this regard. For long term projects, compliance with stringent specifications will prove to be a good investment over time. Specifications are ultimately a starting point for designs. It is worth noting the need for discussion and relaxation of specification requirements where the proposed design falls only marginally outside of the stated parameters. This is especially true where significant additional capital expense will be incurred without much real benefit to the owner. Sensible discussion in this regard requires an in-depth understanding of what the purpose behind specified requirements is. The summary provided in Table 5.3 above may be used as a decision guideline for reducing or avoiding capital expenditure.

6 RE-USING PLANTS, SYSTEMS, EQUIPMENT AND MAJOR STRUCTURAL STEEL COMPONENTS

6.1 Introduction

According to Connelly[11] considerable savings can potentially be made by using second hand systems and equipment but caution is nevertheless raised that the cost may outweigh the savings. Revisiting the bill of quantities, already discussed in Chapter 2, the cost structure must be carefully considered. Besides the additional costs for dismantling, reconditioning, transportation and reassembly, risks must be cautiously analysed and understood. Trade-off studies conducted to evaluate the construction of new versus second-hand equipment or plant may prove the viability for re-use. However, if a long term operation period is envisaged, special care must be taken to ensure that re-used facilities will last for the anticipated life. According to Hennop[31] costs will rapidly increase as soon as any modifications are required to the re-used steelwork. Although detailed upfront inspections can be done, in some cases the real condition of steelwork may only be revealed after dismantling. Unless due care is taken, large assembled structures may be damaged when exposed to rigging loads for which they were not specifically designed. This is particularly relevant where attempts are made to minimise complete dismantling of structures. Certain structures are pre-assembled to minimise construction durations, while temporary bracing might have been purposefully designed to facilitate these major rigging lifts. While repositioning modular and skid mounted types of plants, specifically designed for ease of relocation, may be straightforward, the relocation of complex fixed plant may be problematic. The interface between the civil works and steel structures earmarked for relocation must be carefully managed. Steelwork drawings may not be available. What could be worse is when drawings are available but not accurate. The civil design engineer may need to estimate certain design loadings in order to proceed with the design of infrastructure. Who carries the additional costs when things go wrong and steelwork does not fit on the newly constructed foundations or if design loads are underestimated? Re-work of constructed civil works or modifications to steel structures may potentially attract significant costs not budgeted for whilst the project schedule may be adversely impacted. Longer than expected dismantling durations may impact not only on the construction schedule but also on the anticipated production expectations. If an all new plant is constructed, the old plant may be used until the new facility is ready. This aspect may not be relevant to all projects but it is certainly a consideration where a new mining area is to be entered by an existing operation. Production phasing is of utmost importance and could attract standing time claims if not managed properly. The relocation of components or structures associated with conveyor systems comes with its own challenges. Ground profiles and relative elevations between transfer stations will undoubtedly be different from the conditions originally designed for. Where detail design drawings and information are not available or incorrect, it may severely impact on engineering hours budgeted for. The professional certification of major relocated but modified structures may prove to be problematic. Complete design re-validation may ultimately be required.

A few case studies are presented to demonstrate that the re-use of plant, systems and major steel components are to be evaluated on a case by case basis.

6.2 Case study 1 – ROM tip and overland conveyor system[45]

Background

A certain open cast coal operation was established just over a decade ago. The coal value chain includes a ROM tip, crushing-screening plant, raw coal stock pile, a dense medium separation (DMS) beneficiation plant, product stockpiles, rail export facilities and an overland conveyor to supply a local power station.

The current mining reserve is rapidly reaching the end of its life. A new mining reserve which is located approximately 10 km from the existing reserve needs to be accessed. The existing ROM tip will become redundant while the power station supply contract has expired with the effect that an existing overland conveyor will no longer be utilised. It is anticipated that the mining production rate will remain more or less constant whilst the capability of the existing overland conveyor for coal supply to the power station matches the requirement for the transportation of raw coal from the new tip position to the existing beneficiation infrastructure. There is consequently an opportunity to relocate an entire ROM tip and overland conveyor. The simplified flow sheet for the ROM tip, showing the key components of which associated support structures were considered for relocation, is depicted below in Figure 6.1.

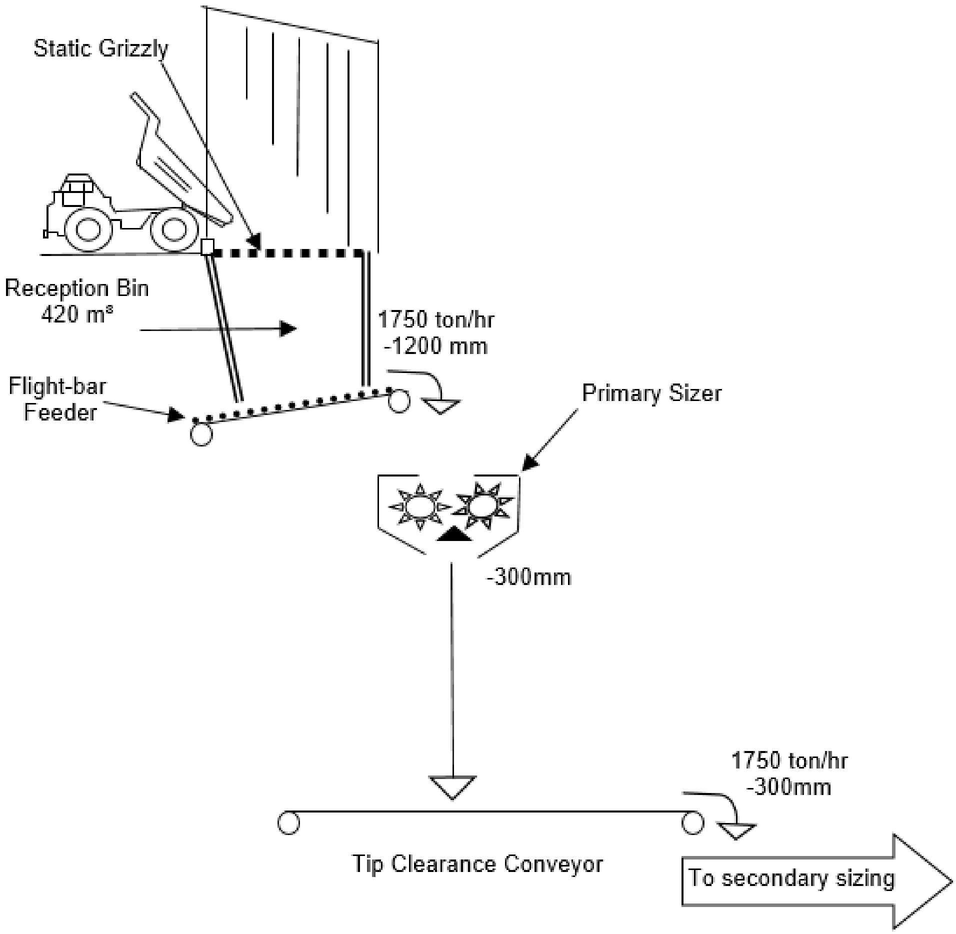


Figure 6.1: Flow sheet for ROM tip.[45]

Relocation study outcome – ROM Tip

The comparative desktop study was done to determine the difference in cost between an all-new tip and the relocated tip. Both options include new civil works while major mechanical equipment must be re-used once refurbished. The summary sheet is shown below in Table 6.1 with costs expressed as a percentage of the total cost for a new tip.

Table 6.1: Tip trade-off relative costing – relocated versus new.[45]

Description	Relocate	New
Tip Civils	25,4%	25,4%
Tip Structures	4,7%	15,3%
Mechanicals - re-use for both options	0,4%	0,4%
Electrical and Instrumentation	16,3%	16,3%
Engineering	2,4%	2,9%
Equipment refurbishments	9,6%	9,6%
P&G Civils	8,9%	8,9%
P&G Mechanical Structural	17,5%	14,5%
P&G Electrical and Instrumentation	6,6%	6,6%
Total	91,9%	100,0%
All values expressed as percentage of the total new establishment cost		

Discussion - Tip

As shown above in Table 6.1, the cost to relocate the existing tip was found to be approximately 8 % cheaper than an all-new tip when major mechanical equipment is re-used. The original tip has been in use for over a decade. The bin has suffered some abuse and is somewhat distorted. The design interface between the bin and feeder was not optimal to the extent that throughput constraints are experienced at high production rates. It is required to remedy this matter for the new installation. Since the ground profile of the new tip site differs from the original position, the civil design will have to be adapted to suit as well as access roadways to major equipment. Some modifications to steel work will have to be carried out on site. Key risks associated with the tip relocation includes:

- The dismantling duration.
- The civil-structural interface.
- Structural integrity of the tip bin for another 15 years of service.

Although the dismantling duration can be covered by contractual arrangements, the risk associated with the civil-structural interface will essentially be carried by the owner. No or poor engineering drawings are available.

The financial benefit for the tip relocation is negligible and poses a significant element of risk to the project. The design and construction of a new tip with re-used major equipment is deemed the safer option.

Relocation study outcome – overland conveyor

The comparative costing between an all-new overland conveyor and the partially relocated conveyor is shown below in Table 6.2 as a percentage of the total cost for a new conveyor.

Table 6.2: Conveyor trade-off relative costing – partially relocated versus new.[45]

Description	Relocate	New
Conveyor Civils	30,1%	30,1%
Conveyor - Structures + Mechanical	24,6%	39,3%
Take-up / drives	0,2%	3,5%
Transfer	0,7%	0,8%
Splice station	0,1%	0,2%
Cross overs	0,7%	0,7%
Equipment refurbishment	0,2%	0,0%
P&G Civils	10,5%	10,5%
P&G Mechanical Structural	21,5%	15,0%
Total	88,5%	100,0%
All values expressed as percentage of the total new establishment cost		

Discussion – Overland conveyor

As shown above in Table 6.2, it will be approximately 13% more expensive to build an all new overland conveyor as opposed to partially relocating the existing conveyor no longer in use.

There is a chance that the previous coal supply contract with the local power station may be renegotiated in which case the relocation option would prove to be the incorrect business decision.

The absence of accurate as-built engineering drawings will present a significant challenge to the engineering consultant. Over-all certification of structures which were partially designed by different parties can only be done if the new engineering consultant re-validates all designs.

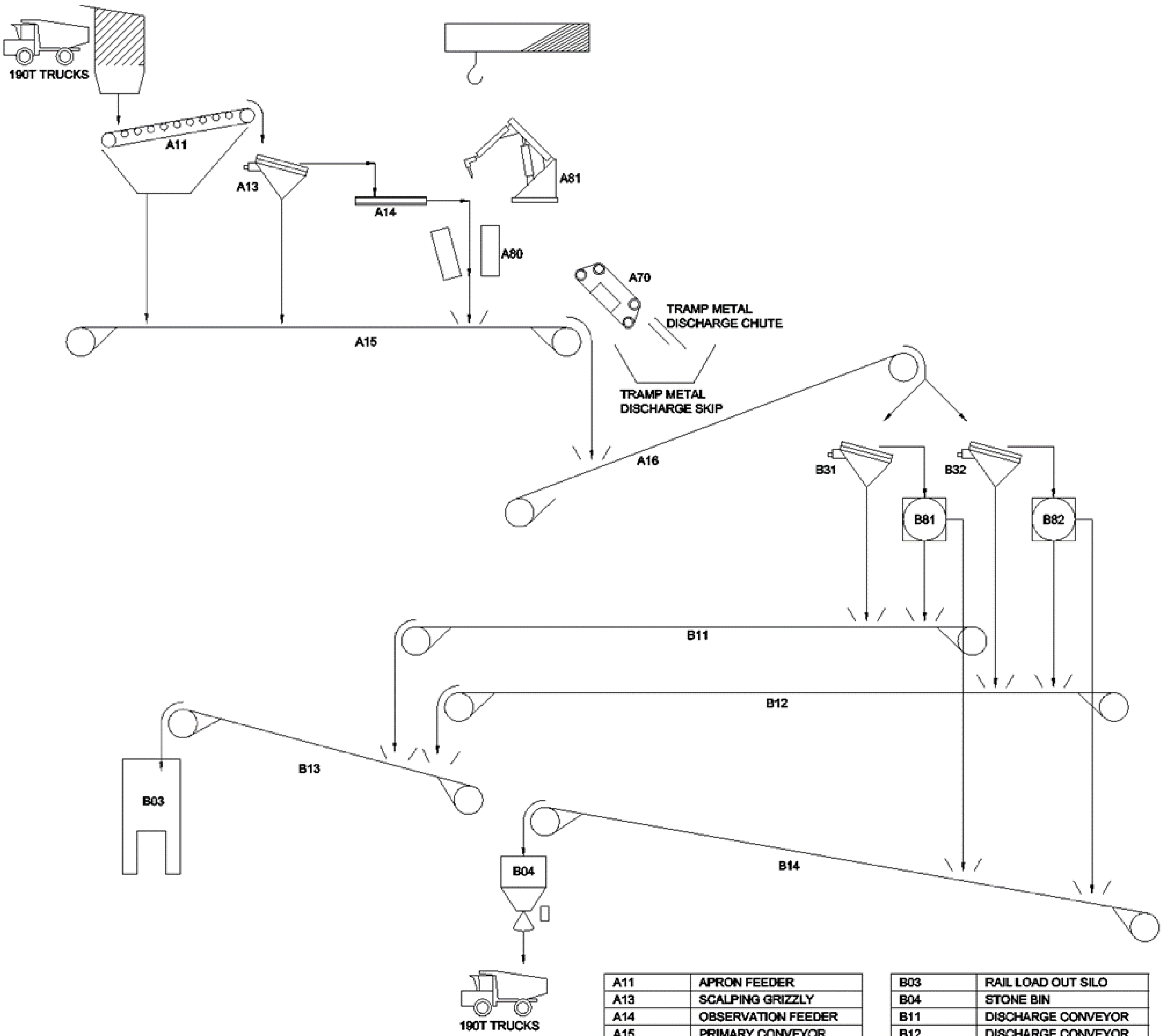
A moderate short term financial benefit may be realised by the partial relocation of the existing overland conveyor. It was decided to rather build an all-new conveyor.

6.3 Case study 2 – Major equipment from ROM tip.[45]

Background

A 25 year old open cast coal operation is nearing the end of its life. There is potential for extending the life of the mine by accessing a small reserve previously undermined which is located 20 km away from the current mining area. It is consequently required to establish a new ROM tip, with a secondary screening-crushing facility. The prospective reserve will potentially prolong the life of mine by 7 years. It is anticipated that the major equipment currently utilised can be re-used at a newly constructed ROM tip site. The mining schedule allows a window period where production will not be delivered from the depleted reserve nor the life extension reserve.

The flow sheet for raw coal handling is depicted below in Figure 6.2. All major equipment including the overhead crane support structure and a 300 ton discard bin was earmarked for re-location.



A11	APRON FEEDER
A13	SCALPING GRIZZLY
A14	OBSERVATION FEEDER
A15	PRIMARY CONVEYOR
A16	SECONDARY CONVEYOR
A70	MAGNET BELT
A80	JAW CRUSHER
A81	PICKER
A82	BYPASS CONVEYOR

B03	RAIL LOAD OUT SILO
B04	STONE BIN
B11	DISCHARGE CONVEYOR
B12	DISCHARGE CONVEYOR
B13	FEED CONVEYOR
B14	FEED CONVEYOR
B31	SCALPING SCREEN
B32	SCALPING SCREEN
B81	BREAKER
B82	BREAKER

Figure 6.2: Flow sheet of tip.[45]

Study outcome – major equipment

In order to compare pricing of the existing equipment with that of newly supplied, the cost of the re-used items is priced on an as-delivered to the new tip site basis. Accurate refurbishment cost was also allowed for. The cost of re-used equipment is expressed as a percentage of the new cost. Table 6.3 below shows the outcome of a comprehensive study.

Table 6.3: Comparative costing of major equipment.[45]

Description	Cost of re-used (% of new)
Rock Breaker	28
Rotary Breaker	31
Apron Feeder	33
EOT Crane	45
Jaw Crusher	59
Crane Support Structure	79
Observation Feeder	80
Scalping Screen	93
Tramp Iron Magnet	106
Discard Bin	115
Vibrating Grizzly Feeder	129

Discussion

Although equipment has generally been in service for 25 years, the apron feeder was replaced 3 years ago. With funds allocated for refurbishments, risks can be mitigated. High preliminary and general charges are driven by rental charges associated with high capacity cranes and low bed transportation equipment. It is nevertheless clear from Table 6.3 that relocation of at least half of the major equipment is financially viable for this project. On the contrary, roughly 50 % of the items considered are deemed uneconomical to relocate or more expensive than buying all-new.

Understanding the condition of major equipment earmarked for re-use is vital. If replacement is required in the early years after re-location, the total cost without factoring business interruption will be excessive. If the true condition is found to be worse than anticipated during the salvaging process, the project could be in a predicament from a financial and schedule point of view if new equipment needs to be procured in a rush.

6.4 Conclusion

From real case studies analysed in this chapter, it can be concluded that:

- The re-use of plants, systems, equipment or structural steel components associated with BMH systems must be considered on a case by case basis with a thorough understanding of the business need, expected future life, condition of equipment and specific project risks. Detailed trade-off studies which take all hidden costs into consideration are required to make an informed decision.
- The re-use of plants, systems, equipment and structural steel components provides not only opportunities but also risks which must be analysed with caution. Key considerations are summarised below in Table 6.4

Table 6.4: Summary of key considerations for re-used elements.

Description of cost or risk element	**New**	**Re-used**
Supply	x	
Production interruption at existing plant / timing to salvage		x
Salvage		x
Salvage - Potential schedule issues if complications arise		x
Salvage - P&G costs out of hand		x
Modifications		x
Modifications - quality issues		x
Condition not fully understood - approved capital insufficient for new		x
Condition not fully understood - schedule slip, lead time		x
Refurbishment		x
Transport	x	x
Transportation inefficiencies - not viable to dismantle structure		x
Erection	x	x
Erection quality & liability		x
Availability and accuracy of drawings - liabilities		x
Professional liabilty on relocated structure		x

7 FINANCIAL IMPLICATIONS OF UNDERINVESTMENT

7.1 Introduction

Mining houses have been greatly criticised in recent years for overinvestment in infrastructure. Although this criticism may be justified, it is vital to also acknowledge that underinvestment occurred. This chapter ties in with Connelly's[11] word of caution noted in Chapter 2. It was advised that the reduction of design cost needs to be done with caution while a quality design may ultimately save on capital expenditure and unexpected future costs. It was further noted that overly aggressive capital reductions may result in inefficient operations which could reduce the overall availability of the plant and result in loss of revenue in the long run. The fundamental question to be answered by decision makers of mining companies reduces to: "If we can't afford the additional capital expenditure during establishment of the mine, can we afford to remedy the situation once the mine is operational?"

A few case studies are discussed to demonstrate the financial implications of underinvestment as a direct consequence of capital reductions during the establishment of the original project. Since every project is unique, the selected case studies serves merely as an attempt to demonstrate the underlying principle of underinvestment.

7.2 Case study 1 – Insufficient capacity of a shaft conveyor and surge silo

Background

The project obtained board approval based on the feasibility study capital estimate based on an anticipated production annual rate. During project reviews, management increased the planned production rate and mining equipment without revisiting the scope and capital allocation of the downstream BMH systems. This was done while the project was in implementation stage. Although this matter was highlighted to management, the feasibility scope for BMH systems had to be implemented as planned.

Problem statement

The simplified flow sheet of the BMH system for the underground mine is depicted below in Figure 7.1

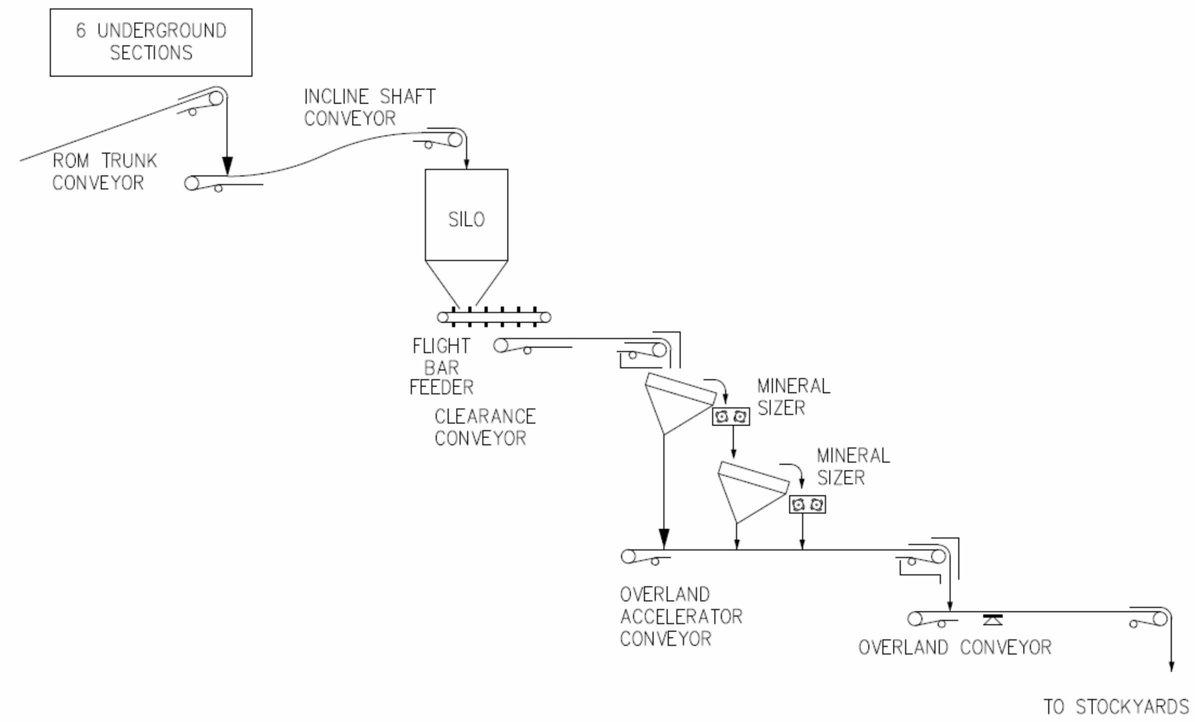


Figure 7.1: Simplified flow sheet of underground mine.[1]

A 3-shift system is utilised at the mine. The production profile per shift generally follows the traditional bell-shaped curve whereby low production outputs are delivered at the beginning and end of every shift. Very high production outputs are achieved approximately in the middle of the shift. Although the BMH system can accommodate the average shift production rates, the instantaneous production peaks exceeds the design capacity. Due to labour complexities, it is not possible to stagger the shift times of the 8 production sections. The shaft conveyor is subsequently overloaded while the surge silo capacity is insufficient to cater for peak production periods to the extent that production losses are incurred according to Lebedev[45]. The mine production is ramped up over a period of approximately 5 years. No production constraints are therefore experienced during the initial years.

The existing shaft belt is too narrow to deal with the required peak production outputs. The underground development haulage is too narrow to accommodate an additional conveyor. Even if feeder breaker rates are reduced to alleviate production surges, the speed of the shaft conveyor needs to be increased to over 6 m/s. The stopping time of the shaft belt is about 7 seconds while that of the main trunk belts is roughly 25 seconds. The material overrun is too much to be contained in the head chute. The underground development cost associated with surge bins is unaffordable.

Simulation studies shows that a 9000 ton silo is required to accommodate the production surges. A 6000 ton silo was constructed. It is not viable to upgrade the BMH systems downstream of the surge silo. The capacity of a silo cannot be increased. Although a throw-out facility would work, environmental constraints do not permit this option.

The mine has now ramped up to full production capacity. Significant production losses will be incurred to accommodate construction activities associated with the shaft conveyor.

Solution

A number of alternatives were investigated. The most viable option requires that a second 6000 ton silo be built while speeding up the existing shaft conveyor which needs to be equipped with flywheels to resolve the overrun dilemma already mentioned. The existing conveyor drives are insufficient to deliver the new duty and need to be replaced. A complete electrical upgrade is required while production levels need to be maintained throughout the implementation of a difficult upgrade project. The shaft conveyor is a key element in the coal supply system. The upgrade solution is viable but nevertheless a compromised situation leaving the operation at risk of production losses if things go wrong.

Financial matters

The financial implication of the decision to avoid the expenditure of the additional capital to meet the business requirement can be summarised as shown below in Table 7.1

Table 7.1: Financial impact of avoided capital expenditure.[45]

Description	What was built	What business required	Cost to upgrade
Base date	2008	2008	2015
Silo	65,2%	97,8%	
Shaft conveyor	34,8%	40,0%	
Total	100,0%	137,8%	
Capital expenditure avoided at project establishment		**37,8%**	
Upgrade capital required (2015)			173,9%
Ratio of upgrade cost to capital initially avoided (escalated to 2015 value)			**2,5**

From Table 7.1 above it is demonstrated that the business was actually required to incur a cost of 37.8 % more when establishing the original infrastructure in question. Since the true business requirement remained constant all along, it eventually costed about two and a half times more than the avoided capital expense to remedy the situation when considered in 2015 values.

7.3 Case study 2 – Oversized product due to capital reductions

Background

It was required to establish a new opencast tip complete with a crushing and screening facility to deliver a raw crushed product to a client of which the downstream beneficiation processes are very sensitive to processing oversized material. The supply contract subsequently included penalty clauses for the supply of oversized material based on specified parameters.

A minus 100 mm product is to be delivered through a process circuit which includes a primary mineral sizer, scalping screen and secondary mineral sizer. Although the feasibility designs included for a tertiary sizing facility, this was omitted at implementation since the project team was of the opinion that product requirements could be satisfied without the additional capital expenditure.

The process flow diagram for the tip is shown below in Figure 7.2.

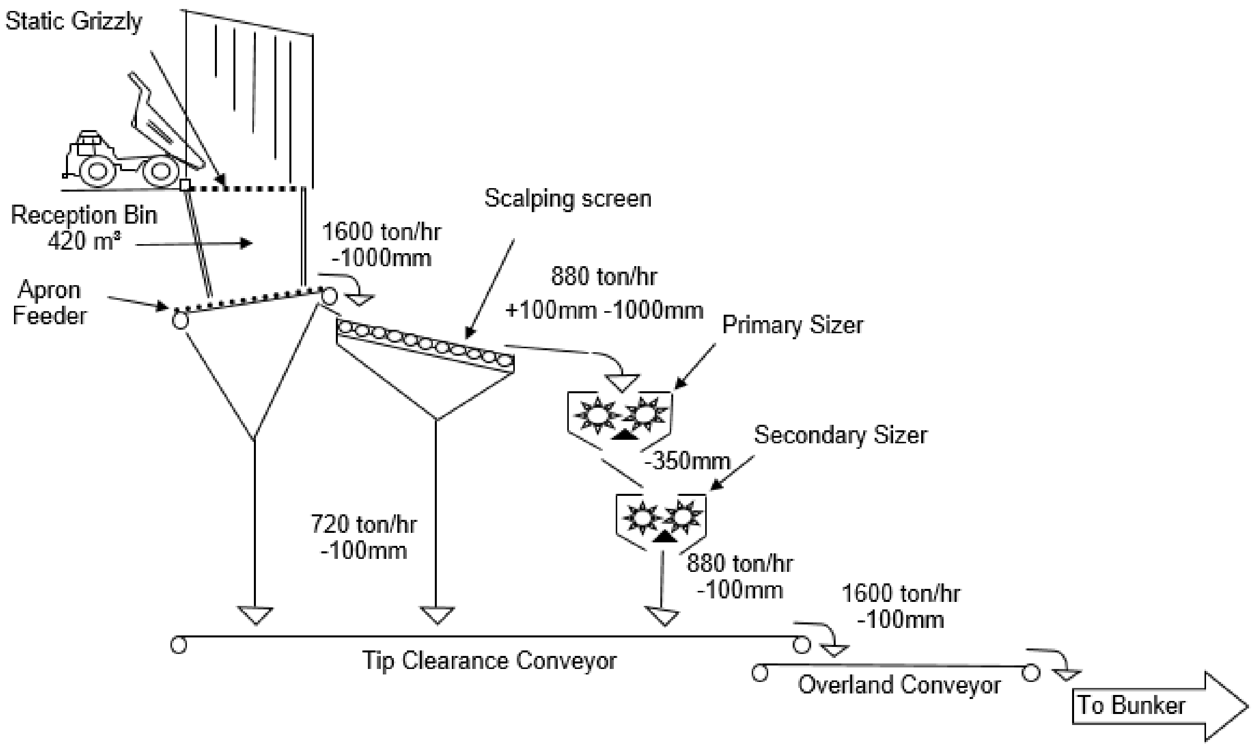


Figure 7.2: Tip process flow diagram as established.[1]

Problem statement and solution

An oversized product is delivered to the client who is imposing penalty charges in accordance with the supply contract agreement. In spite of numerous attempts by the sizer OEM to adapt sizer lacing configurations, the oversize dilemma remains unresolved. The reputational risk of introducing only an alternative sizer brand and not resolving the matter is deemed too great since the client is suffering business interruption because of product which does not meet the contractual specification.

The tip configuration does not allow the introduction of an additional scalping screen or tertiary sizer to deliver a guaranteed sized product. A stand-alone scalping and tertiary sizing facility can only be implemented by constructing bypass feed and return conveyor at great expense.

The revised process circuit for the tip is shown below in Figure 7.2.

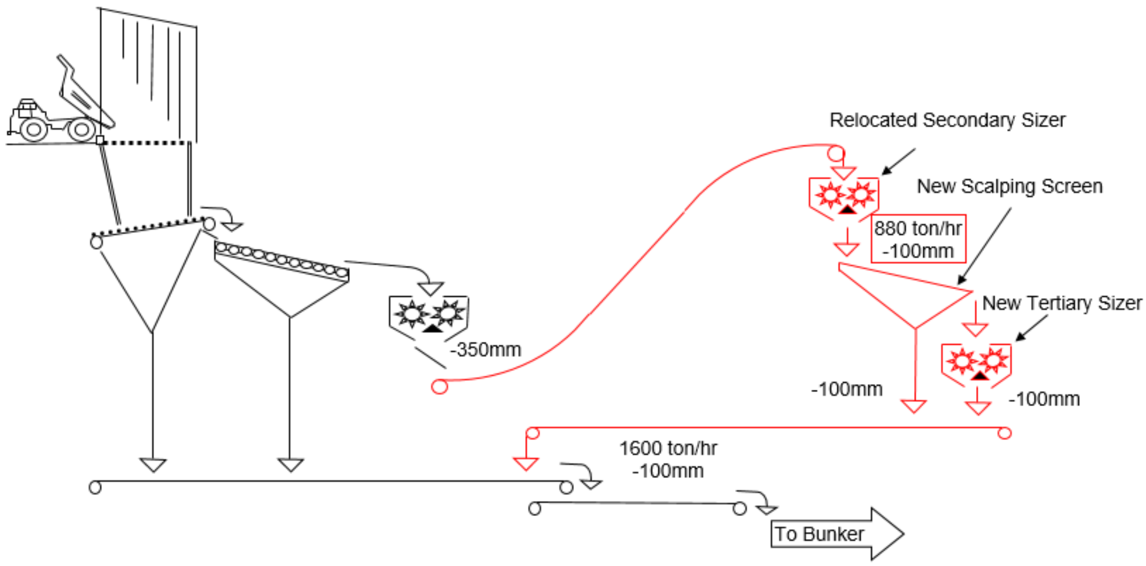


Figure 7.3: Tip process flow diagram as modified.[1]

Financial matters

The financial implication of the decision to avoid the expenditure of the additional capital to meet the business requirement can be summarised as shown below in Table 7.2

Table 7.2: Financial impact of avoided capital expenditure.[45]

Description	What was built	What business required	Cost to upgrade
Base date	2005	2005	2008
Tip establishment cost	100,0%	118,6%	
Capital expenditure avoided at establishment		**18,6%**	
Upgrade capital required (2008)			78,0%
Ratio of upgrade cost to capital initially avoided (escalated to 2008 values)			**3,2**

From Table 7.2 above it is demonstrated that the business was actually required to commit to a cost which was about 19 % higher than the project establishment capital. When the business eventually conceded that expenditure is required to meet the client’s needs, the cost to remedy the situation was more than three times higher than this 19 % initially avoided when considered in 2008 values.

7.4 Discussion and conclusion

It was demonstrated by means of actual case studies how capital reductions made at the time of establishing BMH infrastructure may lead to underinvestment to the extent that the ability of the business to meet its long term goals is compromised. The capital required to remedy the situation at a later stage is usually significant and amounts to multiples of the perceived “initial saving”. This late expenditure combined with loss in revenue due to the inability to deliver the required product will inevitably have a very negative impact on the anticipated return on investment initially estimated. If the initial business case was only marginally positive, the company could possibly be loss making while locked into long term contracts. The inability to meet contractual obligations inevitably impacts on customer relationships and may lead to reputational damage. The potential cancellation of long term contracts and loss of future business could have serious ramifications. The business interruption associated with major upgrades or modifications could be significant. The loss in revenue due to the inability to achieve the required throughput or produce the required product will probably exceed by far the additional capital requirement.

Retrofit solutions are usually much more expensive than systems engineered properly from the onset. The retrofit solution may deliver a compromised outcome because of a more complex infrastructure layout with restricted maintenance access and more assets to maintain. If major equipment or infrastructure is sized just too small, a complete replacement may be required at huge expense. The equipment or infrastructure originally acquired or established at great expense may be useless or of little value when upgrades are required. The impact of additional operational costs associated with retrofit solutions were not considered in the case studies discussed.

From preceding case studies it can be concluded that, in the long run, underinvestment will probably be far more detrimental to a business than overinvestment. The potential consequences of underinvestment must be considered while developing the BMH project scope.

8 SURGE AND STORAGE SYSTEM SELECTION

8.1 Introduction

Surge facilities are often required to cater for instantaneous capacity mismatches in sub-systems in order to ensure economical designs. Likewise certain processes or logistics demand the temporary storage of material. Live capacity surge or storage systems eliminate costly re-handling charges of the bulk material but the capital required to establish these facilities may be a considerable portion of the BMH estimate.

In this chapter, the cost of a wide variety of silos and bunkers is evaluated on a comparative costing basis in order to provide a guideline for the selection of a cost effective system when conducting future project studies. Potential project benefits and disadvantages associated with the selected system are also provided to assist with the initial study considerations.

The investigation was based on revalidated costs from implementation projects and studies, project costs obtained from consultants or EPCM's and past publications. In order to sensibly compare project costs implemented over a broad timespan, cost escalation was applied in line with industry practice. Projects and the cost basis thereof are unique. Accurate approximations of the comparative costs of the systems considered were deemed adequate for the purposes of the study. Some systems considered were established decades ago while others were constructed very recently.

A summary sheet with pictures of various operational and constructed systems are provided in Appendix A for reference. Site inspections were carried out at most of the reference sites.

Storage facilities considered include conventional circular concrete silos with sheeted roof steel commonly used in the mining industry, as well as the following types of bunkers:

- Reinforced concrete, (RC)
- Reinforced concrete used in combination with pre-cast elements, (RC P)
- Reinforced earth with concrete panels at flow surfaces. Longitudinal, (RE L) and circular (RE C) types were investigated.

8.2 Criteria for storage system selection

Capital cost

Costing may be significantly influenced by project specific requirements and conditions such as geotechnical conditions, topography etc. Since estimates were obtained from various sources, comparative costing are indicative only to serve as a selection guideline. Project-specific trade-offs must be done to get accurate costs and to determine the suitability of any specific system. The cost of the BMH feed system must be included in the overall cost model since high lift conveyors associated with large silos account for a significant portion of the capital. For bunkers however, the receiving conveyor of approximately the overall bunker length must be included to obtain a comparable costing structure.

The detailed cost estimates are confidential information and cannot be published. The relative total storage system costs of systems evaluated are nevertheless provided using the most economical system in cost per volume as basis. It is obvious that economies of scale play a significant role in the relative cost. For comparative purposes, the relative costs were determined for storage systems including and excluding the feed conveyors. For bunkers an adjustment was also factored in for the extraction conveyor. The systems and respective capacities of 16 projects analysed are shown below in Figure 8.1.

Table 8.1: Storage systems analysed.[33]

Study	Storage capacity (m^3)
Silos	
Silo 1	1200
Silo 2	1579
Silo 3	2105
Silo 4	6316
Silo 5	9444
Silo 6	10526
Silo 7	10526
Twin silos	18889
Bunkers	
Bunker 1 - (RC)	4211
Bunker 2 - (RC P)	8947
Bunker 3 - (RC P)	15789
Bunker 4 - (RC)	44000
Bunker 5 - (RE C)	10000
Bunker 6 - (RE C)	10000
Bunker 7 - (RE C)	20000
Bunker 8 - (RE L)	25263
Bunker 9 - (RE L)	44000

The relative costs for silos presented above are plotted below in Figure 8.1. As expected, the relative cost per storage volume reduces as the capacity increases. It is worthwhile to note that the twin silos have the lowest relative cost of all silo projects considered. High lift conveyors associated with silo feed systems are expensive systems. Where feed and extraction systems can be shared between multiple silos, the overall cost per storage volume can be reduced significantly. Economical range of storage systems is discussed later.

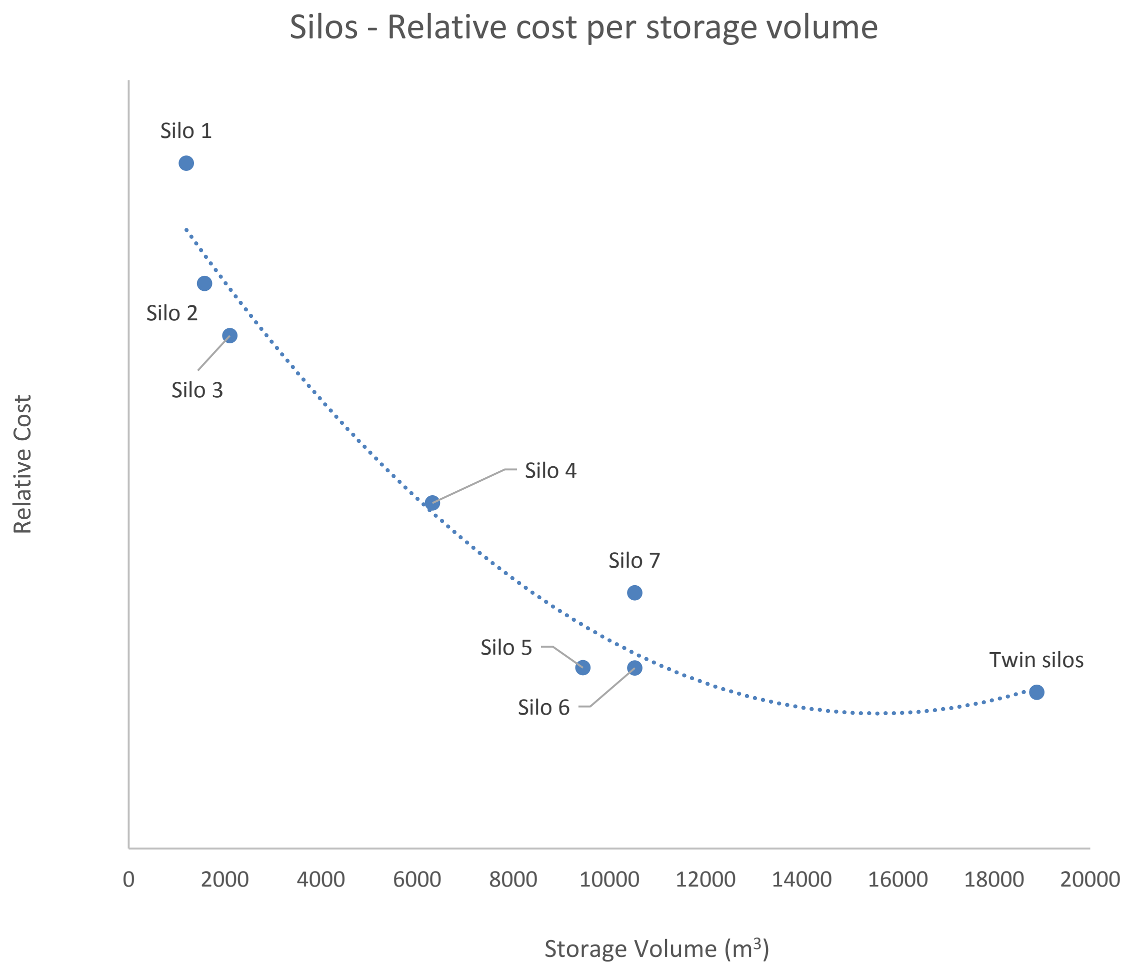


Figure 8.1: Silos - relative capital cost per storage volume.[33]

The relative costs for bunkers presented above are plotted below in Figure 8.2. Once again, as expected, the relative cost per storage volume reduces as the capacity increases. Although the plotted curves suggests that reinforced earth bunkers are usually less expensive than concrete types, detailed project studies are required to determine the most cost effective and suitable solution.

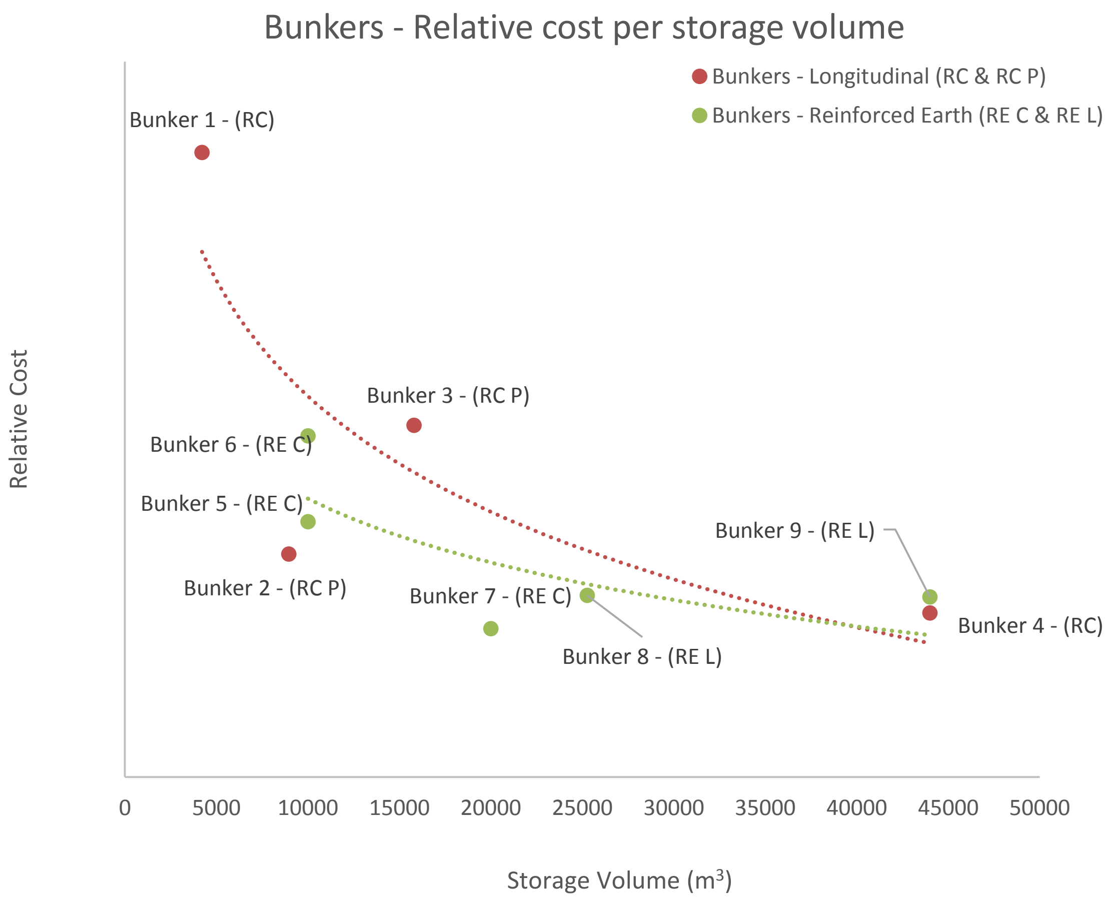


Figure 8.2: Bunkers - relative capital cost per storage volume.[33]

Economical capacity range

The selection of the most cost effective solution type, i.e. silo or bunker, will depend on the required surge capacity. This concept is explained best by the graphical summary from the EMS study[16] conducted in 1975. Refer to Appendix B.

Close correlation was established with work done in 1975 by EMS when comparing the shape of graphs. Graphs produced by EMS were based on consistent cost structures and rates. Costing obtained for this research report was extracted from various sources with some adjustments and corrections made to get all data on a comparative basis. The cost basis of projects are variable which explains why data points are somewhat scattered. The relative costs and hence the shape of the curves are of importance. At low storage capacities, it is not viable to construct bunkers while silos become uneconomical at high capacities. It nevertheless possible to use a number of smaller silos together instead of a large bunker especially where the project only allows for a small footprint area. Graphs presented above in Table 8.1 and Table 8.2 were produced by means fitting the best possible curve through available data points. The economical capacity range of various storage systems can nevertheless be noted. Table 8.23 below provides a selection guideline for the economical capacity range of the different types of storage facilities evaluated. The guideline presented was compiled from analysing past projects and discussions with industry specialists.

Table 8.2: Economical capacity of storage systems.

Surge / storage structure	**Capacity range (m^3)**
Bin (steel or concrete)	Up to 1 000
Silo (concrete)	1 000 to 10 000
Bunker, circular (RE C)	± 2 500 to 15 000
Bunker, longitudinal *(RC) / (RC P) / (RE L)*	> 6 000

Construction

The sliding of concrete form work shuttering makes it possible to construct silos relatively quickly [1]. Although a longer construction time is required for reinforced concrete bunkers, the use of precast elements can speed up the process. The availability of suitable backfill material is a major consideration when constructing a reinforced earth bunker. Earthworks are however more prone to weather related construction delays. While the construction of silos and concrete bunkers can be phased, the configuration of reinforced earth bunkers does not lend itself to a phased approach.

Process criteria

In the coal industry, fines generation of the product must be minimised. Research done in industry[47] shows that the percentage fines generation of feed material is directly proportional to the drop height. Moving head tripper conveyors facilitate a progressive discharge into longitudinal bunkers while minimising material impact and subsequently the generation of fines. Silos are problematic when considering fines generation. The same research[47] suggests that surface bunkers could be operated to minimise fines generation to 1 % while fines generation in silos could easily exceed 5 %. This is a significant figure when considered in terms of revenue loss since coal supply contracts often have penalty clauses which limits the allowable fines content of the product.

Other considerations

The energy required for the feed systems to silos and bunkers are very similar for capacities up to approximately 6 000 m^3 after which silo feed systems become more costly to construct and to operate although the ratio for overall capital cost to storage volume reduces. Bunkers generally require moving head or tripper conveyors which are less reliable and more maintenance intensive when compared to conventional conveyors. Access for maintenance and cleaning of spillage is reasonably good for silos and longitudinal concrete bunkers, but poor for reinforced earth bunkers because of the tunnel construction. Tunnels must be of sufficient width to allow proper access for cleaning operations with skid steer loaders. Reinforced earth bunkers require a significant footprint area which becomes even greater when free draining requirements are adhered to. The potential for differential settlement of bulk fill associated with reinforced earth bunkers must be kept in mind when designing feed systems. Since good alignment of tripper conveyor systems are required to ensure reliable operation simple shuttle systems could instead be used for circular or semi-circular reinforced earth constructions. Reinforced earth bunkers may prove to be an attractive option where suitable bulk backfill material is readily available in close proximity. Additional throw-out capacity can usually be accommodated at the head end of longitudinal bunkers at relatively low expense.

8.3 Conclusion

Guidelines for the trade-off consideration and selection of material storage or surge facilities are provided above. Where relatively small material surge capacity is required, a conventional silo is the preferred choice. It is however possible to construct a number of silos in close proximity to meet a larger volume requirement. Bunkers can usually be justified on projects where large live surge or storage capacity are required. For surge or storage capacities of roughly between 4 000 and 10 000 m^3 the most suitable storage facility can only be determined by a project specific trade-off study. Circular reinforced earth bunkers need to be evaluated for capacities of approximately between 2 500 and 15 000 m^3 depending on project specific requirements and constraints.

A selection guideline based on the evaluation of existing systems, feedback from users at mining operations and specialist design consultants was compiled in table format for future reference. Project specific layouts and considerations are unique. The learnings from this study are nevertheless summarised below in Table 8.3.

Table 8.3: Selection guideline for storage systems.

	Consideration	Silo	Bunker - (RC & RC P)	Bunker - (RE L)	Bunker - (RE C)
1	Economical capacity range, (m3)	1 000 to 8 500	> 6 000	> 6 000	2 500 to 15 000
2	Constructability	Very good	Very good	Acceptable	Acceptable
				Validate availabilty of suitable bulk backfill material. Prone to weather delays.	
3	Settlement & stability	Very good	Very good	Acceptable but poses a potential risk	Acceptable but poses a potential risk
4	Construction duration	Very good	Good	Acceptable	Acceptable
5	Phasing of construction possible	Yes	Yes	No	No
6	Footprint area required	Relatively small	Acceptable	Substantial area required	Substantial area required
7	Fines generation	Very poor	Very good	Very good	Poor
8	Energy for feed systems	Acceptable. Less favourable for high capacity constructions	Acceptable	Acceptable	Acceptable
9	Feed system	Good	Acceptable	Acceptable	Good
10	Operational costs	High	High	High	High
				Bulk backfill works susceptible to erosion.	
11	Cleaning of spillage at loading points	Good	Very good	Poor due to tunnel construction	Poor due to tunnel construction
12	Maintenance access	Good	Very good	Poor due to tunnel construction	Poor due to tunnel construction
13	Environmental considerations	Acceptable	Acceptable	Acceptable	Acceptable

Where:

RC = Reinforced concrete

RC P = Reinforced concrete and pre-cast elements

RE L = Reinforced earth, longitudinal

RE C = Reinforced earth, conical

9 BMH TRANSPORTATION SYSTEMS

9.1 Introduction

This brief chapter is included for completeness of the study since transportation systems usually comprise a significant portion of the BMH scope for typical mining projects. It is however presented from a coal land transportation perspective. It is often required to move a substantial volume of bulk materials a considerable distance from a mining dump station to a beneficiation facility or from the latter to an export facility.

Although various transportation systems are available, the most commonly used includes conventional belt conveyors, rail or road hauling. Numerous trade-off studies have been conducted in the past decades to determine the most viable system for a particular project. While the capital required for any given system is important, previous chapters highlighted the significance of operational expense especially for long term projects. It was pointed out in previous chapters how capital and operational expenditure is generally a trade-off where a cross-over point in the financial model determines where the threshold for capital investment of a system is. The long term cost of fuel and electricity will undoubtedly have a significant influence on operational expense of a system. The appropriate selection of a system is closely related to discussions from Chapter 2 with specific reference to upfront scope definition. The upfront selection of the appropriate transportation technology will undoubtedly have a severe impact towards the efficient use of capital. As already explained, if scope definition is not done correctly, strategy concerning the appropriate specifications is of little benefit. The intent of this chapter is to raise awareness towards the selection of an appropriate transportation system through references and discussion of trade-off studies and research done in recent years. Although projects are unique, the aim is nevertheless to highlight the key parameters which usually drive the selection of a particular system. Proper trade-off studies are required to demonstrate the most appropriate land transportation system. A selection guideline based on detailed studies conducted in recent years is provided at the end of the chapter. It is nevertheless important to remember that project cost structures are not the same. If a detailed transportation trade-off study was conducted in a particular geographical location, the outcome of such a study could be applied with high confidence to a similar project in close proximity. However, extensive validation of cost structures is logically required when compiling costs for what may seem to be a similar project in a different country. Comprehensive research done by Lawrie et al[17] on land transportation of coal is a very useful reference but is based on an Australian context. The Australian labour cost structure is far more expensive than most countries, including South Africa. The project life in years, system capacity and transportation distance are key drivers towards the selection of the most appropriate land transportation system. It would logically make sense to consider building the least possible permanent infrastructure for a short project life requirement.

9.2 Key considerations for most commonly used systems

The discussion below is based on various actual project studies[45] conducted within the coal mining industry over the past decade as well as research done by Lawrie et al.[17]

Belt conveyors

Conventional belt conveyors have been used successfully for many years. If designed and maintained properly, these systems are very reliable. High capacity systems capable of transporting in excess of 15 million tonnes per annum over a 20 km distance are achievable. Operational costs of conventional belt conveyors are extremely low compared to other alternatives. This aspect often becomes a determining factor in the technology selection process especially for long term projects. On the downside, these systems require a significant capital investment and have a long implementation time. Besides the design and construction duration, it is often required to negotiate upfront land purchases from various parties. Licensing and permitting issues may be complex especially when it involves national road crossings or underpasses. Stringent environmental approvals are required particularly when sensitive areas need to be crossed.

Although the ideal overland conveyor is arguably a single flight which is straight and flat, project requirements often demand tight curves to circumnavigate existing infrastructure. Transfer points add significant capital and maintenance costs and must be avoided as far as possible. It is costly to provide electrical power to high capacity drives situated along the conveyor route. Depending on the required conveying lift and length, current conveyor belt technology may not be able to allow a single flight conveyor because of excessive belt tensions.

Although the capacity of overland conveyors can be adapted somewhat by changing the belt speed, ideally the material throughput should be fixed over the life of the project to achieve an optimised design. Although some variation in throughput can be accommodated, it is not possible to adapt to sudden high peak requirements. During the initial years of a long term project, under-utilisation of the system is often a reality during the production ramp up phase which implies a poor return on the capital investment. For certain projects it may be viable to contract haul during the initial years and only construct the conveyor system after a few years. Belt conveyors are nevertheless most suitable for longer term projects where a sound return on investment can be achieved through low operational expense over the life of the system. From numerous studies done for real coal projects in the Mpumalanga region of South Africa, it can be concluded that the overland belt conveying option is usually the most cost effective land transportation method for medium to long term projects where more than 3 million tons need to be moved per year.

Road hauling

Road hauling includes transportation of bulk material with normal road legal trucks as well as special fleets traveling on private roads.

Road legal truck hauling

Road legal truck capacities are usually up to 30 tons. Although contract hauling arrangements provides low capital expenditure options for projects, the operational expense is extremely high and usually not suitable for long term operations unless the capacity requirement is sufficiently low – say below 1 million tons per annum.

As the volume requirement increases, the logistics associated with hauling, loading and unloading becomes challenging to a point where road hauling becomes impractical. Road hauling nevertheless provides very high flexibility since more trucks can be brought in to handle sudden peaks. The throughput capacity is however often governed by traffic congestion at loading and unloading points. The capacity of road hauling systems can be increased up to about 3 million tons per annum with multiple load and dump stations where traffic flow is properly managed. High capacity road hauling places strain on public roads and infrastructure originally designed for a lower load duty. Time in motion studies are recommended high capacity systems to ensure that the desired throughput can be achieved.

Road trains are traditionally associated with private roads. According to Oosthuizens[48] there are street legal road trains available in South Africa with payload capacities of up to 120 ton. The 40 ton trailers are designed such that the axle and wheel loads complies with South African Legislation. Figure 9.1 shows a diagram of this hauling arrangement.

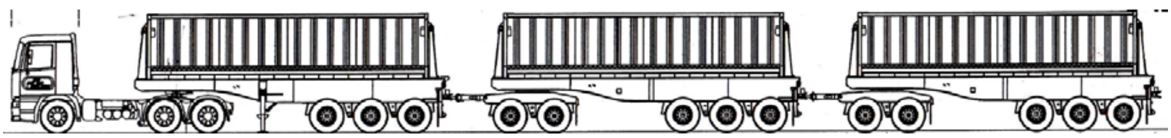


Figure 9.1: Street legal road train – capacity 120 ton.[48]

Road hauling provides maximum flexibility in terms of the loading and delivery locations as well as implementation time. It could be used in conjunction with another system e.g. an overland conveyor to cater for low production tonnage during the initial years or to handle short peaks which are beyond the limitations of the main transportation system.

Road hauling on private roads

Capacities in excess of 10 million tons per annum can be achieved with high capacity road trains. Road trains are special trucks which may have payloads in excess 300 tons. Projects with medium to long term time horizons may benefit from this hauling alternative. A “batching” type of operation require very costly loading and dump stations particularly for high capacity systems. An example of such a system is shown below in Figure 9.2.

Figure 9.2: Road train loading station for high capacity system.[45]

High capacity road train systems require costly upfront infrastructure investment but provide good flexibility in terms of throughput. Road maintenance on private roads adds significantly to the operational expense of this transportation method. Road trains are limited to ascending and descending to inclinations of about 7 degrees. It may be required to purchase land from various owners to ensure a dedicated hauling route. In the interest of safety, normal vehicles are usually not permitted on these dedicated roads.

Although heavy dump trucks typically used in mining operations may be a viable alternative to road hauling options discussed above, studies show that the upfront capital outlay required for the hauling fleet as well as wide, heavy duty roads is usually not cost effective.

External factors such as severe fog in winter times may result in unbearable production losses which could influence the project team's selection. For long term projects, the eventual replacement cost of the trucking fleet may likewise lead to the selection of an alternative.

Rail

Rail studies show that this type of transportation may only be viable for long term projects. It is particularly attractive for high capacity long distance project requirements. There are however instances where short transportation distances may be viable especially where existing rail infrastructure may be utilised. Such opportunities could swing the decision towards rail transportation.

Rail systems have a very long implementation time and is usually extremely costly. Routes are limited to gentle gradients while topographical constraints may increase the traveling distance significantly. Transnet owned and operated systems are very expensive. A study conducted to transport 4 million ton of coal for 21 kilometre for a 50 year project life showed that the operational cost of the Transnet system would be double that of a privately owned system although the capital cost would be drastically lower.

Transportation system selection guideline

Although proper trade-off studies are required to demonstrate the most appropriate land transportation system it is possible to provide a rough selection guideline based on detailed studies conducted in recent years within Anglo American[45] as well as comprehensive research by Lawrie et al.[17] The selection guideline is shown below in Table 9.1.

Table 9.1: Selection guideline for land transportation systems.

Land transportation system	Road truck (30 Ton)	Road train (up to 300 Ton)	Belt conveyor	Rail
Annual throughput capacity (MTA)	< 3	> 2	> 1	> 1
Transportation distance (km)	Any	Project dependent	< 50	Usually long distance
Project life (years)	< 5	> 5	> 5	> 15
Capex	Low (Contract hauling)	High (Special roads)	High	Very high
Opex	Very high	High	Low	Low
Implementation time	Very quick	Long	Long	Very long
Flexibility	Best	Moderate	Poor	Poor

9.3 Alternative transportation systems

Coal slurry transportation pipelines have been used very successfully for many decades. The Black Mesa system[49] in Arizona which delivers about 5 million tons per annum over a distance of 440 km is probably the most renowned. Extensive work was done in the late 1970's by the Office of Technology Assessment in the USA[50] to demonstrate the viability of slurry pumping systems. Considerable volumes of water are required for these systems. In the case of Black Mesa, the water is obtained from wells and ultimately re-used as cooling water at a power plant.

High capacity land transportation of material by means of slurry systems will only be viable in special project conditions. The Minas Rio iron ore projects boasts the world's longest slurry pipeline of 523 km at a capacity in excess of 26 million tons per annum. Unfortunately the construction period and capital originally anticipated for this project was grossly underestimated.

Aerial ropeway systems have been used successfully for decades. It is a transportation system consisting of a series of evenly spaced carriages, each with a relatively small payload that is suspended from a track rope which in turn is strung overhead onto towers. All of these carriages are propelled by a haul rope, in order to transfer material between two fixed locations. Viable systems include long distance transportation up to 38 km at 1 million ton per annum although higher capacities may be achieved[51]. Figure 9.3 below shows the Kuka aerial ropeway system diagrammatically.

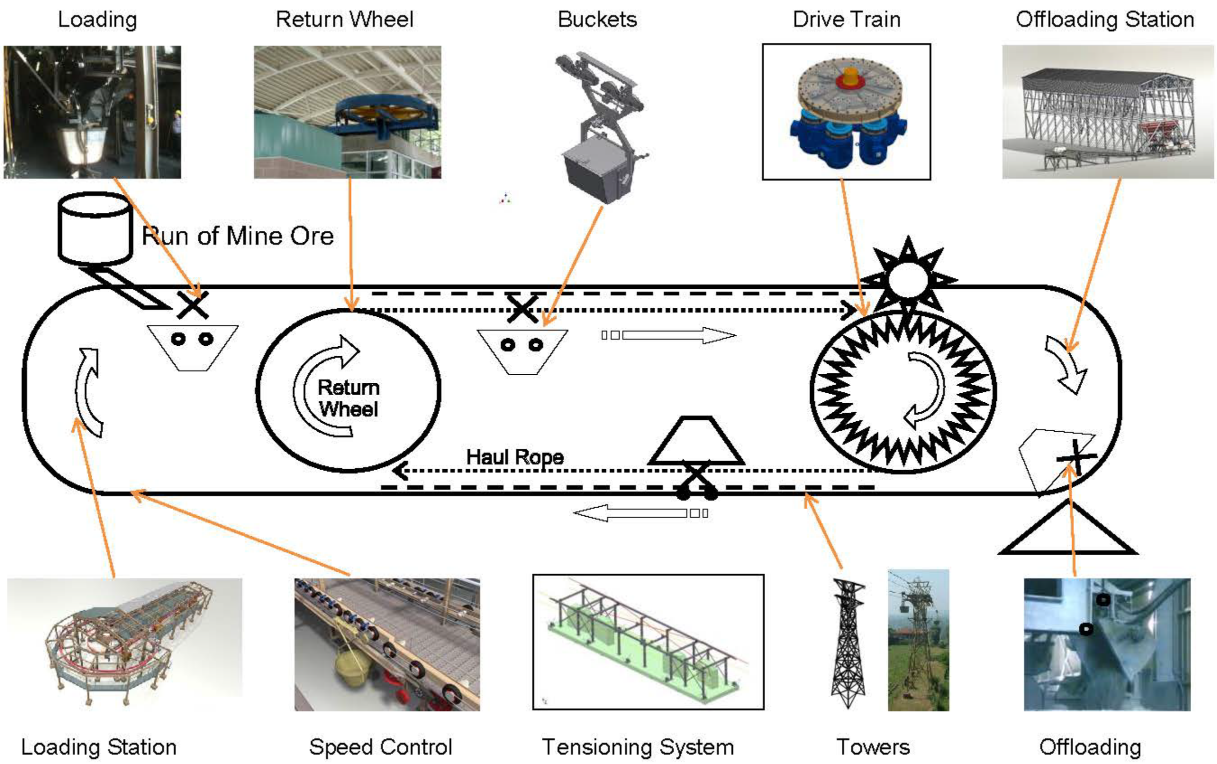


Figure 9.3: Aerial ropeway system.[51]

The above alternative systems may prove to be very attractive for long term projects especially where topographical constraints limits conventional technologies.

9.4 Conclusion

This brief chapter is included for completeness of the study since transportation systems usually comprise a significant portion of the BMH scope for typical mining projects. It is in no way comprehensive but aims to provide a link to early chapters where the importance of correct project scope definition was highlighted. Although reduced operational expense remains desirable, it is of paramount importance for long term high capacity systems where material needs to be transported a considerable distance. The appropriate selection of a land transportation system is of utmost importance and will undoubtedly have a far greater influence on the viability of a project than the selection of the appropriate technical specifications. A guideline selection table with respect to the most commonly used land transportation systems with reference to the South African coal mining industry is provided.

10 CONCLUSION AND RECOMMENDATIONS

10.1 Background

The central question answered by this study is: How can the industry reduce costs on BMH projects in a systematic way while still satisfying the business requirement? The ultimate goal of a business is to make profit. The mining sector has in recent years become less attractive as an investment destination partly due to poor returns as a consequence of over-investment in times of high commodity prices. Although project approvals are invariably subjected to the ability of a project team to demonstrate a viable business case, a culture of being cost sensitive goes a long way towards remaining competitive regardless of prevailing market conditions. The most significant impact towards the reduction or rather the avoidance of capital expenditure can be made during the scope definition phase of the project as demonstrated by the value versus expenditure curve diagram shown in Figure 2.1. Focusing only on specifications to bring about cost reductions when tough market conditions prevail is rather inappropriate. Stringent project specifications indeed attract cost but it would appear as if this is a secondary matter for consideration once a rigorous financial justification for the project has been achieved. The business requirement as referred to in the central question above is inevitably tied in with the project life expectancy whether it be long or short term. A long term project was defined as one exceeding 10 years. Standards and specifications nevertheless have a high potential to impact value on a project. Stringent project specifications may be justified as a long term investment. Whilst over-investment on project specifications is certainly not desired from a business point of view, it must be kept in mind that under-investment could be far worse for a long term project. The costs associated with subsequent upgrades and remedial works will undoubtedly far outweigh the initial cost savings while production pressures, access restrictions etc. may never allow remedial works. For short term projects, the justification for stringent specifications will most likely not be possible. In some instances, the funding models of junior miners require the absolute minimum capital expenditure to obtain a project go-ahead.

Various value improving practices and strategies are available to facilitate cost reductions. The appropriate selection of high value items, systems or technology remains key. Capital expenditure decisions cannot be separated from understanding the ongoing operational expenditure of any system. Significant savings may be achieved by re-using equipment and systems but the associated risks must be understood. The merits of re-using systems, major components or equipment must be evaluated on a case by case basis. Although some South African and international mining company specifications may seem overly conservative, justification therefore can often be found in the recognition that certain special conditions unique to the industry need to be catered for which are not adequately addressed in national standards.

10.2 Project specifications

Selected cost inflating requirements from corporate specifications used in the design of BMH projects were presented. Although specifications used by parastatals and mining companies vary somewhat, very good correlation exists. The documents selected for discussion are therefore deemed representative of industry standards. Some clauses from corporate specifications may be unique to the specific company since they emerged from past incidents or failures which have been incorporated in an attempt to prevent repeats.

Some insights into the project financial model were provided to have a basis from which additional costs due to the compliance with stringent specifications were evaluated. The sensitivity analysis of capital expenditure on the viability of the project ultimately determines to what extent marginally higher costs can be tolerated. Although every project is unique, it is nevertheless worthwhile to note that capital expenditure is only one of many metrics analysed in view of NPV sensitivity. It could nevertheless be a determining factor for some project go-aheads. Variation in product sales price (tied in with the exchange rate for export businesses) and opex costs usually have a greater impact on the NPV of a long term project.

10.3 BMH Expenditure in perspective

A basis for the understanding of trade-off studies and cost analysis was provided. By analysis of the cost breakdown structures of 9 representative projects, each having a total value in excess of ZAR 4bn, it was demonstrated that BMH expenditure in relation to the overall project expenditure was on average below 11 %. This figure is slightly higher when considering the BMH scope as a proportion of the direct cost incurred. For certain brownfields projects however, the cost of BMH systems may occasionally be a higher proportion. For a certain project where the BMH scope totalled 21 % of the total direct cost, it was found that an improvement of between 1 and 2 % could be achieved on the NPV to capex ratio when hypothetically saving 10 % on the BMH expenditure. Capital expenditure and operational expenditure is a trade-off. For long term projects the reduction of opex has a major influence on the viability of the project where short term projects tend to be more capital sensitive.

The effect of project savings achieved through the reduction of the BMH expenditure will contribute somewhat towards the viability of a marginal project whilst having an insignificant effect on the lucrative investment case.

10.4 Stringent specifications in perspective

The compilation of project specifications is tied in closely with the life expectancy and duty requirement of a project as well as the long term business vision of the owners. Stringent project specifications are a worthwhile investment for long term projects and may ensure that significant capital and maintenance expenditure are avoided towards the end of the project life. It would seem logical that engineers developing new projects, under constant pressure of cost reductions, will be inclined towards a short term, capital savings approach. On the contrary, engineers who have battled to get maintenance and remedial work done on 30 year old plants will tend to take a longer term view when it comes to project specification decisions. It is arguably a balance between these opposing methodologies which can bring about the achievement of sound cost-savings on BMH projects. The mere short term avoidance of capital expenditure may result in significant future expenses when the business cannot afford it. Likewise, high upfront expenditure in the wrong areas may prove to be an overinvestment bringing no long term benefits whatsoever. Large mining companies have traditionally only ventured into long term project investments. Project specifications were subsequently developed with a long term view in mind. With declining ore grades the development of many short term projects are now a reality for all mining companies. A mind shift is consequently required to adapt project specifications in line with the life expectancy and duty requirement of the specific project. It must be emphasised that the most significant cost savings will be realised through accurate scope definition. It was demonstrated that stringent project specifications contribute to less than 25 % of the overall BMH expenditure. This could be a considerable amount of money but when viewed in relation to the overall project expenditure it translates into a figure of 3 to 6 % depending on the scope. The significance of these numbers depends on the sensitivity of capital expenditure in the project financial model but will seldom be a determining factor for project go-ahead.

10.5 Re-using plants, systems or equipment

From real case studies analysed it can be concluded that:

- The re-use of plants, systems, equipment or structural steel components associated with BMH systems must be considered on a case by case basis with a thorough understanding of the business need, expected future life, condition of equipment and specific project risks. Detailed trade-off studies which take all hidden costs into consideration are required to make an informed decision.
- The re-use of plants, systems, equipment and structural steel components provides not only opportunities but also risks which must be analysed with caution. A summary of key considerations was provided as a guideline.

10.6 Financial implications of under-investment

It was demonstrated by means of actual case studies how capital reductions made at the time of establishing BMH infrastructure may lead to underinvestment to the extent that the ability of the business to meet its long term goals is compromised. The capital required to remedy the situation at a later stage is usually significant and amounts to multiples of the perceived “initial saving”. This late expenditure combined with loss in revenue due to the inability to deliver the required product will inevitably have a very negative impact on the anticipated return on investment initially estimated. If the initial business case was only marginally positive, the company could possibly be loss making while locked into long term contracts. The inability to meet contractual obligations inevitably impacts on customer relationships and may lead to reputational damage. The potential cancellation of long term contracts and loss of future business could have serious ramifications.

The business interruption associated with major upgrades or modifications could be significant. The loss in revenue due to the inability to achieve the required throughput or produce the required product will probably exceed by far the additional capital requirement.

Retrofit solutions are usually much more expensive than systems engineered properly from the onset. The retrofit solution may deliver a compromised outcome because of a more complex infrastructure layout with restricted maintenance access and more assets to maintain. If major equipment or infrastructure is sized just too small, a complete replacement may be required at huge expense. The equipment or infrastructure originally acquired or established at great expense may be useless or of little value when upgrades are required. The impact of additional operational costs associated with retrofit solutions were not considered in the case studies discussed.

In the long run, underinvestment will probably be far more detrimental to a business than overinvestment.

10.7 Surge and storage system selection

Surge and storage systems are high value items in the BMH scope. The appropriate selection is therefore key within the context of project scope definition. Guidelines for the trade-off consideration and selection of material storage or surge facilities were provided. A selection guideline based on the evaluation of existing systems, feedback from users at mining operations and specialist design consultants was compiled in table format for future reference.

10.8 BMH transportation systems

BMH land transportation systems were briefly discussed for the sake of completeness of the study since transportation systems usually comprise a significant portion of the BMH scope for typical mining projects. Although not comprehensively covered Chapter 9 links up to discussions regarding the importance of correct project scope definition. Reduced operational expense remains desirable, but is of paramount importance for long term high capacity systems where material needs to be transported a considerable distance. The appropriate selection of a land transportation system is of utmost importance and will undoubtedly have a far greater influence on the viability of a project than the selection of the appropriate technical specifications. A guideline selection table (Table 9.1) with respect to the most commonly used land transportation systems was provided.

10.9 Conclusion and recommendations

Project specifications need to be aligned with the business vision and requirements. Project managers need to understand how sensitive the project viability is to capital expenditure so that informed decisions can be made in this regard. This implies a greater reliance on project financial modelling during all study phases of the project.

For long term projects, compliance with stringent specifications will prove to be a good investment over time. It is however clear that short term projects cannot be approached with the same mind-set as long term projects. Specifications needs to be adjusted to meet the business need.

Specifications are ultimately a starting point for designs. It is worth noting the need for discussion and relaxation of specification requirements where the proposed design falls only marginally outside of the stated parameters. This is especially true where significant additional capital expense will be incurred without much real benefit to the owner. Sensible discussion in this regard requires an in-depth understanding of what the purpose behind specified requirements is. Table 5.3 provides a guideline summary for reducing or avoiding capital expenditure.

The effect of having a cost saving culture within a project team is not easily quantifiable but should nevertheless not be underestimated.

The objective of the study was to provide a framework for reducing BMH project costs in a systematic way by considering key cost drivers and potential saving opportunities without compromising the functionality of systems. Figure 10.1 below is a single-diagram summary of the main factors for project teams to consider in order to strike the right balance in meeting the overall business goals when developing BMH projects..

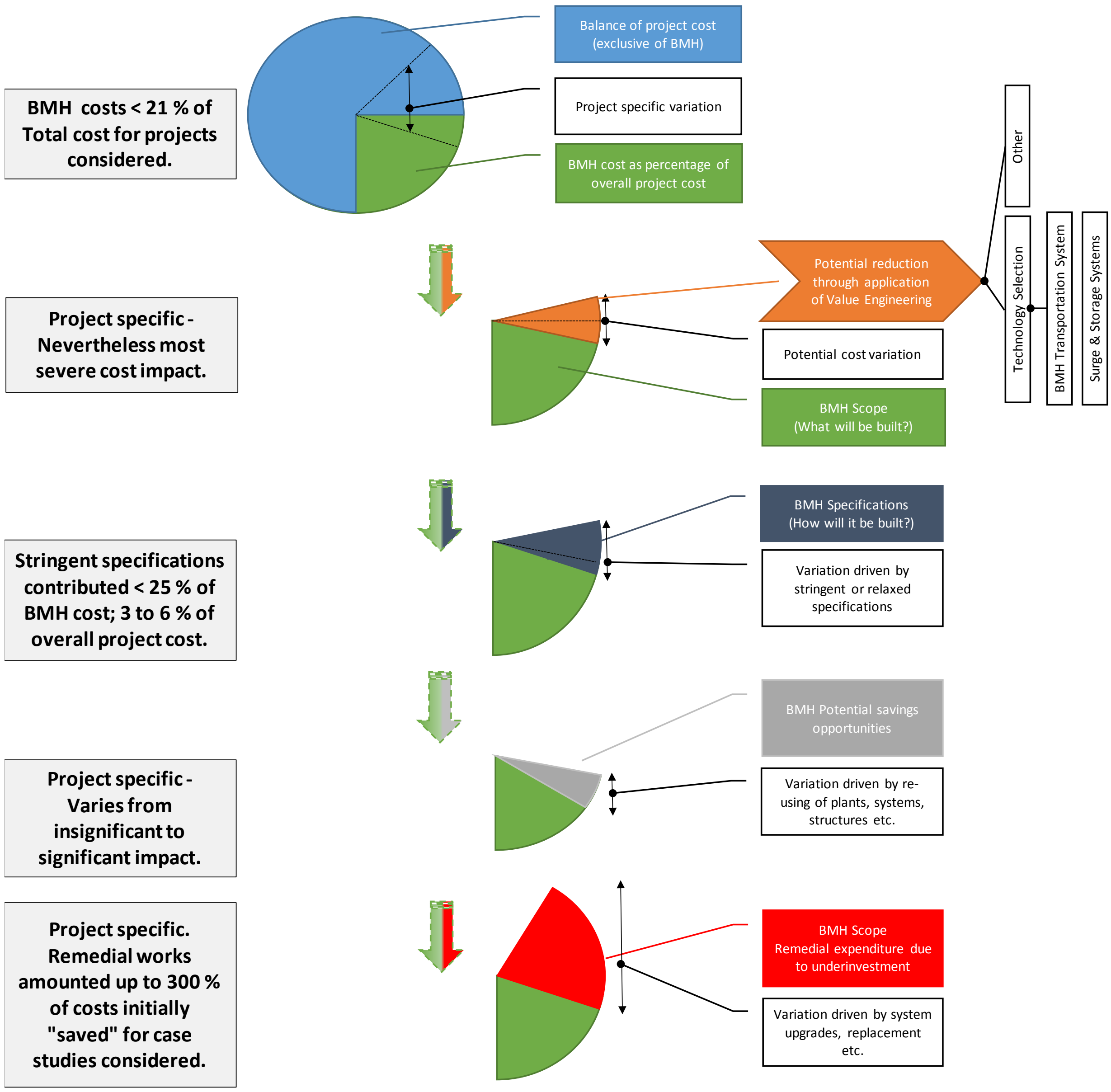


Figure 10.1: BMH cost drivers in perspective – summary of study outcome.

Figure 10.1 above demonstrates that the BMH scope may be a relatively small portion of the overall project. (Based on the projects analysed in this study, less than 21 %). Mining projects are nevertheless unique. The remainder of the diagram aims to demonstrate the extent to which the overall project cost may increase or decrease depending on the BMH scope and the nature of specifications which are imposed. The study showed that the choice of project specifications altered less than 25% of the costs incurred for the BMH scope. The effect of project specifications on the overall project costs was found to be below 6 %. Cost saving opportunities related to the re-use of plants, structures etc. are largely influenced by the availability of existing infrastructure already owned. No definitive rule or guideline can therefore be established. While elements relating to scope, specifications and saving opportunities are focusing on reducing costs, the bottom part of the diagram aims to demonstrate how underinvestment could eventually lead to remedial works if the delivered project is unable to satisfy the business requirement. For a case study considered, the additional costs incurred for remedial works amounted to more than 300 % of the capital expenditure initially avoided.

The most significant impact towards the reduction or rather the avoidance of capital expenditure can nevertheless be made during the scope definition phase of the project which is consistent with the functional thinking concept from Value Engineering. Although stringent project specifications contribute to overall costs, understanding the business requirement remains key. Potential savings opportunities must be carefully evaluated while being cognisant of the potential implications of under-investment. The potential consequences of underinvestment must be considered while developing the BMH project scope.

Figure 10.1 ties preceding chapters together while providing an overall view of aspects having the most profound impact on the costs of sustainable BMH projects. The validity of this model is supported by analysis of real case studies as demonstrated in preceding chapters. The methodology used to derive the framework above is deemed appropriate since it considered and analysed real project and design experiences which are representative of typical BMH projects. Projects are nevertheless unique – figures stated are therefore to be considered as indicative only but nevertheless provide a guideline to project teams.

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12 APPENDIX A

Figure 12.1: Reinforced concrete bunker with pre-cast elements (RC P) [1].

- 8 500 m^3 capacity
- Longitudinal (L)

Figure 12.2: Reinforced concrete bunker (RC) [52].

- 44 000 m^3 capacity
- Longitudinal (L)

Figure 12.3: Reinforced earth bunker (RE L) [52].

- 25 000 m^3 capacity
- Longitudinal (L)

Note footprint size

Figure 12.4: Reinforced earth bunker - internal view (RE L) [52].

- 25 000 m^3 capacity
- Longitudinal (L)

Figure 12.5: Reinforced earth bunker during construction (RE).[53]

- 2 x 10 000 m^3 capacity
- Conical (C)

Figure 12.6: Concrete silos. [1]

- 2 x 8500 m^3 capacity
- Common incline feed conveyor with horizontal cross conveyor

13 APPENDIX B