A method to assess the likelihood and magnitude of initial capital expenditure overruns of future gold mining projects using retrospective data analysis

By

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Abstract

In the mining industry the initial capital expenditure budgeted in the feasibility study is being overrun structurally. These capital expenditure overruns have long been recognised, yet no method is available predicting the probability a mining project will experience an overrun.

This thesis introduces a method to assess the likelihood and magnitude of an initial capital expenditure overrun occurring for future gold mining projects. A database is populated with 65 gold mining projects that have experienced an overrun. For each project, 19 variables are described in the database that define the projects. The variables are analysed using individual variable analysis and multivariate regression analysis to investigate whether a correlation can be found between the variables and the initial capital expenditure overrun. Using the results of the individual variable analysis, a tool is developed to semi-quantify the risk a future gold mining project is exposed to regarding an initial capital expenditure overrun. The tool can visualise the risk a project is exposed to in a 2D risk matrix displaying the likelihood and magnitude of a possible overrun.

For 16 of the 19 variables a possible correlation is found. The variables are grouped together, representing root causes with regards to the initial capital expenditure overrun. The database analysis suggests that relatively small gold mining projects experience a larger capital expenditure overrun than large gold mining projects. In addition, projects owned by relatively large companies tend to experience a larger capital expenditure overrun. Furthermore, projects where a low number of payback years or a high internal rate of return presented in the bankable feasibility study indicate a profitable project tend to experience a smaller capital expenditure overrun. Finally, the database suggests a correlation between the relative gold price and the capital expenditure overrun. Projects from which the bankable feasibility study was published when the gold price was relatively high, tend to experience initial capital expenditure overruns more frequent and with a larger magnitude. Using the correlations resulting from the database analysis, a predictive tool is successfully developed for which future gold mining projects can be assessed on initial capital expenditure overrun risk.

CONTENTS

1 INTRODUCTION

1.1 CAPITAL EXPENDITURE OVERRUNS IN THE MINING INDUSTRY

The mining industry is one of the only industries where large initial capital expenditure (capex) overruns are not considered an exception, but a structural problem (Kuvshinikov, et al., 2017). Newly developed mining projects often struggle to finish within budget, and just as often exceed the budget vastly (Ernest & Young, 2015). This phenomenon generally is justified by the extensive and complex infrastructural developments required for developing a mine, combined with the uncertainty of the subsoil conditions and the grade and dimensions of the ore body. Additionally, the mining industry traditionally is a sector where large capital investments generally are required prior to the start of production. Due to the complex and comprehensive development prior to production, the initial expenditures are large before any revenue is being created (Gordon & Tilton, 2008). This results in the capex overrun not only to be considered large from a proportional perspective, but in absolute terms as well. Mineral consumption in general is increasing rapidly as more consumers enter the market for minerals and as the global standard of living increases. As the relatively easy mineable deposits are reaching the end of exploitation, miners are being driven to new geographies, accessing more complex orebodies at greater depths (Pathegama G. Ranjith, 2017) (Buchanan, 2016). This results in a combination of increasing risk and costs. Due to the increase in remoteness and depth of the orebodies, the initial capital expenditure is rising as well. In addition to the increasing risk and costs for starting a mining project, the average life of mine has declined significantly over the last decade. The average life of a producing gold mine today is only 12 years, compared to 19 years in 2009 (Letwin, 2017). Overall, the increase in capital expenditure required to start a mining project, combined with the decreasing life of mine of gold mining projects, result in the impact of an initial capex overrun is growing from a relative perspective. There is less time to recover from unexpected additional cost made in the initial phase.

Export Development Canada (EDC) performed an analysis on 12 projects to understand the root causes behind capex overruns in 2012. Possible correlations between root causes and capex overruns were found, and the analysis was followed up by a larger study assessing 78 mining projects (Lwin & Lazo, 2016). The study showed an average capex overrun of 37% with most significant overruns registered in mining projects started from 2005 – 2011. An investment bank review of sixteen mining projects carried out in the 1990s showed an average capital cost overrun of 25%, attributed to overly optimistic feasibility studies and poor cost estimation, particularly related to financial fees, interest charges, insurance, legal and consulting fees (McCarthy, 2003). A study performed by Resource Capital Funds (RCF) indicates roughly half of the 63 analysed projects fall outside of the expected ± 15% of the feasibility study capital cost estimate, even after allowing for intentional estimation bias. In this study cost overruns of 100% or more happen in roughly 1 out of 13 projects (Bertisen & Davis, 2007). The data used in these studies are either obtained from the public domain, or obtained for data collection services as SNL Metals and Mining or AME Group. While study information is in the public domain and data collection services, crucial data on true project development costs and their variance from feasibility study estimates are not collected. This means there is no real reference for forecasting (Harris, 2017). According to the prior performed studies and the current condition of the gold market, the gold mine of the future is likely to cost more, have a shorter mine life, while the capex overrun is steadily increasing.

1.2 PROPOSED METHOD TO SEMI-QUANTIFY RISK USING RETROSPECTIVE DATA ANALYSIS

Mining projects can be called unsuccessful for several reasons. This research focusses on projects that fail to deliver on their initially estimated capital expenditures. For this reason, a project is to be categorized as 'over budget' when it exceeds the capital budget that was originally estimated to be needed in the bankable feasibility study. The overrun on the initial capital expenditure estimate is called the initial capex overrun (ICO). The initial capex is relatively well documented in feasibility studies and annual reports. This facilitates the process of data gathering. Furthermore, the initial capital cost generally is documented in United States Dollars (USD), which makes is easy to compare projects to each other without currency conversion.

To determine which projects meet the conditions of having experienced a capex overrun and therefore are qualified 'over budget', a ratio is defined. The ratio between the actual capex spent when commercial production starts, and the capex estimate published in the Bankable Feasibility Study (BFS) is called the Capex Performance (CP). A project is defined to have experienced an ICO when the CP > 1. The SME Mining Engineering Handbook (Darling, 2011) states that by the end of the BFS, the probable error of cost estimates should be 10% to 15% of the total cost estimate. For the purposes of this research, a mining project is considered to have experienced a significant initial capex overrun, and therefore is suited for database population when:

$$\frac{Actual\ initial\ capex}{BFS\ initial\ capex\ estimate} = Capex\ Performance\ (CP)$$

$$\begin{aligned} CP &= overrun & when\quad & CP \geq 1.15 \\ CP &= within\ estimate & when\quad & 0.85 < CP < 1.15 \\ CP &= underrun & when\quad & CP \leq 0.85 \end{aligned} \tag{1}$$

The strategy is to compile a database containing a significant amount of gold mining projects having experienced an initial capex overrun. Of each gold mining project specific variables regarding the project are being documented in the database (e.g. mining method, project location), along with the capex performance. These variables are to be analysed to identify any possible correlation between certain variables of a gold mining project and the capex performance. When a correlation is found, these variables could influence the possible performance of a mining project with regards to capex performance. The results of these variables are to be used as the foundation for a predictive tool with regards to the capex performance. The tool is to give a semi-quantitative risk assessment of a future gold mining project predicting the likelihood a gold mining project is to experience an initial capex overrun, and the corresponding magnitude of the capex overrun.

1.3 Research goal and objectives

Goal:

Assess the semi-quantitative risk exposure on initial capex overrun of future gold mining projects using retrospective data analysis of former mining projects.

Hypothesis:

1. There are direct correlations between specific variables of a project and the capex performance of former gold mining projects.

2. It is possible to assess the risk exposure of future mining projects on capex overrun using a predictive method based on retrospective data analysis of former mining projects.

Objective 1 – Development of a database

A database will be developed containing gold mining projects that have experienced a capex overrun. For each project several technical, economical and geographical variables are to be input in the database, along with the capex performance of the project. This objective is achieved following the following steps:

1.1. Define the selection of variables which gold mining projects can be compared to each other.

1.2. Populate the database using gold mining projects. Multiple sources will be exploited to ensure a database of significant size.

Objective 2 – Analysis of the database

The developed database will be analyzed using individual variable analysis with regard to the capex performance. A multivariate regression analysis is performed investigating any possible inter-variable correlations. The individual variable analysis will be used to develop a semi-quantitative risk assessment tool where future gold mining projects can be assessed on risk exposure regarding the likelihood and magnitude of experiencing an initial capex overrun. The output of the risk assessment can be visualized in the form of a 2D risk heat map. This objective will be achieved following the following steps:

2.1. Analyse the data from 'over budget' mining projects to find possible correlations between the variables and the initial capex overrun.

2.2. Design of a model in where the multiple correlations are combined to one risk assessment tool.

2.3. Demonstrate the functionality of the model using data from a fictional mine.

1.4 Scope

The scope of the research is defined following some general assumptions and boundary conditions:

- Mines located in Russia, China are not included in this research. These countries have a significantly different working method and documentation process (Wubbeke, 2013). This results in a different approach in developing a mining project and therefore can be compared difficultly. Furthermore, documentation regarding mining projects in these countries rarely is publicly available.
- To have a certain level of industrial homogeneity across the database, projects to be included in the database have the final bankable feasibility study of the mining project published not later than 1985. The main commodity of the mine is gold, and their minimum actual initial capex spent is 5 million USD.
- The scope of this thesis is to eliminate subjectivity and to compare projects based on an objective analysis. To ensure an objective analysis, projects are defined using 19 variables.

	In scope	Out of scope
Analysis	• Definition of projects using 19 variables • Data analysis using pie charts, bar charts and scatterplots • Multivariate regression analysis using SPSS • Semi-quantitative risk assessment model	• Root cause analysis of each individual project • Multicollinearity in the database
Geographical	• All countries except Russia, China and Antarctica	• Russia, China and Antarctica • Remoteness of the mine site
Financial	• Cash flow analysis presented in feasibility studies • Financial structure of the mine owning company • Project financing • Gold price	• Economical condition of the country • Inflation of the local currency
Technical	• Mining method • Processing method and capacity	• Rock mechanical properties • Mine equipment
Commodity	• Gold as main commodity	• All other commodities

Figure 1: Scope of the thesis highlighted per subject.

1.5 STRUCTURE OF THE DOCUMENT

Introduction	A general introduction to the thesis subject and the problem definition. It is explained why the research is relevant, especially in the current market conditions. This chapter states the goal, hypothesis, objectives and scope of the thesis.
History of capex overruns	A brief introduction to the several stages of the feasibility study process is presented in this chapter. The definition of capital expenditure (capex) is explained. A project that has experienced an ICO is presented to introduce several variables that might have an influence on ICO.
Methodology	The variables that are investigated with regards to capex overrun are explained in this chapter, breaking them down into technical- financial- and geographical factors. The variables are placed within a relative timeframe of the feasibility study process. Boundaries are set to define the variables. The data acquisition process is subsequently explained in this chapter, including the priority in which data is handled to populate the database.
Database analysis	The gold mining projects used to populate the database are analyzed. The results of the analyses are visualized in the form of pie charts, bar charts and scatterplots. An interpretation of the results is conducted with a review to relevant literature. It is discussed whether a variable is to be used for predictive purposes in the risk assessment model. Finally, the variables are categorized in root cause categories a synopsis.
Risk assessment model	This chapter focuses on the development of the predictive risk assessment tool and demonstrates how to use it. A fictional gold mining project is used to demonstrate the use of the model, the project is placed in a 2D risk matrix.
Discussion	The data acquisition, database analysis and the risk assessment model are discussed. The difficulties and the shortcomings of the data gathering is highlighted, together with the interpreted shortcomings of the mining industry regarding documentation.
Conclusion & recommendations	The conclusions and recommendations of the thesis are presented. The recommendations highlight points of interest for any potential follow up research.
Appendix	A. The origin and use of personal communication is explained B. All the gold projects used for data analysis and the associated variables are documented in the appendix.

2 History of CAPEX Overruns

2.1 From Resource to Mine

The journey from the discovery of a resource to a potential mining project is typically long (6 years and 1.5 months on average (Darling, 2011)), and are a result of an extensive feasibility study process. This feasibility study process consists out of multiple phases, step by step increasing the understanding of the mineral deposit (see figure 2). The goal of this multiphase feasibility study process is to assess the value of the property to the company and to determine to either exploit the deposit, sell it or to hold on to it for technological or market reasons. The feasibility study process deals with uncertainty, and a phased and iterative study approach has evolved as a consequence. It is common practice for the feasibility study process to involve three phases, namely the conceptual or scoping phase, the preliminary or prefeasibility phase, and the final or definitive phase (Mackenzie & Cusworth, 2007).

During each phase, several licenses, permits and approvals are necessary for testing and exploration purposes. When the project progresses in time, the knowledge about the size, depth and the characteristics of the deposit increase. Due to this increase, the size of the documented resources and eventually reserves increase. Figure 2 shows the different phases a mining project undergoes with the associated licenses and the resource/reserve indication according to the JORC code.

Typically, initial assessments of the development potential of a resource project are aimed at assessing the project's key technical and economic characteristics, with subsequent assessments designed to confirm assumptions and reduce the uncertainty associated with the development to an acceptable level. Resolution of technical issues is often seen as the primary focus of a feasibility study, whereas in reality, these technical issues are the basis upon which a business plan is built. Besides these technical challenges a project can face, a mining project can be exposed to a variety of other factors (e.g. political, geographical, financial) used to define the reserve and therefore might have a significant impact on the project's outcome. These potential factors are discussed later in this chapter. This is not to say that technical issues are unimportant – they are a prerequisite to the demonstration of a project's viability (Mackenzie & Cusworth, 2007).

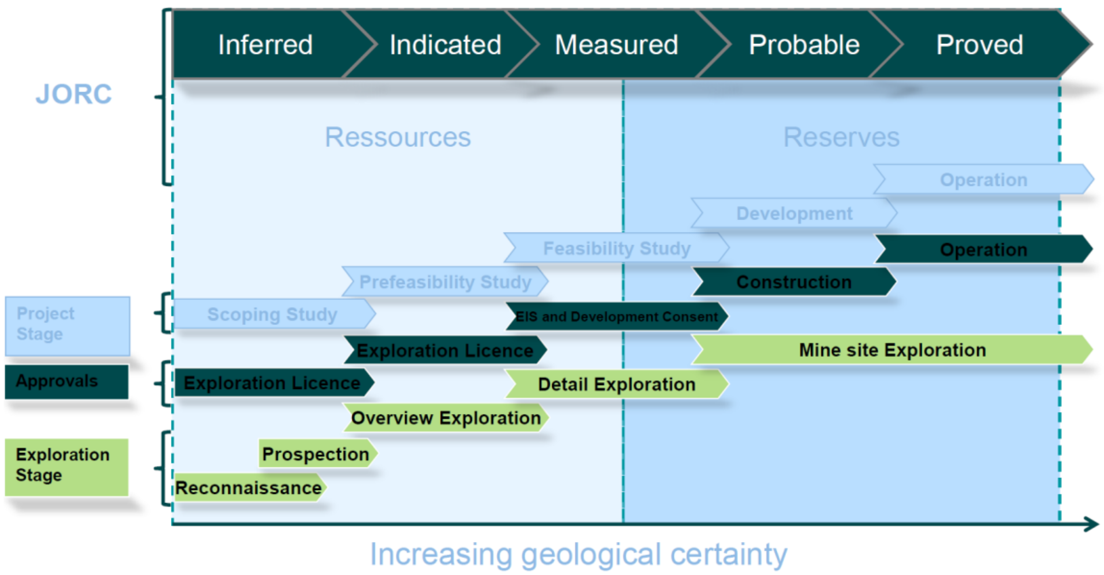


Figure 2: The phases of a mining project. Displayed are the level of depth of exploration and the necessary approvals needed for each project stage. Furthermore, the level of accuracy in the resource classification is indicated for each project stage according to the JORC code (Vergne, 2008).

2.1.1 PRINCIPLES OF THE FEASIBILITY STUDY

Unfortunately, there are no international standards regarding the layout and the content of a feasibility study. However, there are certain guidelines that are accepted in the mining industry. The following definitions of the three phases of a feasibility study process are generally accepted by the mining industry (Rumbu, 2017):

Scoping Study - carried out early in the project life, with relatively limited information. It is frequently used to assess the potential of the project, and as a basis for deciding whether to invest time and money in further development.

Pre-Feasibility Study (PFS) - undertaken at intermediate level, when data on almost every aspect of the project has been generated. The data needs to be in sufficient depth to support realistic estimates of technical performance, capital cost, staffing requirements, operating cost, product value and marketability, project profitability, environmental and social impact, and project risks. It provides a basis for whether or not to commit to the large expenditure and effort involved in a subsequent Final Feasibility Study (FFS). The PFS often lays the foundation for project success or failure, and should perhaps be regarded as the key step in the whole development program, rather than the FFS. Unfortunately, it is not uncommon to see “cut price” pre-feasibility studies leading to costly disasters later on. The PFS is the time to fix the process flow sheet and conceptual plant design to provide a firm foundation for the FFS.

Final (FFS), or **Bankable (BFS) Feasibility Study**– this is the final study prior to a project potentially is approved for development. It involves the finalization of every element of the project. It should be confirmatory in nature, based on the flow sheet fixed during the PFS. Whether there is any difference between a Final Feasibility Study and a Bankable Feasibility Study is a debatable point. However, one can say that a bankable study is generally subjected to a full independent audit (the bank), while a FFS may or may not if the project is to be funded in-house. Preparing for a full independent audit may affect the amount of detail presented in the study, and possibly the degree to which various risks have been addressed. For the purpose of this research, the third phase shall be referred to as BFS.

Typical accuracies specified for the various study levels are (Taylor, 2016):

- Scoping Study: Capex +/- 25-30%
- Pre-Feasibility Study: Capex +/- 20-25%
- Final Feasibility Study: Capex +/- 10-15%

For the purpose of this research, the moment of publishing the bankable feasibility study of a project is a critical moment. Several variables, to be introduced later in this chapter, are dependant of this moment. This moment is to be considered as a milestone for each project and its stakeholders. Before construction commences, this is the last document publishing all relevant data regarding the development of the mining project.

2.1.2 VALUE CREATION IN A MINING PROJECT

Regardless of the outcome of the scoping study, the PFS or the BFS, each phase creates value for the project when successfully executed. For example, a good and competent PFS that concludes it is not interesting to enter the next feasibility study phase creates value, as it defines the project and saves the owner any further potential losses. A key feature of the feasibility study process is the timing when the largest impact on the outcome of the project can made. The ability of an owner to influence the outcome of a project is at its peak when the feasibility study process is defining what the project should and will be. Excellence in project execution is required just to maintain the value opportunity created from a good feasibility study, and excellence in project operation is required to deliver the value. A poorly defined project will not deliver the same outcome as a well-defined project no matter how well executed and operated (figure 4) (Mackenzie & Cusworth, 2007).

During the pre-feasibility study process, alternative project configurations can be studied and decisions made on whether or not to proceed with project development, and if so, what the optimum configuration is. However, once a decision to proceed is made, and design, procurement and construction efforts commence, there is little opportunity to influence the project outcome. These characteristics of the project development cycle is illustrated in Figure 3.

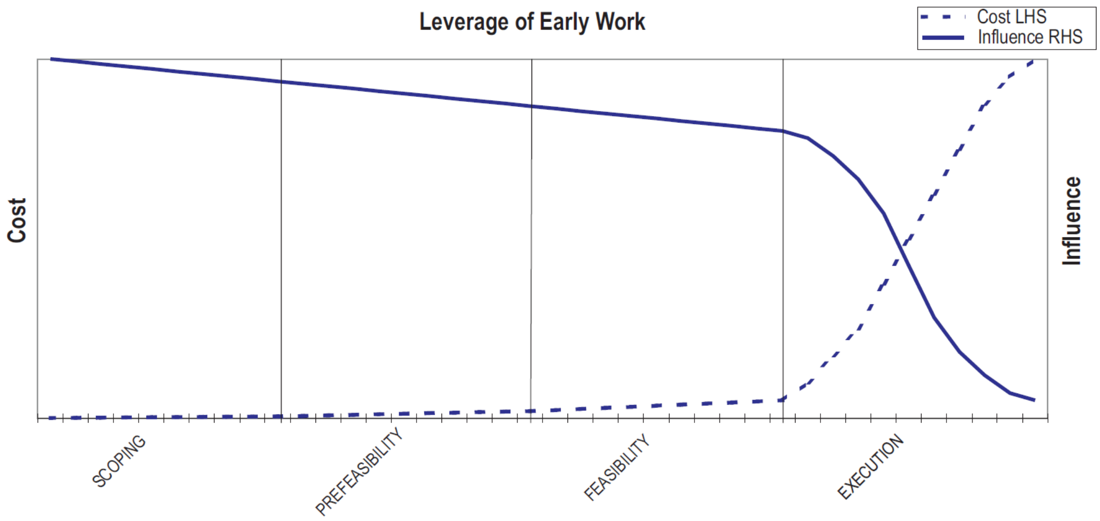


Figure 3: Illustrating influence of decisions and the cost of these decisions, relative to the phase the mining project is in (Mackenzie & Cusworth, 2007).

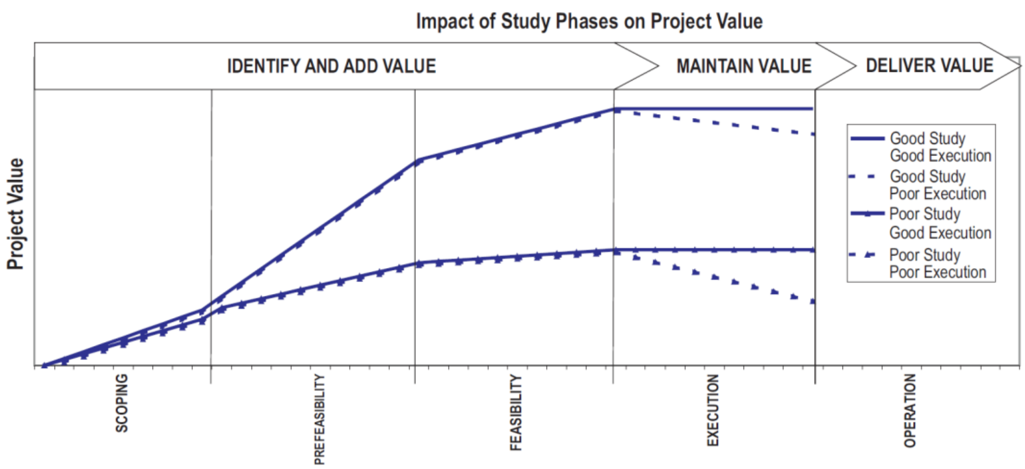


Figure 4: Four different paths a mining project could follow. It can be seen that the initial phase of a mining project is essential and should be used extensively to maximize the value of a project. (Mackenzie & Cusworth, 2007).

2.2 Initial capital expenditure overrun

Mining projects can be called an unsuccessful for several reasons. This research focusses on projects that fail to deliver on their initially estimated capital expenditures. For this reason, a project is to be categorized as 'over budget' when it has experienced a capex overrun of more than 15% of the initial budget. Other causes that could classify a mining projects as unsuccessful (e.g. ramp up time delay, environmental damage, production underperformance) are considered out of scope. It should be noted though, that these other factors can contribute to a capex overrun.

Capital cost overruns are a part of the mining industry, and always have been. A study conducted by McKinsey & Company from 2017 states more than four out of five mining projects come in late and over budget, by an average of 43 percent (Kuvshinikov, et al., 2017). A 2015 report from EY looking at a total of 108 mining and metal 'megaprojects' (costing more than $1B) in showed the majority of projects were running over the initial budget and schedule (Ernest & Young, 2015). Some 69% of the projects were facing cost overruns and half of the projects were reporting schedule delays even after actions to speed up the process were applied (Gleeson, 2017). Other than the study performed by McKinsey and EY, other studies have been conducted focussing on capex overruns over time, from 1964 - 2017. All studies document a significant portion of the mining projects experience a capex overrun. The most worrying aspect of the studies is that there does not seem to be any improvement in reducing the capex overruns over time, worse still they seem to increase.

Capital costs in mines can be split into start-up (initial) and stay-in-business (working) capital costs. Start-up costs focus mainly on accessing the ore body, infrastructure (mining and beneficiation), equipment, environmental compliance, and licensing costs. For underground mines, accessing the ore body involves sinking shafts or adits, whereas for surface mines it involves the development of boxcuts and removal of initial overburden. Capital expenditure requirements can be very diversified. According to the SME Mining Engineering Handbook (Darling, 2011), the industry's requirements for capital spending vary with the location and nature of each mineral deposit. In addition to construction of the mine itself and of the associated processing plant necessary to produce a marketable product, usually an associated infrastructure is needed. Infrastructure covered by start-up capital includes water and electricity connections, offices, workshops, change houses, roads, and employee accommodation. In some instances, small towns and off-mine infrastructure such as rail, roads, and ports need to be developed to accommodate employees and for transportation (Mohutsiwa & Musingwini, 2015). Initial capital expenditure likely will be smaller when the mine is situated near an established town or an existing mining district, with existing supplies of water and power and established transport links, than when located in virgin territory. Even in the former instance, existing facilities will probably need supplementing and upgrading (Darling, 2011). The start-up capital expenditure is normally undertaken as quickly as is practically possible in order to move the project into production so that revenues can be generated (Mohutsiwa & Musingwini, 2015). From a financial reporting point of view, it is essential to create revenue as soon as possible. Feasibility studies almost always include a chapter reporting the discounted cash flow in combination with financial indicators as the net present value (NPV) and the internal rate of return (IRR) (see chapter **Error! Reference source not found.**). To generate good result for these financial indicators, one needs an incoming cash flow relatively fast.

Definitions Regarding Capex

As discussed in chapter 3.5.1, the inconsistency in how projects define capex is to be called troublesome. It is a recurring issue, making it difficult to compare projects from an investors' perspective. For this reason, a general structure is used to define what should be considered capital expenditure. It should be noted that for projects to be added to the database of this research, their capex construction should be similar to this structure. The capex structure list is constructed combining a structure of Runge Pincock Minarco (RPM) (Swendseid, 2015) together with definitions acquired from personal experience. RPM is the world's largest publicity listed independent group of mining technical experts. The company states to have expertise in all mining regions and are experienced across all commodities and mining methods.

Contingency	An amount estimated in a project budget to cover known unknowns. It includes items whose quantities are not estimated since they are not significant, not possible, or not suitable for the intended accuracy of the estimate.
Capital Cost	A cost classification that is depreciated over time. Certain jurisdictions have rules for what costs can or must be capitalized. Capital Costs generally include costs to attain certain level of production (i.e. at certain phases of ramp-up).
Capitalized Revenue	Revenue generated, typically during ramp-up or capitalization period, that offsets capital cost. Capitalized Revenue is very price and production sensitive.
Direct costs	Costs including the following: • Mining equipment • Construction material • Construction equipment • Construction labour • Freight on equipment
Indirect costs	Costs including the following:

- Engineering
- Procurement
- Customs fees
- Security during construction
- Construction management
- Project control
- Construction camp services
- Construction management temporary office facilities
- Temporary utilities (power, water, waste removal)
- Mobilization and demobilization
- Project accounting
- Pre-commissioning labour and materials (for items not included in Owner's cost)
- Government charges
- Vendor assistance and commissioning
- Commissioning spares

Owner's cost

Capital costs including the following up to the point at which these costs become operating expenses (for instance upon mechanical completion or upon 60% of nameplate capacity being achieved—timing is at the discretion of the owner):

- Owners team to monitor a construction project
- Administration costs not directly interfacing with project construction
- Pre-production mining development costs, including the cost to develop the mine to a certain point and additional development if time allows
- Health and safety costs
- Mine equipment costs
- Pre-commissioning labour and materials (for items not included in Indirect Construction costs)
- Environmental evaluations
- Legal costs
- Travel costs
- Permitting costs
- Land acquisition costs
- Operator training costs
- Community and public relation costs
- Power, water and fuel supply systems if not included in Direct and Indirect costs

2.3 Boleo Cu-Co-Zn-Mn project

Projects that experience a capex overrun generally are in that situation to a combination of unique circumstances. To get a better understanding of how an individual project can go through the development process with a cost overrun as a result, an example is analysed in this chapter. Subsequently, the root causes of the cost overrun of this project are identified, laying the foundation for the variables to be used in this research. While the scope of this research is limited to gold mining projects, the project that is analyzed in this chapter is a polymetallic mine. The reason why this specific project is used is the availability of data in all stages of the mining project. An article from the Canadian Metallurgy Quarterly (Dreisinger et al, 2008) is used combined with the detailed analysis of the Boleo project provided by the ING Bank.

The Boleo project is an advanced stage copper / cobalt / zinc / manganese development located in Baja California Sur, Mexico. Originally, the project is designed as a joint venture between Canada's Baja Mining and Korean Consortium (KORES). The deal was honored with *Mining Journal*'s 2010 "Exploration and Development Funding Award" and as *Project Finance*'s 2010 "Latin America Mining Deal of the Year. Discovered in the late 1800s, the property consists of 25 mineral concessions, covering 20,490.9 ha, of which 24 are contiguous (Dreisinger, 2008). Even though the property was staked by Baja Mining in 1992, since recently, KORES took the lead to fund and operate this mine. The project is currently in the course of ramp-up phase. The Boleo project reached its first copper production in January 26^{th} of 2015. The key data of the project can be found in Table 1.

Highlight	Unit	Feasibility (2010)
Mine Life	Years	25
Throughput	Kt/p.a.	55.75
Reserves	Mt	85
Resources	Mt	264.6
Diluted Cu Grade	%	1.5%
Production	Tpa	55,750
Cash Cost	USD / lb Cu	-0.29
Capex	USD mln	$889
NPV at 8% discount	USD mln	$1,306
Payback Period	Years	3.3

Table 1: Key data of the Boleo Mining Project (provided by the ING Bank, 2017)

Deposit - geology

The deposits are sediment hosted and occur within seven strati form, clay-rich horizons or beds, which have undergone step like faulting. The mineralized beds dip gently to the east due to faulting, which is common throughout the project area. Dominant ore composition includes copper and cobalt sulphides (60%) as well as oxides (40%). Zinc and Manganese are also present.

Mining method

The project is a combined underground and surface mining operation providing ore to a hydrometallurgical facility. Underground mining method includes short wall and room and pillar, using continuous miners, which is unconventional for the rock type.

Processing

Proposed processing consists of crushing and milling and leaching. The complex ore requires both oxidative and reductive leaching to ensure recoveries of both oxide and sulphide ores. The leached metals are concentrated in four separate solvent extraction units to produce copper and cobalt cathode, and granular zinc sulphate. High by-product recovery provides very low cash costs.

Construction

Construction was expected to take 2.5 years, funding in 2010, with first production in Q2 2012, with a 1-year ramp-up period.

Loan and debt sizing- key structure

The Boleo project is a joint venture between Canada's Baja Mining and Korean Consortium (KORES). Lenders provided an $823m prefeasibility facility for construction and development. The debt was largely provided by development banks, (EXIM, EDC, KDB) with a $100m portion provided by commercial lenders. The original facility also included a $35m equity sustaining capex facility, provided by Louis Dreyfus (primary off taker). All involved parties are noted in Table 2. Without access to any models or prefeasibility terms, cash flows suggested in the feasibility study (based on $2.91/lb Cu, $28/lb Co) a debt-service-coverage-ratio on a four-year repayment schedule around 1.5x (Figure 5). This was likely boosted by the 50% hedging requirement over the first three years.

Construction cost overrun

Initial equity contribution of approximately $480m, contributed by sponsors as well as a $185 equity raise.

Security

Security details are undisclosed, but what is clear is that security was not enforced and a workout involving equity contribution was reached, whereby KORES took out project finance debt and funded cost overruns, obtaining final ownership of 90%.

Party	
Lenders	Development Banks: Export-Import Bank United States (EXIM), Export Development Canada (EDC), Korea Development Bank (KDB) Commercial Lenders: Barclays, Standard Bank, Standard Charter, Unicredit, West LB
Technical Agent	EDC
Reserve Estimate	Agapito Associates
Metallurgical	Various
Lawyers (bank)	Sullivan & Cromwell

Table 2: The parties involved in the Boleo Project (provided by the ING Bank, 2017)

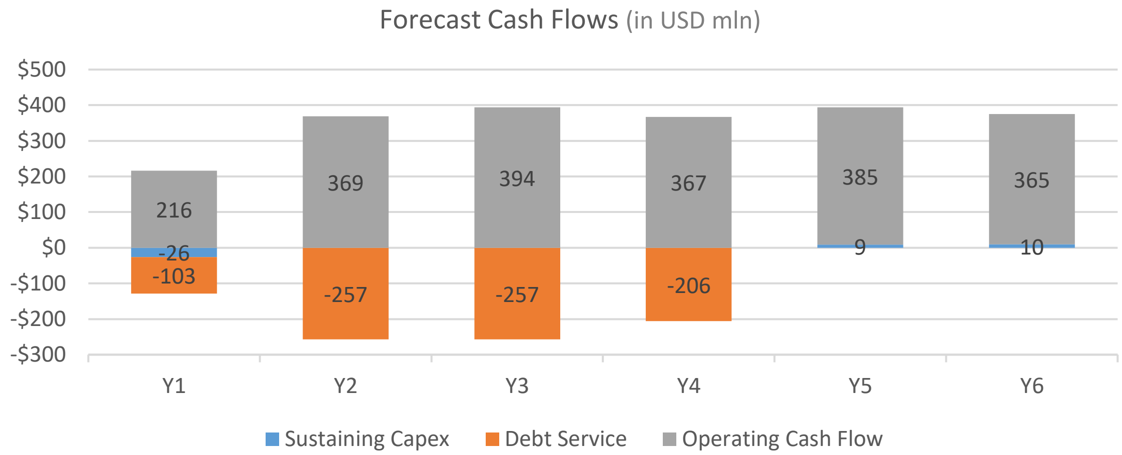


Figure 5: Forecast of the cash flow in the initial phase of the Boleo Project, estimated in the bankable feasibility study (provided by the ING Bank, 2017)

Cost overruns

The initial capex estimate was set at $1.3bn. The final (2014) construction cost is estimated at $1.878bn, accounting to a 44% cost overrun on the original capex projections. Much of the overrun is due to complications and design errors, specifically in the processing plant. KORES has directly funded or guaranteed all outstanding debt raised for additional capex, while obtaining 90% of the ownership of the Boleo Project (Figure 6). At that time, the project was experiencing continual delay on the timeline to achieve operational status. A press release by (10% owner) Baja Mining indicates that the mine expected a $300m cash short fall for 2016.

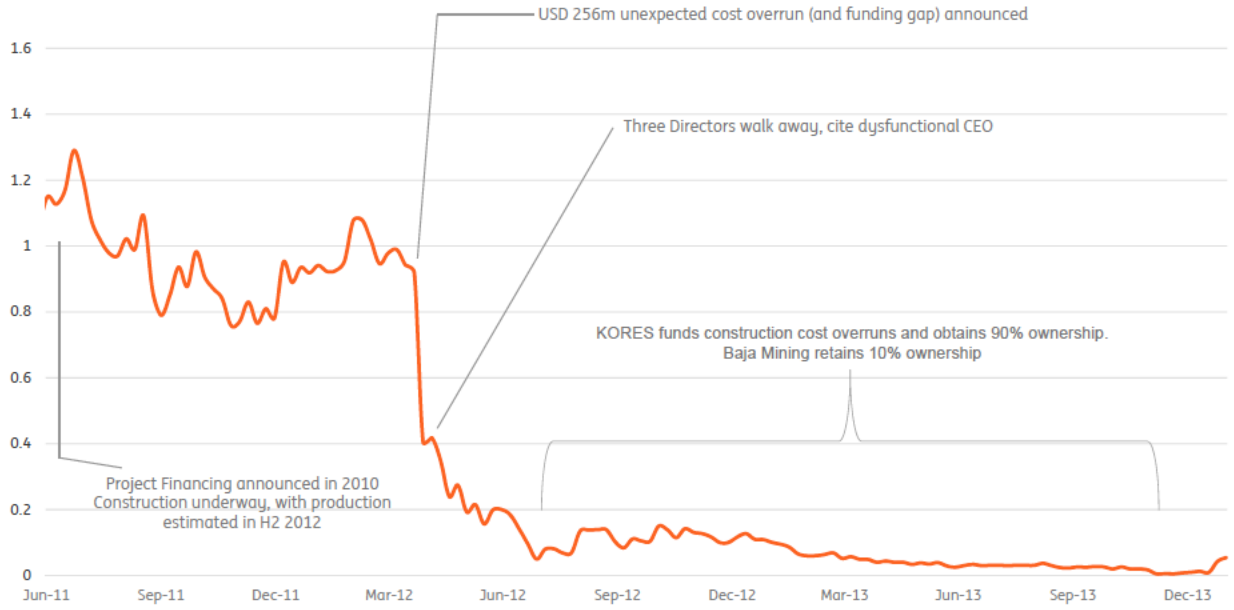


Figure 6: Market capitalization of Baja Mining Company (TSE:BAJ). During this period, the Boleo project underwent a debt restructuring where KORES obtained 90% ownership (provided by the ING bank, 2017).

Mine plan and underground geotechnical issues

The mine encountered very serious problems in the underground tunnels which are much less stable than anticipated. The walls are prone to swelling, destroying structural ground support. Driven by this design error, the mine shifted from 70/30 underground/open pit to 30/70 underground/open pit.

Plant design and complex metallurgy

Mill designed for 1.5% cu grade, however new expectations of the ore grade are set at < 1% because of the open pit pivot of the mine. Early production expected to be ~20ktpa copper cathode and 1,200 tpa cobalt. The change in mine plan only adds to the original problem: the developers underestimated the complexity of the process required to recover 4 separate metals. KORES has devoted itself to achieving an operational plant: “In order to develop refining technology for the Boleo mine, KORES has built and is operating Korea’s first ''hydrometallurgy pilot plant'' which consists of several hydrometallurgical processes. The pilot plant was built to shorten the ramp up period by evaluating problems beforehand that may occur in each process.” - Kores Boleo Copper Project Overview

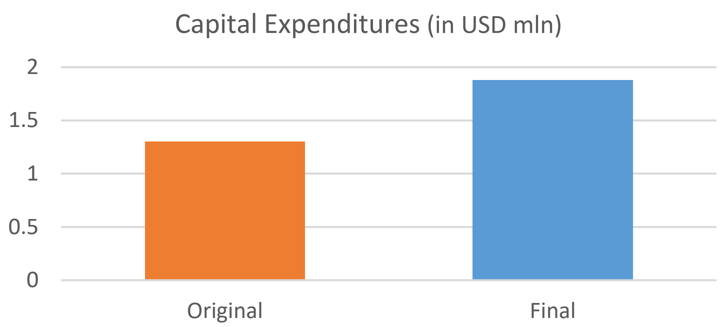


Figure 7: The estimated capital expenditure compared to the actual capex spent (44% overrun)

Cash cost escalation

The cash costs of the project were estimated at an average of -$0.29/lb Cu over the life of mine due to high by-product credits. Current projections at $0.50/lb Cu in 2017, are over $0.80/lb Cu higher than original. It is highly unlikely the original cash costs will ever be realized.

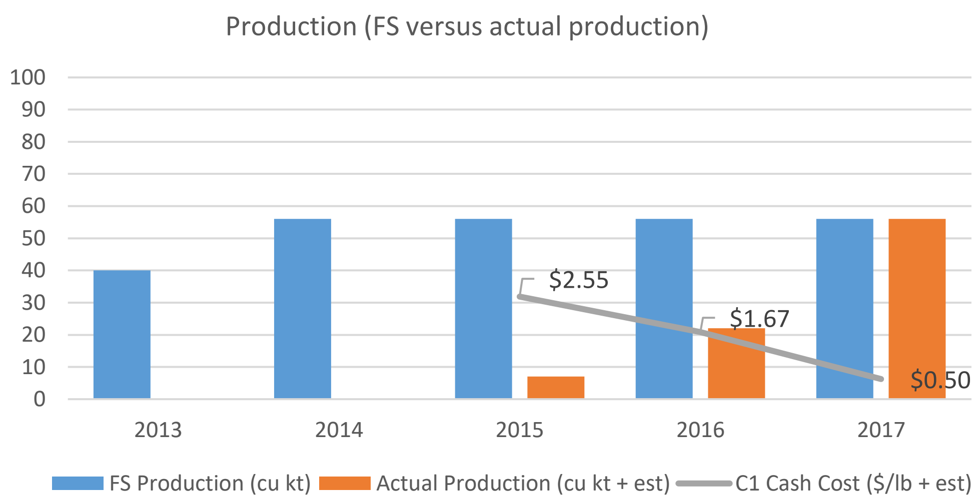


Figure 8: Prediction of the production published in the feasibility study compared to the actual production. The cash cost published in the BFS was estimated to be -$0.29/lb Cu.

Root causes

It is noticeable that even retrospectively it still is challenging to define the root cause of the Boleo mining project to have experienced a capex overrun. It is a combination of circumstances, as is generally the situation with capex overruns. Nonetheless, the following aspects are likely to have had a big impact on the overrun of the project:

- Underestimation of the complexity of processing
- Mine design

These root causes can be considered variables, specific for this project. In the next chapter general variables are defined that can be applied to every mining project.

3 METHODOLOGY

3.1 FACTORS THAT COULD CAUSE MINING PROJECTS TO UNDERPERFORM

There can be several reasons for a mining project to experience an initial capex overrun (ICO). The analysis in chapter 2 shows there generally is not one root cause to point out as the origin of the ICO, rather it is a combination of factors that resulted in the project to experience an ICO. Technical issues presented in the feasibility study are often the primary focus when investigating the root cause analysis of a capex overrun. These technical issues are the basis upon which an asset delivery and business plan is built. Therefore, these technical issues are an important part of the root cause analysis. However, these technical issues are not the only prerequisites to the demonstration of a project's viability. The feasibility study process must demonstrate that not only have the technical issues been satisfactorily addressed, but also that the broader commercial, economic and geographical issues have been considered in the development of a business plan (Mackenzie & Cusworth, 2007).

To conduct an analysis not primarily focusing on the technical issues of the feasibility study, this research utilizes 19 variables to define a mining project from a technical, financial and geographical perspective. The variables are used to compare projects to each other in terms of ICO. The common factors are analysed, and potential correlations between the variables and ICO are reviewed. Finally, the correlations are used to develop a predictive tool on ICO, which is discussed in chapter 5. The specific variables and boundaries are selected as a result of comprehensive discussions with personal communication (see appendix A Personal communication). The variables can be measured objectively, and the possible correlation regarding the probability and the magnitude of the ICO is investigated. The variables are subdivided into the following three general categories: **technical**, **financial** and **geographical**. The definitions and boundaries of these variables, as well as how they are used for statistical purposes, are discussed in this chapter. Table 3 displays all the variables and their corresponding categories.

Category	#	Variable
Technical	1	Mining method
	2	Greenfield or brownfield
	3	Origin of the feasibility study
	4	Processing plant capacity
	5	Processing method
Financial	6	Capex estimate
	7	Market capitalization
	8	Relative project size
	9	Debt-to-equity ratio
	10	Company listing maturity
	11	Company share price history
	12	Capital intensity
	13	Internal rate of return
	14	Payback period
	15	Net present value
	16	Relative position in commodity cycle
	17	Initialization time
Geographical	18	Project location
	19	Owner location

Table 3: The variables used to define a gold mining project and to compare relative to the capex overrun.

3.1.1 RELATIVE POSITION OF THE VARIABLES IN THE PROJECT TIMELINE

In chapter 2 it is briefly discussed how the phases of the feasibility study process work, and at which point in this process the largest impact on the outcome of the project can be made. For this reason, it is analysed where the variables are positioned in time, relative to the feasibility study process. This relative position represents the amount of impact a variable potentially could have. To show this graphically, the variables are placed in the feasibility study process timeline shown in Figure 9. The placement on the timeline for each variable is located when a final decision is to be made in the feasibility study process using the variable. As can be seen in Table 3, the three categories technical, financial and geographical are appointed respectively the colours red, black and blue. These colours are used to indicate the category in the timeline.

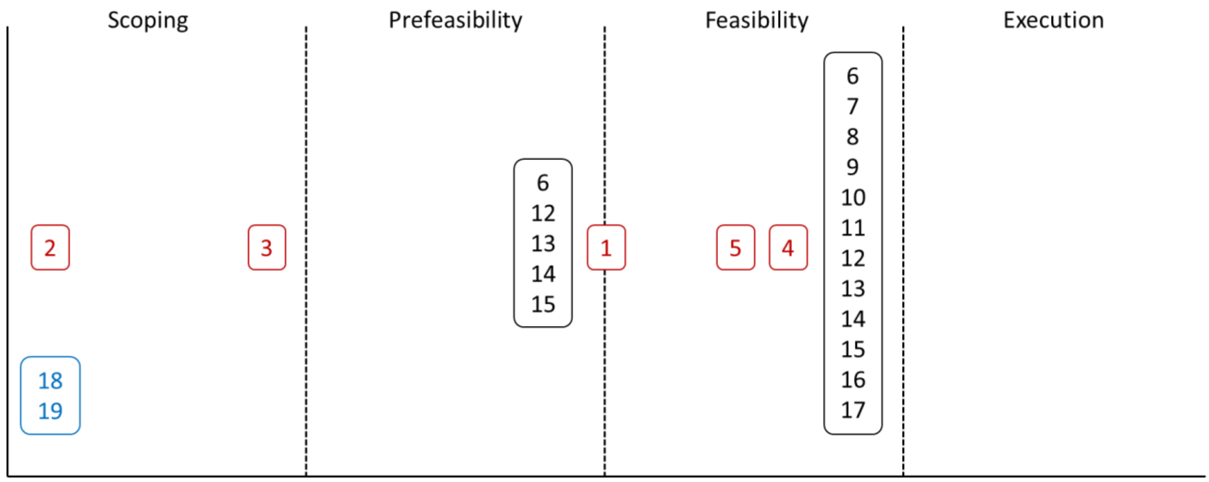


Figure 9: Position of the variables relative to the project phase. The numbers are explained in table 3.

The majority of the 19 analysed variables are financial variables. As can be seen in Figure 9 financial variables are measured and used at the end of the prefeasibility study and at the end of the feasibility study. The consequence is that the full extent of the analysis and the corresponding risk assessment tool discussed in chapter 5, is only available at the end of the feasibility study process. In agreement with figure 4, during the final part of the feasibility study process only little impact can be made on the project outcome, which comes at high cost. For this reason, the full risk analysis should not be considered a tool to improve the outcome of the project execution, it should rather be used from an investors' perspective. This means that when a project is rated as high-risk project based on the variables in the final stages of the feasibility study process, it is advised to abandon the project rather than invest in the project improvements. Based on the analysis it is better to find a project with better prospects.

3.2 TECHNICAL FACTORS

3.2.1 MINING METHOD

One of the most basic distinctions in defining a mining project is the determination whether it will be a surface mine or an underground mine. This choice is dependant of several factors including deposit geometry, deposit depth and host rock competence. Generally, with open pit mines overburden is removed exposing the ore body. This allows the mining company to remove ore grade material and transport it to the processing plant. Open pits are more desirable when the ore body is situated in relatively close proximity to the surface, which minimises the extent of costly waste material to be removed. In contrast, underground mines involve the construction of complex underground infrastructure from which is used to access to the ore body. Underground mining activities and constructions contain significantly higher risks. For example, ore reserve estimation is more difficult for deeper ore bodies due to the depth with which they occur from the surface and the additional expense involved in drilling. Furthermore, underground mines have safety issues emanating from possible rock falls. (Ferguson, et al., 2011). Open pit mines tend to be cheaper than underground mines per ton of material mined. Sometimes the mining method is determined by legal, social and environmental regulations. For the purpose of the research, there is a third category that is defined next to open pit and underground mines. When a mine starts as an open pit mine, but the BFS states that within one year after commercial production development to underground workings start, the mine is classified as a hybrid mining project.

The initial phase of the development regarding open pit and underground mining projects differ substantially from each other. Furthermore, the difference in corresponding costs and risk is high. This makes the mining method a suitable variable to analyse regarding ICO.

For statistical analysis the variable is defined using the following three categories:

- Open Pit
- Underground
- Hybrid

3.2.2 Greenfield or brownfield

A greenfield project is defined as a project that has never experienced any construction regarding the development of a mining project. When prior sampling has been done in an earlier phase, but the decision at that time was to not continue further exploration of the deposit, it is still considered a greenfield project. Brownfield projects can be subdivided into two categories. Category one is projects that have been mined in the past but stopped for any reason, and continued mining activities in a later stadium. The second category is mines that are developed in the close vicinity of another (formerly active) mine, and can use the geological data and infrastructural development of the other mine. Though a distinction can be made between these two categories of brownfield projects, for the purpose of this research they are both classified as brownfield project.

Greenfield projects depend on new drill core data quality and quantity, as well as the interpretation by the geologists. Brownfield projects can rely on existing data and experience from formerly executed activities, in addition to drilling and geological interpretation. This applies to the handling of the mining activities, as well as the acceptance of the ore in the processing plant. Therefore, geological risk is in general lower for brownfield projects than for greenfield projects. Furthermore, brownfield projects are normally already equipped with basic infrastructure elements as roads and airstrips. In some cases, brownfield projects are constructed at locations where the processing plant of former mining activities is still existent. Typically, these processing facilities require a capital injection to achieve production status, but this capital injection would be smaller than building a new processing plant.

For statistical analysis the variable is defined using the following two categories:

1. Greenfield project
2. Brownfield project

3.2.3 Origin of the feasibility study

Mining projects often face significant investment risks and its profitability is strongly dependent on the initial investment projected in the feasibility study. It is therefore essential that the people responsible for this document are qualified and competent. The authors of the feasibility study have significant influence and therefore power over the progress and development of the project. For the purposes of the research, the responsible feasibility authors are subdivided into two categories: in-house authors or external authors. In-house authors might publish a feasibility study with another mind-set than external authors. Both parties have different interests at stake at time of publishing. In practice, every feasibility study process relies on input from external parties. Feasibility studies have various degrees of external input ranging from those who are managed externally by a range of external consultants to those completed in-house – where the developmental firm manages elements of the feasibility such as resource assessment, metallurgical studies, process design, environmental management plans and capital cost estimates and implementation schedules. The identification of specific external consultants in the feasibility release potentially provides a signal of independence to the market in much the same manner as auditors have been noted to play a role in improving financial statement disclosure (Ferguson, et al., 2011)

When the feasibility study process is led by people from within the owning company, it is defined as an in-house author study. When an external party is responsible for the execution of the feasibility study, it is defined as an external author.

For statistical analysis the variable is defined using the following two categories:

1. In-house author
2. External author

3.2.4 Processing plant capacity

The capacity of the processing plant is an indication of how big the entire mining gold project is. Not all processing methods use the same processing facilities, but generally all include an initial crushing phase with a specific capacity. The capacity of the crusher is used as a value to compare the capacity of processing plants from different projects to each other. Even though projects have similar production capacities, the capex estimate can differ significantly due to circumstances as extreme weather conditions or remote location. This can make it difficult to compare projects of similar size. Another obstacle could be that processing plants tend to be fairly unique because of certain ore conditions and by products. Regardless of the expected comparison difficulties, it is analysed whether the processing plant capacity shows a correlation with the ICO.

For statistical analysis the variable is defined using the following four categories:

1.	Small	X < 1000 ktpa
2.	Medium	1000 ≥ X > 2000 ktpa
3.	Large	2000 ≥ X > 5000 ktpa
4.	Mega	X ≥ 5000 ktpa

3.2.5 Processing method

There are several methods to extract the gold from the ore. Which method is appropriate for a specific project is dependent on the composition of the ore. High recovery is the goal for gold processing plants, and is strongly determined by grain size distribution, association and liberation size of gold minerals in the ore to be treated and in the metallurgical products. (Zhou & Gu, 2008) Gold ores are commonly classified by the metallurgist into two major categories: free-milling and refractory. Typically, free-milling ores are defined as those where over 90 per cent of gold can be recovered by conventional cyanide leaching. Refractory ores are defined as those that give low gold recoveries or give acceptable gold recoveries only with the use of significantly more reagents or more complex pre-treatment processes (Zhou & Gu, 2008). Different processing methods need corresponding different facilities and relevant infrastructure. This has influence on the capex estimate. For that reason, the analysis is made whether the processing method has a correlation with the ICO.

During the gathering of data all common gold ore processing methods were considered and accepted. At the end of the database population, the amount of different processing methods registered in the database was four.

For statistical analysis the variable is defined using the following four categories:

1. Carbon-in-leach
2. Carbon-in-pulp
3. Flotation
4. Heap leach

3.3 Financial factors

3.3.1 Bankable feasibility study capex estimate

The initial capital expenditure estimate of the project is another indication of the project size. However as discussed, a high capex estimate can also be influenced by other factors than project size. It is the combination of the size of the project and the circumstances of the project that determine the capex estimate. The size of the capex estimate has an influence on the structure of the financing of the project. Small project typically can be funded by one or two investors, where larger projects frequently require more complex financing structures, involving more stakeholders. In general, these stakeholders all have a say in the projects development and the approach of the feasibility study. As the size of the capex estimate gives an indication of the project size and the financing structure, it is analysed for possible correlation with the ICO.

For statistical analysis the variable is defined using the following four categories:

1.	Small	X < $100M
2.	Medium	$100M ≥ X > $250M
3.	Large	$250M ≥ X > $1B
4.	Mega	X ≥ $1B

3.3.2 MARKET CAPITALIZATION AT BANKABLE FEASIBILITY STUDY PUBLISH DATE

The market capitalization is the total market value of a company's outstanding shares. It is a commonly accepted way to estimate a company's size. The market cap is chosen to represent the company size as a variable because it is easy to calculate (it does not require detailed financial reports) and easy to compare. It is often the case that mining projects are a product of joint ventures between multiple parties. When this is the case, the market cap of the largest company will be leading. The market cap used to compare to the capex overrun is measured at the time of BFS publishing. As the market cap gives a good indication what kind of company is behind the project in terms of size, it is analysed to see if a correlation with the ICO is to be found.

For statistical analysis the variable is defined using the following four categories:

1.	Micro cap	X < $100M
2.	Small cap	$100M ≥ X > $1B
3.	Medium cap	$1B ≥ X > $5B
4.	Large cap	X ≥ $5B

3.3.3 RELATIVE PROJECT SIZE (CAPEX / MARKET CAP) AT BANKABLE FEASIBILITY STUDY PUBLISH DATE

The relative project size ratio is calculated by comparing the BFS capex estimate to the market capitalization of the owning company at BFS publish date. It shows the size of the project compared to the size of the company. This indicates whether a project is entirely responsible for the health of a company, or only partly. It is imaginable that the relative size of the project has influence on how a project is approached. When a single asset company experiences an initial capex overrun, it needs to find extra funding from external parties, as there are no revenues from other projects that can compensate for the unexpected extra costs resulting from the overrun. Therefore, a single asset junior company is exposed to a higher amount risk when a project experiences an ICO, than a large multinational mining company like Rio Tinto, who was the capability to cope with an ICO internally. With this in mind it would be expected projects with a large relative project size are more careful, and therefore more accurate with their capex estimate.

For statistical analysis the variable is defined using the following four categories

1.	Small	X < 15%
2.	Medium	15% ≥ X > 50%
3.	Large	$1B ≥ X > 100%
4.	Massive	X ≥ 100%

3.3.4 DEBT-TO-EQUITY RATIO AT BANKABLE FEASIBILITY STUDY PUBLISH DATE

The debt-to-equity ratio (D/E ratio) is used to measure a company's financial leverage, calculated by comparing a company's total liabilities by its stockholders' equity. The D/E ratio indicates how much debt a company is using to finance its assets relative to the amount of value represented in shareholders' equity. Because the mining industry is a capital-intensive industry, the D/E ratio is relatively high compared to other industries.

Debt financing can be advantageous because there is no loss of ownership. Furthermore, it can be relatively cheap for large companies. However, interest on the debt has to be paid regardless of the performance of the project or commodity price, therefore making it more vulnerable to the market. With equity financing on the other hand, one makes sure to not be exposed to an interest burden and cash is more readily available. However, this structure results in a loss of ownership and therefore a loss in potential profits. Generally, a company raises capital in both ways and delicately balances the ratio between debt and equity.

However, junior companies usually have no other choice than equity due to the high risk of exploration success. A study of PricewaterhouseCoopers showed the following regarding the financial structure of junior mining companies in 2012:

- Exploration phase: D/E ratio of 9%
- Development phase: D/E ratio of 42%
- Production phase: D/E ratio of 47%

Large mining companies (BHP Billiton, Rio Tinto, Vale, ArcelorMittal) generally have a debt-to-equity ratio of 47% (PwC, 2012).

The structure of how a mining company is financed could have influence in the approach and evaluation of projects. For example, companies with a high leverage could 'push' projects on the market with external financing, at times further research is actually needed. For the owning company this could result in the mine achieving production earlier, but with a capex overrun. The external financer will most likely step in with extra funds when more money is needed for the project to commence, and the revenue flow is started earlier. This example indicates the different perspective at which high leveraged companies can look at the developing phase of a mining project. To investigate whether a correlation can be found, the D/E ratio is analysed.

For statistical analysis the variable is defined using the following three categories:

1. No Debt 0% debt
2. Low Debt 1% – 20% debt
3. High Debt >20% debt

3.3.5 COMPANY LISTING MATURITY AT BANKABLE FEASIBILITY STUDY PUBLISH DATE

The company listing maturity is defined as the time a company is listed on the stock exchange of the corresponding country where the head office is located. This maturity time indicates the age and maturity of a company and the experience that comes with it. One could argue that longer listed companies should experience less initial capex overrun (ICO) due to their lessons learnt in former project. On the other hand, one might say experienced companies likely have more capital and therefore can cope with a possible ICO more easily. Junior companies often are completely dependent on the success of a single project and therefore are therefore dependent on protecting their investment in the project development. For this reason, it is analysed whether a correlation can be found between the company listing time and the ICO.

For statistical analysis the variable is defined using the following four categories:

1. $X < 5$ years
2. 5 years $\geq X >$ 10 years
3. 10 years $\geq X >$ 15 years
4. $X \geq 15$ years

3.3.6 COMPANY SHARE PRICE HISTORY

Listed companies publish their financial results twice a year. They generally provide trading updates twice a year as well. These figures and statements give the investment community an insight into a company's performance. Furthermore, companies are obliged to publicly notify any event that could influence their stock price, such as a takeover bid or the launch of a new product. These are known as regulatory announcements (London Stock Exchange PLC, 2013). If the owning company makes an announcement regarding problems concerning the mining project around the time of BFS publishing, this will surely have an effect on the share price. On the other hand, any unexpected positive news regarding the project shall have a on the share price too. The financial situation of the company at BFS publishing might also have an influence in the final say when the decision has to be made to extend the feasibility study research, or to go ahead with the project as it is and file for funding. Therefore, the relative company share price might be used as an indicator to evaluate the condition of the mining project. To analyse whether the state of the share price has any correlation with the ICO, it is compared to the relative company share price at BFS publishing. The relative share price is defined as the share price at BFS publishing relative to the share price six months prior to the BFS publishing.

For statistical analysis the variable is defined using the following four categories:

1. Share price down X < 100%
2. Share price stable 100% ≥ X > 125%
3. Share price profit 125% ≥ X > 200%
4. Share price high profit X ≥ 200%

3.3.7 Capital intensity (capex estimate/processing capacity)

The capital intensity is of a project is defined as the initial capital expenditure estimate published in the BFS, compared to the ore handling capacity of the initial crushing phase of the processing plant in tpa. It is a measure of how the initial investment translates to production capacity of the mine. Preferably the capital intensity is as low as possible, as this means production can be realized with little investment, and therefore the payback period will be minimal. In later stages of the mining project, the operational expenditure and the processing plant capacity is more often used as a measure of success.

For statistical analysis the variable is defined using the following four categories:

1. Small X < 40 $/tpa
2. Medium 40 $/tpa ≥ X > 60 $/tpa
3. Large 60 $/tpa ≥ X > 100 $/tpa
4. Extreme X ≥ 100 $/tpa

3.3.8 Internal rate of return

Internal rate of return (IRR) is a metric used in capital budgeting measuring the profitability of potential investments. Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. IRR is uniform for investments of varying types and, as such, IRR can be used to rank multiple prospective projects a firm is considering on a relatively even basis. Assuming the costs of investment are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first (Investopedia, 2017).

One of the big disadvantages of the IRR method, is that it should not be used to compare projects of different size or duration, as the IRR doesn't consider the project size. Therefore, one could argue the IRR is unsuited for this analysis, as typically mining projects generally are of both different size and duration. However, the IRR analysis is a general measure of the quality of a mining project. One could argue it is wrong to compare the IRR values of two different projects to each other, as the companies hurdle rate might be determining, but one could say high IRR projects in theory are expected to be high quality projects. Another reason for using the IRR to compare projects is the high availability of this variable in feasibility studies. The IRR is a popular financial analysis in general, and the mining industry is no exception. To investigate if high quality projects equals low capex overrun, it is analysed whether a correlation can be found between the IRR value and the ICO.

For statistical analysis the IRR is plotted against the ICO on a scatterplot.

3.3.9 Payback period

The payback period represents the number of years required in the cash flow analysis for the accumulated cash flow to equal initial investments. Normally, the payback period is expected to be one to three years for high risk projects, and six to ten years for low risk projects (Kennedy, 1990). The payback period analysis is an investment evaluation especially interesting for high risk projects, therefore interesting for the gold mining projects. Open pit gold mining projects generally have relative short payback periods because of the relatively small capital expenditure and high gold prices.

The payback period is, like the IRR, an indication of the quality of a project. Projects with a short payback period are in general more interesting for investors than projects with long payback periods. Therefore, typically the goal is to ensure the lowest payback period possible in the feasibility study. For this reason, the payback period is analysed to see if a correlation with the initial capex overrun (ICO) can be observed.

For statistical analysis the payback period in years is plotted against the ICO on a scatterplot.

3.3.10 NET PRESENT VALUE

The Net Present Value (NPV) is the combined difference between the present value of cash inflows and the present value of cash outflows. The present value is determined by a discount rate. The discount rate considers not just the time value of money, but also the risk of the industry and uncertainty of future cash flows (Investopedia, 2017). The risk included in the discount rate can and should include several risks, including political, environmental, financial and technical risk. However, this is difficult to quantify and always prone to subjectivity. Therefore, a disadvantage of the NPV analysis, is the method and structure of how the discount rate is calculated.

The NPV analysis has been widely used in the mining industry since the 1960s (Kennedy, 1990). NPV is also used to compare mining projects to each other. This method however is questionable, as the discount rate per mining project can be very different due to unique circumstances, and the life of mine can differ significantly. Though the NPV analysis for gold mining projects arguably is questionable and it is difficult to compare to other projects, it is a widely used method. Virtually all bankable feasibility studies document an NPV, in the most cases even multiple NPV values at different discount rates. Because the NPV method is a financial indicator and is so readily available, the NPV analysis – at different discount rates – is to be analysed for potential correlations with the ICO.

For statistical analysis the NPV is plotted against the ICO on a scatterplot.

3.3.11 RELATIVE POSITION IN THE COMMODITY CYCLE

Commodity market prices have been following certain patterns for decennia (Merrow, 2006). When the market gets saturated the prices decline. This price decline results in a decrease of production and new projects are put on hold. As the supply shrinks, the prices rise and the market gets interesting again. Capital is injected in production capacity and new projects. As the market finally becomes saturated, the commodity price declines and the commodity cycle start over. This is an oversimplified explanation of the commodity cycle, since there are various causes that influence the price and demand variation for commodities. However, a combination of the oversimplified combination and other causes result in the commodity cycle. It should be noted that gold is often a hedge against political uncertainty or macro-economic uncertainty and therefore is less influence able to market saturation. This has a great influence on the gold price. The gold price that is considered high and what is considered low can change every cycle, and the length of a cycle is variable too. For the purpose of this research it is analysed whether the timing and the magnitude of projects that have experienced an ICO can be related to their corresponding position in the gold price cycle. To achieve this analysis, primarily the relative gold price needs to be analysed, indicating how 'attractive' the gold market was at specific times.

To define how 'attractive' the market is, the gold price is compared to historic gold prices. By doing so, the relative position in the gold cycle is obtained. For example, if one wants to know the current position of the gold price relative to the last twelve months, one compares the spot price of today by the average gold price of the last twelve months. When this value is above 100%, the gold price today is higher than the average of the last 12 months and therefore the market is defined as 'attractive'. When the value is below 100%, the gold price today is lower than the average of the last 12 months and therefore the market is 'unattractive'. This is how market attractiveness is defined for the purposes of this project.

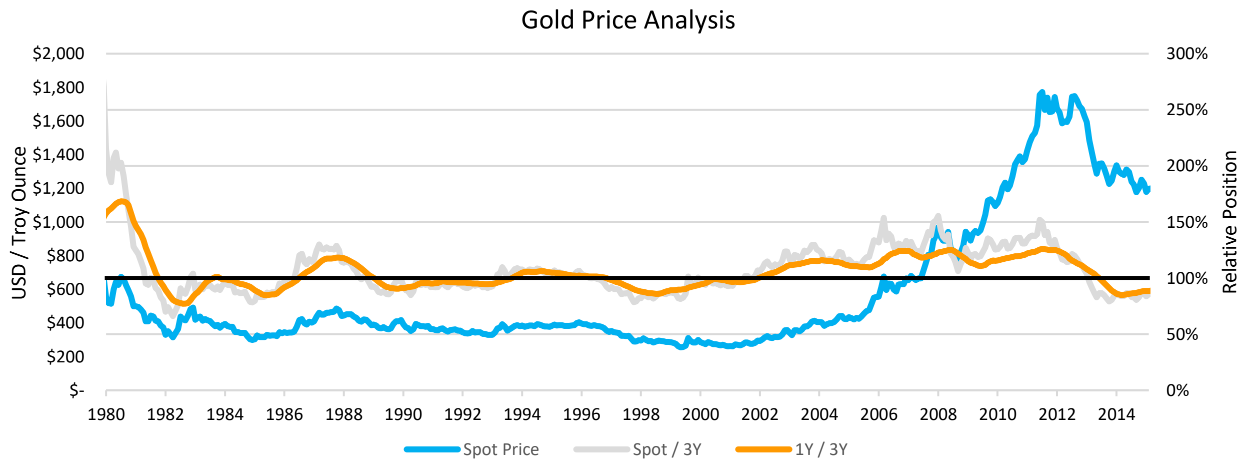


Figure 10: This graph represents the relative 'attractiveness of the gold market. The blue line represents the spot price of gold in USD per troy ounce (left axis). The grey line represents the gold spot price divided by the three-year average of the spot price at that moment (right axis). The orange line represents the one-year average of the spot price divided by the three-year average of the spot price (right axis). When the blue or grey line is above the black 100% line, the market is considered 'attractive'. (London Stock Exchange PLC, 2013)

Figure 10 shows an analysis of the relative gold price and the corresponding 'market attractiveness'. The blue line indicates the gold spot price of the London Stock Exchange (London Stock Exchange PLC, 2013). The grey line indicates the spot price at a given moment in time, relative to the three-year average gold price prior to that moment. The orange line shows the one-year average of the gold price divided by the three-year average of the gold price. The latter gives a smoother version of the market attractiveness analysis. As can be seen comparing Figure 10 and Figure 11, more gold projects are started in the time gold prices are high and the market is attractive. This is a normal phenomenon explained by the traditional commodity price cycle. What should be noted from this comparison is that in spite the fact that there are some harsh dips in the gold market, several projects are being started nonetheless.

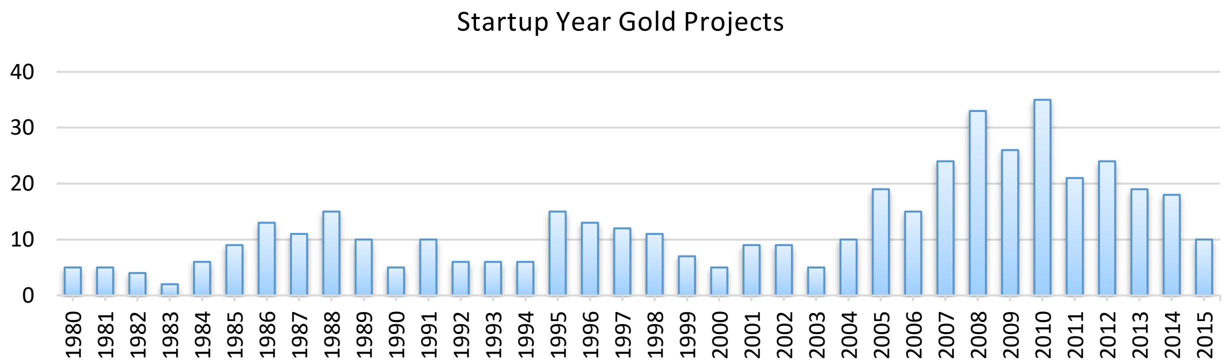


Figure 11: The number of gold projects that started production per year.

For analysing purposes, the capex overrun of a project is plotted on the relative gold price graph at the corresponding BFS publish date. Furthermore, the number of projects that experienced an ICO is plotted on the graph, as well on their corresponding BFS publish date.

3.3.12 Initialization Time

The time it takes for a project to start mine development construction after the BFS is published is called the initialization time. The initialization time can depend on several factors e.g. funding, licensing, political instability etc. A junior mining company might need more time to get the full funding and licensing complete to start construction, whereas a senior mining company might rely on existing contacts. When projects start construction immediately after funding is approved, it can be the case that the permitting is not completely finalized yet. It can be rewarding to start initial construction that doesn't require permitting, while permits are being approved. However, it can be considered a risk as well because the approval time can vary significantly, resulting in initial project development delays. On the other hand, when the time between BFS publishing and construction start is relatively large, certain contractual obligations with external parties may not be valid anymore or need to be paid off. For example, agreements with contractors or equipment delivery will need to be renegotiated and permits might need extension. Other external factors that change can have an impact on initial agreements too. Because of the possible impact the initialization time might have on the ICO, it is analysed whether a correlation can be found with the ICO.

For statistical analysis the variable is defined using the following four categories:

1. < 1 month
2. 1 – 6 months
3. 6 – 12 months
4. > 12 months

3.4 Geographical factors

3.4.1 Project location

Aside from the deposit itself, the location of the project is of great importance in the process of determining whether a project will be feasible to develop. Extreme climate conditions, natural disasters and the presence of diseases are examples of risk that can be present due to the geographical location. Other location risks can be related to the governmental environment. The political risk of a geographical location is taken into account in the project location. Countries where the political system is structurally instable are less favourable for developing a mining project, as permits and contracts are less final than in political stable countries. Regions where the local currency is extremely volatile are an enhanced risk too, as the local personnel is generally paid in the local currency. Another more obvious influence to consider is the availability of skilled personnel. When this is not available, the production costs will increase significantly.

These examples show the project location can have great influence on the feasibility of the project, and therefore possibly also on the performance of the project in the sense of a capital cost overrun. For comparison purposes the world is subdivided into six mining regions (Figure 12). One could argue some of the combinations are oversimplified and the world should be divided into more regions. E.g. the middle east could be defined as a separate region, not combined with Asia. With the current amount of entries and focus in the database, the current distinction is chosen as desirable.

For statistical analysis the variable is defined using the following four categories:

1. Latin America
2. Africa
3. Europe & Russia
4. Asia
5. Australasia
6. North America

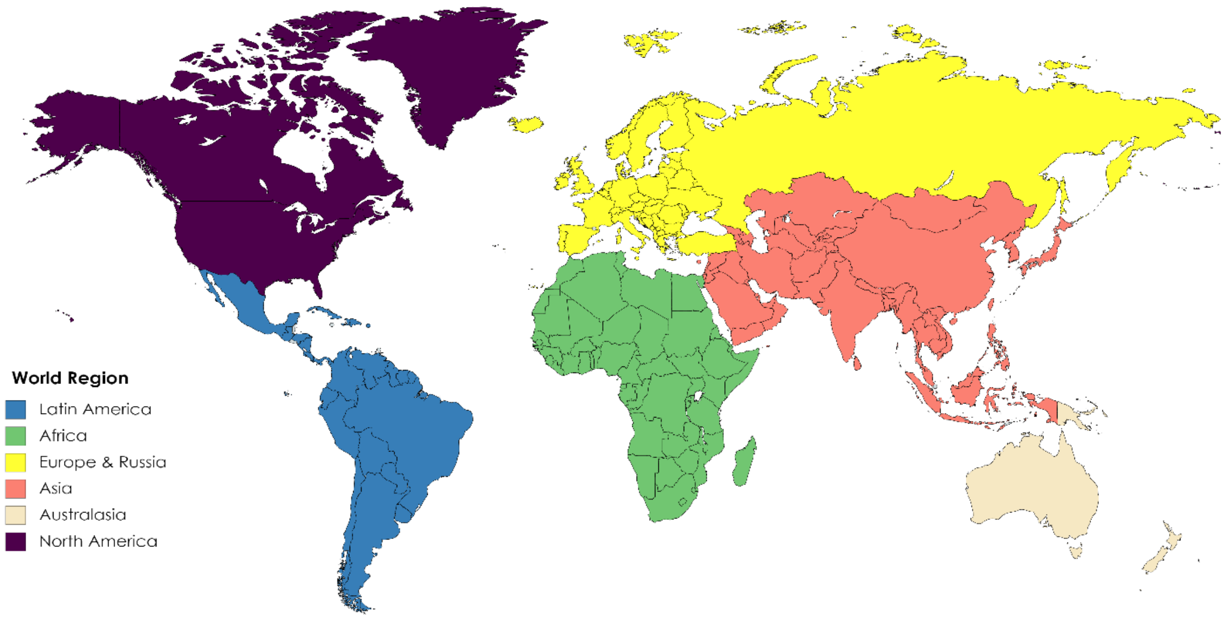


Figure 12: A map of the world subdivided into six mining regions

3.4.2 OWNER LOCATION AT BANKABLE FEASIBILITY STUDY PUBLISH DATE

Mining companies are based in Australia, Canada, The United States, South Africa or Europe. The entries in the database is not different, and the vast majority of the owning companies is located in Australia, Canada or The United States. These countries are western first world countries and share a lot of similarities. Regarding the mining industry however, there are some noticeable differences. The most noticeable difference is the code for reporting of exploration results, mineral resources and ore reserves. Australia uses the JORC code, Canada the NI 43-101 and the USA the SME Guide. Though the codes are similar, it is an observable fact there are differences industry wide, only based on where the owner company is located. These differences are discussed in chapter 3.5.1.

Another difference is the level of transparency required by the governmental institutions. The fact that companies in Australia only have to publish a summary, when those with North America listings publish the entire report is not right. It puts Australia-focused investors at a distinct disadvantage to those in Canada (Gleeson, 2017). These differences suggest there might be a relation in where the owner company is located and the performance of the project in terms of ICO. Because the largest influence in the project is exercised pre-production, and as a good baseline to compare projects among each other, the moment of measuring the owner location is at the BFS publish date.

For statistical analysis the variable is defined using the following four categories:

1. Australia
2. Canada
3. United States
4. Other

3.5 DATA ACQUISITION PROCESS

The data acquisition process is to be considered the backbone of the research and the corresponding results. The quality of the database, the correlations and the predictive model are based on the initial input of data. For this reason, a high level of confidence in the sources needs to be ensured to populate the database. Feasibility studies & annual reports come from either the official company sites, SEDAR or EDGAR, or personal communication. SEDAR is the official website of the Canadian Securities Administrators or CSA that provides access to most public securities documents and information filed by issuers with the thirteen provincial and territorial securities regulatory authorities in the SEDAR filing system. The statutory objective in making public this filed information is to enhance investor awareness of the business and affairs of issuers and to promote confidence in the transparent operation of capital markets in Canada. EDGAR is the United States version of SEDAR, part of the U.S. securities and exchange commission, where all companies, foreign and domestic, are required to file registration statements, periodic reports, and other forms electronically through EDGAR. A significant portion of the data comes from research conducted by external persons, and is acquired from personal communication. All contacts have extensive experience in the mining industry or in the investment banking industry, with a focus on metals and mining. The nature of the contacts can be found in Appendix A.

Figure 13 shows the hierarchy system used for the data acquisition. The hierarchy of the sources is ranked based on the reliability of the source combined whether the information is classified as 'reported'. The highest classified data (Company annual report) is considered reliable and is classified reported. Sources that are only classified 'reported' are ranked higher than sources that are only considered 'reliable'. Annual reports are considered higher priority data source than the half-yearly or quarterly reports because the reports tend to be more extensive and are based on a longer time period. All the 'lower ranked' data sources are preferably verified with sources from a higher rank. If there is any inconsistency or ambiguity in data sources, the 'higher ranked' data source trumps the lower ranked source. Data with that is audited and/or comes from a source with high confidence is considered 'reliable'. Data from official company sources is considered 'reported'.

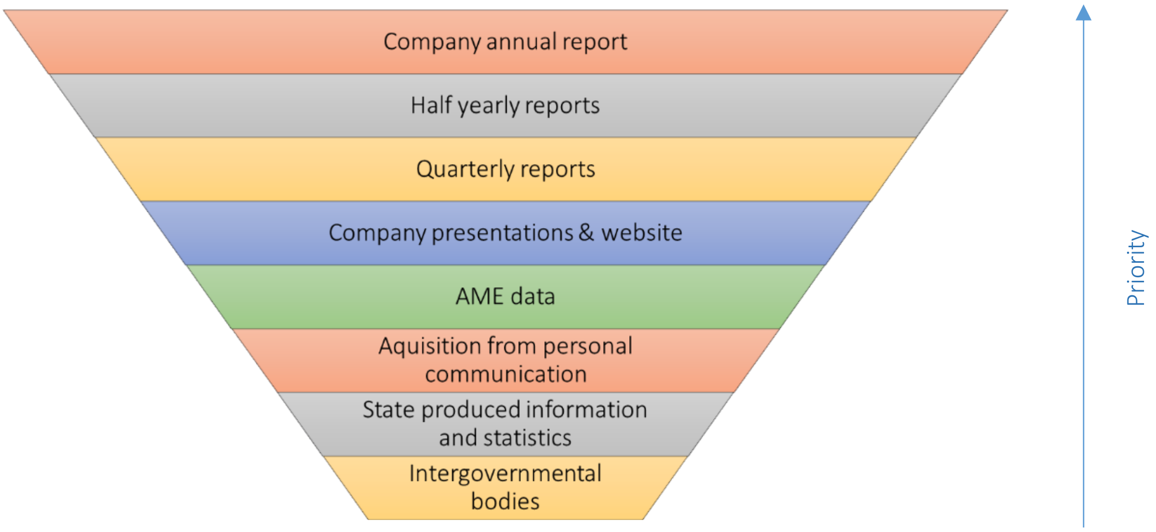


Figure 13: Data source hierarchy used to populate the database. If multiple data sources state different information regarding the same topic, the higher priority data source is used.

Annual report
- The company annual report is the pinnacle of available data. This is an official document produced by the company and is audited.
- This information is 'reliable' and classified as 'reported'
- This classification encompasses 10-K's Annual Information Forms (Canada) and other reporting required of companies under disclosure requirements

Half yearly report
- The half yearly report is typically audited.
- This information is 'reliable' and classified as 'reported'

Quarterly Report
- Quarterly reports are typically not audited and as such are subordinate to audited financial data.
- This information is 'reliable' and classified as 'reported'

AME Group
- AME primarily uses publicly available data and therefore will be comply with most of the other data sources
- As annual reports are official documents that comply with Annual Information Forms legislation, annual reports have senior priority over AME group data.
- This information is 'reliable'

Company presentations & website

- This information is not audited
- However, often companies will disclose information in corporate presentations which are a valuable source of information.
- All this information is 'reported'

Acquisition from personal communication

- Data acquired from personal communication is acquired due to personal contacts within the companies. Data is used from persons with experience in the relevant industry.
- This data is ‘reliable’ due to significant industry in relevant industries
- Appendix A highlights the origin of the personal communication and the content used.

State produced information and statistics

- Varying state agencies collect different amounts of information about the mining sectors.
- There are differing approaches. Some government bodies estimate numbers, others collect and publish information from companies. For example, ABARE (Australian Bureau of Agricultural and Resource Economics) estimates information and has no access to information other than what is in the public domain. In Peru however, the Ministry of Mining and Energy collects and reports detailed mine by mine statistics. This means that the ABARE information is at best an estimate, whereas the Peruvian data would be reported.
- Caution must always be taken in using this information, especially to determine whether it is admissible into the database, and if it should be considered estimated or reported

Intergovernmental bodies (Such as the United Nations)

- The United Nations collects production and trade data across varying commodities. This is delivered through UN Comtrade, the UN Study Groups and UNCTAD
- It must be used with caution and is always subordinate to company produced information.
- It is known that inconsistencies exist in the definitions used in the compilation of this style of information. Due to these inconsistencies, this is the lowest ranked source.

AME Group

AME group is a large data provider regarding natural resources projects. ING Bank uses AME for wholesale banking purposes, for that purpose the information provided by the database is being considered facts. As the research is constructed in collaboration with the ING Bank, access to the AME database was guaranteed and the database has been used extensively. The following is stated by AME Group marketing team for the purpose of this research to illustrate their core business:

“AME was founded in 1971 by a team of engineers and geologists. We bridge between technical asset valuation and the market. Our consultancy covers over 10,000 individual natural resources assets across 20+ commodities, including exposure to the Energy, Metals and Mining sectors. AME collects all public data on the assets it covers, as well as leveraging our links to industry to provide the most in depth bottom up market analysis available. Our Evo engineering models and machine learning allow our teams to provide granular site cost assessments inspecting everything from the equipment used onsite up.” (AME Group marketing)

FactSet

For historical financial information regarding mining companies (e.g. debt-to-equity ratio, market capitalization), a financial data provider named FactSet is used. FactSet is a leading provider of financial data and analytic applications for investment management and investment banking professionals around the globe. Access to FactSet is a result of the collaboration with the ING Bank.

3.5.1 DIFFICULTIES IN THE DATA ACQUISITION PROCESS

The projects that are required for the data population are generally not the most successful projects executed by the owning companies, and therefore it was not expected companies were eager to share the key data figures regarding these projects. Mining is a very conservative sector and one not best disposed to talk about its failures (Harris, 2017). Nonetheless, the data acquisition process can be described as a lengthy and intense period, dominated by setbacks. Eventually, several key persons from the mining industry and financial institutes contributed significantly in developing a database of mining projects that experienced an ICO. Another difficulty experienced during the data acquisition process is the inconsistency of data. It is surprising that there are almost no guidelines regarding the documentation of feasibility studies and annual reports. Companies from the same country often maintain a similar style in reporting, but when looked in detail, the figures that are being reported are almost consistently inconsistent. This makes it difficult to compare projects. Furthermore, companies based in Canada are obliged to publish a lot more detailed reports compared to Australian based companies. The fact that companies in Australia only have to publish a summary, when those with North America listings are obliged to publish in depth details is skewed; it puts Australia-focused investors at a distinct disadvantage to those in Canada. (Gleeson, 2017).

There are international guidelines as the JORC, NI43-101 etc. It is beneficial for the industry to have these guidelines, as they provide a framework for projects to follow. For the investors this is beneficial as well, as it makes it easier for them to valuate mining projects. It is also a positive thing that all dominant mining regions developed their own set of guidelines, as this shows understanding of the importance of the issue. It is considered negative however that the mining industry has not realized it is essential these multiple guidelines need to merge into one international accepted standard of reporting. There are Standards and Codes developed by members of the Committee for Mineral Reserves International Reporting Standards (**CRIRSCO**), however in the feasibility studies investigated for the purpose of this research this has not resulted in similar reporting. Figure 14 illustrates the global division in reporting standards. Per region the following guidelines are defined:

- JORC-Code (Australia)
- NI43-101, CIM-Standard (Canada)
- National Committee (Chile)
- PERC (Europe)
- NAEN (Russia)
- SAMCODES (South Africa)
- SME (USA)

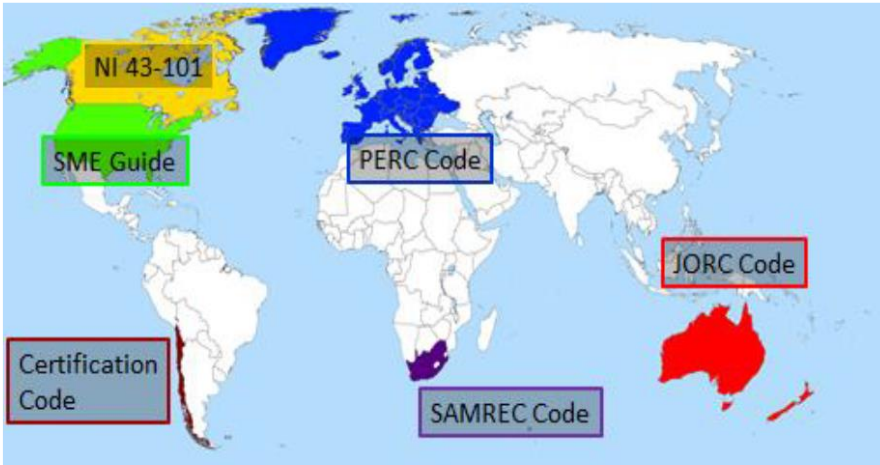


Figure 14: The international mining reporting standards per region (InfoMine)

In spite of these systems being relatively coherent, the process of finding comparable data in this research is experienced unexpectedly challenging. Even in the case when BFSs use the same reporting standards (e.g. JORC), the actual documented data figures often differ significantly from each other. The structure of the documents can be similar, but the actual reported content differs in such a way, that consistent data comparison for an entire database without data manipulation is impossible. Another finding is application of Net Present Value (NPV) as a financial indicator used in feasibility studies. It is questionable whether an NPV analysis is appropriate to evaluate mining projects in the first place, but the fact is that the majority of the companies do. To be able to make a comparative analysis among projects, it is essential input factors as capital expenditure and operational expenditure are defined the same, which in the majority of the cases is not true. Furthermore, the discount factor(s) at which the cash flows are discounted should be the same. The data acquisition process showed that the definition of the discount factor varies significantly, and the discount factor almost seem to be an arbitrary value between 0% and 15%. At BHP Billiton for example, an extra 2% is added to the discount factor if the project is located in Africa (L.D. Smith, personal communication, August 5, 2017). No distinction is made among different countries in Africa; it is considered a risk to engage in mining activities in the continent. Due to these inconvenient differences, it is difficult - if not impossible - to compare certain project to each other. As the Internal Rate of Return (IRR) analysis uses the same framework as the NPV analysis, the same uncertainty goes for IRR analysis in terms of project comparison.

3.6 DEVELOPMENT OF THE DATABASE

Gold mining projects that experienced an initial capex overrun are selected using the sources and according to the data priority mentioned in chapter 3.5. The project and all the available associated variables are imported into a database in the form of a Microsoft Excel spreadsheet. Every project is represented by a row, all the variables of represented in column D to column BJ (Figure 15).

In case of a follow up research, the database can be updated with new projects. A new row needs to be made, and all the columns filled out. When a new project and its characteristics are added, the database analyses the project automatically and the data statistics of the database are updated. Furthermore, the severity and the frequency risk assessment (discussed in Chapter 5) is updated, and the project is placed in the risk matrix automatically.

B	C	D	E	G	H	I	J
ID	Name	Country	World Region	Capex Overrun	Actual capex	Capex estimate	Absolute overrun
CJH	Ahafo Gold Operation	Ghana	Africa	37.7%	$ 482,000,000	$ 350,000,000	$ 132,000,000
CGP	American Girl Canyon	USA	North America	136.0%	$ 26,662,000	$ 11,299,000	$ 15,363,000
CGP	Andacollo (gold)	Chile	Latin America	45.6%	$ 66,682,000	$ 45,800,000	$ 20,882,000
CJH	Aurizona Gold Operation	Brazil	Latin America	29.0%	$ 61,285,700	$ 47,500,000	$ 13,785,700
CJH	Ban Houayxai Gold/Silver Mine	Laos	Asia	40.0%	$ 210,000,000	$ 150,000,000	$ 60,000,000
CGP	Basin Creek	USA	North America	49.7%	$ 5,300,000	$ 3,540,000	$ 1,760,000
JAB	Batu Hijau	Indonesia	Asia	17.5%	$ 1,810,000,000	$ 1,540,000,000	$ 270,000,000
CGP	Bella Vista	Costa Rica	Latin America	41.7%	$ 35,000,000	$ 24,700,000	$ 10,300,000
CJH	Benso Gold Mine	Ghana	Africa	45.1%	$ 72,700,000	$ 50,100,000	$ 22,600,000
JAB	Bissett (Rice Lake)	Canada	North America	32.9%	$ 55,153,000	$ 41,496,000	$ 13,657,000
JPPW	Boddington	Australia	Australasia	33.9%	$ 1,908,000,000	$ 1,425,000,000	$ 483,000,000
CJH	Bonikro Gold Mine	Ivory Coast	Africa	20.4%	$ 87,086,500	$ 72,305,000	$ 14,781,500
JAB	Brewery Creek	Canada	North America	18.1%	$ 58,846,000	$ 49,843,000	$ 9,003,000
JAB	Briggs	USA	North America	18.6%	$ 31,700,000	$ 26,734,000	$ 4,966,000
CJH	Caete Gold Operation	Brazil	Latin America	52.8%	$ 110,282,000	$ 72,180,000	$ 38,102,000
CJH	Canadian Malartic Gold Mine	Canada	North America	30.0%	$ 942,642,000	$ 724,900,000	$ 217,742,000
CGP	Carson Hill	USA	North America	28.6%	$ 13,500,000	$ 10,500,000	$ 3,000,000
CGP	Cerro Mojon	Nicaragua	Latin America	25.3%	$ 19,670,000	$ 15,700,000	$ 3,970,000
CJH	Chirano Gold Operation	Ghana	Africa	73.7%	$ 74,500,000	$ 42,900,000	$ 31,600,000
CGP	Colomac	Canada	North America	44.9%	$ 200,000,000	$ 138,000,000	$ 62,000,000
CJH	Detour Lake Gold Mine	Canada	North America	44.9%	$ 1,498,350,000	$ 1,034,058,240	$ 464,291,760
CGP	Dolores	Mexico	Latin America	53.3%	$ 210,000,000	$ 137,000,000	$ 73,000,000
CJH	Edikan Gold Operation	Ghana	Africa	18.3%	$ 175,000,000	$ 147,900,000	$ 27,100,000
CGP	El Choco	Venezuela	Latin America	36.0%	$ 52,500,000	$ 38,600,000	$ 13,900,000
CGP	El Sauzal	Mexico	Latin America	33.3%	$ 134,600,000	$ 100,980,000	$ 33,620,000
CJH	Essakane Gold Mine	Burkina Faso	Africa	15.2%	$ 453,000,000	$ 393,355,000	$ 59,645,000
JAB	Fort Knox	USA	North America	36.8%	$ 350,000,000	$ 255,803,000	$ 94,197,000
JAB	Gold Road	USA	North America	47.4%	$ 14,100,000	$ 9,564,000	$ 4,536,000
CGP	Golden Bear	Canada	North America	104.0%	$ 81,600,000	$ 40,000,000	$ 41,600,000
CGP	Golden Reward	USA	North America	32.9%	$ 26,178,000	$ 19,700,000	$ 6,478,000
CJH	Goldex Gold Mine	Canada	North America	58.3%	$ 213,700,000	$ 135,000,000	$ 78,700,000
CGP	Gualcamayo	Argentina	Latin America	27.7%	$ 190,600,000	$ 149,200,000	$ 41,400,000
CGP	Hycroft (Lewis Mine)	USA	North America	39.1%	$ 32,000,000	$ 23,000,000	$ 9,000,000
JAB	Illinois Creek	USA	North America	41.9%	$ 31,228,000	$ 22,000,000	$ 9,228,000
CGP	Jamestown	USA	North America	30.4%	$ 90,000,000	$ 69,000,000	$ 21,000,000
CJH	Kittila Gold Mine	Finland	Europe & Russia	148.1%	$ 335,000,000	$ 135,000,000	$ 200,000,000

Figure 15: Screenshot of the database. The variables are projected from column D to column BJ.

4 DATABASE ANALYSIS

This chapter discusses the analysis and the interpretation of the database. Primarily, the relation between the variables and the initial capex overrun (ICO) are visualized in the form of pie charts, bar charts and scatterplots. Significant observations are discussed, and when possible confirmed or rejected using relevant literature listings. For each variable it is discussed whether the analysis will be used for predictive purposes in the risk assessment model discussed in Chapter 5. To summarize the analysis, a synopsis is discussed where the variables are categorized in parent groups.

Database summary	
Number of projects	65
Number of different countries	26
Bankable feasibility study publish date	1985 - 2010
Average capex overrun	45%
Number of variables per project	19

Table 4: Summary of the projects analyzed in chapter 4

4.1 Technical factors

4.1.1 Mining method

4.1.1.1 Data observation

The vast majority of the dataset (76%) consists out of projects that initially started as open pit projects. These open pit projects experience the smallest ICO in general, with an average of 39%. The underground projects experience a larger ICO with 50%. Projects that are developed as a hybrid project experience by far the highest ICO with 71%. In absolute terms, the open pit projects experienced the largest overrun, with an average of $86 million per project. This means the open pit projects required larger initial capital investment than the underground and hybrid projects. This is not expected, as the initial capital cost used to develop underground mines is generally larger than the initial capital cost for open pit mines.

4.1.1.2 Data interpretation

The data suggests underground projects tend to overrun more than open pit projects. This is not unexpected, as underground projects are exposed to more complex engineering challenges. Safety issues are also a larger issue in underground projects due to the underground working conditions, which may result in construction delays and capex overruns (Botin, 2009). In general, in underground mining developments there are more aspects that can go wrong, and therefore eventually will go wrong. This agrees with the trend seen in the data analysis. Hybrid projects are according to the database the projects that overrun the highest. These projects combine the aspects of surface mining and underground mining in one project. A possible explanation could be that combining surface and underground mining exposes a project to an excessive amount of risk due to the complexity of such a project. It requires a great amount of engineering and logistical planning to facilitate two mining different mining methods at one site. No documented data is found to verify this statement.

The results of the mining method will be used for risk assessment purposes.

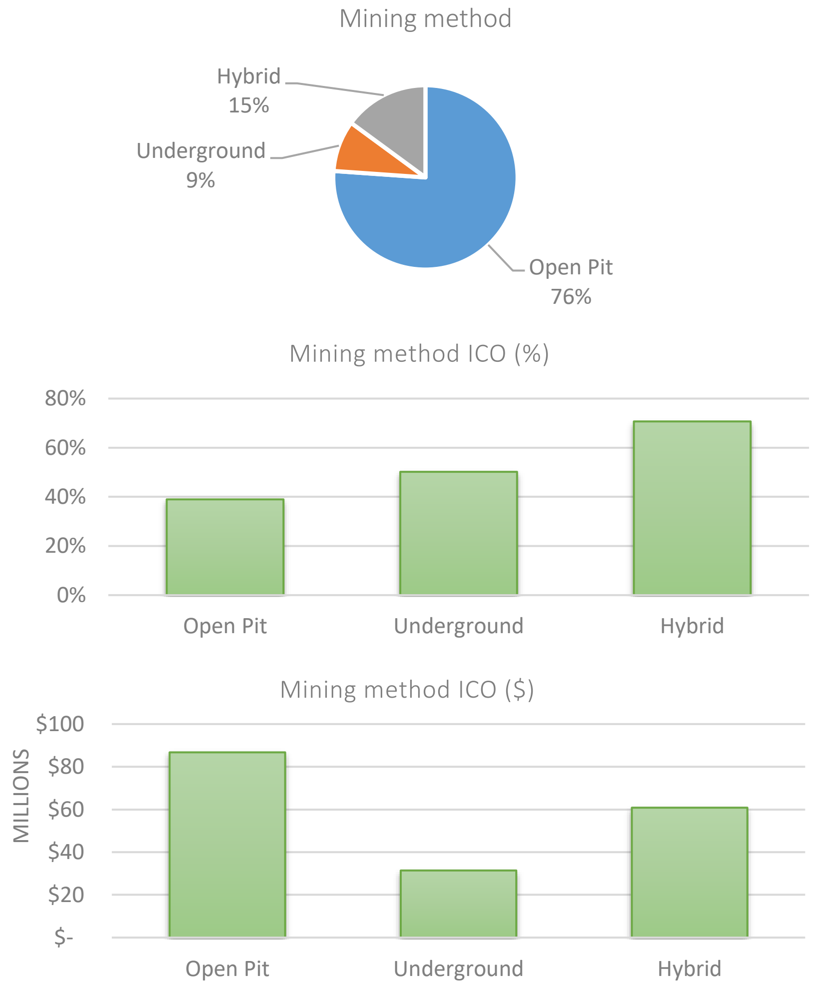


Figure 16: Data visualization of the initial capex overrun compared to the mining method.

4.1.2 GREENFIELD VS BROWNFIELD

4.1.2.1 Data observation

Greenfield projects represent 79% of the projects. The data suggests that brownfield projects tend to overrun more than greenfield projects, however the difference is marginal at 1,5%. The brownfield projects of the analysed database seem to experience an absolute capex overrun slightly larger than the greenfield projects.

4.1.2.2 Data interpretation

Unfortunately, no literature data was found regarding the distribution of greenfield and brownfield projects worldwide. However, based on the data acquisition process of the thesis, the assumption is made the majority of new mining projects are greenfield projects. This agrees with the database.

The literature suggests that brownfield projects tend to be less risky in terms of initial investments due to experience from formerly executed activities and therefore brownfield projects should experience a smaller ICO (Botin, 2009). The database suggests the opposite. According to the analysis for both the relative and the absolute capex overrun a higher average value for brownfield projects is shown. The difference is small in a relative comparison. It is unexpected that brownfield projects in the database have a larger ICO as both literature listing as personal communication indicates otherwise.

Due to the marginal difference and the inconsistency with literature listings, this analysis will not be used for predictive purposes.

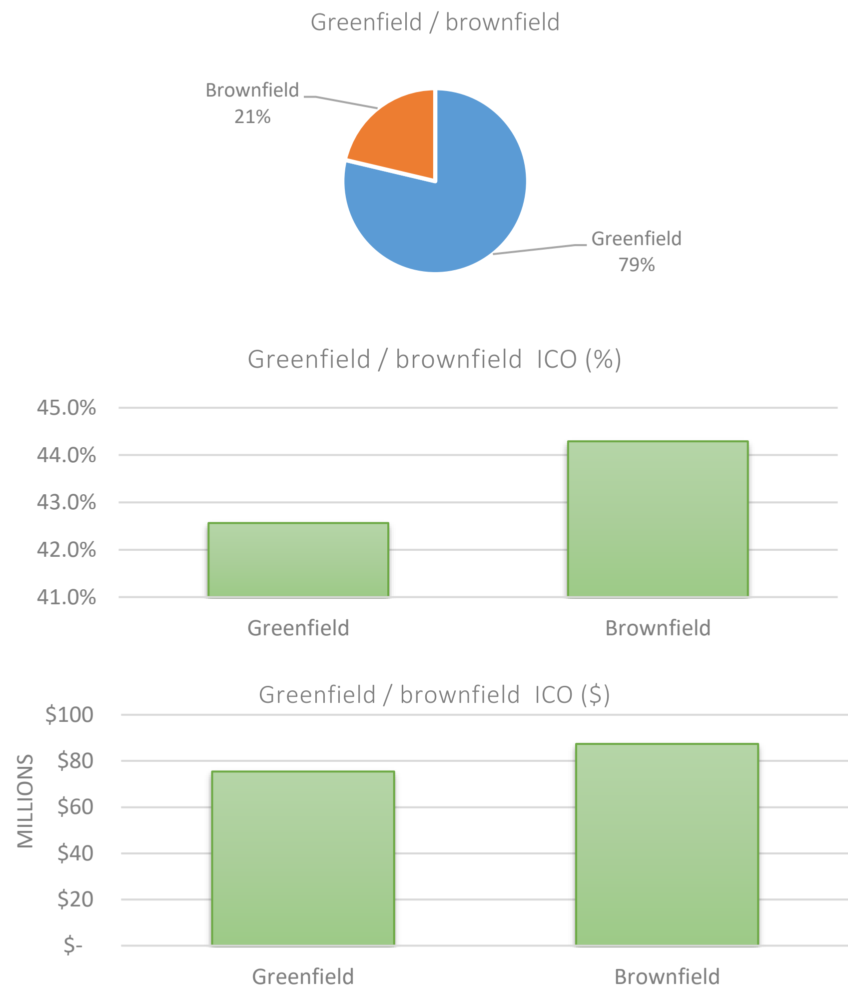


Figure 17: Data visualization of the initial capex overrun compared to the greenfield vs brownfield distribution.

4.1.3 Feasibility author internal vs external

4.1.3.1 Data observation

Roughly a third of the gold projects have had in-house feasibility authors during the feasibility process. The data suggests that these projects on average experience an ICO of 37,5%. This is 7% lower than the projects where the feasibility study has been written by external parties. In absolute terms, we see a similar observation.

4.1.3.2 Data interpretation

The vast majority of the projects have had an external party in charge of the feasibility study process. Unfortunately, due to a lack of data, no comparison can be made to the percentage of external feasibility study projects of all gold projects. The larger average ICO for external authors however is noticeable and significant. An argument is that internal authors are personally involved the project (in terms of a profit bonus or relative end of the year bonus), and will be more eager to stand up against management when certain proposed changes are being discarded. An external author aims to deliver a good value project as well, but at the same time might be less eager to stand up against management of their customer. This theory agrees with a theory proposed by Paul Harris, where the following is stated in the Mining Journal of July 2017:

“The use of consultants is widespread in the industry as they bring expert knowledge and opinion for a temporary, if expensive, period. However, their clients often guide where they want to the consultant to get to with a study driven by considerations such as a target capital expenditure figure or production rate. This pressures them to give optimistic outcomes. Very few consultants will put their heads on the block, disagree with the owner and say that a decision is wrong. Consultants don’t stand up vociferously against things that clients want to do that they don’t believe are in their client’s best interests, which is something they should do.”

The dataset analysis and the theory regarding the feasibility author agree, and state projects with in-house authors experience smaller capex overruns. This result is to be used for risk assessment purposes.

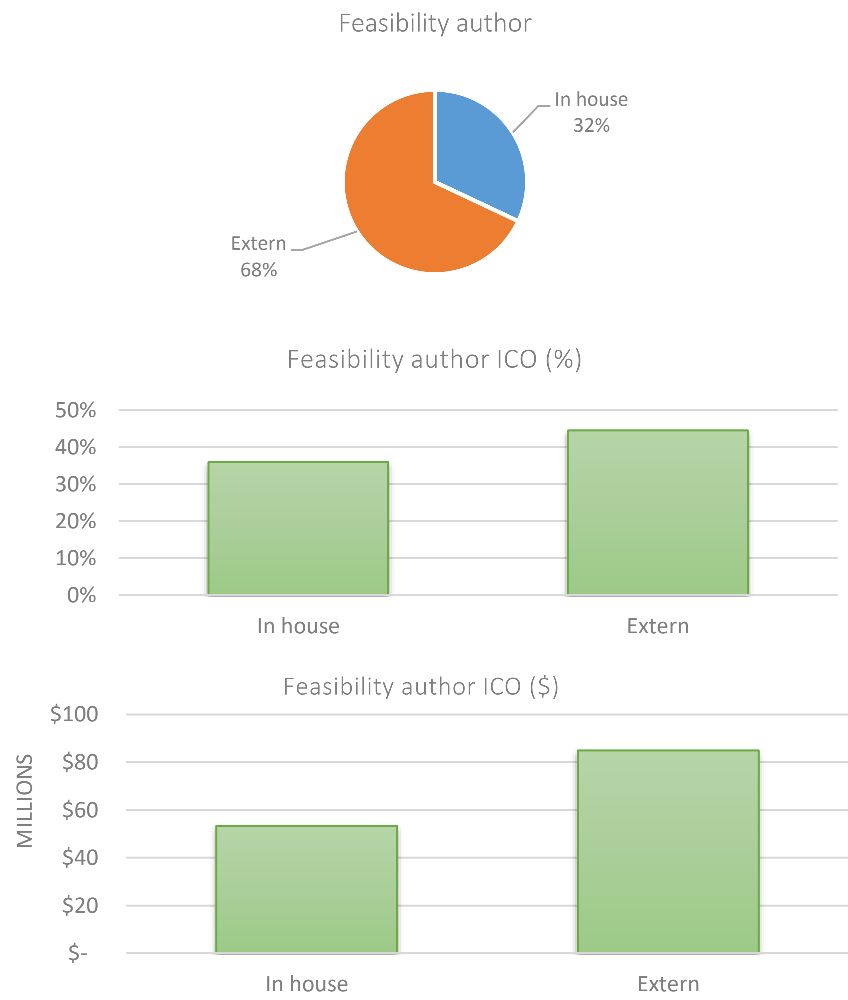


Figure 18: Data visualization of the initial capex overrun compared to the feasibility author

4.1.4 Processing plant capacity

4.1.4.1 Data observation

The pie chart in Figure 19 shows the data is evenly distributed in terms of processing plant capacity using the selected boundaries. The gold projects with processing capacity < 1000 ktpa have experienced averagely 80% ICO. Projects with processing capacity > 1000 ktpa averagely show a smaller average ICO, varying between 40% – 50%.

The absolute ICO in dollars for the database projects is larger when the processing plant capacity gets larger. This makes sense as the project generally is larger when the processing plant is larger, thus more expensive.

4.1.4.2 Data interpretation

The data suggests gold projects with small processing plants tend to experience a significantly larger ICO than projects with larger processing plants (>1000 ktpa). When a gold project requires a small processing plant, it typically means the entire project is relatively small. When the mining project itself is relatively small, the initial capital expenditure is relatively big compared to the total cost of the project. This is due to the fact that certain investments need to be made (e.g. infrastructure) regardless of the project size. When an unexpected expense occurs, this expense will be relatively big compared to the entire initial investment. When this same unexpected expense occurs in a larger project, this will be smaller on a relative scale.

The suggestion made by the data that smaller capacity processing plants tend to experience a higher capex overrun in the case an ICO is present, is found plausible. This observation will therefore be used for risk assessment purposes.

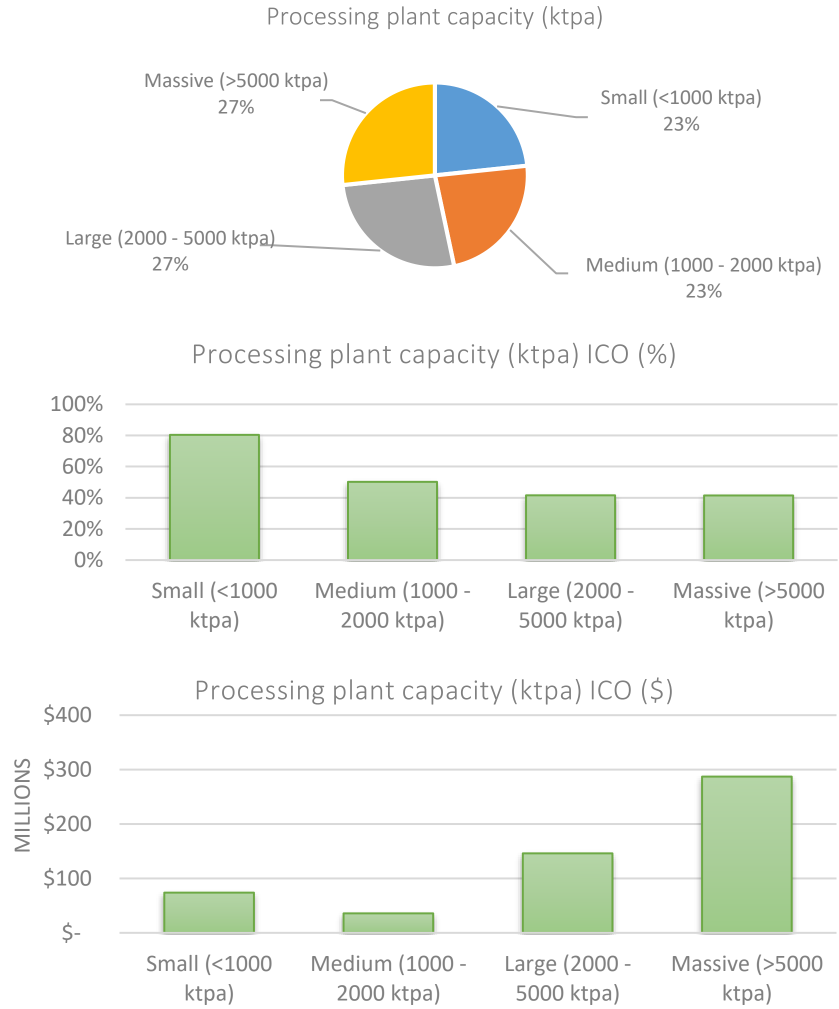


Figure 19: Data visualization of the processing plant capacity compared to the initial capex overrun

4.1.5 Processing method

4.1.5.1 Data observation

The vast majority of the gold projects in the developed database (92%) make use of a leaching method, namely heap leaching (HL) or carbon-in-leaching (CIL). Flotation seems to be the best performer in the bar charts, however this is based on only one project and it's a relatively old (BFS 1985) in the database. Carbon-in-pulp (CIP) is and HL are performing similar, with an average ICO of ¬ 43%. The CIL projects experienced a larger ICO of 52%.

4.1.5.2 Data interpretation

Due to the small sample size of the flotation projects, flotation projects are not used for prediction purposes. The two dominant processing methods (HL and CIL) have a difference of 9% with regards to the ICO. Though this difference is present, it is not exceptionally large. The processing methods are relatively similar and therefore similar investments for both techniques are required (La Brooy, et al., 1994). Furthermore, documentation does not suggest any difference in the development phase of the project (La Brooy, et al., 1994). Due to the similarity of these processes it is difficult point out a root cause to this analysis. The relatively small difference in the ICO and the lack of confirming literature result that the processing method is not to be used for risk assessment purposes.

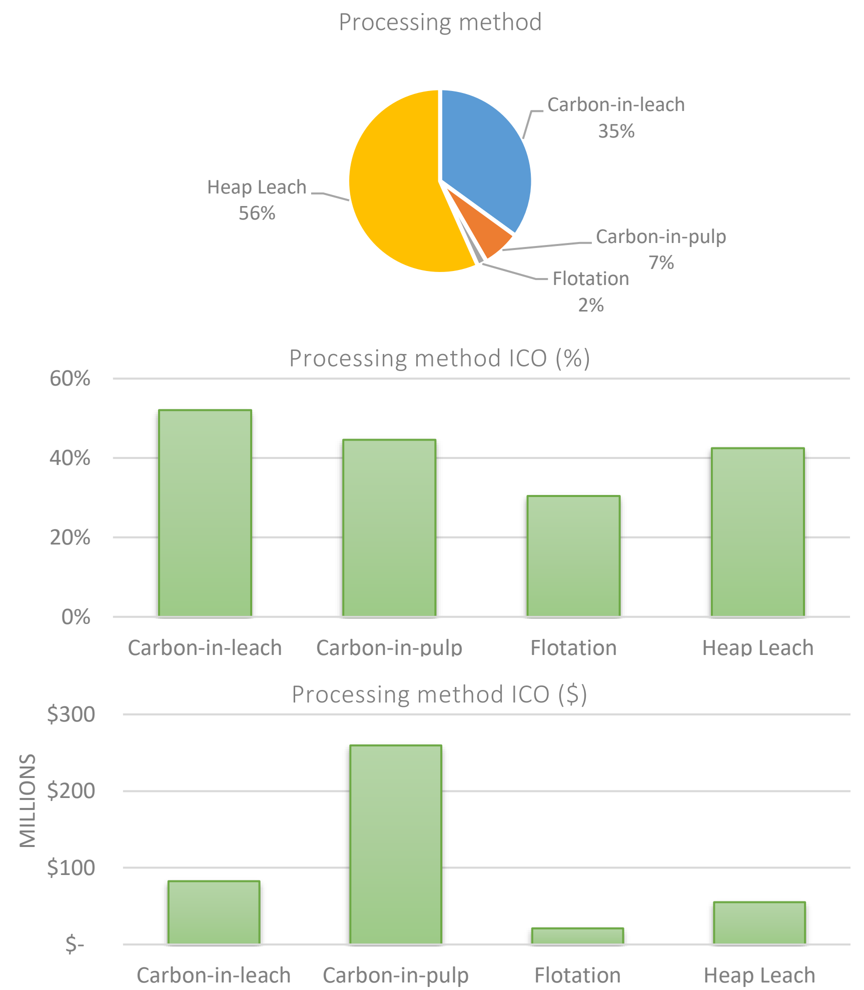


Figure 20: Data visualization of the different processing methods compared to the initial capex overrun.

4.2 Financial factors

4.2.1 BFS capex estimate

4.2.1.1 Data observation

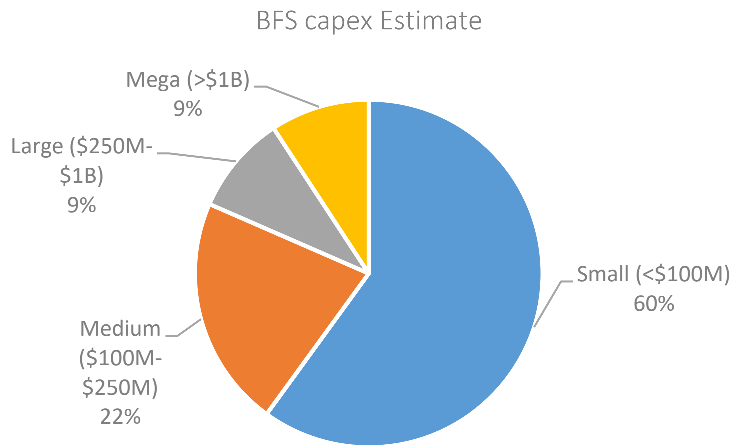
A large part of the projects is considered small mining projects (<$100m). Combined with the medium sized projects, these two account for more than 80% of the database. When a project experiences an ICO, small and medium projects averagely see an overrun between 45% - 50%. Larger projects (>$250M) generally experience a smaller overrun, between 30%- 40%. The bar chart comparing the absolute overrun in dollars is not displayed, as larger projects obviously experience larger overruns in an absolute sense.

4.2.1.2 Data interpretation

The observation that the majority of the projects are small projects is surprising considering the average initial capital cost of gold mining projects generally is relatively high.

The data suggests smaller projects (<$250M), that is projects that have a relative small initial capex estimate, experience a larger ICO than larger projects (>$250M). This agrees with the observation seen in the analysis in subchapter 4.1.4 Processing plant capacity. The argument made in that subchapter stands here as well, suggesting the same unexpected expenditure has a relatively larger impact on a smaller project then on a larger project.

As the trend seen in the data analysis regarding the BFS capex estimate agrees with earlier findings, the result is taken into account for risk assessment purposes.



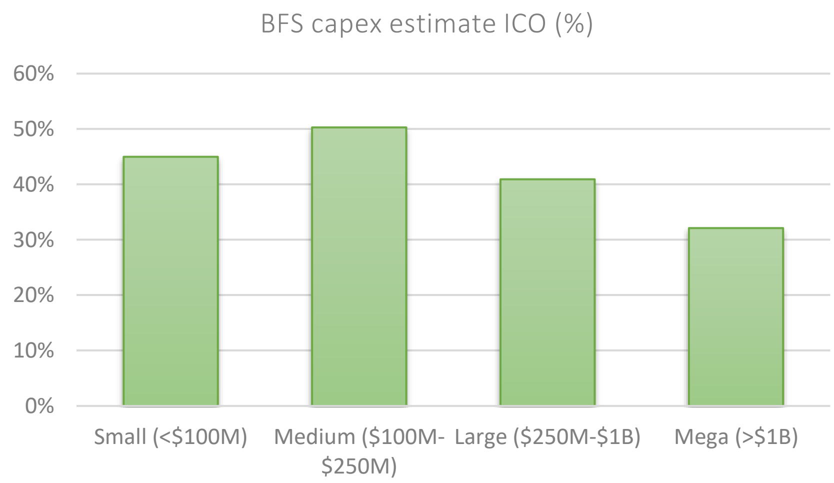


Figure 21: Data visualization of the bankable feasibility study capex estimate compared to the initial capex overrun.

4.2.2 Market capitalization of the company at BFS publish date

4.2.2.1 Data observation

The size of the project owners is quite evenly distributed. The data suggests small companies tend to have a smaller ICO than major companies, however the difference is marginal (<10%). In absolute terms, the major companies experience much larger overruns This is expected because the projects of major companies normally are larger as well.

4.2.2.2 Data interpretation

Over the last 20 years the role and importance of the junior sector has risen. Juniors accounted for 70% of the total number of deposits found and 50% of the value created. Major & moderate producers were responsible for 18% of the projects and 35% of the value. (Schodde, 2017). The distribution of the analysed data roughly agrees with these statistics. Regarding the quality of the feasibility study, Paul Harris wrote in the following in the Mining Journal 2017: "Company size invariably plays a role in this, as smaller juniors don't have the cash to undertake the same level of testing as larger companies do. Tier-one miners have very strict guidelines and checklists to make sure nothing is missed, whereas juniors are prepared to take short cuts." (Harris, 2017). This is contractionary with the analysed database, which suggests the junior companies are more precise as they experience a smaller ICO.

It could be the case that major mining companies may have the capacity to self-fund projects, so a definitive feasibility study does not represent the same milestone it does for a junior. A junior is under pressure to justify its next capital raising and a high quality definitive feasibility study is how they can do this. The major companies also have tried and tested routes for building mines. They will have deep ties with contractors built up over years, so a typical construction blueprint will already be in place. Junior developers have to put more effort in estimating these numbers correctly.

Due to a shown correlation in the dataset and the consistency of the observation that relatively small companies tend to overrun less, the results of the market capitalization analysis shall be used for risk assessment purposes.

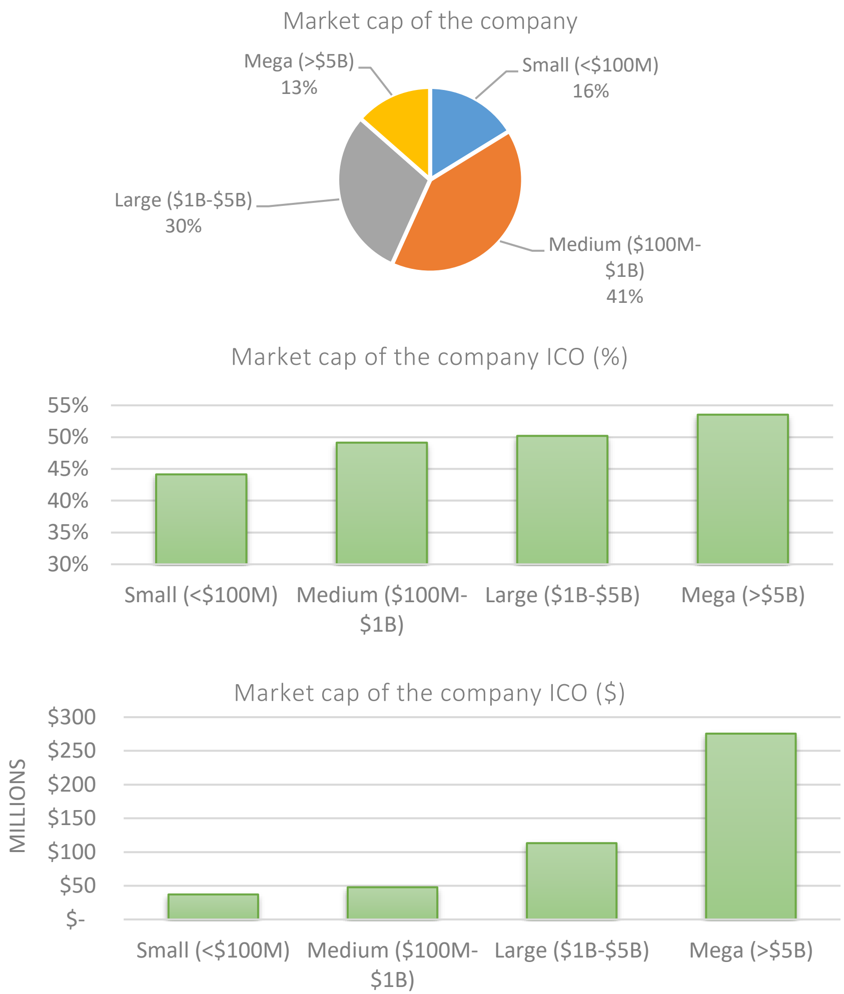


Figure 22: Data visualization of the market cap of the owning company compared to the initial capex overrun.

4.2.3 Relative project size (capex / market cap)

4.2.3.1 Data observation

The database shows more than half of the analysed projects' initial capex estimate are a small part (<15%) of the owning company. What else can be observed from Figure 23 is that the data suggests that projects that are relatively big to the company (>15%) tend to overrun less. The average difference between relatively small projects and one-asset company projects is ~15%.

4.2.3.2 Data interpretation

When a mining project is relatively small compared to the market capitalization of the company, this is an indication the company itself most likely is a relatively large company. Subsequently, when projects are relatively large compared to the market capitalization of the company, this indicates the company itself most likely is a smaller company. The data suggests that major companies, where the project is one of several projects, tend to overrun more than junior companies. Big companies likely have a stronger financial position and are have more access to immediate capital to deal with unexpected expenses, and therefore can cope with an overrun situation more easily than a junior company (Mular & Baratt, 2002). A major company might want to get the project into production, generating revenue, accepting the additional risk regarding a possible ICO. If an ICO occurs, major companies normally have the financial strength to deal with this, or otherwise have incoming revenue from other projects that can be used to pay for the ICO. Junior companies likely are completely depended on the success of the one project, making the projects 'make-or-break' situations for the company. An ICO is fatal for the company, as there is most likely is no financial strength to deal with this kind of setback, and the investors likely will have to be approached for extra funding. Due to this, junior companies probably are more careful making sure an ICO does not occur than major companies.

Due to the excessive presence in the analysed projects, and the high ICO on average, the small projects are being considered an extra risk. This will be taken into account for predictive purposes.

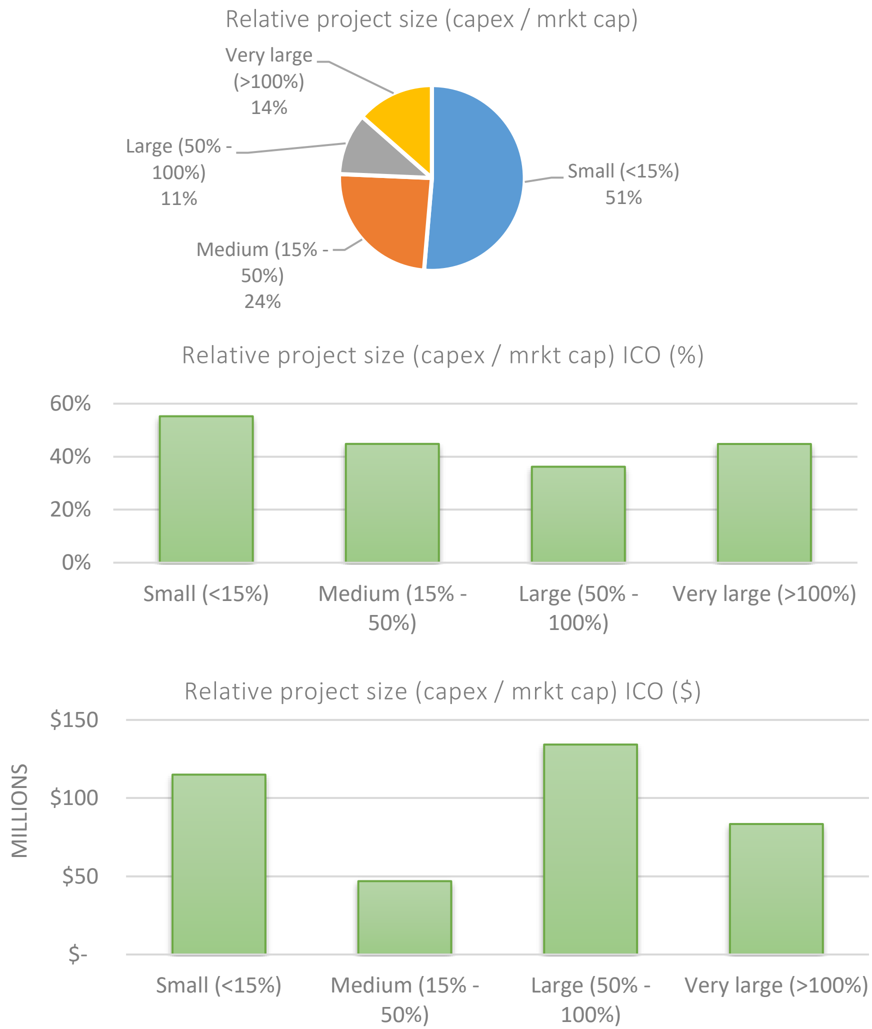


Figure 23: Dataset visualization of the relative project size compared to the initial capex overrun.

4.2.4 DEBT-TO-EQUITY RATIO AT FEASIBILITY

4.2.4.1 Data observation

A third of the projects do not have any outstanding debt at all, which means they are fully funded by equity. The other projects in the database are equally divided between little leverage and no leverage. The projects with no debt on average experience 38.8% overrun, where the projects with high leverage on average experience 73.2% overrun. Projects with little debt on average have 51.2% capex overrun.

4.2.4.2 Data interpretation

The data suggests there is a positive correlation with the amount of debt and the magnitude of an ICO. Projects that are financed with a high amount of debt (>20%) tend to overrun significantly more than projects that are financed without any debt. An explanation could be that companies that do not have any outstanding debt on their projects have more incentive to make a project start successful, as the initial capital invested is from the shareholders themselves. It is their own money that is at stake and they are hold accountable for the success of the project. As discussed in chapter 3.3.4, junior companies are generally limited to equity due to the high risk of achieving an exploitation phase with the project. Banks are not eager to issue debt, and the debt-to-equity ratio of junior companies in the exploration phase is generally low. The assumption is made that the companies within the analysis with little to no debt and overrun less are represented by the junior mining companies. The companies with relatively high leverage are generally larger mining companies.

The capex performance study performed by EDC (Lwin & Lazo, 2016) indicates mining projects with a relatively high debt tend to exceed the initial capital budget more than projects with low debt. This agrees with the results from the database.

The data shows a strong correlation for the D/E ratio and the analysis agrees with literature listing. Furthermore, the interpretation that relatively small companies tend to overrun less is consistent with earlier observations. The result is taken into account for risk assessment purposes.

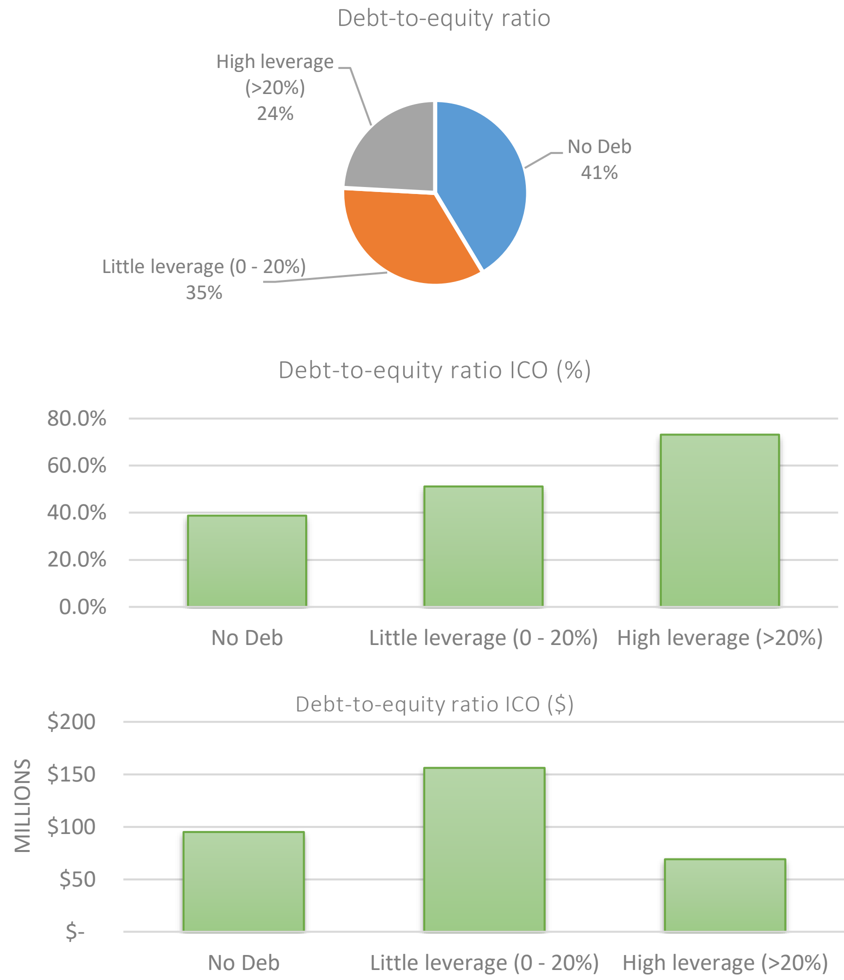


Figure 24: Data visualization of the projects regarding the debt-to-equity ratio compared to the initial capex overrun

4.2.5 COMPANY LISTING MATURITY AT BFS PUBLISH DATE

4.2.5.1 Data observation

The period companies have been listed is evenly divided using the selected boundaries. What can be seen quite obviously in Figure 25, is that the relative ICO seems to increase when the company listing time increases. Companies that have been listed for 5 years or less, averagely experience an ICO of ~30%. Companies that have been listed between 5 – 15 years overrun ~45%. Companies that have been listed for more than 15 years averagely experience an ICO of ~60%.

4.2.5.2 Data interpretation

The data suggests that the younger companies perform better in terms of ICO than the older companies. Younger companies typically are junior companies, whereas the major companies normally have been active for a longer period of time. Therefore, it is assumed the companies that have been listed for <5 years are to be considered junior companies, whereas the companies that have been listed for longer than >15 years are to be considered major companies. It should be noted that companies formed by merger and acquisitions can be considered large companies even though they have been listed for a relatively short time.

Following this assumption, a similar trend is seen in this analysis regarding the company size. Junior companies typically are very dependent on the outcome of the project and do not have the financial capacity to deal with ICOs, whereas major companies want to achieve production fast to generate revenue, accepting a possible extra amount of risk regarding the initial development stages.

Due to the clear trend that can be seen in the data analysis, and the agreement regarding the size of the company seen in the other analysis, the listing time at BFS publish date is to be used for predictive purposes in the model.

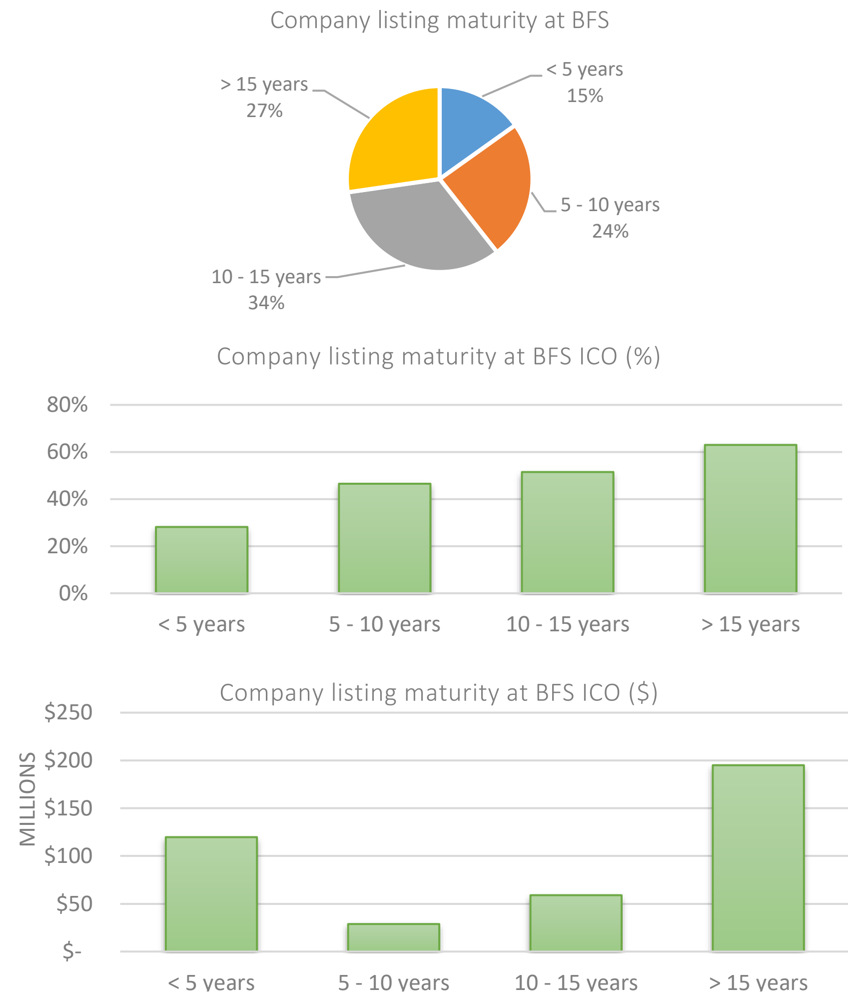


Figure 25: Data visualization of the projects regarding the time the owner companies have been listed at the stock market at BFS publish date compared to the initial capex overrun.

4.2.6 SHARE PRICE HISTORY OF THE COMPANY

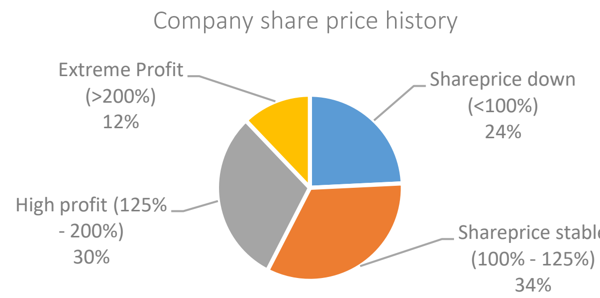
4.2.6.1 Data observation

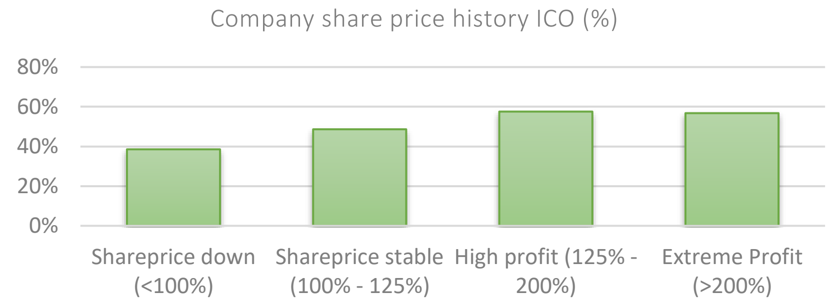
The majority of the projects (76%) show an increase in the share price at the BFS publishing date, relative to six months earlier. The data suggests that project where the company share price is healthy, tend to overrun more than projects where the company shares are unhealthy.

4.2.6.2 Data interpretation

The suggestion that companies where the financial health of the shares has decreased compared to six months earlier tend to experience a smaller capex overrun is counter intuitive. No literature is found validating this observation. A theory for the scattered data could be that the major companies are only slightly impacted on their share price in correlation to one singular project. In the time period of six months before the BFS publish date, news about other projects could have more impact on the share price than the project registered in this database.

As the correlation found between the company shares health and the ICO is weak, and no literature is found to substantiate the correlation, it will not be used for predictive purposes in the risk assessment model.





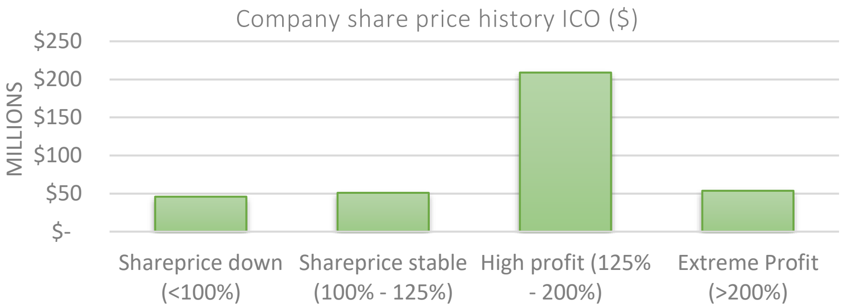


Figure 26: Data visualization of the projects regarding health of the shares of the owning company compared to the initial capex overrun.

4.2.6.3 Capital intensity (capex estimate / ktpa)

4.2.6.4 Data observation

The projects sorted on capital intensity are evenly distributed using the selected boundaries. The relative ICO nor the absolute ICO seem to have any relation related to the capital intensity, as the data is scattered.

4.2.6.5 Data interpretation

The data suggests there is no correlation between the capital intensity and the ICO. The literature does not document on correlations between capital intensity and ICO. It is interesting to notice that the capex estimate and the production capacity as separate variables do seem to show a correlation with the ICO, but as a function of each other do not.

As there is no correlation observed in the database analysis, and no literature documents are found stating a possible correlation, this variable is not to be used for predictive purposes.

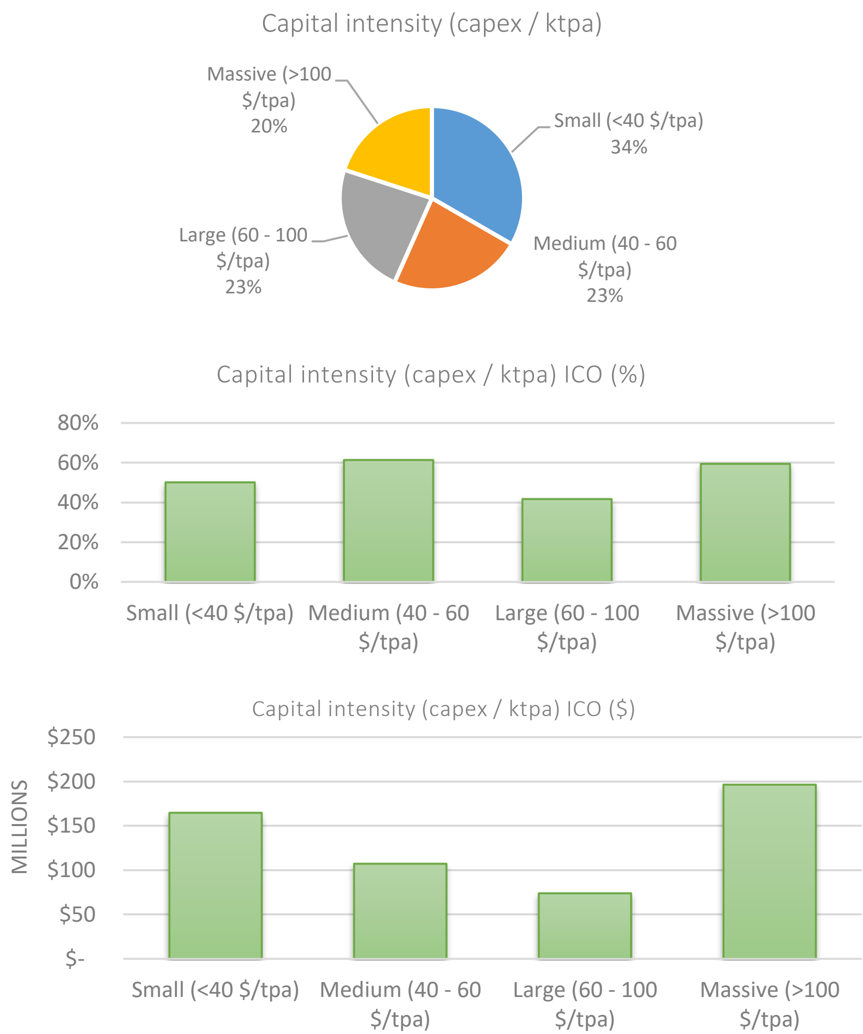


Figure 27: Data visualization of the capital intensity of the projects compared to initial capex overrun.

4.2.7 IRR

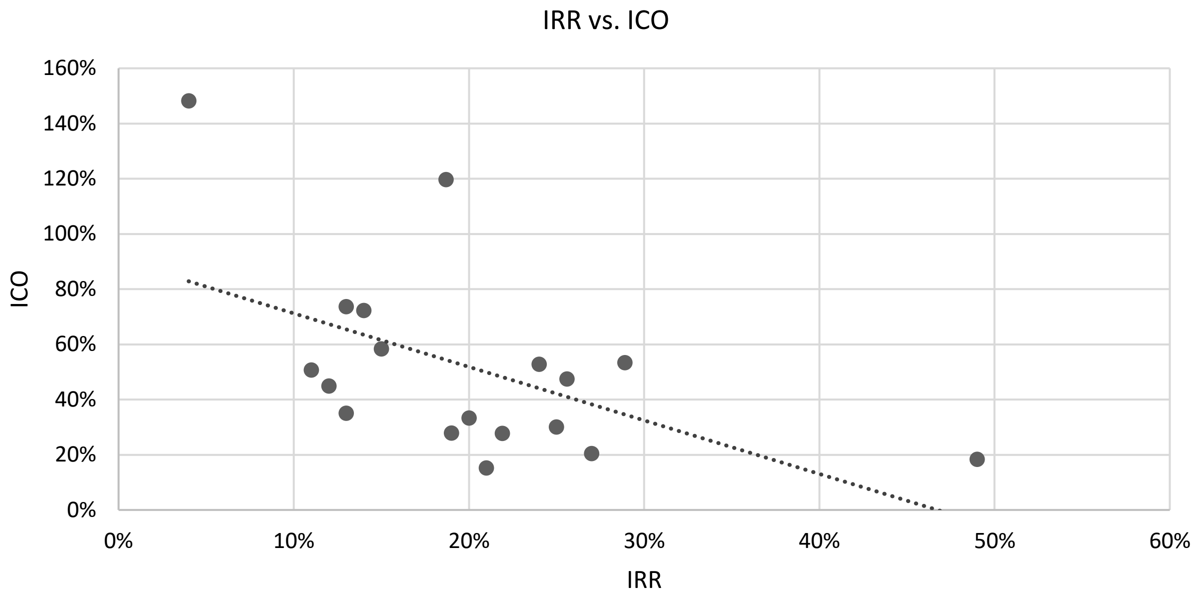


Figure 28: A scatterplot of the relative Initial Capex Overrun (ICO) versus the Internal Rate of Return (IRR)

4.2.7.1 Data observation

The scatterplot shows the IRR documented in the BFS relative to the experienced capex overrun. The majority of the projects are centred within the 10% - 30% IRR region, where the ICO of the most projects varies between 20% - 80%. When including the three big outliers, and looking at the general direction of the scatterplot, one could argue there is a relation between IRR and ICO. This relation would suggest that a higher IRR would result in a lower ICO in the case an overrun is experienced.

4.2.7.2 Data interpretation

The IRR generally is a measure of project quality. This analysis indicates that the better the estimated quality of the project is, the smaller the expected capex overrun is. This observation agrees with the hypothesis. The IRR analysis is to be used for predictive purposes in the risk assessment model using a formula presented in Chapter 5.

4.2.8 Payback period

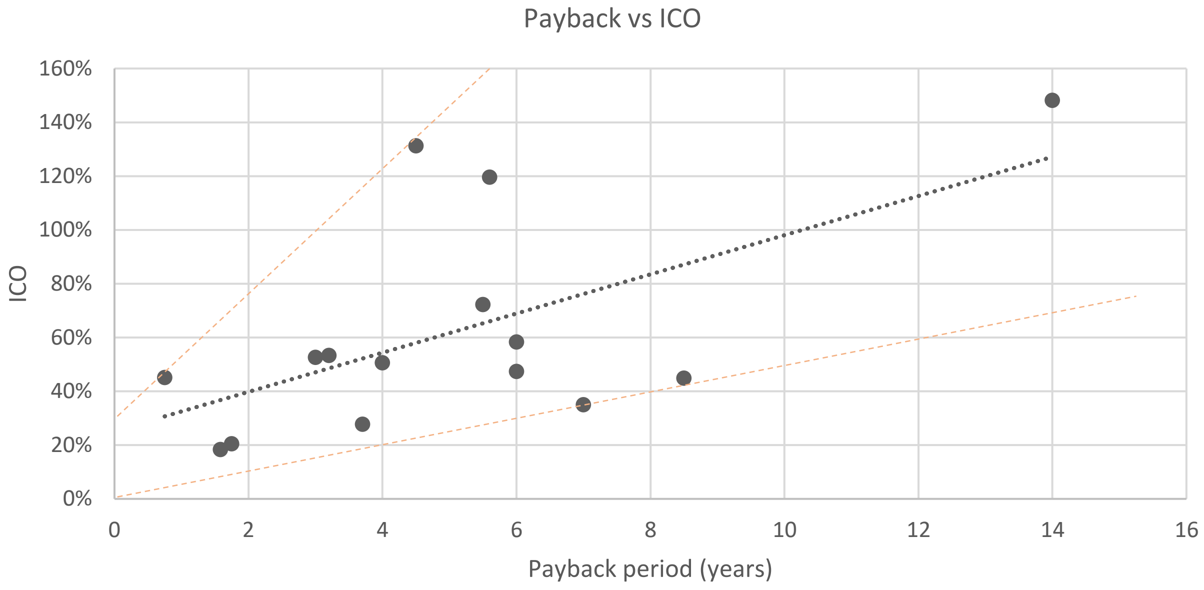


Figure 29: A scatterplot of the relative Initial Capex Overrun (ICO) versus the Payback period

4.2.8.1 Data observation

The scatterplot from Figure 29 suggest there is a positive correlation between the amount of payback years estimated in the BFS, and the ICO experienced during mine development. The deviation is significant, and gets larger when the amount of estimated payback years increases.

4.2.8.2 Data interpretation

Primarily the amount of payback years can be interpreted as a quality indicator of a mining project. A lower amount of payback years indicates a higher quality project. Same as for the IRR analysis, the observation that relatively high-quality projects expect a smaller capex overrun agrees with the hypothesis. A supporting theory is that once the commitment has been made that the payback period will be short (<2 years), there lays a certain amount of pressure on the initial execution phase of the project. Therefore, the initial phase is prepared accurately. If the BFS states a project will take at least six years to get break even, the pressure in the initial phases is much less as the time for revenue generation can be spread out over a longer period, resulting in more room for capex overrun.

Though the spread of the scatterplot is large, a correlation is observed in the database analysis. The payback period analysis is to be used for predictive purposes in the risk assessment model using a formula presented in Chapter 5.

4.2.9 NET PRESENT VALUE

4.2.9.1 Data visualisation

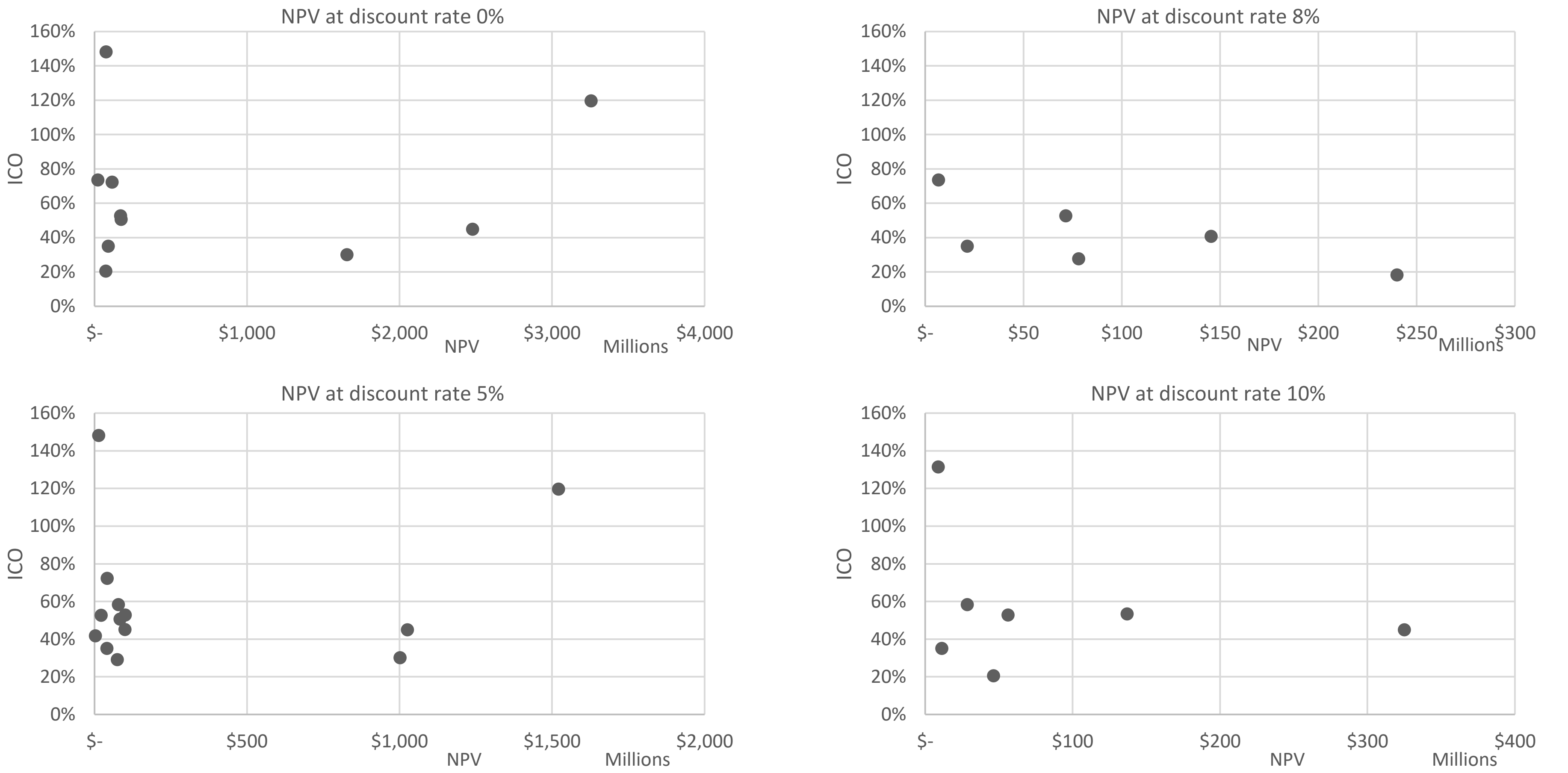


Figure 30: Four scatterplots, showing the Initial Capex Overrun (ICO) versus the Net Present Value (NPV) at different discount rates (0%, 5%, 8%, 10%).

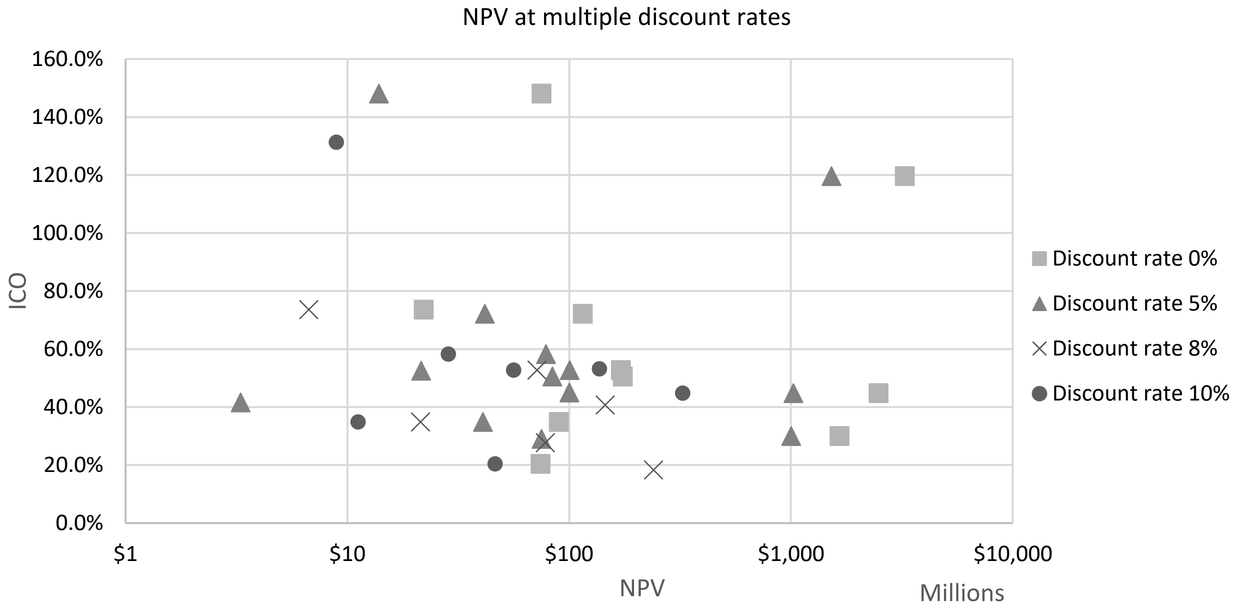


Figure 31: Scatterplot of the Initial Capex Overrun (ICO) versus the Net Present Value (NPV) at different discount rates in one plot. The x-axis is in a log-10 scale, as there are several high values present in the plot.

4.2.9.2 Data observation of the Net Present Value

The number of projects that can be compared per individual discount rate is low, as not all the feasibility studies document NPV with the same discount rates. This results in a small dataset per discount rate to analyse. In the NPV analysis at discount rate 8%, there seems to be a negative correlation with the ICO. However, there are only six data points in this analysis. Aside from two outlying data points at discount rate 0% and 5%, there seems to be a general trend that the projects with a high NPV value in dollars generally result in a relatively low ICO if an ICO is experienced. Figure 31 shows the NPV's of the four discount rates combined in one plot, with the x-axis in a log-10 scale for readability due to several high values. However, no correlation seems to be present.

4.2.9.3 Data interpretation of the Net Present Value

The observation that high value NPV projects generally result in a relatively low ICO is not unexpected. It is possible that low value NPV projects are more often subject to an excessive amount of financial engineering than high value NPV projects, making the project look better on paper. Especially regarding initial capital costs. Since these costs are barely discounted, the NPV of a project may improve dramatically as a result of underestimated capital costs. In other words, NPV is related to capital cost on a roughly dollar per dollar scale. The lower the capital cost the higher the NPV, the higher the NPV the better the project in the eyes of the financier, and the better the project the more likely it will reach the top of the pecking order for financing. (Bertisen & Davis, 2007). These projects that are financially 'over'-engineered then are more likely to overrun, and overrun harder.

Even though one could suggest a correlation is found in the analysis, the results of the analysis displayed in Figure 30 are not strong enough to justify the development of a predictive formula. Due to the difficult comparisons and the inconsistencies in the analysis, the NPV correlation will not be taken into account in the predictive model.

4.2.10 RELATIVE POSITION IN COMMODITY CYCLE

4.2.10.1 Data visualisation and observation

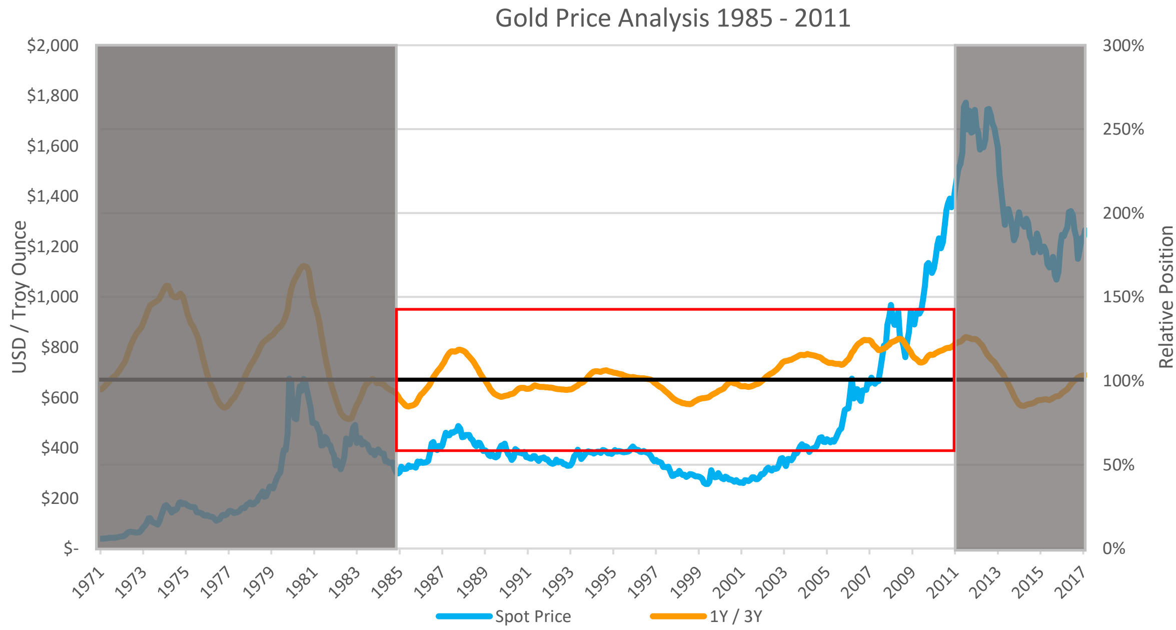


Figure 32: This graph represents the relative 'attractiveness of the gold price. The blue line represents the spot price of gold in USD per troy ounce (left axis). The orange line represents the one-year average of the spot price divided by the three-year spot price (right axis). When the grey or the orange line lies above the black 100% line, the market is considered 'attractive'. The focus of the analysis is on the period 1985 – 2011 (red rectangle) as the projects in the database are from this period (London Stock Exchange PLC, 2013)

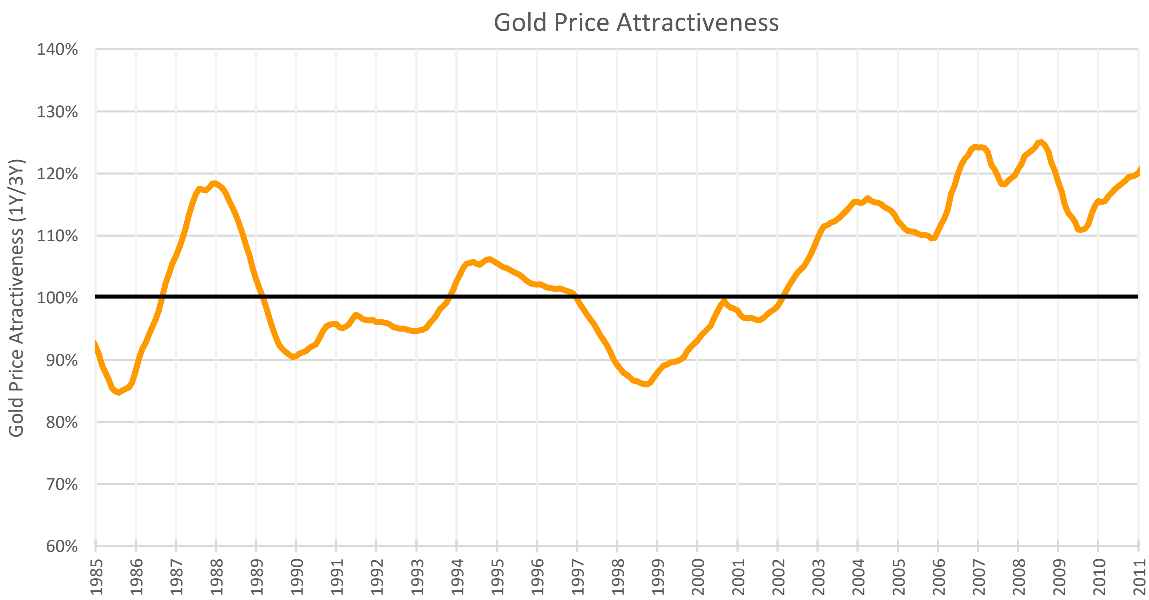


Figure 33:. This graph displays the period of 1985 – 2011 and shows the gold price attractiveness, defined as the one-year average gold price relative to the three-year average gold price. When the orange line is above the black 100% line, the market is considered 'attractive'. (London Stock Exchange PLC, 2013)

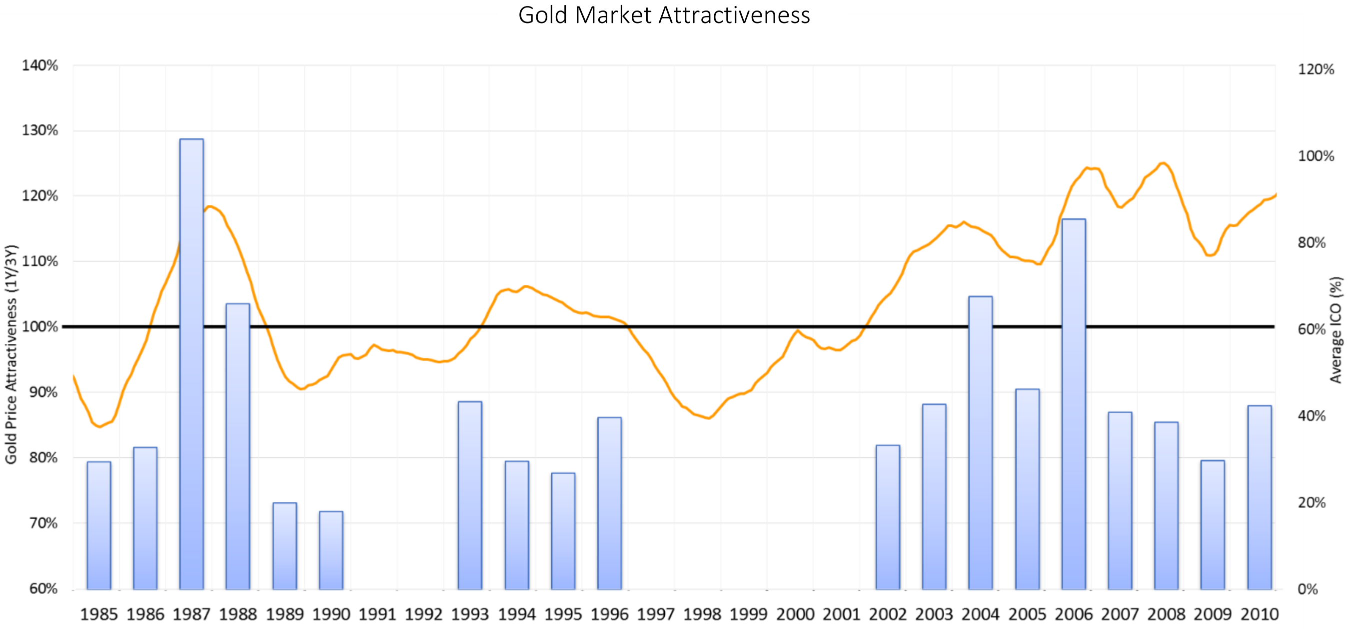


Figure 34: This graph shows the average capex overrun of the gold projects in the database collated per year. The orange line represents the relative gold price, which indicates the 'attractiveness' of the gold market. When the orange line is above the black 100% line, the market is considered 'attractive'.

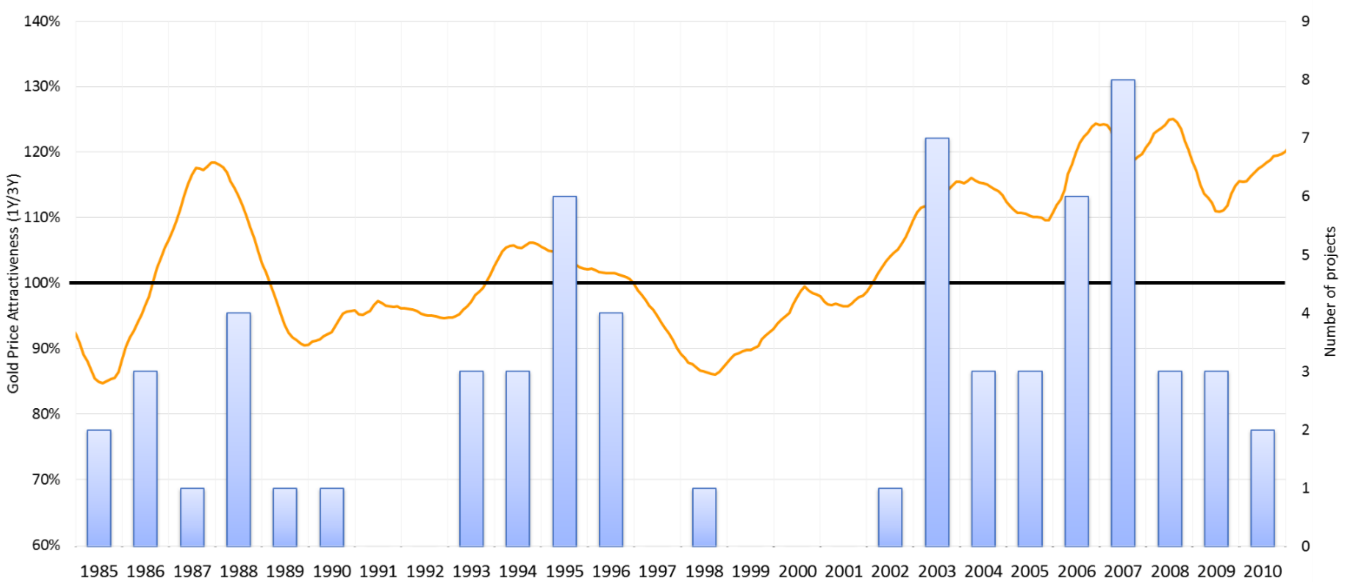


Figure 35: This graph shows the number of gold projects that experienced a capex overrun registered in the database, collated per year. The orange line represents the relative gold price, which indicates the 'attractiveness' of the market. When the orange line is above the black 100% line, the market is considered 'attractive'.

4.2.10.2 Data observation

Figure 34 shows the possible correlation between the relative gold price (gold market attractiveness) and the magnitude of the ICO of the projects that published their BFS in the same period. A distinction can be made in the magnitude of the relative gold price. When the relative gold price is between 100% -110% the market is considered 'attractive'. When the relative gold price is above 110%, the market is considered 'extremely attractive'. The gold projects from which the BFS was published in 1987 and 1988 on average have experienced a relatively high ICO. During this same period ('87 – '88) the relative gold price is high, peaking at almost 120%. In a period like this, the gold market is considered 'attractive'. A similar effect between the attractiveness of the gold market and the average magnitude of the ICO of the registered projects in the database can be seen in 2004 and 2006. The height of the relative gold price seems to be positively correlated to the height of the capex overrun. For projects where the relative gold price was 100% - 110% the average capex overrun is 30.1%. For projects where the relative gold price was larger than 110%, the average capex overrun is 54.4%. In figure 35, a comparable correlation can be observed. This correlation however is expressed in the presence of projects that experienced an ICO and the relative gold price. In the period 1989 – 1992 the relative gold price was low and the market was to be considered 'cool'. In this period ('89 – '92) only two projects are registered in the database that have experienced an ICO. In the consecutive period ('93 – '96) where the gold market was to be considered 'attractive', 16 projects were registered in the database experiencing an ICO. Similar effects can be seen in the consecutive 'unattractive' market period 1997 – 2001 and in the 'attractive' market period 2002 – 2010. In total, 86% of the projects that experienced a capex overrun had their BFS published in 'attractive' commodity market conditions.

4.2.10.3 Data interpretation

Projects that published their BFS at the moment the relative gold price was high (>100%) and therefore the gold market was 'attractive', tend to overrun more and higher on average. This possible relation most likely is a combination of several characteristics resulting from the relative gold price. First of all, a theory is that during 'attractive' commodity prices the executing stakeholders of the project have more incentive to put a potential project in the development phase as soon as possible. This way the relatively high gold price can be exploited as soon and as long as possible. This decision sometimes could mean a project is initiated before the project is actually ready for development. This can result in a capex overrun to be expected more often. Mining projects always reach point where the following choice has to be made: further detailed research/engineering to increase the accuracy of the study OR to go ahead, apply for funding and start development. When the gold price is high and therefore the market is attractive, the project will more likely make the decision to apply for funding and develop the project, than when the prices are low and the market is unattractive. In some cases, however, it might be the more logical choice to enhance the accuracy of the feasibility study to get a more comprehensive understanding of the development construction and the therefore the capex estimate. It is also possible executive stakeholders are aware of this additional risk, but the expected additional generated revenue due to the high gold prices make it worthwhile.

During the prosperous times of a 'attractive' commodity market, there is a high demand for skilled personnel in all aspects and departments of mine development and mining engineering. As a result, some initiated projects during this 'attractive' times will have to settle for less skilled and experienced personnel for the developing phase of their mining projects. This temporary shortage of skilled personnel applies for all educational levels, from the mine developer to the contractors and for managing personnel. In a 'unattractive' commodity market the less skilled people are the first ones who will be let go. This results in relatively high skilled personnel responsible for mine development in a 'unattractive' market. This phenomenon supports the theory of poor mine development and poor development execution in a 'attractive' commodity market. The relative gold price gives a direct indication for investors whether the market conditions are fit for investing from a capex overrun perspective. This relatively easily calculated variable therefore has a powerful predictive capacity. According to this theory, the projects that published their BFS study in 2014 – 2017 should generally experience less frequent and less intense capex overruns. This is because the relative gold price was under 100% for this period (see Figure 32). It is observed that the number of projects experiencing an ICO registered in the database are significantly higher during a 'attractive' commodity market. Simultaneously, the number of projects registered during 'unattractive' commodity market is very low, and even zero for multiple years. It is expected that the general number of projects initiated during a 'unattractive' commodity market is lower than in a 'attractive' market. However, Figure 11 indicates even during the 'unattractive' times, plenty of gold projects were being developed. Furthermore, it should be noted that the analysis regarding the correlation between the presence and magnitude of ICO and the relative commodity price was conducted after the database was populated. In 'extremely attractive' market conditions, projects seem to overrun slightly more than during 'attractive' market conditions. This distinction and definition shall be used for the predictive model. Combining the interpretations, the data seems to suggest there is a strong correlation between the relative position in the gold price cycle and the presence and the magnitude of an ICO. This correlation will be used for predictive purposes.

4.2.11 INITIALIZING TIME

4.2.11.1 Data observation

The vast majority of the analysed projects (87%) started construction within a year after BFS publishing. The projects that started almost immediately after BFS publishing on average experienced a relatively large ICO of 58%. Projects that started construction between 1 – 12 months after BFS publishing, on average experienced a capex overrun between 40% - 46%. When it takes more than 12 months before construction starts after BFS publishing, projects on average experience the largest overrun (75%). The average time between BFS publishing and the start of construction is 5.3 months for the developed database.

4.2.11.2 Data interpretation

Up until 12 months after BFS publishing the data suggests there is a negative correlation with the ICO. In this time permits can be requested and deals can be made with contractors, where there is still time for delay. The data suggests the ideal moment to start construction is between 6-12 months after BFS publishing. When construction of a project is started directly after BFS publishing, the average capex overrun is slightly higher. This could be due to permitting and contracts that not have finalized yet, resulting in a delay and capex overrun. When it takes longer than 12 months however to start construction, the ICO of the projects increase drastically. This could be because permits, commitments and contract made are not valid anymore after 12 months or have to be renegotiated. Examples could be to contractor agreements, or equipment price, delivery and maintenance. The absolute overrun in dollars shows a similar negative correlation up until 12 months between BFS publishing and construction start. The ICO peak after 12 months is also visible in the absolute overrun, even more present than in the relative overrun analysis.

The negative correlation combined with the ICO peak after 12 months between BFS publishing and construction start show enough potential to use it for predictive purposes.

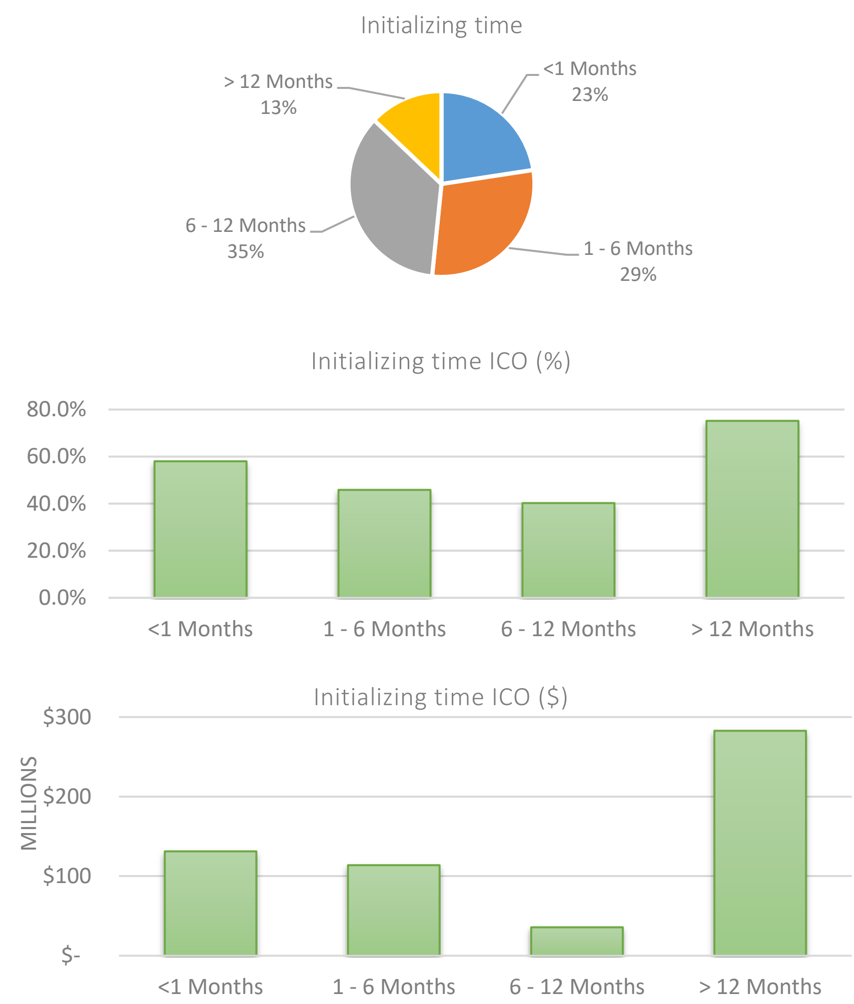


Figure 34: Data visualization of the initializing time of the projects compared to initial capex overrun.

4.3 Geographical factors

4.3.1 Project location

4.3.1.1 Data observation

The vast majority of the projects are located in North America, Latin America or in Africa. Only 12% of the projects are located somewhere else. The relative ICO is more or less the same for all project locations, where Latin America scores the best with an average ICO of 41%, and Africa scores the worst with an average ICO of 50%.

4.3.1.2 Data interpretation

The data shows little difference in ICO based on the project location. As mentioned, BHP Billiton adds an additional 2% on the discount rate if the project is located in Africa. Even though the average ICO for African projects is slightly higher, this seems like an exaggerated measure. It is noticeable that big mining country Australia is not significantly present in this database. This could be as the majority of the gold mining projects located in Australia are owned by companies located in Australia. Australian based companies are not exposed to the same regulations as e.g. companies based in North America and are not required do not report as much. This results in few suitable projects, and therefore an underrepresentation of Australian projects in the database.

Due to the little difference gathered from the analysed data, the project location is not included as a variable in the predictive tool.

Based on literature listings however, project location does have a relation with the initial performance of a mining project. The most important impact of the geographical location of the project is the relationship with the political risk. Projects that are located in politically unfavourable countries tend to underperform significantly more than in stable countries (Tufano, 1996). These governments are demanding greater control over mineral deposits and often are often seeking higher royalty payments, resulting in large delays.

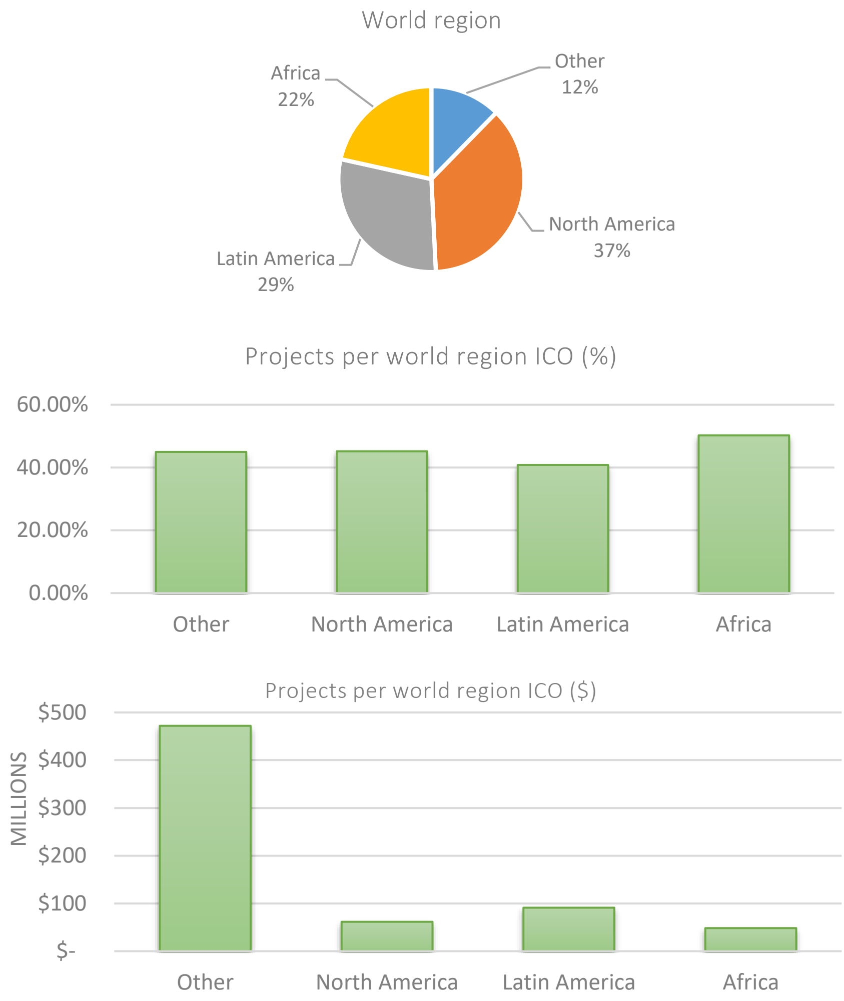


Figure 35: Data visualization of the projects distributed per world region compared to initial capex overrun.

4.3.2 Owner location at BFS publish date

4.3.2.1 Data observation

More than half of the projects (63%) are owned by companies having their head office in Canada.

In terms of relative ICO, Australian based company project score slightly better than US based company projects (resp. 31% vs 38%). Compared to Canadian based company projects, the Australian based projects score significantly better with an average ICO of 19% lower than the Canadian based company projects.

4.3.2.2 Data interpretation

The abundance of Canadian projects is a result of data acquisition due to personal communication. Six of the nine persons used for personal communications are from the North American region. Their focus was mostly on local projects, and therefore the database is biased in terms of owner location distribution.

The result regarding the relative ICO are surprising. Canada is the most transparent of the three major countries regarding feasibility study publishing and publishing data financial and production data in annual reports. One would expect that this 'forced' transparency results in relatively high-quality feasibility studies, as they are freely available for everyone to verify. Subsequently, these high-quality studies should generally result in a low ICO. The data however suggests Canadian based companies tend to overrun by almost 20% more relative to Australian based companies when a capex overrun is experienced.

Due to the significant difference in average capex overrun, the owner location is used for predictive purposes.

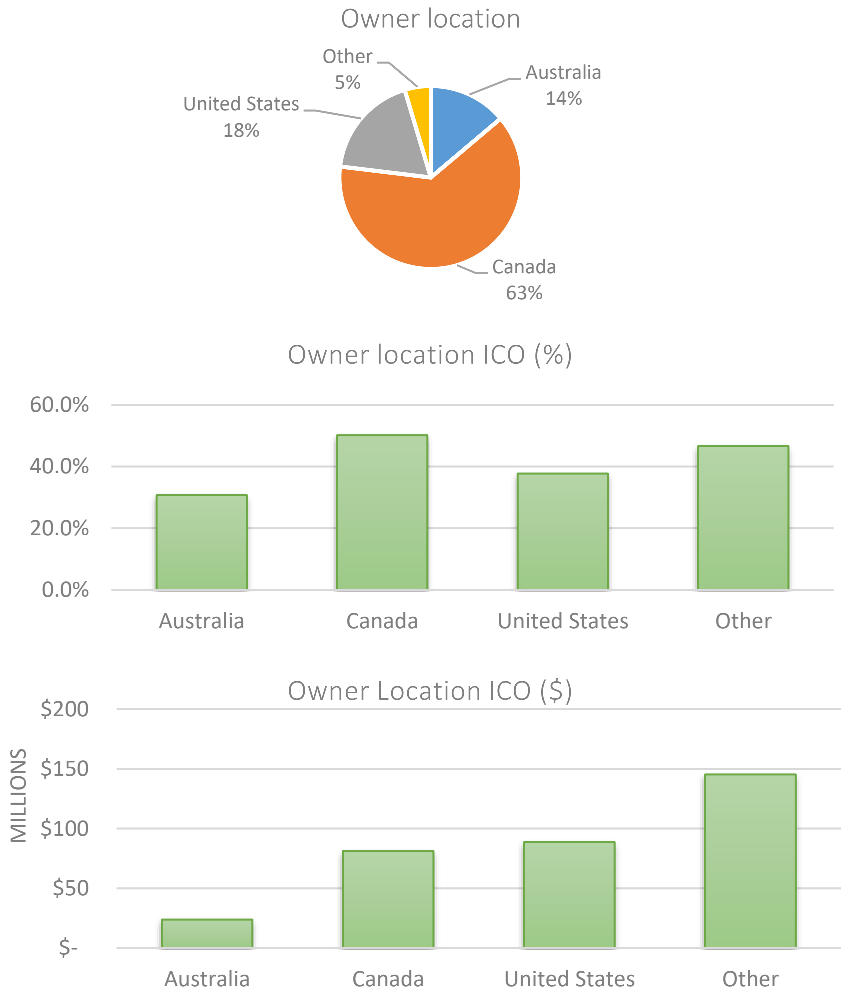


Figure 36: Data visualization of the projects divided by owner company location compared to initial capex overrun.

4.4 SYNOPSIS OF THE INTERPRETATIONS

The results of the analysis of the 19 variables is summarized in Table 5. As discussed for each variable individually the factors are grouped in where a correlation is to be found plausible, and factors where no correlation or a weak correlation is found. Subsequently, the variables that show a correlation with the ICO are divided into four parent groups and a miscellaneous group. The parent groups combine variables that have the same root cause.

Correlation plausible	No/weak correlation
Mining method	Greenfield vs brownfield
Feasibility author	Company shares health
Processing plant capacity	Capital intensity
Relative project size	Net present value (NPV)
Debt-to-equity ratio	Project location
Company listing maturity	Processing method
Internal rate of return (IRR)	
Payback period	
Commodity market attractiveness	
Initializing time	
Owner company location	
Market capitalization	
BFS capex estimate	

Table 5: Synopsis of the possible variable correlation with the ICO

Size of the project

The variables '<u>Processing plant capacity</u>' and '<u>BFS Capex estimate</u>' both are an indirect result of the size of the mining project. Both factors indicate that smaller mining projects tend to overrun more than larger mining projects. It is expected this is due to the cost distribution of small mining projects. General elements at a mine site as infrastructure, infrastructural industry regarding the mining process and housing facilities need to be built regardless of the project size. Due to this, these expenses are relatively higher for small projects, and when an overrun is experienced it therefore is relatively more than the same expenses for a larger project.

Company size

The variables '<u>Market capitalization</u>', '<u>Company listing maturity</u>', '<u>Relative project size</u>' and '<u>Debt-to-equity ratio</u>' are a considered as an indication of the size of the owning company. The analysis indicates that relatively small mining companies tend to overrun less than major mining companies. This might be a result of the dependency of the company on the project. Larger companies might be willing to take more risk in the initial developing stages of a mining project, as these companies want the project to achieve production as fast as possible. They have the capacity to cope with an ICO. The smaller companies are much more dependent on the initial phases of the project, and in the most cases do not have the financial reserve, nor income from another project to allow for an ICO to happen. Therefore, they most likely invest more in preventing an ICO to happen.

Financial indicators projected in the BFS

The variables '<u>Internal rate of return (IRR)</u>' and '<u>Payback period</u>' indicate an estimate of the quality of the project. The higher the IRR the higher the estimate of the quality of the project. The lower the amount of payback years, the higher the estimated quality of the project. The analysis illustrates that the better the estimated quality of the project, the lower the ICO.

Market attractiveness
A strong correlation is found in the market attractiveness analysis in relation to a capex overrun. From an investors' perspective this variable is interesting as it directly states whether the market conditions are fit for investing with regards to a capex overrun. This strong correlation and predictive capacity justify for the variable to be its own group parent and not to be undervalued. The analysis shows that projects of which the BFS is published in 'attractive' market conditions tend to overrun more often and more.

Miscellaneous
For the remaining plausible correlation variables, the root causes are considered to be significantly divergent and therefore they cannot be categorized into a parent root cause. These variables are to be considered stand-alone. Despite not being part of a parent group, these individual variables are used for predictive purposes in the model. The stand-alone variables are:

- Mining method
- Owner company location
- Initializing time
- Feasibility author in-house vs external

5 RISK ASSESSMENT MODEL

5.1 DATA HANDLING

The results of the database analysis and interpretation of Chapter 4 are combined to develop a predictive model. This model is used to perform a semi-quantitative risk analysis of future gold mining projects regarding the initial capex overrun. Primarily, a multiple regression analysis is performed in IBM's SPSS Statistics, a software package used for interactive, or batched, statistical analysis. This analysis is performed to quantify the statistical correlation among the relevant variables. The relevant variables are the ones where a correlation is found plausible, and are documented in the synopsis in Chapter 4.4.

Subsequently, the distribution of the variables in the database is compared to the distribution of the variables documented in literature. This comparison shows if a variable is overrepresented in the thesis database. This comparison is used to construct an ICO likelihood risk assessment tool. The ICO magnitude and likelihood risk assessment tools are finally combined into a risk matrix. A future gold project can be positioned within the matrix, based on a score conducted by the correlations. The position of the project within the matrix indicates the predicted danger zone it is in.

Due to a simplification, all variables are considered independent, where some variables obviously are dependent. With the current size of the data, it is statistically not possible to quantify the interdependencies between the variables. However, to highlight the possible and probable interdependencies, they are plotted in a dependency matrix.

5.1.1 CATEGORICAL VARIABLES

The database is populated by numerical variables (e.g. BFS capex estimate) and categorical variables (e.g. mining method). Before linear regression can be applied to the dataset, the categorical variables first need to be transformed into numerical 'dummy' variables. A dummy variable is an artificial variable created to represent an attribute with two or more distinct categories/levels.

The number of dummy variables to represent a single attribute variable is equal k – 1 where k is the number of levels in the categorical variable (see table 6).

Project #	Category	Mining Method
1	1	Open pit
2	1	Open pit
3	2	Underground
4	2	Underground
5	3	Hybrid
6	3	Hybrid

→

Project #	Category	Open pit	Underground
1	1	1	0
2	1	1	0
3	2	0	1
4	2	0	1
5	3	0	0
6	3	0	0

Table 6: An example of how a categorical variable is transformed into a numerical variable. This is done for mathematical purposes.

After the categorical variable is transferred to a numerical variable, predictor estimates the risk according to the following formula.

$$y = \beta_0 + \beta_1 d1 + \beta_2 d2 + \varepsilon \tag{2}$$

In the case exemplified in Table 6, β_0 represents the risk value in case the mine is considered hybrid. As both d1 and d2 are 0 in this case, the predictor value is $y = \beta_0$. In the case the mining project is an open pit project, the variables d1

= 1 and d2 = 0. The predictor value in this case is y = β0 + β1. Likewise, the predictor value for an underground project is y = β0 + β2. The term ε is the error term.

5.1.2 SPSS ANALYSIS

The analysis of the variables conducted in Chapter 4 shows some of the variables suggest correlations with ICO, where some of the variables do not show any correlation with ICO. The variables that were found plausible to have a correlation are used as independent variables in a multivariable regression analysis. A regression analysis is used to predict the value of a variable based on the value of other variables. The variable that needs to be predicted is called the dependent variable. The variables that are used to predict the other variable's value is called the independent variables, or the predictor variables. The regression analysis is executed with IBM's SPSS.

R	R Square	Std. Error of the Estimate
,709	.503	.243

Table 7: Summary of the SPSS analysis of the database

Table 7 shows a summary of the SPSS analysis key data. The R square value indicates that 50.3% of the ICO can be predicted by a linear combination of the input variables. This is acceptable as the size of the dataset is quite limited (Bujang, et al., 2017).

	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
(Constant)	-.732	.602	
BFS_capex_estimate	-2.471E-10	.000	-.257
Initializing_time	.004	.004	.110
Market_cap	-1.155E-05	.000	-.087
Relative_project_size	.012	.019	.073
Debt_equity_ratio	.005	.002	.243
Listed_maturity	.007	.011	.080
Plant_capacity	1.729E-05	.000	.366
Position_in_cycle	.978	.347	.329
OwnerAustraliaDummy	-.324	.186	-.377
OwnerCanadaDummy	-.177	.169	-.288
OwnerUnitedStatesDummy	-.152	.172	-.198
InHouseDummy	.010	.086	.015
OpenPitDummy	-.218	.105	-.316
UndergroundDummy	-.128	.141	-.125
IRR	-.256	.910	-.043
Payback_period	.047	.032	.242

Table 8: SPSS multivariable regression analysis results

The SPSS analysis shown in Table 8 shows how the value of the ICO can be estimated based on the input variables using the unstandardized coefficients. The standardized coefficient beta indicates the value of the coefficients that would be obtained when the independent and the dependent variables would be standardized. This way the variables would on be on the same scale and the magnitudes can be compared. Due to the probable presence of multicollinearity, the individual quantification of the variables might be inaccurate. This means the model presented by the multivariate regression analysis can only be used when all variables are known.

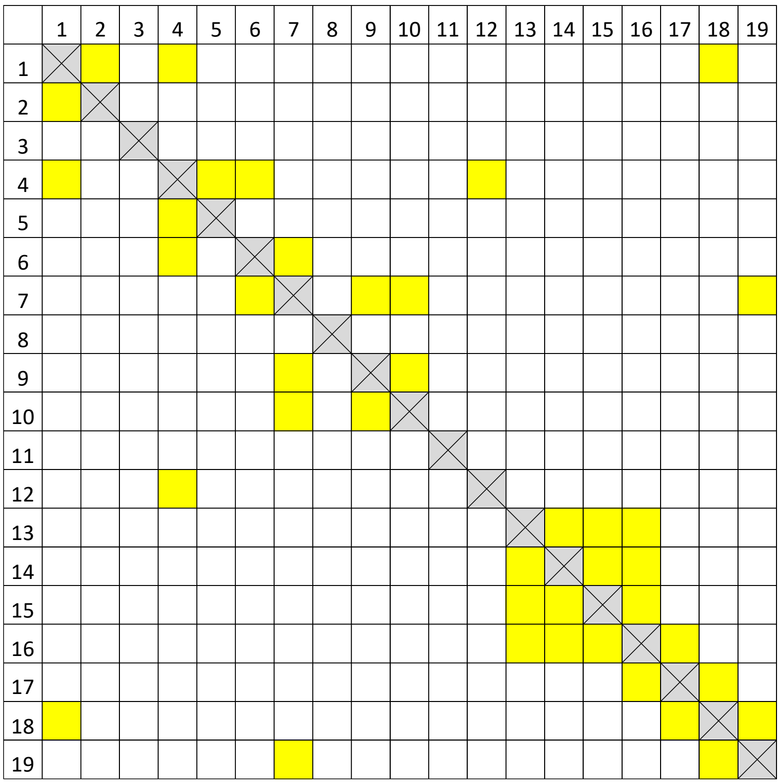
5.1.3 MULTICOLLINEARITY

The assumption is made in the SPSS linear regression that the predictor variables are all independent. However, several of the variables are likely to be dependant to one or more other variables. This effect is called (multi)collinearity.

Multicollinearity is present in almost every database. However, multicollinearity has no impact on the overall regression model and associated statistics such as R^2, F ratios and p values. It should also not generally have an impact on predictions made using the overall model. Multicollinearity is a problem though, when the individual predictors are to be quantified. If two or more predictors are correlated then it is inherently difficult to tease apart their effects (Baguley, 2012). A well-respected PhD candidate from the TU Delft (Tom Wambeke) suggests to treat the variables as independent variables. Wambeke furthermore suggests that if the attempt is to be made in making a regression analysis with multiple dependent variables, more data is required to tease their individual effects apart. Subsequently, the use of the singular value decomposition in regression analysis is recommended. This way the existence of collinearity in the dataset in the regression analysis is included. Due to the limited size of the database and the statistical complexity accounting for the collinearity presence, the predictor variables for this database are considered independent.

As mentioned, it is likely some of the variables are dependent to each other. For some variables it actually is quite obvious a dependency exists. For example; if a mining project is located in Australia, it is more likely to be an open pit project than an underground project, simply because Australia's mining industry is more focused on open pit projects. On the other hand, when a project is located in South Africa, it is more likely to be an underground project because the mining industry in South Africa is more focused on underground projects. This makes the variables 'Mining Method' and 'Project Location' dependent.

Even though the interdependencies will not be taken into account for predictive purposes, it is indicated which variables are believed to show some correlation. These possible interdependencies are based on the thesis research process, in particular on the data acquisition process and the personal communication. Further research where the multicollinearity is considered might consider these proposed interdependencies. Figure 37 shows a matrix of the variables, where the possible dependencies between the variables are highlighted in yellow.



#	Variable
1	Mining method
2	Greenfield vs brownfield
3	Feas. author internal vs external
4	Processing plant capacity
5	Processing method
6	BFS capex estimate
7	Market capitalization
8	Relative project size
9	Debt / equity Ratio
10	Company listing maturity
11	Company shares health
12	Capital intensity
13	IRR
14	Payback period
15	NPV
16	Position in commodity cycle
17	Initializing time
18	Project location
19	Owner location

Figure 37: Matrix of the variables indicating interdependencies between the variables. A yellow box indicates there is a possible correlation between the variables. These possible interdependencies are not used for predictive purposes.

5.2 PREDICTIVE MODEL DEVELOPMENT

The goal of the model is to aid investors by giving an initial indication of the project risk regarding capex overrun. The model gives an answer to the following question:

How likely is it the estimated capital budget of a gold project will be exceeded, and if it is being exceeded, by how much?

To answer the question, the data analysed in Chapter 4 is used to develop a risk assessment tool for assessing future gold mining projects in terms of the likelihood of experiencing an ICO and the corresponding magnitude.

ICO Magnitude

To assess a future project on ICO magnitude risk, every variable is subdivided into the same subdivisions as described in Chapter 4. Per variable, the project is granted an amount of 'risk points'. The amount of risk points per variable are determined using the data analysis from Chapter 4. The amount of risk points to be granted per subdivision, per variable can be found in Table 9. The 'payback period' and 'IRR' variable are not subdivided, but use a formula to determine the amount of risk points a project is granted.

When the risk points are granted, they are accumulated to generate the ICO magnitude risk rating. When a project does not have a known value for a variable, the value is to be left blank. By doing this, the model calculates the weighted average amount of risk points for the associated variable according to the database, ensuring a project is not under- or over assessed.

5.2.1 MAGNITUDE PREDICTOR

	Rating
Mining method	
Open Pit	1
Underground	2
Hybrid	3
Feasibility study author	
In house	1
Extern	2
BFS capex Estimate	
Small (<$100M)	3
Medium ($100M-$250M)	3
Large ($250M-$1B)	1
Mega (>$1B)	1
Owner company location	
Australia	1
Canada	2
United States	1
Other	1
Market cap at BFS	
Micro (<$100M)	1
Small ($100M-$1B)	2
Medium ($1B-$5B)	2
Large (>$5B)	3
Relative project size (capex / mrkt cap)	
Small (<15%)	2
Medium (15% - 50%)	1
Medium (50% - 100%)	1
Large (>100%)	1

	Rating
Debt-to-equity Ratio	
No Deb	1
Small Debt (0 - 20)	2
Extreme (>20)	3
Company listing maturity at BFS	
< 5 years	1
5 - 10 years	2
10 - 15 years	2
> 15 years	3
Processing plant capacity (ktpa)	
Small <1000 ktpa	3
Medium 1000 - 2000 ktpa	1
Large 2000 - 5000 ktpa	1
Massive >5000 ktpa	1
Initializing time	
<1 Months	2
1 - 6 Months	1
6 - 12 Months	1
> 12 Months	3
Relative Commodity price	
<100%	1
100% - 110%	2
>110%	4

Table 9: The risk rating of eleven of the relevant variables in terms of Initial Capex Overrun (ICO) magnitude. The number of X determine the amount of 'risk points' to be granted to the project for the associated variable.

Payback period

The analysis from Chapter 4 is used to develop a formula for assessing the ICO magnitude risk regarding the payback period. When no Payback period is documented in the BFS, the average of the database is used to calculate the amount of risk points. To limit the impact of the payback period risk ratingThe maximum risk value to be obtained for payback period is four.

$$x = \frac{1}{2}Y \tag{3}$$

$x = Risk\ rating$
$Y = Payback\ period\ (years)$

Internal Rate of Return (IRR)

The analysis from Chapter 4 is used to develop a formula for assessing the ICO magnitude risk regarding the IRR. When no IRR is documented in the BFS, the average of the database is used to calculate the amount of risk points. To limit the impact of the IRR risk rating, the maximum risk value to be obtained is four. The minimum value is zero, indicating a project has a IRR >60%.

$$x = 4 - \frac{I}{15} \tag{4}$$

$x = Risk\ rating$
$I = Internal\ Rate\ of\ Return\ (\%)$

5.2.2 FREQUENCY PREDICTOR

	Literature Statistics		Database Statistics			Rating
	#	%	#	%	Relative difference	
Mining method						
Open Pit	270	60%	49	75%	26%	2
Underground	127	28%	6	9%		1
Hybrid	54	12%	10	15%	28%	2
Owner company location						
Australia	128	22%	9	14%		1
Canada	186	32%	41	63%	96%	2
United States	27	5%	12	18%	296%	2
Other	238	41%	3	5%		1
Market cap at BFS						
Micro (<$100M)	48	34%	6	16%		1
Small ($100M-$1B)	60	43%	15	41%		1
Medium ($1B-$5B)	24	17%	11	30%	73%	2
Large (>$5B)	8	6%	5	14%	136%	3
Processing plant capacity (ktpa)						
Small <1000 ktpa	159	42%	7	23%		1
Medium 1000 - 2000 ktpa	61	16%	7	23%	44%	3
Large 2000 - 5000 ktpa	82	22%	8	27%	23%	2
Massive >5000 ktpa	75	20%	8	27%	34%	2
Relative Commodity Price						
<100%						1
100% - 110%						2
>110%						4

Table 10: Rating of the variables in terms of Initial Capex Overrun (ICO) likelihood. The distribution of the projects in the database regarding the variables is compared to the distribution of the projects from literature. The relative difference shows how much a variable is overrepresented in the database compared to the literature.

ICO Likelihood

To assess the risk rating regarding the likelihood of a project experiencing an initial capex overrun, the distribution of the dataset per variable is compared to the distribution per available variable found in literature. Subsequently, a similar approached to the ICO magnitude risk rating is maintained. Per variable, the project is granted an amount of risk points based on the statistics comparison. The amount of risk points to be granted per subdivision, per variable can be found in Table 10. When the risk points are granted, they are accumulated to generate the ICO likelihood risk rating. The literature statistics consists out of a combination of personal communication, ING Bank data and FactSet statistics.

5.2.3 RISK MATRIX

The magnitude and likelihood risk rating values are then input into the ICO risk matrix, displayed in Figure 38. The x-axis of the risk matrix displays the risk rating in terms of ICO likelihood, the y-axis shows the risk rating in terms of ICO magnitude. The position of the project in the risk matrix indicates the zone where a project is located according to the model. The boundaries of the zones are positioned using a combination of the total amount of risk points for both the ICO magnitude and the ICO likelihood. When a project falls in the green zone, the risk exposure can be considered acceptable, and no further actions are required. It is always interesting though, to see where the majority of the risk rating assessment origins from, both in terms of magnitude and likelihood. When a project falls in the yellow zone, caution is advised with the project. It is recommended the origin of the risk ratings is investigated, and further research regarding the risky points is conducted before funding is approved. If a project is located in the red zone, it is strongly advised extensive research is performed regarding the points of risk. It should be discussed whether the project is appropriate for funding at the moment, and the use of hedging instruments is advised.

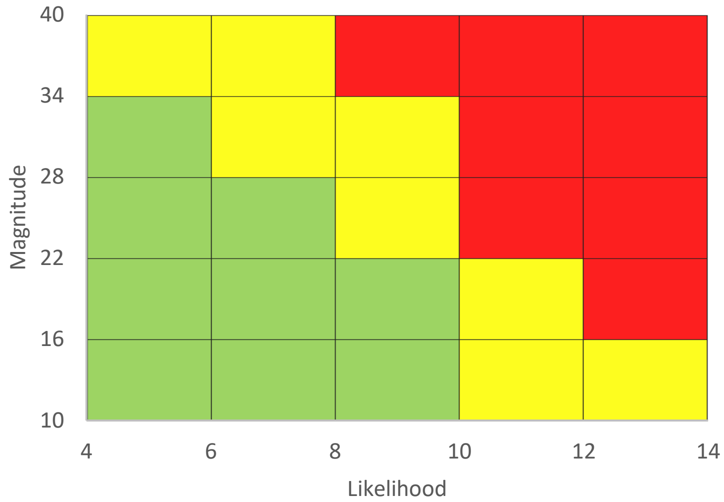


Figure 38: The risk matrix displaying all the projects to populate the database. The x-axis shows the risk points regarding likelihood a gold mining projects will experience an Initial Capex Overrun (ICO), the y-axis shows the risk points regarding the expected magnitude of an ICO when experienced.

5.3 Example of the model

To illustrate the use and the effectivity of the model, an example assessment is highlighted in this chapter. Preferably, a real-life case would have been used to demonstrate the use of the predictive model. However, all projects that have experienced an initial capex overrun – and therefore would have been suited for demonstration – have been used to expand the database. Therefore, a fictive gold mine named the Veleta Gold Mine is used to for demonstration purposes. The project has the following specifications:

Veleta Gold Mine		ICO magnitude risk rating	ICO likelihood risk rating
BFS publish date	1/5/2006		
Mining method	Open pit mining	2	1
Greenfield vs brownfield	Greenfield project		
Feas. author internal vs external	In-house feasibility author	1	
Processing plant capacity	800 ktpa	3	1
Processing method	Heap leach		
Capex estimate	200M USD	3	
Market capitalization	1B USD	2	2
Relative project size	30%		
Debt / equity Ratio	Unkown		
Company listing maturity	3 years	1	
Company shares health	25% profit last 6 months		
Capital intensity	250 USD/tpa		
IRR	13%	3.13	
Payback period	2.5 years	1.25	
NPV	450M USD		
Position in commodity cycle	115%	4	3
Initializing time	4 months	1	
Project location	South Africa		
Owner location	Canada	2	2
		23.8	9

Table 11: Characteristics of the fictional Veleta Gold Mine and the corresponding likelihood and magnitude risk rating

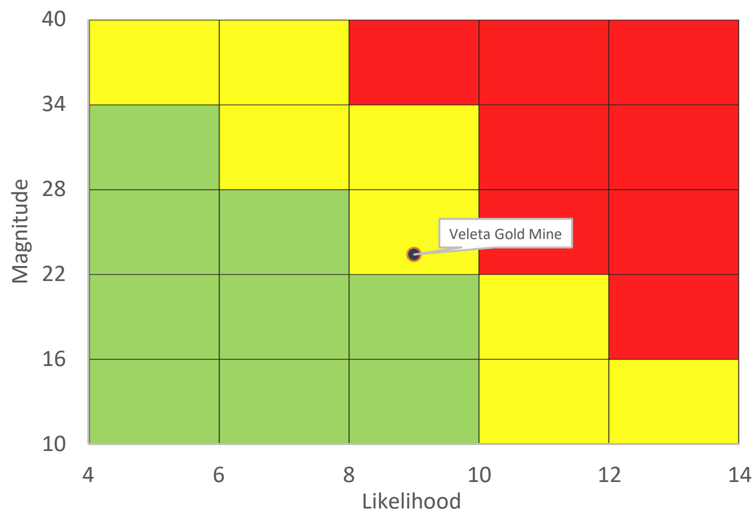


Figure 39: Risk matrix displaying the position of the Veleta gold mine after risk assessment.

The model indicates in figure 41 that the Veleta gold mine is located in the yellow zone, suggesting caution is advised and the root causes of the risk assessment should be looked at. In the case of the Veleta gold mine, a factor that contributes significantly to the ICO magnitude risk rating is the 'Position in commodity cycle'. At the moment the BFS is published (2006), the gold price was relatively high and the market was 'attractive'. As discussed in chapter 4.2.10, an attractive commodity market has several negative consequences including approval of mediocre projects and a lack of skilled personnel. This should be a point of issue, and it is advised verification research is done to the quality of the project and the level of skill of the employees responsible for the project.

Furthermore, it can be seen in table 11 that the two factors 'Processing plant capacity' and 'BFS capex estimate' combined result in six points together to the total ICO magnitude risk ranking. Going back to the data analysis synopsis, discussed in 4.4, these two factors are an indication the project is relatively small for the gold mining industry. According to the thesis database, small projects tend to overrun relatively high. Therefore, it is advised to see whether the owning company has any experience in small gold mining projects, and is aware of the corresponding risks.

Combining these two points, the main issue point would most likely be a question of personnel. Due to the small size of the project, it is advised skilled employees are hired on all levels, with experience in small gold mining projects. However, due to the high commodity price, the market is probably saturated with gold projects, making skilled personal a scarce commodity. The final advice suggested by the model is to not save on personnel, and carefully select them.

6 DISCUSSION

Underperformance of a mining project

During the initial phase of the thesis framework construction, the original idea was to compare 'failed' mining projects to each other. One can argue when a mining project is to be considered a failure. To make it manageable, several definitions of failure were constructed, including capex overrun, opex overrun, ramp-up time delay and production under performance. Unfortunately, it proved infeasible to gather the amount of data necessary for a significant analysis. The decision was made to limit the scope to capex overrun. However, it is assumed that some of these definitions of failure are correlated to each other. The ramp-up time delay and the ICO are most likely correlated, meaning that projects that are delayed during their initial construction phase, most likely will experience a capex overrun. This results in a dependency between capex overrun and ramp-up time delay, which could be included in a predictive model on mine 'failure'. The other definitions of mine failure could be compared to each other in a similar way, resulting in a greater understanding of mining project 'failure'.

What is a gold project?

Almost all the projects in the database are polymetallic gold mines, meaning they produce more than one commodity. One commodity is the main commodity, where the other are side-products generating 'credits' to lower the cash costs. The main commodity – the one with the highest revenue potential – normally determines the name that is given to the project. However, to some parties this is a matter of perspective. The Peñasquito mine in Mexico for example, is a polymetallic mine which produces silver, gold, lead and zinc. It is Mexico's largest gold producer, but at the same time the second largest silver producer of the country. Furthermore, there are projects where it is dependent on the commodity price which commodity is to be called the main commodity. When the gold price plummets for example, the second commodity of the project (e.g. silver) becomes the commodity with the largest revenue potential, transforming a gold mine to a silver mine overnight.

For the purposes of this research, initially a threshold model was developed to evaluate whether a project was to be called a gold project and therefore suited for the database. This threshold was based on the expected size of the gold revenues of the project relative to the expected revenues of the other commodities, documented in the BFS. This approach however is not completely valid, as the updated reserves documented in annual reports during production often differ significantly. A mine that is called a gold mine in the BFS could be called a silver mine when it has reached production. Another problem with this approach is that the majority of the projects do not publish in detail about the composition of their expected revenues in the BFS. Momentarily, projects are used that are clearly documented as gold mines in all feasibility studies and company published documentation. It would be better for the model however, if a certain threshold system would be used to determine which projects are suited for analysis, as the selection process momentary might seem arbitrary.

Limitations of the variables

As can be seen in Figure 9, the majority of the variables are positioned in a relatively late stage of the project phase, namely during the feasibility study. A full assessment of the project using this model therefore can only be achieved after the BFS is published. This results in that the outcome of the risk assessment can only have a limited impact on the project outcome. The model would improve if more variables would be added, preferably in an earlier stage of the feasibility study process. This way, a preliminary assessment could be made using the model, allowing for risk to be identified at an earlier stage, increasing the impact it could have on the outcome of the project.

The selection of the variables has been established after discussion with several persons with relevant experience in the mining industry and/or the financial industry. A total of 35 possible variables have eventually been narrowed down to 19 variables. The final selection was based on the possible relevance to a capex overrun, the objectivity of which a variable could be measured and the probability that enough data could be found. The number of technical variables is limited. One variable that originally was to be included in the research, was the ore classification. Indirectly this is linked to the processing method as well. From the perspective of metallurgical processing, gold ores can be classified into free-milling and refractory ores. However, several properties of the ore, such as sulfide and quartz concentration, ensure that the differences are so large that they can no longer be compared with each other. Another straight forward variable that was considered is the geological deposition of the ore body and the surrounding rock. Ultimately this variable is not used due to a combination of differences in the complexity of the geology and a lack of adequate geological data.

Data acquisition

One of the most interesting observations of the research is conducted during the data acquisition process as opposed to the database analysis. It is to be considered unexpectedly difficult to obtain adequate data to populate the database. To properly compare data, one requires comparable data. Due to the inconsistencies in reporting in the mining industry, this is a prerequisite that is hard to meet. The mining industry knows several reporting standards (JORC, NI43-101, etc.) which are all relatively similar, but still do differ significantly. These differences in reporting make it difficult to compare projects, even when the projects themselves are similar. To intensify the nature of this issue, even when reporting is executed using the same reporting standard, reports still differ notably from each in terms of what they report and in what detail. The result is that the database is not filled out for every variable for every project. It is considered an incomprehensible and undesirable truth that in a fundamental industry as the mining industry there is so little standardization regarding reporting. It is believed that a genuine universal reporting standard will result in superior execution of mining projects globally.

From 2002 on, all projects are constructed during 'attractive' market conditions

The projects in the database where the BFS was published after 2002 were all initiated in a 'attractive' commodity market. The market turned 'unattractive' again in 2013. This means there was a period that would be considered 'attractive' for 11 years. This is the longest period in the era span of the database. Furthermore, 55% of the projects documented in the database originate 2002 or later. This indicates the database may be overrepresented by projects from this relatively long 'attractive' period. It is not unexpected that a significant portion of the projects are from this period, as this is the period where new technologic developments resulted in a more accessible and efficient way of storage of documentation.

Limitations of the database and model

The database compares the actual capital expenditures spent to the estimated capital expenditures as documented in feasibility studies. These do not take into account any possible inflation or deflation. It is expected, and therefore assumed, that due to a relative short construction (2 years), the impact of any local inflation or deflation can be considered neglectable. However, in the case of extreme inflation of a local currency, a project can experience a capex overrun even though the execution of the project was impeccable. Ideally, the database and the model would account for inflation and deflation.

The predictive method of the model is defined in a way that it accumulates all risk points granted to each variable. This implicates there is a linear relation between variables. This is most likely not the case however, as it is likely certain variables are correlated. The interdependency between the variables could be determined using advanced statistical analysis, however it requires a larger database to obtain usable results. Another limitation of the current database is the lack of data regarding gold mines in general. Literature statistic regarding the distribution of the variables was not readily available to the extent needed for the ICO likelihood risk rating. The result is that only 7 variables are used for the ICO likelihood risk rating, contrary to the 13 used for the ICO magnitude risk rating. The accuracy of the likelihood prediction therefore is significantly less than the accuracy for the magnitude prediction.

The database is populated only by projects that have experienced a significant ICO. This results in a biased database compared to the reality. Therefore, the predictive model momentarily predicts the likelihood of a project experiencing a capex overrun, and the possible magnitude of a capex overrun when a capex overrun is experienced. The risk matrix is subject to the same limitations of the biased database. The zones and boundaries of the risk matrix are defined by the entries in the dataset, which are projects that have experienced a significant ICO. Therefore, the risk matrix is biased. The boundaries of the risk matrix ideally would be defined by a database representing all gold mines.

7 Conclusion & recommendations

The goal of this research thesis is to retrospectively analyse gold mining projects that have experienced an initial capex overrun (ICO). The results of this analysis are subsequently used to develop a semi-quantitative predictive risk assessment tool. For this purpose, 19 variables are defined, for which gold mining projects objectively can be compared to each other and the capex overrun. The variables are categorized in the following three groups: technical, financial and geographical. To indicate the impact a variable can have on the execution of a project, the variables are positioned on a relative timeline of a feasibility study process. It is assumed that the largest impact on project execution can be made during the early stages of the feasibility study. For the majority of the variables, their relative position on a timeline is in the final stages of the feasibility study process. This illustrates that the risk assessment made using these variables is not to be used as a tool to try and enhance the outcome of the project execution. It should rather be used as a tool indicating whether to invest in a certain project based on the likelihood and the potential magnitude of an initial capex overrun. A significant observation experienced during the data collecting process is the complexity of collecting similar data concerning mining projects. The inconsistency of data, led by the different reporting standards, makes it challenging to compare projects.

The database is populated with 65 gold mining projects with an average capex overrun of 45%. Every mentioned variable of a project is analysed individually with respect to the capex overrun. The analysis demonstrates 13 variables show a potential correlation with the ICO, whereas 6 of the variables show no or weak correlation. The correlations are subdivided into the following five groups: 'Size of the project', 'Company size', 'Financial indicators', 'Position in the commodity cycle' and 'Miscellaneous. Primarily, the database suggests that relatively small gold mining projects in terms of processing plant capacity and capex estimate tend to overrun more than larger gold projects. It is expected this is due to cost distribution of small mining projects. General elements at a mine site as infrastructure, infrastructural industry regarding the mining process and housing facilities need to be built regardless of the project size. Due to this, these expenses are relatively higher for small projects, and when an overrun is experienced it therefore is relatively more than for larger projects. Secondly, the data analysis indicates that projects run by junior mining companies tend to experience a smaller ICO than mid-size or major mining companies. Larger major companies might be willing to take more risk regarding the ICO, as they want to see the project achieving production as fast as possible. Smaller companies are much more dependent on the initial phases of the project, and are likely to be more involved in preventing a capex overrun from happening. Furthermore, the analysis illustrates a correlation between the financial indicators documented in the BFS and the ICO. The financial indicators display an estimation of the quality of the mining project in their calculation. The higher the estimated quality of the project, the lower the expected ICO. Finally, a strong correlation is found comparing the relative position in the gold commodity cycle to the ICO. In an attractive market conditions, gold mining projects tend to overrun more often, and with a larger magnitude. The more attractive the market is, the higher the expected capex overrun is. A combination of limited availability of skilled personnel, together with questionable projects being realised during 'attractive' market conditions, is expected to be part of the cause for the increase in presence and magnitude of ICO.

A model is developed using the individual analysis of the variables relative to the ICO. The assumption is made that all variables are independent from each other. This model assesses projects on ICO magnitude risk and ICO likelihood risk. Combining the ICO risk assessments on magnitude and likelihood, the assessed project can be placed in 2D risk matrix, indicating a level of risk the project is exposed to. A multivariate regression analysis of the database indicates that 50.3% of the ICO can be predicted by a linear combination of the input variables. This analysis however assumes the variables are independent to each other, which likely is not the case. Due to multicollinearity present in the database, the individual dependency of the variables to the ICO cannot be used for predictive purposes

The research shows it is possible analyze mining projects that have experienced a capex overrun in an objective analysis. Correlations can be found regarding 13 variables of gold mining projects and the capex overrun. Using these correlations as foundation, it is possible to semi quantitatively assess a future gold mining project on ICO magnitude risk and ICO likelihood risk.

Recommendations

Analyse what projects do in the upcoming 'unattractive' period

According to the relative gold price analysis, the gold market experienced a 'unattractive' market conditions period from 2014 – 2017. Following to the theory presented in chapter 4.2.10, the gold projects where the BFS was being published in this period should experience a relatively small ICO. These projects could be reviewed to justify or refute the presented theory.

Add real option valuation as a variable

Real option valuation an evaluation method that is being used increasingly in the mining industry. It is a tool to adapt and revise mining projects under uncertainty and future variable movements. This variable is more suited for the valuation of mining project in comparison with currently used financial indicators, and could increase the accuracy of the predictive model significantly.

Use of the parent groups as input for the model

When assessing a future gold mining project on risk, the parent group could be used as a trigger to be granted an extra risk point. When all variables of a parent group agree with each other, this strengthens the risk analysis made for that parent group. Momentarily this is not applied due to the presence of multicollinearity; this would falsely imply intervariable correlations are present.

Add non ICO projects

The database currently is populated by projects that have experienced a significant ICO. This obviously generates a biased database relative to the reality. To make the database match with the reality, projects that have completed construction within budget (85% – 115% of the capex estimate) and projects that experienced a capex underrun (<85% of the capex estimate) could be added to the database. The individual analysis of these projects likely would give new insights regarding projects that are within budget or experienced a capex underrun. The database containing all the projects could be used as a reference database for the average statistics of gold mining projects. This will be suitable to increase the accuracy of the ICO likelihood rating.

Add ramp-up time delay

To add a dimension to the database, a variable could be added whether the project experienced a ramp-up time delay and how long. Reasons for ICOs often include ramp-up time delay. However, sometimes projects are being delivered on time but still have experienced a significant capex overrun. The distinction could be made between projects that have experienced a ramp-up time delay and an ICO, and projects that came in on time and experienced an ICO.

Account for multicollinearity

The predictive capacity of the model would strongly improve when the multicollinearity presence of the regression analysis can be dealt with. The use singular value decomposition in regression analysis is a way to include the existence of collinearity in the dataset. However, to apply this method the database would have to be expanded.

Market attractiveness for other commodities

The most interesting correlation found during the database analysis, is the correlation between the relative gold price and the ICO. A similar research could be performed to the relative position in other commodity cycles. If a similar correlation can be found, it would enhance the theory regarding the market attractiveness analysis for gold. This could eventually result in a predictive tool based on the weighted average of all commodity cycles.

Benchmark projects against similar projects

Benchmarking project capex estimates and construction times against similar mines already built would be recommended. Even though every mining project is unique, there is no better guide on cost and time than something that has been designed and built under similar conditions in the past.

A PERSONAL COMMUNICATION

Lazo, J. (Senior Technical Advisor) & **Lwin, T.** (Managing Principal) (Export Development Canada (EDC))

- Two phone meetings (April 25 and May 4, 2017) and several e-mail conversations (April – May 2017). The discussed topics are the selection of variables.

Haubrich, C. (National Bank of Canada – Associate)

- E-mail contact discussing the selection of variables and the inefficiency of the NPV analysis regarding mining projects (April 2017)
- Source of data

Bertisen, J. (Resource Capital Funds – Analyst)

- One phone meeting (April 20, 2017) and two e-mail conversations (April 2017) discussing the approach and setbacks regarding a similar study including mining capex overruns.
- Source of data.

Smith, L.D. (Lawrence, Devon, Smith & Associates - Principal Consultant)

- Two phone meetings (August 5 and August 10, 2017) and several e-mail conversations (August, 2017). The discussed topics are the general view on capex overruns, ramp-up delays and opex overruns.

Gypton, C. (Hecla Mining – Project Manager)

- Two phone meetings discussing the selection and impact of the variables (May 1 and May 18, 2017)
- Source of data.

Wambeke, T (TU Delft – PhD Candidate)

- One telephone conversation discussing the statistical approach on multicollinearity (July 23, 2017).

Kindt, P. (IHead of Metals & Mining EMEA) & **Van Heukelem, A.** (Global Head of Metals & Mining) ING bank

- Numerous conversations discussing generally all aspects of the research, in particular the selection for capex overrun and the financial variables (March – August 2017).

B Database summary

Project name	Country	Capex Overrun	Actual capex	Capex estimate	Completion date	Owner at feasibility study
Ahafo Gold Operation	Ghana	37.7%	$ 482,000,000	$ 350,000,000	Aug-06	Moydow Mines International Inc.
American Girl Canyon	USA	136.0%	$ 26,662,000	$ 11,299,000	Aug-90	Eastmaque Gold Mines Ltd
Andacollo (gold)	Chile	45.6%	$ 66,682,000	$ 45,800,000	Oct-95	Dayton Mining
Aurizona Gold Operation	Brazil	29.0%	$ 61,285,700	$ 47,500,000	Feb-11	Luna Gold
Ban Houayxai Gold/Silver Mine	Laos	40.0%	$ 210,000,000	$ 150,000,000	Jun-12	PanAust
Basin Creek	USA	49.7%	$ 5,300,000	$ 3,540,000	Aug-88	Pangea Resources
Batu Hijau	Indonesia	17.5%	$ 1,810,000,000	$ 1,540,000,000	Mar-00	PT Amman Mineral Internasional
Bella Vista	Costa Rica	41.7%	$ 35,000,000	$ 24,700,000	Dec-05	Glencairn Gold
Benso Gold Mine	Ghana	45.1%	$ 72,700,000	$ 50,100,000	May-09	Golden Star Resources Ltd.
Bissett (Rice Lake)	Canada	32.9%	$ 55,153,000	$ 41,496,000	Mar-97	Rea Gold corporation
Boddington	Australia	33.9%	$ 1,908,000,000	$ 1,425,000,000	Nov-09	Newmont Mining
Bonikro Gold Mine	Ivory Coast	20.4%	$ 87,086,500	$ 72,305,000	Oct-08	Equigold Mining
Brewery Creek	Canada	18.1%	$ 58,846,000	$ 49,843,000	Oct-96	Viceroy Resource corporation
Briggs	USA	18.6%	$ 31,700,000	$ 26,734,000	Mar-97	Canyon Resources corporation
Caete Gold Operation	Brazil	52.8%	$ 110,282,000	$ 72,180,000	Sep-10	Jaguar Mining
Canadian Malartic Gold Mine	Canada	30.0%	$ 942,642,000	$ 724,900,000	May-11	Osisko Mining Corporation
Carson Hill	USA	28.6%	$ 13,500,000	$ 10,500,000	Nov-86	Western Goldfields
Cerro Mojon	Nicaragua	25.3%	$ 19,670,000	$ 15,700,000	Sep-97	Greenstone Resources Ltd
Chirano Gold Operation	Ghana	73.7%	$ 74,500,000	$ 42,900,000	Nov-05	Red Back Mining
Colomac	Canada	44.9%	$ 200,000,000	$ 138,000,000	Apr-90	Northgate Exploration Ltd
Detour Lake Gold Mine	Canada	44.9%	$ 1,498,350,000	$ 1,034,058,240	Jan-13	Detour Gold
Dolores	Mexico	53.3%	$ 210,000,000	$ 137,000,000	Dec-08	Minefinders
Edikan Gold Operation	Ghana	18.3%	$ 175,000,000	$ 147,900,000	Dec-11	Perseus Mining Limited
El Choco	Venezuela	36.0%	$ 52,500,000	$ 38,600,000	Nov-04	Bolivar Gold
El Sauzal	Mexico	33.3%	$ 134,600,000	$ 100,980,000	Oct-04	Glamis Gold

Project name	Country	Capex Overrun	Actual capex	Capex estimate	Completion date	Owner at feasibility study
Essakane Gold Mine	Burkina Faso	15.2%	$ 453,000,000	$ 393,355,000	Jul-10	IAMGold Corporation
Fort Knox	USA	36.8%	$ 350,000,000	$ 255,803,000	Oct-96	AMAX Gold Inc
Gold Road	USA	47.4%	$ 14,100,000	$ 9,564,000	Dec-95	Addwest Minerals
Golden Bear	Canada	104.0%	$ 81,600,000	$ 40,000,000	Jan-90	Homestake Canada
Golden Reward	USA	32.9%	$ 26,178,000	$ 19,700,000	Dec-89	Golden Reward Mining Company
Goldex Gold Mine	Canada	58.3%	$ 213,700,000	$ 135,000,000	Aug-08	Agnico-Eagle Mines Ltd.
Gualcamayo	Argentina	27.7%	$ 190,600,000	$ 149,200,000	Apr-09	Yamana Gold
Hycroft (Lewis Mine)	USA	39.1%	$ 32,000,000	$ 23,000,000	Apr-88	Hycroft Resources
Illinois Creek	USA	41.9%	$ 31,228,000	$ 22,000,000	Feb-97	Dakota Mining
Jamestown	USA	30.4%	$ 90,000,000	$ 69,000,000	Sep-87	Sonora Mining
Kittila Gold Mine	Finland	148.1%	$ 335,000,000	$ 135,000,000	May-09	Agnico-Eagle Mines Ltd.
Komis	Canada	57.4%	$ 11,100,000	$ 7,053,000	Nov-96	Golden Rule Resources
Kumtor Gold Mine	Kyrgyzstan	25.6%	$ 452,000,000	$ 360,000,000	May-97	Cameco Corporation
La Trinidad	Mexico	22.9%	$ 7,498,000	$ 6,100,000	Oct-96	Eldorado Gold
Lapa Gold Mine	Canada	72.2%	$ 175,000,000	$ 101,600,000	May-09	Agnico-Eagle Mines Ltd.
Lawyers	Canada	32.9%	$ 57,400,000	$ 43,200,000	Jan-89	Cheni Gold Mines
Los Filos	Mexico	64.4%	$ 307,500,000	$ 187,000,000	Jun-07	Goldcorp
Loulo Gold Operation	Mali	88.2%	$ 150,550,000	$ 80,000,000	Nov-05	Randgold Resources Limited
Mana Gold Mine	Burkina Faso	52.6%	$ 92,304,000	$ 60,500,000	Apr-08	Semafo Inc
Marlin	Guatemala	40.9%	$ 197,300,000	$ 140,000,000	Oct-05	Glamis Gold
Meadowbank Gold Operation	Canada	50.6%	$ 946,000,000	$ 628,000,000	Mar-10	Cumberland Resources
Mineral Ridge	USA	32.3%	$ 25,400,000	$ 19,200,000	May-97	Cornucopia Resources
Mt Hamilton	USA	17.9%	$ 24,000,000	$ 20,348,000	Nov-94	Rea Gold Corperation
Mt Muro	Indonesia	16.3%	$ 85,581,000	$ 73,592,000	Aug-05	Strait Resources
Padre Madre	USA	26.6%	$ 4,801,000	$ 3,793,000	Dec-87	Eastmaque Gold Mines Ltd
Penasquito	Mexico	119.6%	$ 1,937,000,000	$ 882,000,000	Oct-09	Goldcorp
Pinos Altos Gold/Silver Operation	Mexico	47.4%	$ 339,000,000	$ 230,000,000	Nov-09	Agnico-Eagle Mines Ltd.
Refugio (Maricunga)	Chile	20.1%	$ 152,500,000	$ 127,000,000	Oct-96	Bema Gold corporation
Sabodala Gold Mine	Senegal	35.0%	$ 220,000,000	$ 163,000,000	Apr-09	Mineral Deposits Limited
San Andres	Honduras	26.5%	$ 39,100,000	$ 30,900,000	Feb-99	Greenstone Resources Ltd
San Gregorio	Uruguay	50.1%	$ 48,293,000	$ 32,170,000	Feb-97	Rea Gold corporation

Project name	Country	Capex Overrun	Actual capex	Capex estimate	Completion date	Owner at feasibility study
Santa Gertudis	Mexico	20.0%	$ 24,000,000	$ 20,000,000	Jun-90	Phelps Dodge
Siana Gold Mine	Philippines	40.8%	$ 88,000,000	$ 62,500,000	Apr-12	Red 5 Limited
Taparko-Bouroum Gold Operation	Burkina Faso	131.3%	$ 107,834,000	$ 46,617,139	Sep-07	High River Gold Mines
Tasiast Gold Mine	Mauritania	27.8%	$ 78,317,000	$ 61,258,000	Dec-07	Rio Narcea Gold Mines
Tolukuma	Papua New Guinea	37.0%	$ 40,125,000	$ 29,282,000	Apr-95	Emperor Mines
Tongon Gold Mine	Ivory Coast	34.1%	$ 375,400,000	$ 280,000,000	Dec-10	Randgold Resources Limited
Tulawaka Gold Mine	Tanzania	17.6%	$ 57,600,000	$ 49,000,000	Apr-05	Barrick Gold
Veladero	Argentina	18.7%	$ 540,000,000	$ 455,000,000	Nov-05	Barrick Gold
Youga Gold Mine	Burkina Faso	106.9%	$ 90,810,000	$ 43,900,000	Jul-08	Etruscan Resources

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