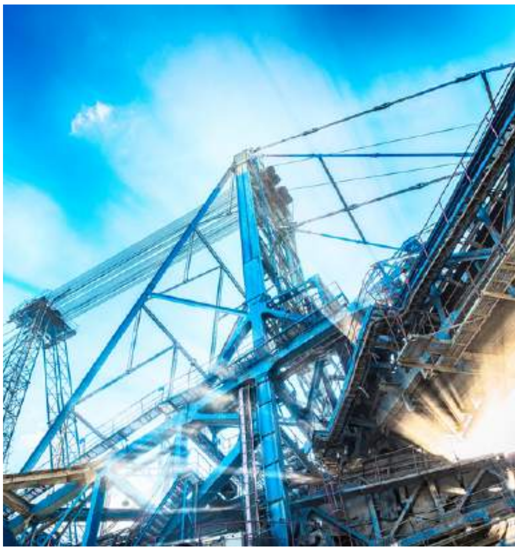
PERSPECTIVE

Risk Analysis in the Mining Industry

May 2022



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ABOUT US

With more than 13 years of experience, and more than 350 successful projects implemented worldwide, GEM is the leading consulting firm in the mining industry.

Our mission

We are a provider of excellent industrial engineering products and services for the mining industry. We seek to maximize the value of our clients' business by improving their ability to make strategic decisions, through innovative services delivered effectively by a highly qualified professional team.

We have six areas of expertise:

Analytics	Training	Economy
Strategy	Evaluation	Optimization

"A NEW PERSPECTIVE"

"We trust that our experience and knowledge in management and economics, accumulated in more than 13 years of existence and more than 350 projects developed internationally, are a valuable source of knowledge for the mining industry. This is why we have started this publication quarterly called Perspective. Using plain language, we will present some of the issues with the greatest impact for companies, operations, projects and other stakeholders in the industry, offering a new and/or renewed Perspective on the subject.

With so many topics of interest to the industry, we decided to start this publication with an in-depth review of risk analysis in mining operations and projects.

Trying to maintain the objectivity of the analysis at all times, this document summarizes the main aggregate results that we have been able to derive together with more than 20 mining companies and 80 projects in recent years. Thus, we have also incorporated some of the most relevant academic sources to substantiate the causes of deviations in mining projects.

In order to offer a more specialized look, we decided to go deeper with a higher level of analysis of the industry.

of copper in Chile and Peru, which together produced about 37.5% of the world's copper mine production in 2021.

Although at the beginning of this century few companies dared to quantify the risk of their projects and operations, today practically all the main mining companies in the world maintain risk analysis and management systems at the corporate level, as well as in their operations and Projects.

It even seems unthinkable today to make strategic decisions without a deep and quantitative understanding of the vulnerabilities and opportunities that these decisions entail.

This is not, however, pure chance. The internal and external environment of mining has become more uncertain in the last two decades, and probably some sources of uncertainty (prices, environmental regulations, relationship with communities, technical challenges, among others) will only increase in the future.

We hope that Perspectiva, available in English and Spanish, will become a reference in the mining world for all those who wish to know and delve into cutting-edge problems and tools. In this way, we are convinced that this publication will allow us to continue supporting the mining industry to maximize the value to be extracted and captured from its business decisions."

Juan Ignacio Guzmán
CEO of GEM

RISK ANALYSIS IN THE COPPER INDUSTRY

ESTIMATE VS REALITY

Through an international tender in 2004, Xstrata Copper obtained the right to explore "Las Bambas" copper deposit, located about 72 km southwest of the city of Cusco, Peru.

The feasibility study was obtained in 2009, and two years later, the EIA approval.

The total capital cost was estimated at USD 4.2 billion, and the production at 400,000 tons of copper under the regime. With this, the construction of the mine began in 2012, a period in which the price of the metal was close to USD 4 /Lbs.

In 2013, Glencore acquired Xstrata, making it the new owner of the mine.

There was already progress in the construction and infrastructure of Las Bambas in 2014, when the prospects for the price of the metal also decreased. It was this year that the consortium made up of MMG Limited, Guoxin International Investment Co. Ltd. and CITIC Metal Co. Ltd. acquired this copper deposit.

Finally, the first production of copper concentrate was achieved in December 2015, as part of the commissioning activities.

Commercial production began in July 2016. The updated total capital cost: USD 7,4 billion, 75% higher than the estimated value in the engineering stage.

In the first full year of commercial production, this exceeded 450,000 tons of copper in concentrate, and the mine is currently studying stage 2 of operation development and the fourth EIA.

Development cases such as the one described above are not an exception in the mining industry. Market estimates may change. New and better technical solutions are developed and new political, social and regulatory requirements can be established after the investment decision.

In practice, it is known that there are always uncertainties, which, when materializing a project, constitute risks that can affect the final value of mining projects. Thus, many investments do not reach the original promised return.

For this reason, the objective of this report is to study the main variables that affect the economic value achieved by mining projects, analyze the aggregate impact observed in the industry and shed some light on the reasons that explain these deviations from what has been indicated in the literature.

This study is based on the best practices of the mining industry and GEM's experience in Risk Analysis and Management of individual and aggregate projects, as part of a portfolio of investment projects. In this way, we hoped to detect opportunities for improvement in the current estimation process.

ANALYSIS METHODOLOGY

This consists, first of all, in an Ex Ante study of 53 Risk Analyzes carried out by GEM, for 27 projects of different mining companies between 2010 and 2021, considering the identification of the main uncertainties, their individual contribution to the Value at Risk (VaR) of the project, and the analysis of the estimation of the uncertainty in relation to the value estimated by the project teams.

Second, it includes a Ex Post evaluation focused on the cost overruns and overtime experienced by mining projects, based on a large database of mining projects in the world executed between 1994 and 2021, which includes 237 estimates of 88 projects in different stages from engineering to construction .

As part of the review, different hypotheses from the literature are explored that seek to explain in isolation the bias and variability experienced by mining projects, in particular, for copper mining in Chile and Peru.

As a result of the analysis, it is evident that mining projects present a deficit in the estimation of CAPEX and execution terms, presenting cost overruns and overtime.

In the following pages, the analysis and discussion of the observed results is presented, contrasted with some explanations identified in the literature, regarding deviations between the early and materialized estimates.

I. EX-ANTE EVALUATION

Below, is a compilation of different Risk Analysis studies carried out by GEM, particularly in the copper mining industry in Chile and abroad.

The objective is to show the main uncertainties identified, their individual contribution to the project's Value at Risk (VaR), and the measurement of the total uncertainty of the project's value with respect to the value estimated by the estimation team (deterministic value).

Figure (1) below corresponds to a diagram of the considered database, which contains a total of 53 Risk Analysis studies carried out by GEM on 27 copper mining projects between 2010 and 2021.

Figure 1 - Database Schema

Database GEM Ex Post Assessment → 53 Risk Analysis → 27 mining projects

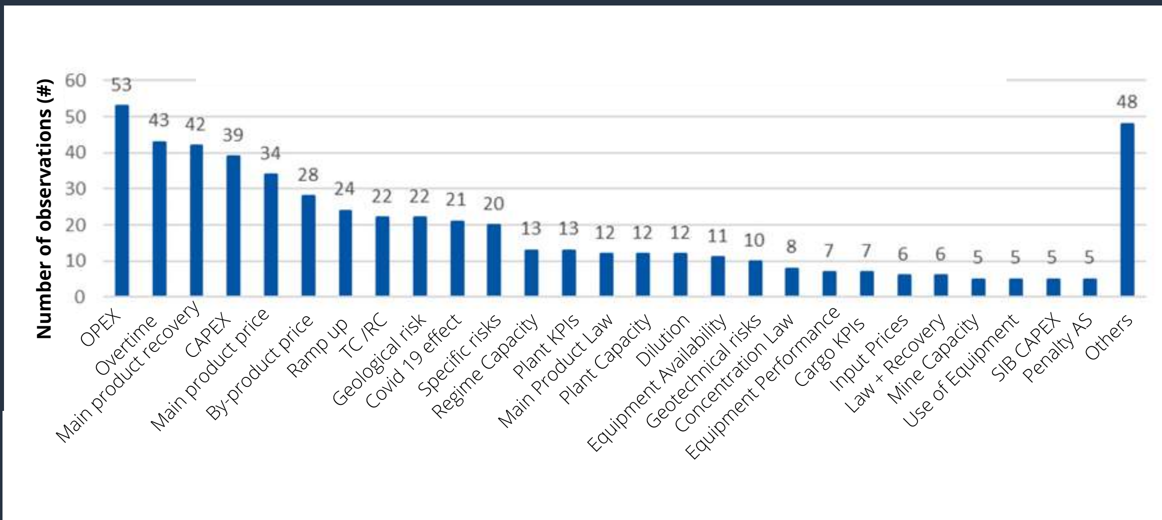
In order to assess the impact of the deviation of the estimates on the value of the project, the analysis of the database focuses on the collection of the following variables (figure 2): i) identified risks, ii) probability of fulfilment of Net Present Value (NPV), iii) Value at Risk (VaR), iv) probability of loss, v) contribution of risks to VaR and vi) risk bias.

Figure 2 - Variables

1. Identified risks
2. NPV compliance probability
3. VaR (Value at Risk)
4. Loss probability
5. Risk contribution to VaR
6. Risk bias

Graph 1 shows the record of observations referring to the risks identified in the Risk Analysis studies developed by GEM for the copper industry.

Graph 1- Mining Industry Risks

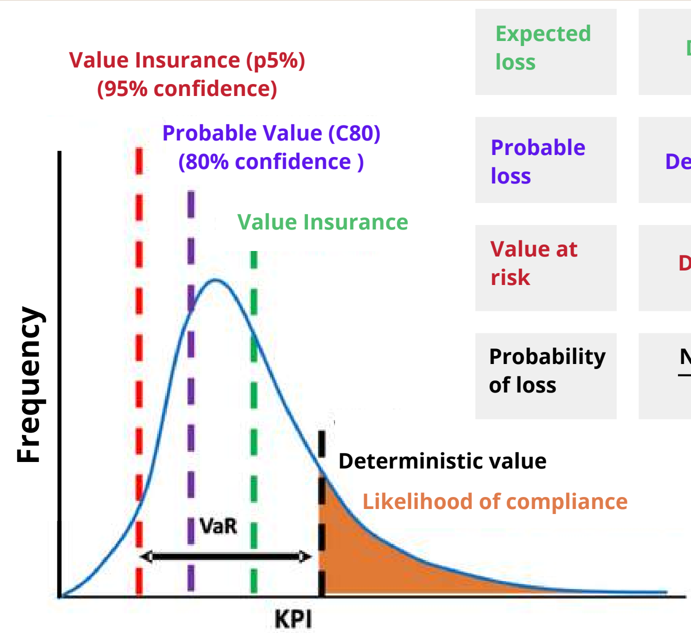


WHAT ELEMENTS MAKE UP A GEM RISK ANALYSIS?

Through Monte Carlo simulation, the risk analysis is obtained, which has the following metrics:

- Value at risk (VaR): It is the value which can be lost (or created) if the risks materialize. Result of the difference between the Deterministic Value and the Safe Value.
- Loss probability: It is the number of times in which the simulation returned a negative NPV value over the number of iterations.
- NPV Compliance Probability: It is the number of iterations in which the NPV is greater than the deterministic value.

The following scheme incorporates the described metrics:



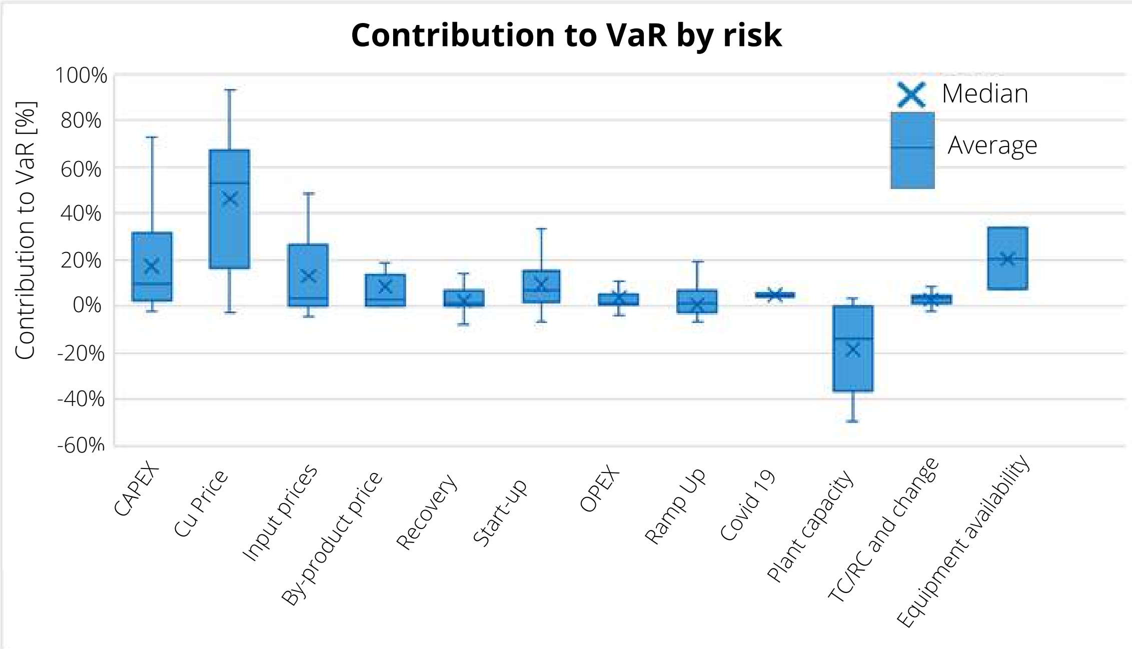
Expected loss	Deterministic value- Expected value
Probable loss	Deterministic value - Probable value (C80)
Value at risk	Deterministic value - Safe value (P5%)
Probability of loss	No. of interactions with negative NPV / 10,000

It is observed that the OPEX (Operating Expense) is considered in all the Risk Analysis studied. Other risks considered in most of the analyzes correspond to the delay in the execution period, the recovery of the main product, CAPEX (Capital Expenditure), the price of the main product and the price of by-products.

It is important to note that the graph above does not account for the impact of these risks, and its objective is only to illustrate the risks most considered in industry studies.

The following graph (2) shows the impact on the Value at Risk of the projects for the main risks identified.

Graph 2 - Impact on the Value at Risk of the projects for the main risks identified



The lower limit of the box corresponds to the 25th percentile and the upper limit to the 75th percentile of the data set. The band outside the box corresponds to the minimum and maximum value.

It can be seen that the risk with the greatest impact on the Value at Risk in the projects studied corresponds to the price of the main product, which contributes 46% to the VaR on average.

Likewise, other variables with a high impact on the value of the project correspond to CAPEX, Start-up, plant capacity and equipment availability.

Uncertainties with a low impact on VaR, such as OPEX, imply that the industry, in general, considers that if the uncertainty materializes, the NPV will not be significantly affected. This is explained with GEM's model for OPEX, which includes the reaction or adjustment of this item to the price of the main commodity and, consequently, its contribution to the Value at Risk. In other words, although there is an operational variability that is contained in the OPEX uncertainty, GEM's Risk Analysis also considers eventual cost adjustments in the face of possible rises/falls in the price variable.

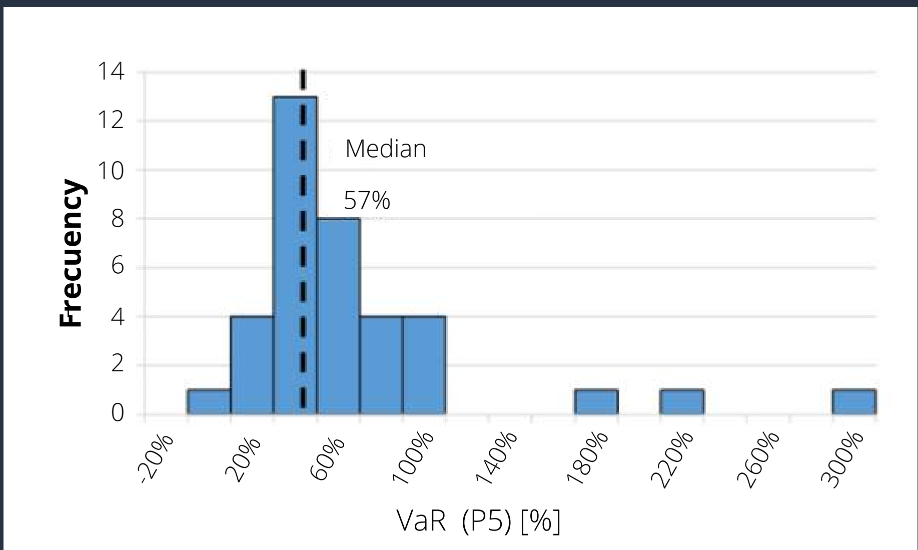
Fiinally, for GEM's Risk Analysis database, the level of uncertainty of the measurement through the calculation of the Value at Risk (VaR) on the estimated NPV, which is presented in the following figure (graph 3).

This ratio gives a measure of the risk level of each project, and allows comparing projects of different sizes and characteristics, by virtue of each company's own risk tolerance.

A value close to zero is optimal for this ratio, where the safe value (P05) would be equal to the estimated NPV and the rest of the simulation values would be greater than the estimated NPV. On the other hand, a high value of the ratio of VaR over NPV indicates that the safe value of the project is small with respect to the estimated NPV, and, therefore, the Value at Risk is high.

The graph 3 shows that the average value of the VaR over NPV is 57%, which means that, on average, the safe value of the projects in the database is 43% of the NPV estimated prior to the Risk Analysis.

Graph 3 - VaR over estimated NPV



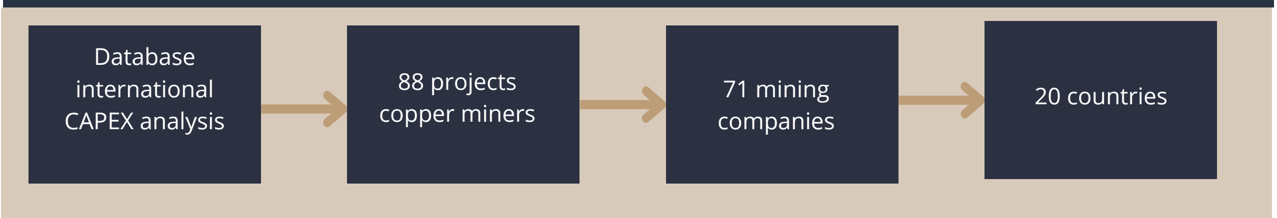
II. ASSESSMENT OF COSTS OVERRUNS AND DEADLINES IN THE MINING INDUSTRY

As stated in the previous section, the capital expenditure and the start-up date of a mining project are sources of uncertainty relevant to its success.

For this reason, this chapter describes the Ex Post analysis carried out by GEM of the cost overruns and overtimes of 88 copper mining projects carried out internationally between 1994 and 2021.

The following figure (3) outlines the database used:

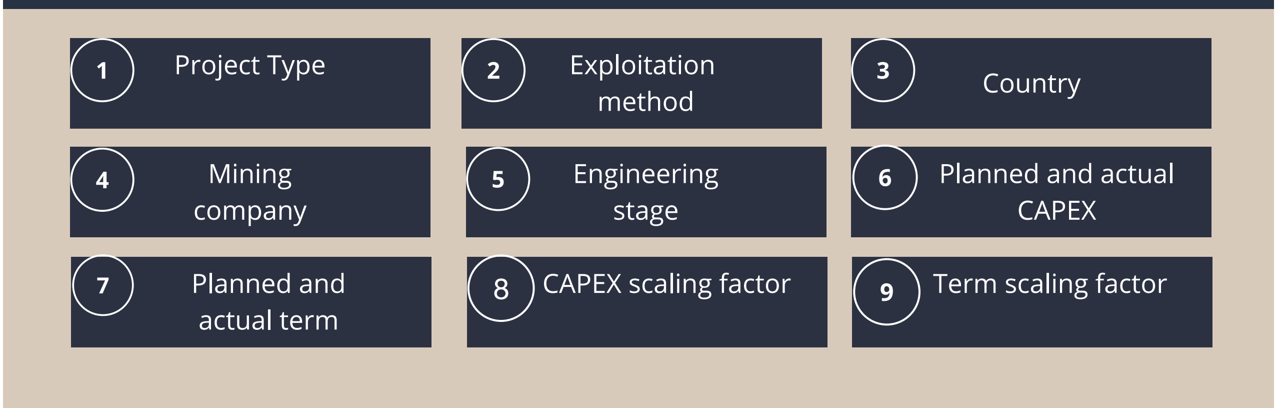
Figure 3 - Database



The information includes various mining companies and different stages of engineering (from pre-feasibility to construction).

The projects analyzed in this database correspond to Greenfield and Brownfield type projects. The variables that are handled are the following:

Figure 4 - Variables



Among the multiple ways of grouping and studying the information, different hypotheses collected in the literature are explored that could partially explain the bias and variability experienced by mining projects.

Thus, in order to characterize the information, the following categorizations are used: i) type of project (Greenfield and Brownfield), II) method of operation (Open, underground, mixed), III) stage of engineering and iv) size of the project (CAPEX).

In the database there are 34 Greenfield-type projects and 54 Brownfield-type projects. The most studied exploitation method corresponds to open pit, with 60 observations, followed by underground with 20 observations and 8 of mixed type.

Finally, regarding the categorization of the engineering stage, there are 94 projects in a finished state, 36 under construction, 90 in feasibility and 17 in the pre-feasibility stage.

As a point of reference, the main metrics recorded in the database are presented in the attached table 1:

Table 1 - Database statistics Ex Post Analysis

Variable	Unit	No. Projects	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	87	5,6	0	0	9,2	0	12
Overrun	%	87	21,4%	12,4%	0%	35,4%	-8,6%	64,4%

As shown, the database indicates that the average cost overrun of mining projects is 21% higher than the planned value, with a standard deviation of 35%. Regarding the average delay of the projects, this is 5.6 months with a standard deviation of 9.2 months. These indicators of cost overruns and overtime generate a great opportunity for improvement for the projects, since these could be evaluated with greater precision, anticipating the bias of the Risk Analysis of copper mining projects.

On the other hand, there is great variability between the study data, which reflects in a good way the world situation of built projects. For example, regarding the CAPEX scaling factor, it is possible to see that there are projects that end up costing 16% of the estimated total (minimum value).

This type of project corresponds to those with less intensive use of capital (within USD 60 to USD 120 million).

There are projects with a cost overrun of up to 2.97 times the estimated value, corresponding to a mine in Congo with an estimate of USD 787 million and a materialized CAPEX of USD 2.3 billion.

Likewise, it can be seen that there is great variability in the execution periods of the projects, with an average delay of approximately 6 months to projects with a delay in the execution period of up to 4 years.

When analyzing the database discriminating between open pit and underground type projects, the following table 2 is obtained for open pit mining projects.

Table 2 -Ex Post Analysis Statistics: Open Pit Mining Projects

Variable	Unit	No. project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	60	4,9	0	0	7,5	0	12
Overrun	%	59	20,5%	8,0%	0%	37,3%	-11%	62,9%

For the case of underground mining, the following indicators contained in table 3 are obtained.

Table 3 - Ex Post analysis statistics: Underground mining projects

Variable	Unit	No. project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	19	6,1	0	0	11,5	0	18
Overrun	%	20	29,4%	17%	0%	30,3%	0%	69,4%

It is possible to observe that underground mines have, on average, a higher CAPEX scaling factor than open pit operations. This may be due to the fact that underground mining projects are more complex in their construction. This is one of the most important cost overrun factors according to the literature (Segelod, 2018),[1] unlike open pit projects that focus on sequencing mineral extraction.

In addition to presenting greater delays due to the complexity of construction, underground mining also suffers from greater preparation time before production.

1 Segelod, E. (2018). Project Cost Overrun. DOI: 10.1017/9781316779675

Now, distinguishing between engineering stages, it is observed that a more advanced stage manages to get closer to the real CAPEX and has a smaller deviation with respect to the execution deadlines of the projects.

Table 4 contains the indicators for feasibility engineering.

Table 4 - Ex Post Analysis Statistics: Feasibility Studies

Variable	Unit	No. project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	90	5,5	0,25	0	8,6	0	12
Overrun	%	90	23%	13%	N/A	41,9%	-8,8%	69,4%

It can be noted that the cost overrun, as the engineering stages progress, decreases until the final CAPEX materializes in the construction stage. This may be due to the greater certainty that exists as more studies are carried out.

Table 5 - Ex Post analysis statistics: Pre-feasibility studies

Variable	Unit	No. Project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	17	7,5	12	12	9,9	0	12
Overrun	%	17	40,2%	24,1%	N/A	52,3%	-15,5%	111,1%

The following tables show the impact on the indicators when discriminating the projects by virtue of their capital expenditure.

For CAPEX projects of less than USD 250 million, the following indicators are available, contained in table 6.

Table 6 - Ex Post analysis statistics: Small projects

Variable	Unit	No. Project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	35	5,2	0	0	9,8	0	12
Overrun	%	36	21,8%	7,8%	0%	38%	-8,8%	45,2%

For CAPEX projects between USD 250 million and USD 750 million, the statistics are contained in table 7.

Table 7 - Ex Post Analysis Statistics: Medium Projects

Variable	Unit	No. Project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	22	6,3	0,5	0	8,8	0	12
Overrun	%	22	21,1%	8,6%	N/A	39,9%	-14,4%	71%

For CAPEX projects above USD 750 million, the indicators in table 8 are available.

Table 8 - Ex Post analysis statistics: Megaprojects

Variable	Unit	No. Project	Average	Median	Mode	Standard Deviation	P10	P90
Project's delay	Months	30	5,4	0	0	8,8	0	12
Overrun	%	29	21,3%	15,4%	0%	27,6%	-7,9%	62,9%

It can be inferred that the cost overrun (and overtime) of copper mining projects is independent of the size of the project in terms of CAPEX, since they present indicators without a clear comparative trend.

III. ASSESSMENT OF COSTS AND DEADLINES IN THE COPPER MINING INDUSTRY IN CHILE AND PERU

Similarly, it is interesting to understand the uncertainty 'estimated capital expenditure and execution times' in isolation in the region that concentrates the largest copper production in the world: Chile and Peru. For this, a universe of copper projects greater than USD 100 million on Greenfield, Brownfield, Redfield and infrastructure projects such as desalination, aqueducts and mineral pipelines in the last 11 years is considered.

For the analysis of cost overruns in these two countries, Greenfield, Brownfield, Redfield and infrastructure projects were taken (unlike the international database where only Greenfield and Brownfield projects were considered).

The database has information on 118 projects of 49 mining companies, from which it was possible to obtain information regarding the cost overrun of 29 projects.

Table 9 shows the number of observations by type of project, where it is observed that Brownfield and Greenfield type projects prevail.

Table 9 - Observations by type of project within the Ex Post Evaluation in Chile and Peru

Type of project	Unit	No. observations
Brownfield	s/u	49
Greenfield	s/u	45
Redfield	s/u	3
Infrastructure	s/u	21

The following graph (4) shows the histogram of cost overruns for the projects studied in Chile and Peru (which is higher than copper mining projects worldwide). It is observed that most of the projects exceed the estimated CAPEX, while only one of the projects studied shows a saving in CAPEX.

Graph 4 - Cost overrun histogram

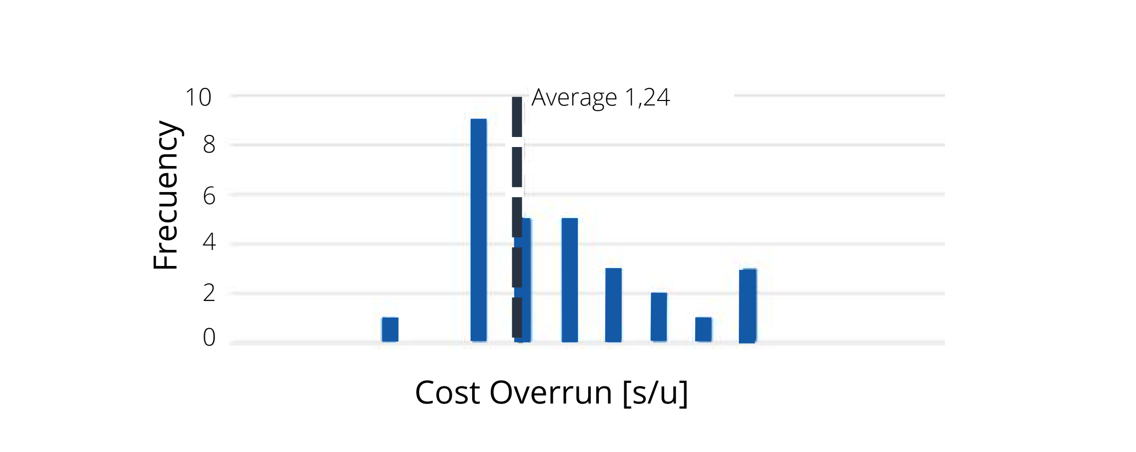


Table 10 complements the previous figure with information regarding the delay of the project.

Table 10 - Ex Post analysis statistics: Chile and Peru

Variable	Unit	No. Project	Average	Median	Mode	Standard Deviation	P 10	P 90
Project's delay	Months	18	6,7	7	7	4,8	0	11
Overrun	%	29	24%	17,3%	N/A	20%	3,6%	51,8%

From this information, an average cost overrun of 24% is shown.

The average delay of projects is 6.7 months with a standard deviation of 4.8 months. It is worth mentioning that most of the projects have a delay of 7 months.

In relation to the parameters observed worldwide, there is a higher cost overrun in copper mining projects in Chile and Peru, which may be due to the increase in the overtime of projects executed in these countries.

ANALYSIS AND DISCUSSION

The results do not seem surprising. Faced with the materialization of the various uncertainties that a mining project faces, an appropriate evaluation of the development and execution of the project must include the consideration of additional elements and/or savings, price changes, changes in scope and goals, and the modification of expectations and requirements from the planning and approval stage.

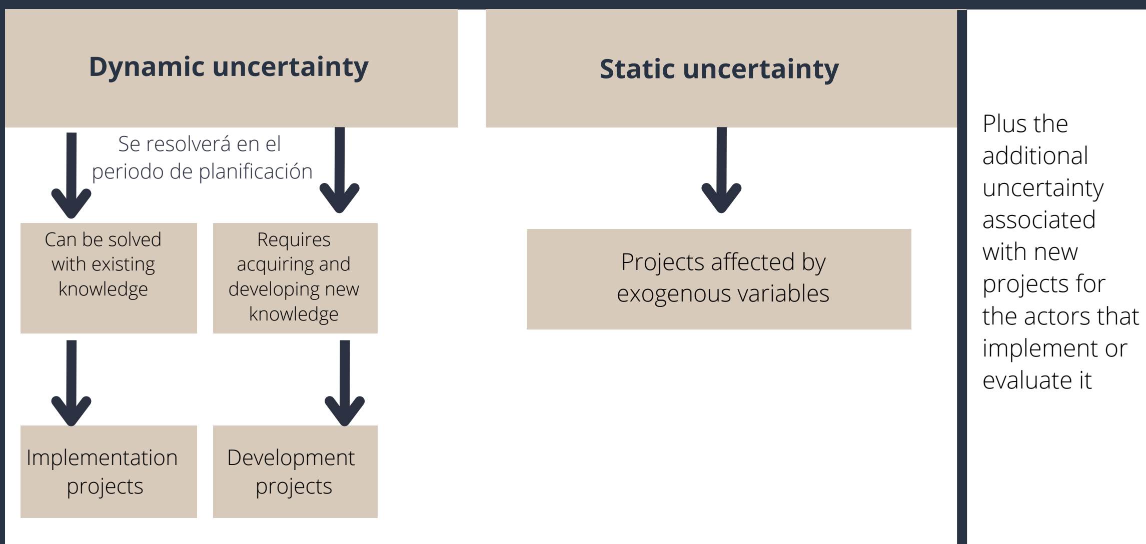
To do this, Segelod (2018)[2] proposes, first, to distinguish between static uncertainty and dynamic uncertainty.

On the one hand, static uncertainty originates from external factors, such as political changes, laws, regulations, natural disasters, or exchange rates, and is a form of uncertainty that is always present and will not go away until the project is complete.

The dynamic uncertainty is resolved to the extent that the project is completed and more reliable information is available.

In the following figure (5), we see schematically what was mentioned above.

Figure 5 - Project uncertainty



Segelod (2018)

2 Segelod, E. (2018). Project Cost Overrun. DOI: 10.1017/9781316779675

Furthermore, a higher level of risk will be found in those projects that from a technical point of view require new knowledge, in which the detailed specifications cannot be delivered before the investment decision.

In that case, planning is a learning stage, starting with a vague vision to be grounded. It requires ideas and alternative solutions to events that could radically modify the planned vision.

However, technical ignorance is far from being the only catalyst that explains the differences between the return obtained and the return committed in the investment decision.

As summarized by Plebankiewicz (2018),[3] projects face technical, economic, contractual, psychological, and political challenges that must be carefully considered at the time of investment approval.

3 Plebankiewicz, E. (2018). Model of Predicting Cost Overrun in Construction Projects. Sustainability, 10(12), 4387. https://doi.org/10.3390/su10124387

Table 11. Project uncertainties. Plebankiewicz (2018)

Category	Cause	Impact of the Project*
Technical	Price increase	ΔP
	Poor project design	ΔQ
	Incompleteness of estimates	ΔP, ΔQ
	Scope changes	ΔQ
	Inappropriate organizational structure	ΔP, ΔQ
	Inadequate decision process	ΔP, ΔQ
	Inadequate planning process	ΔP, ΔQ
	Additional works	ΔQ
	Replacement work	ΔQ
Economic	Lack of incentives	ΔP
	Lack of resources	ΔP, ΔQ
	Inefficient use of resources (poor financing)	ΔP, ΔQ
Contractual	Bidding strategy (open, selective)	ΔP
	Sourcing Options (design-build; design-build)	ΔP
Psychological	Optimism bias among local officials	ΔP, ΔQ
	Cognitive bias of people	ΔP, ΔQ
	Risk aversion	ΔP, ΔQ
Political	Deliberate cost underestimation	ΔP
	Budget manipulation	ΔP

Source: Plebankiewicz (2018)
ΔP Price change
ΔQ Scope changes

Faced with these difficulties, to estimate the real value of the project and reduce its uncertainty, it is recommended to at least:

- Define in detail the items included and costs considered in the investment amount.
- Assess whether the stipulated estimates represent the most likely outcome.
- Recognize whether estimates have been adjusted for price and inflation changes (scaling).
- Determine the eventuality of considering changes in the project.
- Include the costs and impacts of the project at the company level and not just the project.

CONCLUSIONS AND RECOMMENDATIONS

In this Perspective report, we identified the main risks of the copper mining industry (measured by the number of occurrences), which are considered in Risk Analysis according to a set of studies carried out by GEM in the mining industry.

In all these studies, we observed that the OPEX (Operating Expense) risk is considered.

In the vast majority of them, the risk of delay in the execution time of the project, the risk of the main product recovery, and the CAPEX (Capital Expenditure) risk are also considered.

In more than half of these studies, the main product (copper) and sub-products price volatility are considered.

We studied the contribution to the Value at Risk (VaR) of the main uncertainties present in the Risk Analysis studies, in order to concretely determine the impact that the industry provides for these uncertainties.

We determined that the price of the main product (copper) is the uncertainty that is assigned the most weight within the contribution to the Value at Risk (VaR); that is, if the uncertainty were to materialize, the impact on the value of the project would be significant.

To a lesser extent, we observed the same behavior on CAPEX, which contributes greatly to the Value at Risk, reaching almost 20% on average.

Given the contribution to VaR of the price of inputs, price of by-products, recovery, execution time and ramp up, we concluded that these risks have a negative impact on the value of the project. This allows us to infer that the value of the price of by-products, recovery, etc., used to calculate the value of the project is underestimated, generating a bad estimate of the NPV.

From the Ex Post evaluation of cost overrun and overtime, it is possible to verify that in copper mining projects there is an average cost overrun of 21% and an overtime of 6 months, however, these data show great variability.

These indicators generate a great improvement opportunity for the projects, since they could be evaluated with greater precision, anticipating the bias of the Risk Analysis of copper mining projects.

A better understanding of these factors is very important for investors, project manager, finance managers, and for improved allocation of resources in organizations and society.

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