Integral Management of mining projects in a world of Dynamic Complexities: Challenges and opportunities.

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ABSTRACT: This paper aims at providing an explanation as to why certain mining projects face major difficulties that can lead to their failure, even when a considerable part of the investments has already been made. This research reviews the literature on the topic and was developed after 35 years' experience of the author, who led two projects of a very different nature; the first one was a mining-port investment –amounting to US$ 600 million– in a remote and almost uninhabited island in Magallanes (Riesco Island), including an open pit coal mine and port facilities which have been in operation for the last six years and export to different countries around the world and to Chile's north region. The second project was the expansion of CODELCO's El Teniente Mine (New Mine Level), a project worth more than US$ 4 billion. The common ground in such different projects is Dynamic Complexity and a new understanding of uncertainties, which both are defined and explained from the standpoint of the learning process as well as from the relationship among different aspects of a mining project. The article make three recommendations in order to manage the Dynamic Complexity, first the concept of Site Investment in the early stages of the project. Second an application of the Geotechnical Baseline Report, not only related to the focus made by theirs authors (Essex, 2007), but also related to capture a Bank of Key Assumptions (related to the Site Investment process) in order to manage the uncertainties, considering the definition made by Perminova (2008). Finally, the article emphasizes the role of the Board of Directors in the definition of the appetite for risk (Enrione, 2014), along with the introduction of a Technical Committee that creates a healthy stress between the Project Manager and the Board of Directors as the ultimately responsible party.

Key words: Mining projects, Dynamic Complexity, Corporate Governance, Uncertainties, Site Investment, Geotechnical Baseline Report, Risk Management, Megaprojects, Environment, Learning Process.

1. DYNAMIC COMPLEXITY IN MINING PROJECTS AND ITS RELATIONSHIP WITH UNCERTAINTIES.

1.1. Main characteristics of projects.

Projects have a number of features that makes them unique and different from companies in operation. Projects aim at achieving an investment studied at the engineering level, with limited information about reality, in a constrained period of time and budget, with a work team that has not necessarily worked together before, and often in an environment where various stakeholders have differing interests. These characteristics create conditions that must be taken into account in order to define the structure of the project, from its earliest stages of study up to the stage where investments begin to materialize.

According to Turner and Cochrane (1993), there are four types of projects with well-defined (or not) work methods and/or goals. This results in the Goals and Methods Matrix, shown in Figure 1 below.

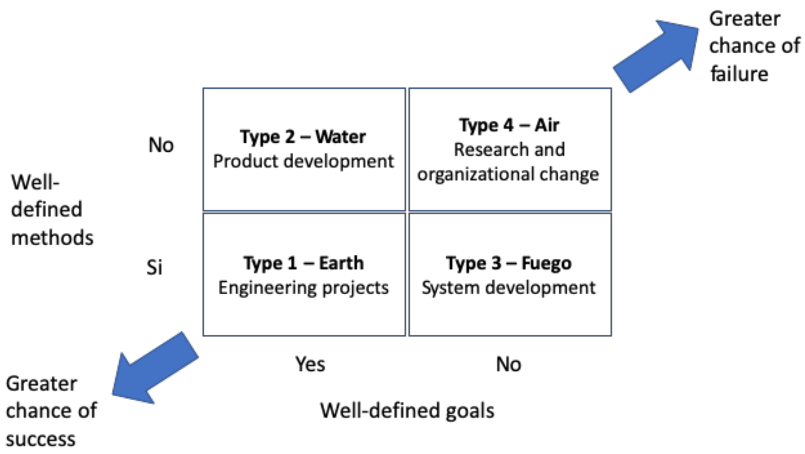


Figure 1: Goals and Methods Matrix (Turner and Cochrane, 1993).

The categorization of Earth, Water, Fire, and Air tries to portray the difficulties in each of the cases in order to define goals and methods. In the case of Water, the reference is to a troubled flow, with a strong sense of purpose, but with a random journey. For Fire, a strong intensity is required for the definition of an effort that can fade away. Finally, Air refers to the difficulty of being captured. According to these authors, during 1993, the element most concrete and easy to capture was Earth. If complexities inherent to the territory and its stakeholders are considered, engineering projects have drifted to types related to Water, Air, or Fire.

The tendency may exist to think that projects associated to mining industry and ore benefit fall exclusively under Type 1 projects. In the case of megaprojects (with an investment around the 1 Billion dollar or higher), however, certain components such as environmental issues, technologies, and potential markets, among others, are beyond Type 1 projects. In the case of mining projects, the complexities inherent to large projects are added, as well as the difficulties linked to the reconnaissance of the rock mass connected to its interaction with environmental issues, making the definition of goals and methods difficult.

These same authors suggest a logical sequence between a project's purpose or goal and its scope and, in turn, among them and the organization created for its materialization. The variables of time, quality, and costs are later defined; as shown in Figure 2 below.

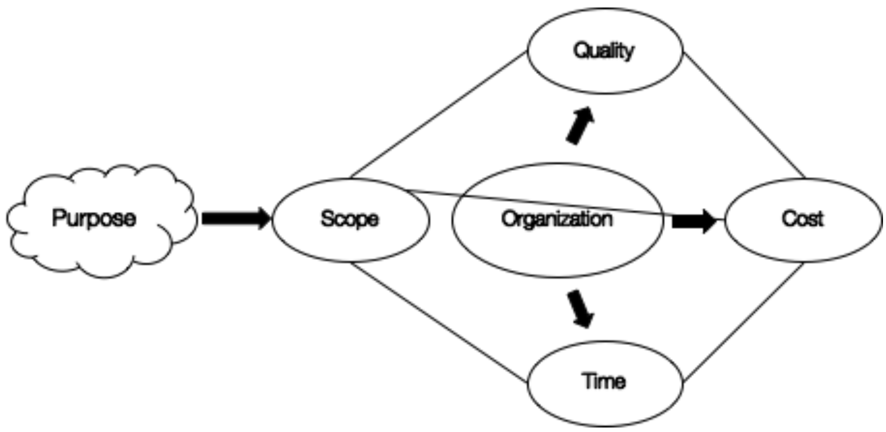


Figure 2: Five project goals, definition sequence (Turner and Cochrane, 1993).

This structure defines some of the essential elements of projects, which makes them different from operations underway (Turner and Cochrane, 1993):

- Work is unique.
- The organization is created for this work, it is a new organization.
- A single big change takes place, and it is finalized in a particular day when the project is complete and starts to operate, but it is designed to be sustainable over time.
- In many cases, the project must share some restrictions imposed by operations, forcing major adjustments among their components.

- In the case of large mining projects, a large number of stakeholders are involved.

For the former structure to make sense, governance should promptly address the following tasks (Turner and Cochrane, 1993):

- *Create a shared vision for the project, identifying its context, purpose, and goals,*
- *Focus the team's attention on the purpose of the project and the method to achieve it,*
- *Obtain consent for the plans, defining the scope of the work, the organization, and restrictions regarding quality, costs, and time,*
- *Succeed in making the team work, agreeing on the operating mode and communication channels.*

The Independent Project Analysis (IPA) has defined the Business and Engineering Alignment Meeting (BEAM) as the crucial gathering at the start of a project. The team reaches a common understanding regarding the project's requirements at the end of FEL 1 (Front End Loading, or the approval gate for the first stage of a project).

For programming and planning purposes, a project is divided into three specific structures (Turner and Cochrane, 1993). These structures should gradually be taking shape up to the moment when their construction is decided:

i. Product Breakdown Structure (PBS): A "cascade" of deliverables in which the project can be subdivided, with a number of subsystems and its different components.
ii. Organization Breakdown Structure (OBS): The definition of the resources required, indicating the different subjects, and activity types, among others.
iii. Work Breakdown Structure (WBS): "Common elements or work items that support an integrated project administration and control method" (Serpell, 2001), allowing "a person or a small group, usually not specialized, to gain proper control over it".

In sum (Turner and Cochrane, 1993), the project is a WBS developed by the resources and skills defined in the OBS, while the facilities are the list of elements in the PBS.

In the mining industry, definitions are made in a very traditional bottom-up fashion –as defined by the authors (Turner and Cochrane, 1993)– associating projects to Type 1. Therefore, the risk of using the same mental models over and over again is run, even though some of the conditions might have changed, thereby leading to subsequent difficulties.

1.2. Complex systems.

According to Williams (2002), a complex system is composed by a large number of parts that interact with each other, some of them interdependently, where the whole is more important than each of the parts. The behavior of the system goes beyond the sum of its parts; because of this, the potential responses to the "inputs" made to the system in construction are difficult to predict *a priori*. The relationships between the parts can take different forms:

- Discretely: Each part contributes with a special element to the "whole", and no other relationships between the elements are established.
- Sequentially interdependent: The "output" of an element is the "input" of the next, and so forth. This sequence does not consider a recursive process.
- Sequentially dependent: Unlike the former, recursive processes exist between the inputs and outputs of each element, therefore a blend of discrete and sequential relationships can happen, but with a recursive process.

In addition to this complex system, as defined, some of these elements could be in a process of change with regards to a first design, either programmed in advance or not, whereby the unbalanced relationship between them will prevent the of drawing conclusions. While changes in projects –when these are under construction– are unwanted and try to be avoided, it is impossible to shut them out. Therefore, they must be regulated and controlled in accordance to best practices, while being increasingly aware of Dynamic Complexity. The change of an element changes the element itself and its relationship with the whole, generating the Dynamic Complexity of the system, as discussed in the next chapters.

According to the mentioned author (Williams, 2002), the Dynamic Complexity of projects relates to two dimensions: one is structural and the other one is related to uncertainties, as shown in the following Figure3.

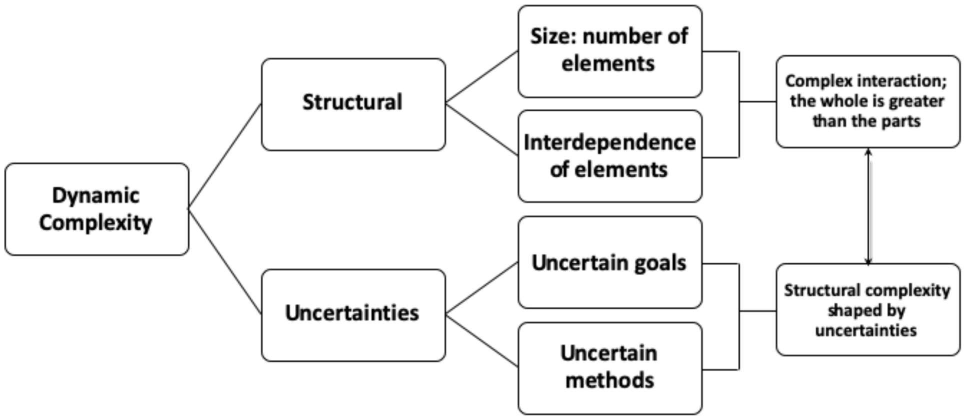


Figure3: Dynamic Complexity: Structural and uncertainties according to Williams (2002).

1.3. Elements that contribute to the Dynamic Complexity of a project.

In a specific study about projects, Bosch-Rekveldt et al. (Bosch-Rekveldt and others, 2011) – in addition to a global review of the existing literature about complexity– conducted a survey with several managers of six projects (three for each one), in different fields, the findings of which were compared with the literature. The selected projects were of an investment size between USD20 million and 600 million, located in different continents, with a single owner and others in joint ventures. The research covered every aspect, from a project's initial stages to its commissioning. Along with contrasting the results of the surveys with what is suggested in the literature, the scholars classified the variables identified into three features that are characteristic of a project: technical, organizational, and environmental; and identified 14 categories which add complexity to large projects, according to the following Table 1.

Technical Aspects (T)	Organizational Aspects (O)	Environmental Aspects (E)
Goals	Size	Risks
Scope	Resources	Stakeholders
Risks	Risk	Location
Tasks	Project Team	Market conditions
Experience	Trust	

Table 1: Categories defined in TOE

Within each of these categories, the authors included 50 elements identified as potential contributors to Dynamic Complexity. Of these, nine are present in the six projects studied:

- How innovative the technology is and how familiar it is for team members (Experience category, under Technical Aspects).
- The number of project stakeholders, i.e., firm, project team, communities, government, and others, who contribute with different visions, some of them in contradiction with the project's goals (Stakeholder category, under Environmental Aspects).
- The availability of required human and material resources, since the team may lack the required expertise; or pure and simple, there could be a mismatch between their actual experience and what has been previously defined (Resources category under Organizational Aspects).
- Different administration, tools and/or methods for project management (Size category, under Organizational Aspects).
- The use of different types of contracts with construction firms that share a similar environment (Resources category, under Organizational Aspects).
- Interrelation between the project's new processes and those already existing, thereby introducing an additional stakeholder with a heavy weight in decision-making (Tasks category under Technical Aspects).
- Trust in the chosen contractor, as well as in the resources and its counterpart of the

project team, as they will have to endure the hardships of reality (Trust category under Organizational Aspects).

The "Darnall-Preston Index" is quoted in order to systematize the analysis of Dynamic Complexity in mining projects. Unlike Bosch-Rekveldt et al, these scholars suggest four families of topics, broken down as follows (Darnall and Preston, 2010):

i. *External: Environmental attributes that exist at the beginning of the project, such as size, term, and available resources.*
ii. *Internal: Related to clarity of the project's goals, clarity of the scope, complexity of the organization, and existing agreement(s) between stakeholders, in line with the matrix presented by Turner and Cochrane (1993).*
iii. *Technological: How innovative the technology is and how familiar it is for the team members.*
iv. *Environmental and Sustainability: Legal, cultural, political, and ecology-related issues.*

These authors use the term technology associated to the manufacturing of products and not to the project stages uses of technology. In the case of mining projects, a wider perspective will be used, both related to the technology used during construction as well as the technology used in the production stage, including within this dimension ore benefit techniques and ore production within the mine.

Within each of these dimensions, Darnall and Preston (2010) define topics which are complementary and/or analogous to the 50 elements mentioned by Bosch-Rekveldt et al (2011), leading to the flow chart shown in Figure 4 below.

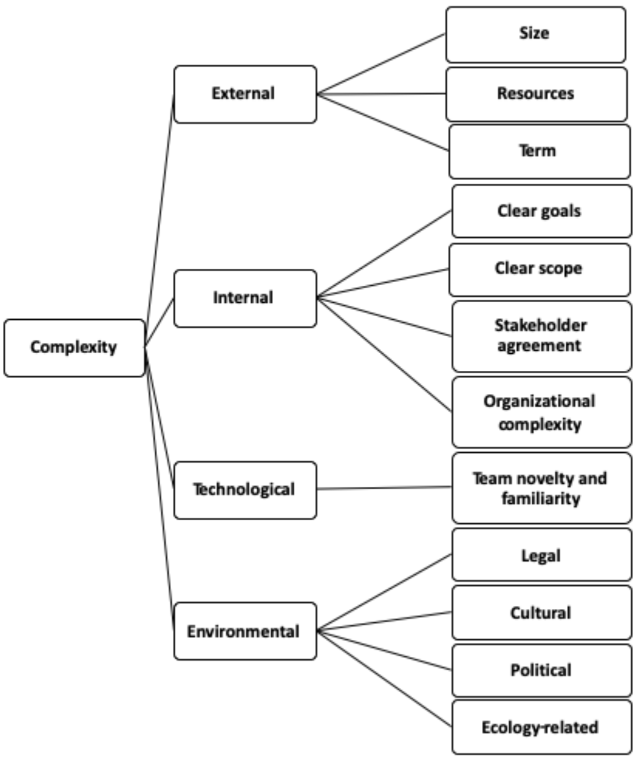


Figure 4: Complexity structure according to Darnall- Preston (2010).

1.4. Dynamic Complexity and the difficulties of learning within it.

Starting from reliable evidence, projects require designs which subsequently need to be built within limited time frames. During such time and under a specific budget, a schedule and scope must be complied with, ensuring the quality of the facilities to produce certain elements. According to Sterman (2006), people tend to be overconfident in their judgment and, in some way, display wishful thinking, evaluating expected results as more likely than unexpected ones. There is also a certain tendency to assign people's behavior to inherent factors more than to factors associated to their environment. In addition to the above, projects must make assumptions based on elements which are not fully known, with a limited ability to make trials and/or tests. The conclusions to be drawn of this process would have sometimes more uncertainties than certainties.

As indicated above, a complex system is made up of a large number of parts that interact with each other, with different levels of dependency. Furthermore, in the case of projects (Sterman, 2006), not just the actions of the project team and their closest stakeholders are present – theoretically lined up with the project's goals– but also the actions of other agents who pursue different goals. In some occasions, the goals of the latter are totally opposed to those of the project's, leading to collateral effects that add up to the project team's actions. Considering that from the beginning of the engineering up to startup 10 years can go by, the system is not only complex but displays Dynamic Complexity; this calls for an organization with special attitudes that support both learning and the use of the lessons learn in the next stages of the project.

Corporate learning process takes place through feedback (Sterman, 2006), generating "a loop-type" process based on simple feedback that changes actions; and a "double loop", which is when feedback not only changes actions, but also the mental models of people and organizations, as shown in Figure 5 below. Learning takes place not just through the feedback present in the system, but will also significantly depend on a number of soft issues, such as cultural standards and established rules, some of which are conditioned by corporate structures. All of these shape and/or modify the mental models of people and of the group. The loop process mentioned above calls upon existing mental and group models –i.e., what we understand and know about our surroundings– leaving possible uncertainties out, as will be defined further below. The double loop process is produced when, as a consequence of unmet expectations and perceptions, group models must be changed and with them, new criteria need to be set for the rules and thus, new strategies. Through this second loop, using the same information received before, different decisions are now made, leaving a more meaningful learning. For this to take place, a complete cycle of decision-making – feedback – new decisions must take place, with potential trial and error consequences.

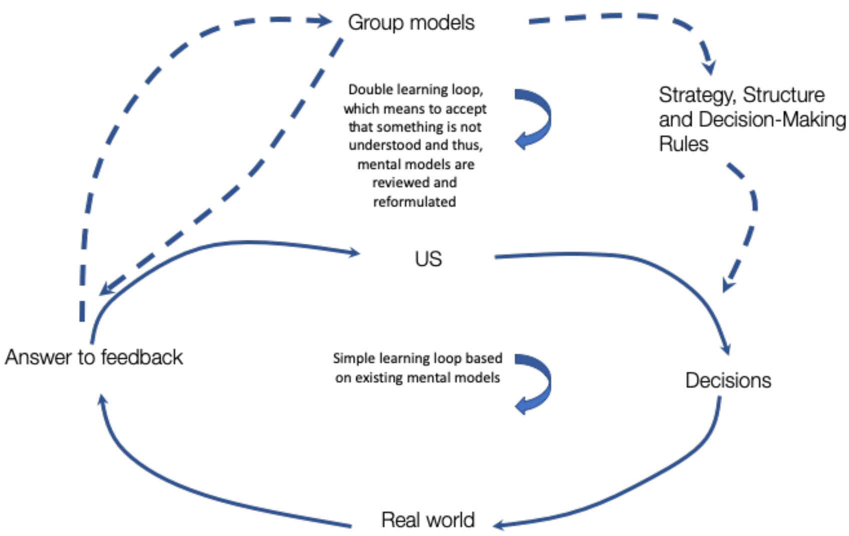


Figure 5: Double loop learning process (Sterman, 2006)

One of the difficulties faced by organizations is that they could be receiving information that requires the double loop process but are unaware of it. This can happen due to many issues: endogamic environments, fear, selective perception that rules out some facts, etc. Postponement of this double loop process – which can easily happen– can cause major problems. Given the large amount of information handled in the modern world, within the scope of projects –similarly to the problems of society in general– people are forced to simplify models and thus, make timely decisions. According to J. Sterman (2006), this will lead to errors as a consequence of a "limited rationality and misperceptions in the feedback".

In the sphere of engineering and projects, the creation of virtual models of reality, in addition to trials or experiments at industrial scales, allow for the acceleration of the learning process, as shown in Figure 6 below (Sterman, 2006). The double loop is accelerated in time by placing a virtual world in parallel to the real world, enabling the handling of simpler models capable of reproducing, in part, the reality they are modeling at very high speeds, thus leading to timely decision-making. An example of this is the development of geological and geotechnical models, which combined with mathematical models, can predict from rock mass behavior to potential economic and financial outcomes for the project. In spite of how "easy" this may seem, there are situations that cannot be simulated by these models, which added to the videogame trap, can sometimes result in a lot of playing and little thinking.

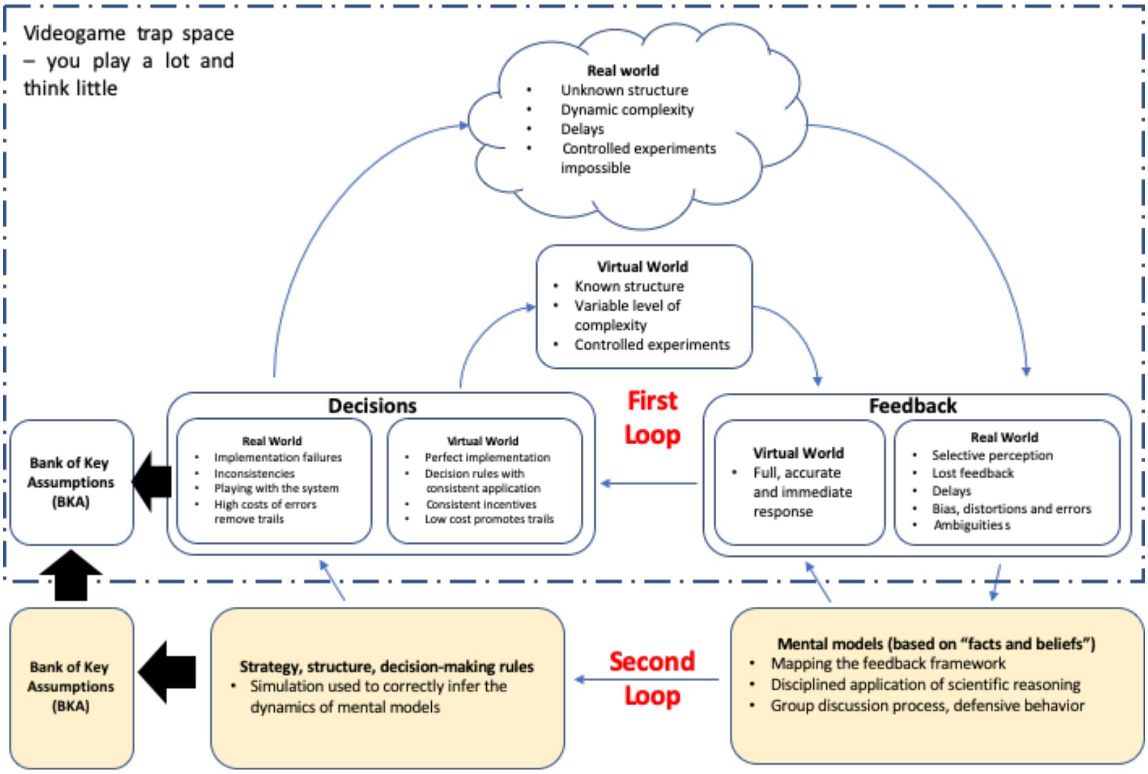


Figure 6: Double loop learning process, with support from the virtual world (Sterman, 2006; modified by J. Pedrals).

The previous figure shows the double loops learning process. The first loop is defined as the videogame trap, where you can play a lot and think little. This learning process will be further discussed below, to focus on the development of the Bank of the Key Assumptions (BKA). Originally established at the beginning with a set of mental models from the project team, the learning process should generate a new BKA based on the lessons drawn from the project's actual conditions faced along the construction.

1.5. Redefinition of uncertainties and their contribution to Dynamic Complexity

This section seeks to redefine the word uncertainty in mining projects, in such a way as to devise management strategies to follow through the different engineering stages up to construction and commissioning. The link between uncertainties and risks must be understood, hence redefining the contribution of uncertainties to the projects' Dynamic Complexity.

Several definitions of the term "risk" have been suggested:

– According to the PMBOK Guide (2013) "A risk in a project is an uncertain event or condition, which, if occurring can have a negative or positive impact on at least one project objective, such as time, cost, scopes, or quality".
– On the other hand, the same PMBOK (PMBOK, 2013) indicates that appetite for risk "is the degree of uncertainty that an entity is willing to accept, in pursuit of a reward".
– For Risk Management, ISO 31000 (Norm ISO 31000:2009) states that "risk is the effect of uncertainty on objectives".

The definition of risk implies the word uncertainties, with an author (Buchtik, 2012) stating that “risk has to do with uncertainty and with how much information regarding a situation is available. The more information there is, the lower the risk”. Therefore, risks would be a consequence of uncertainties.

Perminova and others (2008) describes the definitions for uncertainties provided by several authors:

- From the theory of organization, uncertainty is presented as "emanating from some set of objectives (but largely unmeasured) environmental characteristics”.
- “A condition of the environment of the decision maker such that he finds it impossible to assign any probabilities whatever to possible outcomes of an event”, which is part of Dynamic Complexity. Since projects have elements that are sequentially dependent, a level of uncertainty will be inevitably associated to each one. In this case, the impossibility to assign a probability of occurrence to a certain event is due to the fact that the “rules of the game” are not fully known. According to this definition, uncertainties could be a potential threat even greater than risks, for which the probabilities can actually be calculated.
- From the sphere of psychology, uncertainties are described “as a state of mind characterized by a conscious lack of knowledge about the outcomes of an event”, where “uncertainty exists ‘‘in the mind of the person who doubts”. This definition suggests that not just the environment can create situations of uncertainty, but within the team project itself, situations of uncertainties can emerge given the reaction of people in response to their context.

Taking into consideration the link between risks and uncertainties, Perminova raises a pragmatic principle whereby all beliefs or facts (what has been called mental models in Figure 6, based on facts and beliefs that give rise to the BKA) are fallible, but challenging them requires a counter argument, i.e., another fact or belief. It can therefore be argued that risk relates to the calculation of probabilities based on certain facts while uncertainty refers to whether we are sure of certain facts. With that in mind, the author defines uncertainties as “a context for risks as events having a negative impact on the project’s outcomes, or opportunities, as events that have beneficial impact on project performance”.

Finally, Perminova suggests as follows:

> *Uncertainty is an event or a situation, which was not expected to happen, regardless of whether it could have been possible to consider it in advance. In other words, uncertainty is when the established facts are questioned and thereby the basis for calculating risks (known negative events) or opportunities (known positive events) is questioned.*

The relevance of this definition is that uncertainties go beyond what risk management traditionally considers its field of action. Uncertainties would take place outside the mental and group models of the project teams, hence new dynamics are needed to manage them.

The mining industry has developed a number of tools to develop and use models that help predict rock mass behavior during construction, as well as the metallurgical outcomes of ore recovery processes. All of this takes place along with environmental modeling in compliance with current laws, but mediated by different stakeholders. These models are supported by data sets, information, and efforts by professional teams, which finally form, in accordance with Perminova, the “facts or beliefs” (quoted above as mental models). During the construction process, information will slowly be revealed in the form of new data and/or problems which will test these facts and beliefs (called BKA, see Figure 16). The former will help verify the testing of the models, or alternatively, complex problems that lack an explanation and which may need to be revisited. In the case of mining projects, this is the concept of uncertainties that needs to be redefined, forcing organizations to look at reality in a different way, i.e., establishing a different organization framework in order to be increasingly critical.

Finally, it is important to stress that (Perminova and others, 2008) uncertainties are a relevant feature of evolving processes. For this reason, the ability of organizations to understand and manage uncertainties and turn them into opportunities is a characteristic of organizations that will be able to cope with ever-changing conditions.

1.6. Summary: What is Dynamic Complexity in mining projects?

MIT Management Sloan School (Davies and others, 2017) suggests that the reasons behind the difficulty for managing megaprojects are related to "technical challenges, changes in design and operational requirements, cost increases, disputes over responsibility, and new regulations", thereby generating a context of uncertainties.

Is it possible to generalize and look for those common elements that contribute to the Dynamic Complexity of mining projects, variables which are the focus of this paper?

This analysis will be undertaken from the perspective of positivism, in the sense that if an organization relies on appropriate human and material resources, along with the application of the best existing standards, it will be able to prevent or would have prevented some of the problems which can lead projects to major difficulties as in some of them happened.

Taking as a basis Figure3 proposed by Williams (2002), along with the definition of uncertainties by Perminova, and the dimensions proposed in the Darnall-Preston Index, the variables of Dynamic Complexity in mining projects can be defined, as shown in Figure 7 below.

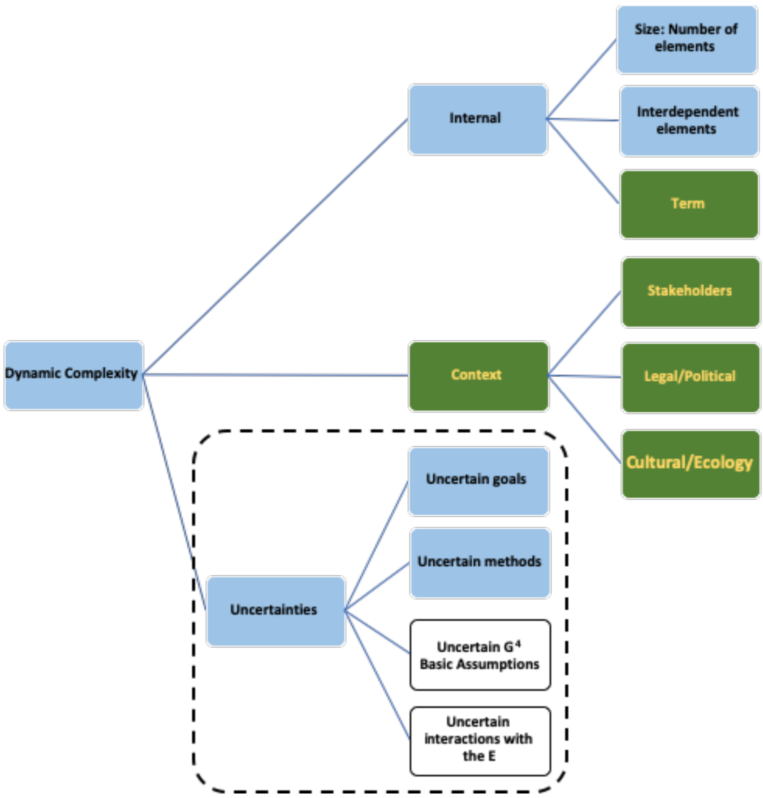


Figure 7: Dynamic Complexity variables in mining projects.

In this figure, in light blue are the dimensions defined by Williams; the topics added in the Darnall-Preston Index and/or mentioned by O. Perminova are in green; while in white are those elements specifically added for mining projects, which are related to the characterization of rock mass and environmental interactions.

The arrangement given to these dimensions follows, in a certain way, William's idea of structural complexity, which we call internal, adding a dimension concerning the environment. The uncertainties dimension –which contributes significantly to Dynamic Complexity– is made explicit.

Figure 8 shows the topics suggested in the work by Bosch-Rekveldt et al, present in all the projects discussed (in light green). While missing in the figure above, they are understood as implicit in some of the dimensions considered. In Figure 8, only the strongest relationships among these elements are shown in order to simplify the analysis.

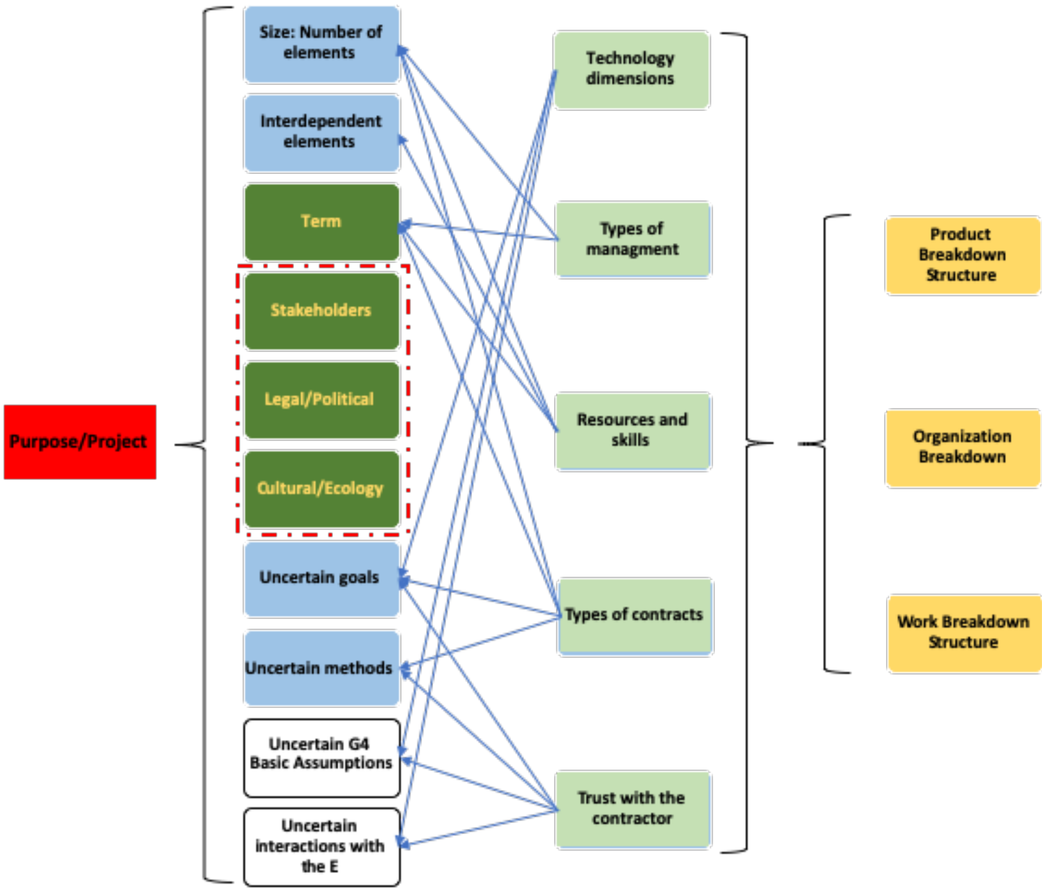


Figure 8: Connection among complexity variables, with the elements introduced by Bosch-Rekveldt et al.

Stakeholders and legal/political, and cultural/ecology dimensions cut through the entire project, reason for which their relationships with other dimensions are not shown. Similarly, variables that relate to internal complexity affect others that have to do with the environment and vice versa.

Some of the elements that distinguish mining and infrastructure works (tunnels, roads, etc.) from other types of projects relate mainly to:

- The characterization of the rock mass and how it impacts construction methods.
- Ore production processes and the subsequent benefit.
- The relationship between construction and subsequent operations with environmental issues.

Earth sciences (geology, geo-mechanics, geotechnics, and geophysics) are considered in the dimension "Underlying G4 Basic Assumptions". All of them are required to understand the characteristics of the rock mass and its future interaction with the environment, construction equipment, and finally, with treatment plants. During the construction process, this dimension will be one of the important sources contributing to the Dynamic Complexity of projects, partly due to the boundaries of responsibility among the different stakeholders involved in the construction process. This issue will be addressed with more detail in Chapter 3 and 4.

2. SITE INVESTMENT FOR THE CHARACTERIZATION OF THE ROCK MASS AND INTERACTION WITH THE ENVIRONMENT.

One of the unique features of large mining projects that contribute to Dynamic Complexity and uncertainties is defining the characteristics of the rock mass and its behavior in light of the construction process and the production phase. The reactions of the rock mass range from micro scale –for example drilling speeds (in the drilling and blasting cycles)– to macro scale, where the reactions of the rock can include from deformations of the chambers under construction up to sudden easing, such as rock bursting or unforeseen water flows, or an unexpected combination of all of the above. These phenomena can take place from the time construction begins, up to when the project is built and operating, not just affecting construction assumptions but also those related to the operational stage. Additional issues are related to the project's interaction and further operation with the environment, which also requires a characterization process that will add even more complexity and uncertainties.

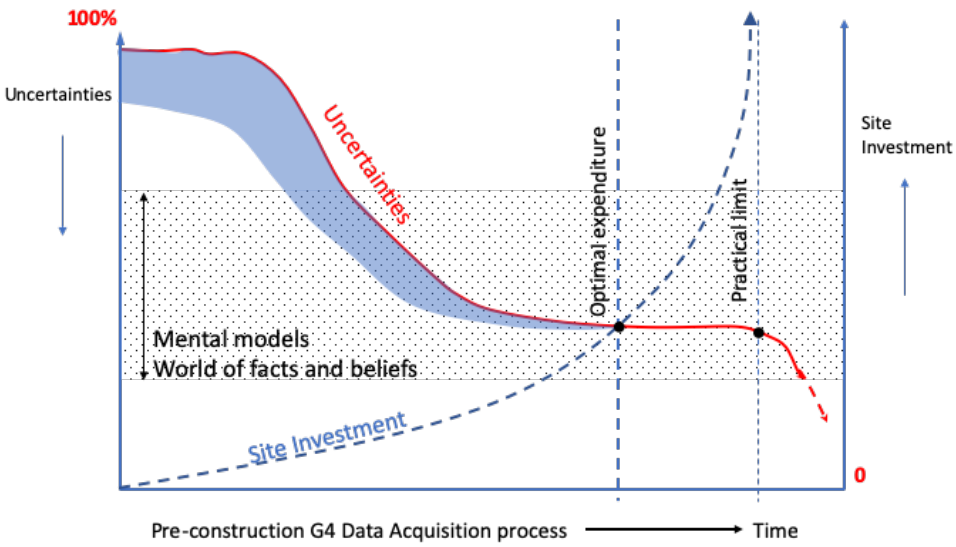
The planning of a mining project considers the gathering of Geo-Mining-Metallurgy information, as well as the characterization of the project's environment. The amount of information available to meet the profile engineering, prefeasibility and feasibility stages increases gradually as the project evolves.

In general terms, exploration and reconnaissance campaigns must acknowledge three areas:

– Information to characterize the ore body and its geology, for the modeling that will determine geo-metallurgical variables and finally, the project's economic indicators.
– Information about the surroundings and the environment to determine the project's socioeconomic and environmental aspects.
– Information regarding G4 (geology, geo-mechanics, geophysics, and geotechnics), including hydrogeological aspects to develop analytical models to be used in the different project stages.

The information identified above will feed an engineering team to start the project's planning and design process. This planning process is recursive, i.e., the first relatively simple models are built to launch a first round in the single and double loop cycle of the learning process mentioned above, using industry best practices. As the process moves forward, it establishes the facts and beliefs that will be a part of the so called mental models –named BKA in the Figure 6 and Figure 16.

Information gathering on the ground to create data bases and models mentioned above is called Site Investment. According to T. Carter (2011), an early investment in the field –with its resulting analysis– can reduce negative impacts that result from uncertainties (this author calls it "risk of unforeseen problems"), as shown in Graph 1 below, adapted from Carter (2011). The dotted hatch pattern area in the Chart represent the sphere of facts and beliefs of the project team (they become part of the BKA mentioned in the learning process), where the Optimum expenditure and the Practical limit can be reach.



Graph 1: Uncertainties versus Site Investment (Carter, 2011; modified by J. Pedrals).

As shown in the chart above, the drop in the theoretical curve of uncertainties is initially 100% asymptotic, reaching a small decrease after a significant percentage of the investment is made in the field. The way this information is processed is key and has to do with the learning process described in the chapter about Dynamic Complexity, where the project team building with knowledge, experience, and strong critical capacities is essential to achieve efficiency and effectiveness in the Site Investment. A proper discussion regarding the data and models raised is critical to escape the previously mentioned videogame trap. The analysis of the information and data collected must ensure that the second loop of learning is reached, as many times as required, in order to modify the facts and beliefs it is necessary. In the next two charts in Figure 9 below it is shown two different situations.

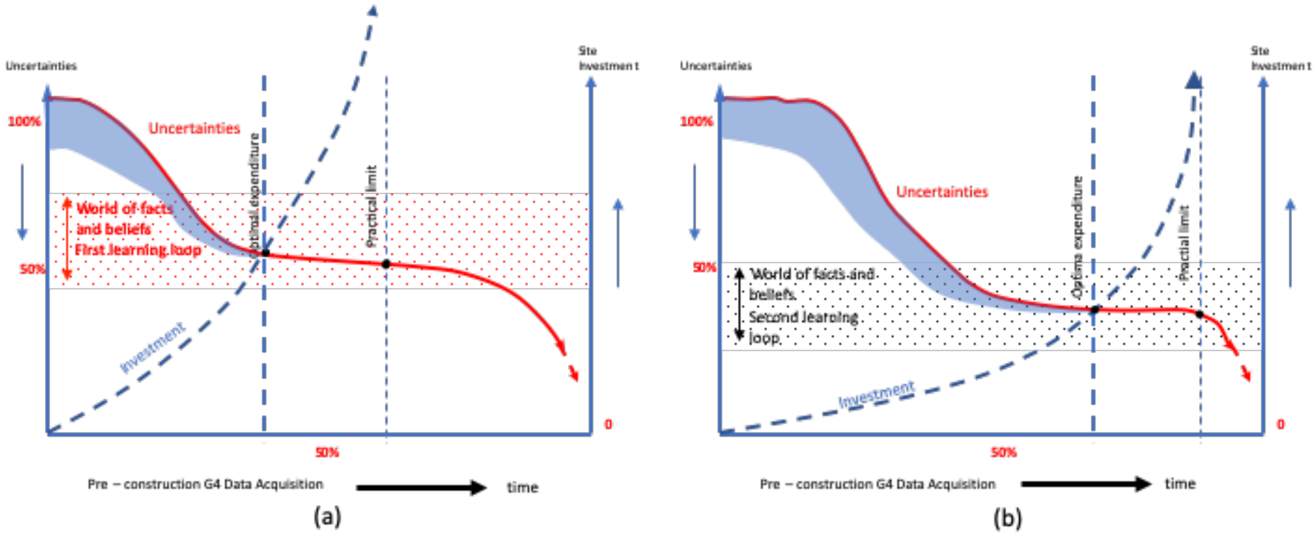


Figure 9: Two situations for facts and beliefs of the second learning loop.

The only information comparable in these two charts is the investments made. Their facts and beliefs are different in terms of content and definitions. In chart (a), the team "believes to have converged" to the optimal point with a relatively low amount of Site Investment, while in chart (b), the team "believes to have achieved it", at a larger investment. In the second case, theoretically, more than 50% of the main uncertainties have been revealed, while in the other case, the percentage is lower. In this case, uncertainties will be uncovered when the project is already under construction, including all the problems involved in unexpected changes, environmental consequences, etc.

The certainty of the project team of having broken through the videogame trap will only be supported by the project's governance, a topic that will be addressed in chapter 4.

The final product of the Site Investment should be the Geotechnical Memorandum for Design (GMfD) along with the information explained in the following chapter. The GMfD drafts are the BKA mentioned above – the facts and beliefs of the project team. The preparation of this document is crucial and should be in charge of a multidisciplinary team, including people who can contribute with different views to the corporate teams, and avoiding endogamic environments that can hinder the double loop learning process mentioned above. The GMfD to be considered for the construction of the Geotechnical Baseline Report (GBR) should have several iterations along the Site Investment process, all which needs to be supported by a governance scheme, based on the discussion in the chapter 4.

The GMfD should include at least the following (Essex, 2007):

- Comments and discussion regarding data;
- Introduction of possible initial data interpretations.
- Assessment of constraints and discussion regarding the need for additional information.
- Evaluation about how subsurface and rock conditions can impact optional approaches for the project's design and construction.
- Evaluation on how rock conditions can affect the future mining of the deposit, as well as the results of the metallurgical processes.
- Evaluation of project risks regarding optional construction approaches.
- Evaluation of potential impacts to adjacent facilities.
- Geotechnical design criteria for subsurface structures, both permanent and temporary.

The other document to be prepared at the end of the Site Investment should be the Social–Environmental Memorandum for Design (S&EMfD) – with the same purpose than the GMfD but focus on the social and environmental perspective of the project – in addition to creating a BKA to manage uncertainties.

The activities mentioned above are related to the project's BKA and are expected to prompt the construction team to question the data validity and the models defined. In particular, the activity of "assessing data limitations and validity" is directly connected with the Site Investment on the ground, a mechanism that supports a significant reduction of uncertainties around the definition of underlying assumptions. This activity is expected to render two specific results: i) the definition of more activity on the ground so as to enhance the amount of information collected; ii) a list of assumptions on which interdisciplinary workshops should be developed so as to question the validity of assumptions and lead to an analysis of potential uncertainties.

Project design is expected to begin any time, for which T. Carter develops Chart 2 below. As stated above, once the design begins, the impacts associated with uncertainties can no longer be reduced and will be only revealed during the construction stage, with all the ensuring risks and impacts involved. The separation between Site Investment and design should not be understood as sequential, since the construction is the final Site Investment that helps prove the correctness of the facts and beliefs or, alternatively, make the corrections required by the project.

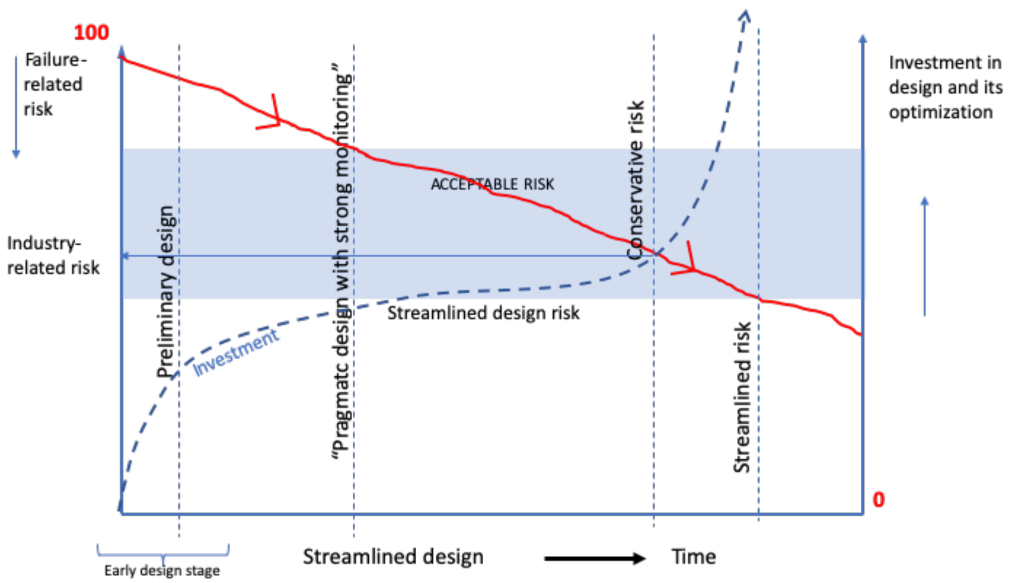


Chart 2: Risk due to failure and investment in design and optimization (Carter, 2011; modified by J. Pedrals).

The chart above establishes a relationship –for different risk levels– among three types of designs: i) a preliminary design, typical of a project's profile engineering (FEL 1) that could be reached simultaneously with an advanced stage of Site Investment, thereby supporting a better analysis of the project team; ii) a pragmatic design expected to be adopted to accelerate the project in a "known environment" situation, assuming all possible mental models and abstaining from the concept of Perminova's uncertainties (FEL 2); iii) a conservative design (FEL 3), which will be the one that minimizes risks and uncertainties involved in large contemporary projects in situations of Dynamic Complexity.

3. THE GEOTECHNICAL BASELINE REPORT (GBR), A TOOL TO REDUCE A PROJECTS' DYNAMIC COMPLEXITY

3.1. Goals and features of the GBR

The construction of new projects and/or important expansions of current companies are accomplished through specialized contractors who receive a construction mandate, usually after long bidding processes involving abundant and varied information.

The most complex construction contracts are those related to underground works and/or rock excavations, since rock mass responses to work design and construction techniques is only revealed when the construction is finished.

Considering the above, an important source of conflicts in projects and, therefore, in their complexity has to do with the boundaries of responsibility between client and supplier, so this chapter is mainly focussed to give a management tool in order to improve in these kind of projects, the underground ones.

Since the 70's (Essex, 2007), it is a global practice to introduce different geotechnical reports into underground construction contracts. These reports often lack clear standards, are poorly written, and contain confusing geotechnical interpretations, sometimes as a reflection of national realities. The response from the international industry was the edition of the Geotechnical Baseline Report, issued in 1997, with a second edition in 2007. This tool is presented by its authors as a way to (Essex, 2007) "inform owners about the importance of the GBR content, to define financial risks" and improve the conditions of information in bidding processes.

The main goals of the GBR in terms of reducing Dynamic Complexity in the management of construction contracts are (Essex, 2007):

- *Presentation of the geotechnical and construction considerations that formed the basis of design for the subsurface components and for specific requirements that may be included in the specifications;*
- *Enhancement of the Contractor's understanding of the key project constraints, and important requirements in the contract plans and specifications that need to be identified and addressed during bid preparation and construction;*
- *Assistance to the Contractor or DB team in evaluating the requirements for excavating and supporting the ground; and*
- *Guidance to the Owner in administering the contract and monitoring performance during construction.*

In addition to these benefits, given the definitions of Site Investment and uncertainties stated above, the GBR is also a tool to:

- Develop a BKA based on the facts and beliefs raised in the Site Investment process, providing a tool for the management of uncertainties.
- Systematize the characterization of the rock mass in such way as to generate objective knowledge that can help all the parties involved in the construction process.
- Facilitate the transfer of risks to the contractors, achieving more competitive environments and reducing complexity in the management of these contracts, in light of possible changes in the conditions found during the construction stage regarding the BKA defined in Site Investment process.

As stated by the author (Essex, 2007), more than a collection of baselines, GBRs "is the primary contractual interpretations of subsurface conditions". For this reason, the report should discuss these conditions in enough detail to accurately communicate these conditions to the bidders, engineering firms and other parties that require this information.

In sum and in addition to all the general information regarding location, owner, main engineering firms, etc., the GBR is expected to include all the elements to help contractors understand the singularities of the ground where the works will take place, including (Essex, 2007):

- Sources of geological and geotechnical information, with reference to the Geotechnical Data Report (GDR – described in more detail below), as well as other geology and geotechnical reports.
- Description of the geologic setting characterization of the project's ground, which in addition to referring to the GDR, is expected to provide a brief description of geologic and groundwater setting, origin of deposits, maps and figures, including the geological profiles along tunnel alignments and general works to be built. Furthermore, site exploration and testing programs, boring works performed, etc., should be included.
- Previous construction experience that might provide relevant background. As will be mentioned below, this is important in terms of the basic assumptions expected to lead to an analysis of potential project uncertainties.
- Works design considerations, which should include design-related definitions of the types of works to be built, types of ground support considered and recommended amounts, environmental constraints or considerations in construction methods, instrumentation, data gathering required for the construction process, etc.

Complementary to the GBR and the GMfD is the Geotechnical Data Report (GDR) and the Differing Site Conditions (DSC). Below is a brief description of their contents:

- Geotechnical Data Report (GDR): Detailed information that complements the GBR and specifically describes the sources of information included in the GBR, including geological landscape, ground characterization, exploration program carried out, tests, etc.

- Differing Site Conditions (DSC): this document must be a Construction contract clause that can trigger conversations between the contractor and the principal with respect to the conditions found on site that are substantially and materially different from what was originally defined in the GBR. The text presented by R. Essex (2007) is:

  DIFFERING SITE CONDITIONS (APRIL 1984)

  (a) The Contractor shall promptly, and before such conditions are disturbed, give a written notice to the Contracting Officer of (1) subsurface or latent physical conditions at the site which differ materially from those indicated in this contract, or (2) unknown physical conditions at the site, of an unusual nature, which differ materially from those ordinarily encountered and generally recognized as inhering in work of the character provided for in the contract. (b)The Contracting Officer shall investigate the site conditions promptly after receiving the notice. If the conditions do materially so differ and cause an increase or decrease in the Contractor's cost of, or time required for, performing any part of the work under this contract, whether or not changed as a result of the conditions, an equitable adjustment shall be made under this clause and the contract modified in writing accordingly.

3.2. Managing uncertainties and transferring risks to the contractor

The documents that compose the GBR –all part of the Construction Contract that includes the Differing Site Conditions clause mentioned above– follow this order: first the GBR and then the GDR. According to the recommendation made by the authors, the GMfD can be handed over to the bidders, it should not be part of the contract since it is prepared well beforehand the GBR.

Taking into account the approach used in the GMfD –in connection with the Site Investment and the iterative process that originated it– all its reissues should be considered a draft. Even during the construction process, this document needs to be revisited and updated over and over again, in such a way as to use it as part of the double loop learning process mentioned above.

Based on the information contained in the (Eskesen and others, 2004) “Guidelines for tunneling risk management”, the following information flow between the project owner and the contractor is proposed, as shown in Figure 10 below.

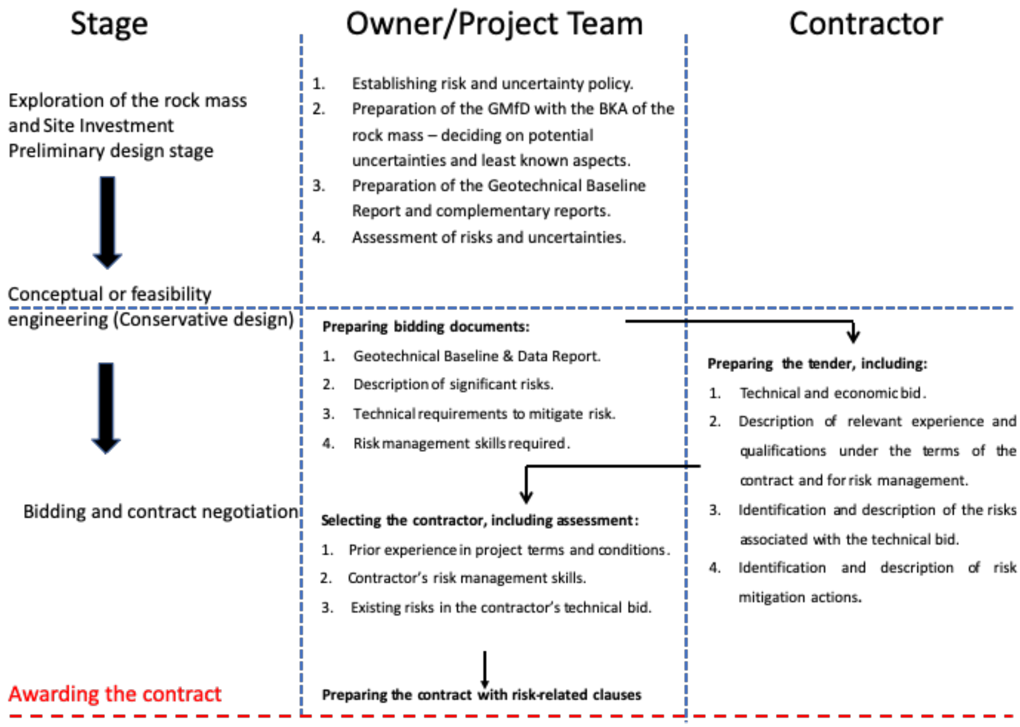


Figure 10: Project team-contractor information flow (Eskesen and others, 2004; modified by J. Pedrals).

This Site Investment practice to characterize the rock mass should also be followed in those more sensitive project issues, such those related to social-environment and their interaction with the project. A team now formed by engineers, biologists, anthropologists, historians, among others, is expected to prepare a report that can inform the project design, including the main assumptions to manage and reduce uncertainties associated with the general environment and surroundings (the S&EMfD).

3.3. Generation of more competitive environments with "full" information

Good fences not only make good neighbors, but it the case of business relationships, clear rules help to minimize ambiguities and provide contractors with a leveled playing field. This is one of the missions of the geotechnical baseline of the GBR, i.e. to define the expected conditions in the field, as well as the amounts and qualities of the works to be built, leaving uncertainties and elements that are not in the hands of the contractor in charge of the project. This approach can help prevent contractor's contingencies that are exclusively related to elements under his control, without increasing the costs of the proposal.

The geotechnical baseline defines a condition for which the different bidders in a bidding process must set their prices according to their productivities and skills, making it possible to develop conservative, moderate or aggressive proposals, as shown in Figure 11 below.

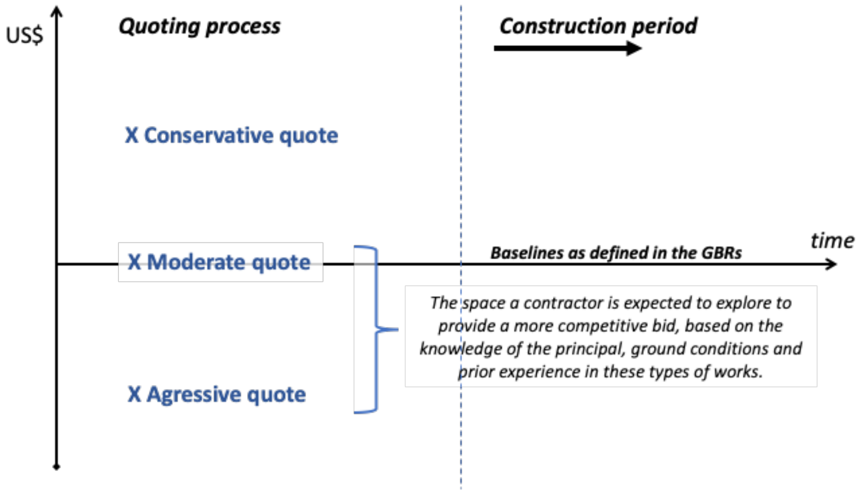


Figure 11: Quotation types with respect to the geotechnical baseline.

The contractor's decision to offer any of these proposals (conservative, moderate, or aggressive) will be associated to the definitions made in the GBR baseline, as well as to their expertise and sense for risk. The ability of the contractor to understand the description of the works and the conditions detailed in the GBR will be crucial to make a responsible and balanced proposal in terms of the risk undertaken. The latter will depend on the quality and knowledge of the expert professionals working with the contractor.

In real life, there will be reasonable explanations to award the contract to an aggressive, moderate, or conservative bid. Aggressive quotations are always liked because the *ex-ante* figures seem very attractive. In more reflexive environments however, a more conservative quotation can be awarded, for example, based on the experience of the contractor and the soundness of their proposal.

During the construction period, the reality of the rock mass will show a situation that might be more or less aggressive than what was detailed in the baseline, while the proposal accepted could have been conservative, moderate, or aggressive. Considering this, the following potential possibilities emerge:

US$ ↑

Type of Bid	The reality on the ground during construction: More adverse than the GBR's (more controversial scenario)	The reality on the ground during construction: Less adverse than the GBR's (less controversial scenario)
Conservative: (Less chance of winning)	THE CONTRACTOR WILL RAISE MORE CONTROVERSIES THE OUTCOME WILL DEPEND ON THE CONTROVERSIES AND DIFFICULTIES (MEDIUM-HIGH COMPLEXITY) Box A	THE CONTRACTOR WILL RAISE A FEW CONTROVERSIES THE PROJECT WOULD HAVE PAID A HIGH PRICE FOR THE WORKS (LOW COMPLEXITY) Box B
Moderate (Average chance of winning) Aggressive (More chance of winning)	Box C THE CONTRACTOR WILL RAISE MANY CONTROVERSIES THE OUTCOME WILL BE HIGHLY COMPLEX	Box D THE CONTRACTOR WILL RAISE CONTROVERSIES THE PROJECT WOULD HAVE PAID A LOW PRICE FOR THE WORKS, EXCEPT FOR SOME CONTROVERSIES (AVERAGE COMPLEXITY)

MORE COMPLEX ↓

← MORE UNCERTAINTIES

Table 2: Possible bid scenarios with respect to the geotechnical baseline

The scenario where the most aggressive bid is chosen, coupled with more adverse rock mass conditions (Box C), is a high complexity scenario based on the uncertainties that could emerge and on typical claims and litigations.

Aggressive bids in complex contracts –such as underground works and rock excavations– lead to difficult to solve contractual situations when more unfavorable than expected conditions are found in the field.

With quality information in the geotechnical baseline, along with a thorough selection process instead of looking for easy explanations –i.e. "the lowest quotation"– the project can be developed under a less complex and uncertain scenario (closer to Box B).

Figure 12 shows the rules of the game for claims in the case of a moderate bid.

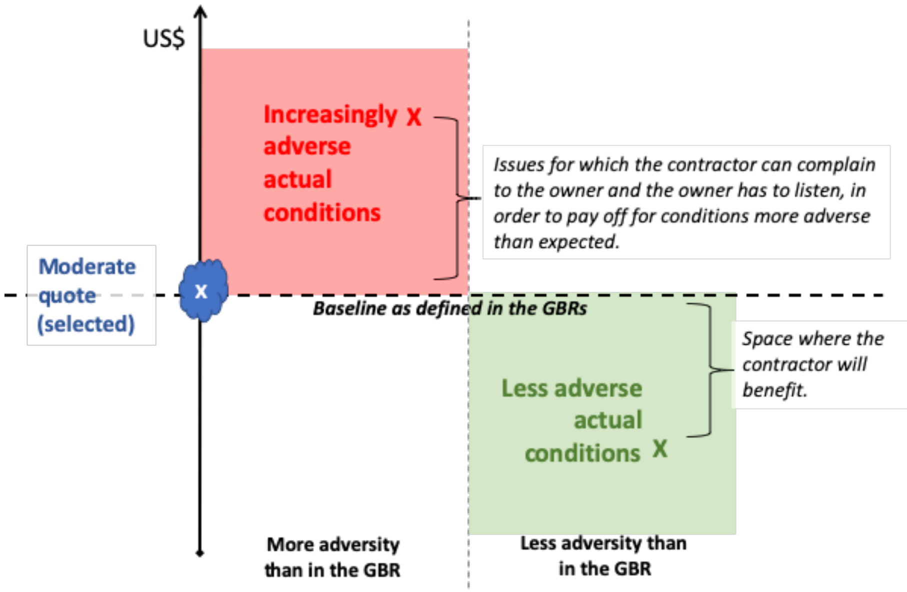


Figure 12: Possible differences with the contractor with regards to the type of bid

Quotations can be more adjusted to reality when the elements that are not part of the baseline are offset. This is because they leave out assumptions related to issues beyond the control of the contractor, thereby reducing their own uncertainties and leaving them on the side of the project's owner.

There are several other types of contracts or mixed of them, which define a specific risk condition to the owner and the contractor, shown in the following figure (Brox, 2017).

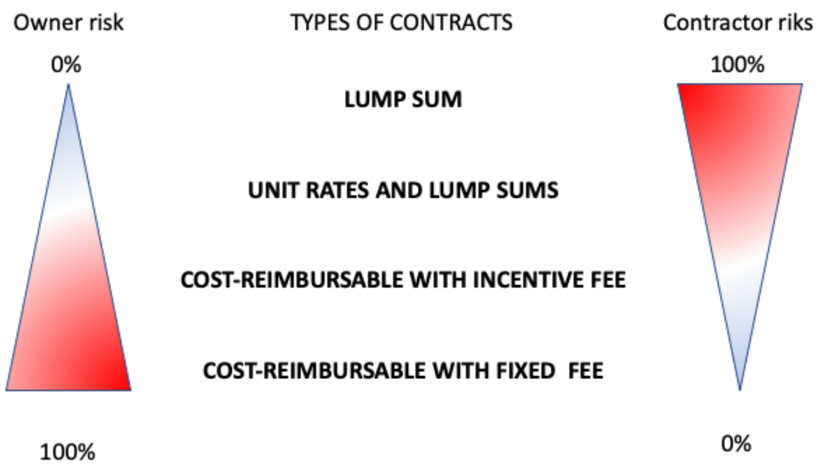


Figure 13: Different types of contract – risk relations (Brox, 2017).

The trend would be select the unit rates contracts if the company, the project team and the country have experience in underground projects, along with the GBR suggestion made.

4. GOVERNANCE TO MANAGE UNCERTAINTIES AND REDUCE PROJECTS' DYNAMIC COMPLEXITY.

There is countless literature in books, specialized papers (Crawford and England, 2004), and others promoted by consulting firms about business and project administration, so much that some authors have assimilated it to a trendy concept (Johansen, 2000). In spite of this, failures due to different types of problems in projects and/or in companies under operation still prevail (Garicano and Rayo, 2016). This is mainly explained by inadequate governance structures of projects and the failure to mainstream the concepts of complexity and uncertainties, as defined in this article.

This chapter introduces some definitions regarding the minimum governance required by projects, as well as the practices needed to capture, at an early stage, the concept of uncertainties thereby reducing complexity, based on the concepts of Site Investment and the GBR.

Given the features that make projects unique and different from companies that are already established –as underlined in previous chapters– there are three recommendations to adopt stronger processes which can ensure smooth projects, namely:

i. Separate the company's regular operations from its investment projects.
ii. Use of Site Investment in the project's conceptualization stage in order to prepare the GMfD and the Social–Environmental Memorandum for Design (S&EMfD) – with the same purpose than the GMfD but focus on the social and environmental perspective of the project – in addition to creating a BKA to manage uncertainties.
iii. Support the role of the Board of Directors with a Technical Committee that has the proper blend of expertise and independence, and which ensures a healthy stress environment within the project team.

4.1. Separating the project from routine operations

Given the characteristics mentioned above, the first key decision has to do with separating the project from the company's operations. Given the speed of project changes, the team requires flexibility and efficiency, both features impossible to attain if more rigid operational procedures are used.

The coexistence of project environments with operations results in (Briceño, 1994) the "pollution of operational processes with exceptional procedures –for which the project has permission– but which are not recommended as permanent mechanisms". Coupled to this is the need to have sound accounting practices, both in operations and in project construction, which is not made easy when these two realities coexist.

4.2. The importance of Site Investment in the conceptualization stage

One of the industry's best practices is mentioned in the IPA (Rohrbaugh, 2010) as the Front End Loading (FEL) system or approval gates. According to the FEL system, projects must comply with several stages for their correct development. Each of these stages can end in an independent report, ensuring that the contents and analyses in the reports meet industry standards.

Figure 14 below shows the definition of the FEL system and Approval Gates (Merrow, 2011), based on the IPA definitions.

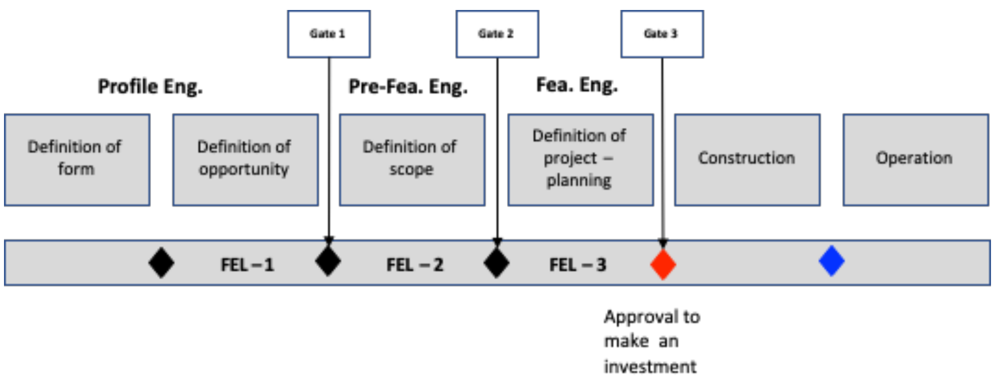


Figure 14: FEL and gates in project development (Merrow, 2011).

There is detailed information regarding the FEL system and the minimum deliverables that should be met. This section will therefore connect the IPA system with the concepts of

Site Investment and Dynamic Complexity identified above –supporting the definition of the GMfD and the S&EMfD– whereby the first is considered part of the GBR documents.

By introducing the early processes of definition of reserves, engineering and environmental definitions to Figure 14 above, in addition to Site Investment in general, the conditions will be set to prepare the GMfD and the S&EMfD, as shown in the following Figure 15.

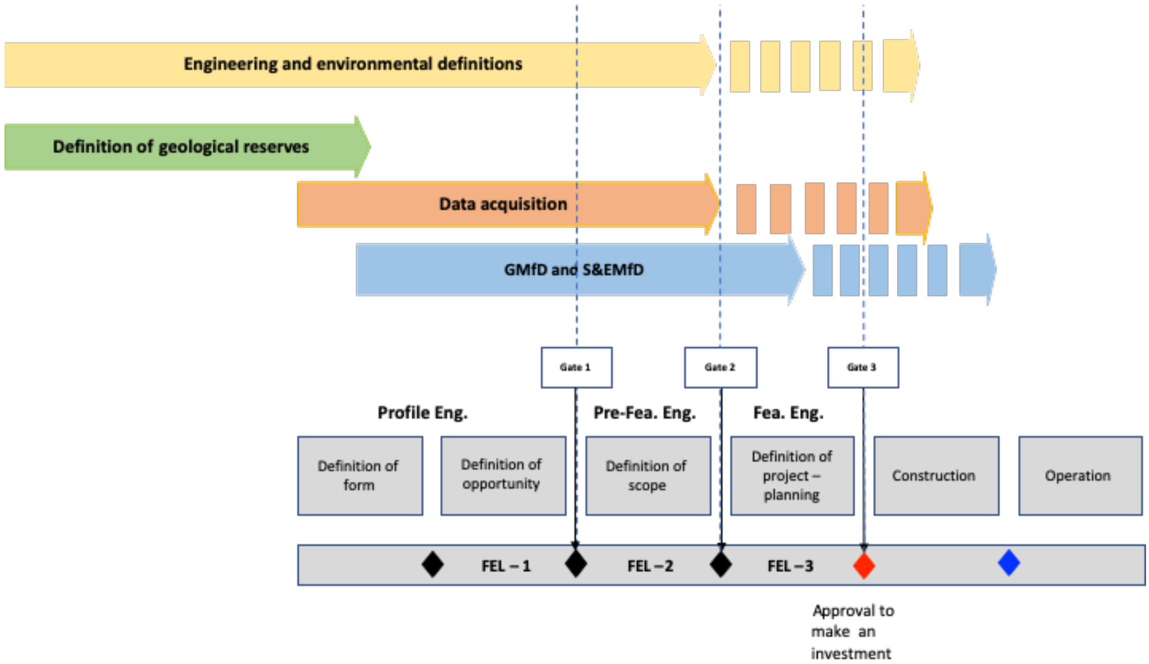


Figure 15: FEL considering environment, Site Investment, and GMfD (Merrow, 2011; modified by J. Pedrals).

The segmented boxes in the figure show certain processes –activities related to environment, Site Investment, and the preparation of the GMfD and the S&EMfD– which although required to have specific deliverables for FEL 1, 2, and 3, cannot be fully grasped by the project team until project completion (built). During all this time, the team of experts is expected to adopt a critical attitude regarding the information generated by the construction process in order to understand if the key assumptions are actually aligned with reality.

One of the most important project activities is developed during profile engineering: i.e. conceptualization, along with the definition of goals and methods. According to Figure 15 above, this should enable the project team to prepare the GMfD and the S&EMfD –along with the foundations and engineering typical of this stage– gathering all the information and main models related to the characterization of the rock mass. This is the stage when shareholders should pay particular attention to the project team, to ensure that the project is properly addressing the key information and regular technical-economic indicators, as shown in Figure 16.

Project governance must be aware that this process is carried out by people who are in a context of Dynamic Complexity. As shown in Figure 6 in Chapter 2, the project team is expected to have been challenged in such a way so as to adopt the double loop learning process, and as a result, end up with a BKA that minimize the uncertainties.

The following Figure 16 illustrates the process to define goals and methods, where the activities are all recursive among them, a property of Dynamic Complexity.

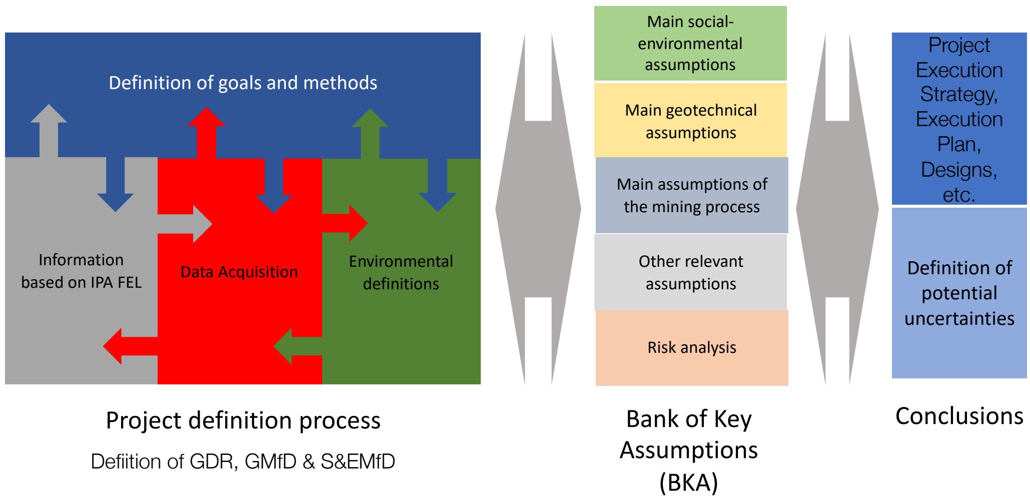


Figure 16: Definition of BKA and the GBR, GDR, GMfD, S&EMfD, and assumptions for uncertainties.

This process is to be understood as dynamic and interdependent in all its stages, even after FEL 1, 2, and 3, and when the project is under construction. In this last construction stage, the BKA and its conclusions should be frequently revisited, along with the GMfD and S&EMfD, to verify the consistency of the information being gathered. This will also help identify likely gaps and address them as appropriate.

4.3. The role of the Board of Directors and the integration of a Technical Committee

Given the vast amount of existing literature on organization types and expert profiles (Morris and Pinto, 2004), this section will deal with the emphasis required for governance to manage the typical uncertainties and Dynamic Complexity involved in mining projects.

The most important issues to highlight include the roles of project, engineering, and construction managers, and the relationships among them. Depending on the project stage, some will show more or less leadership, clearly assuming that their continuity and/or replacement are extremely important success factors for the project, particularly in the case of the Project Manager.

The Figure 17: Project construction and engineering spheres depicts two spheres throughout the life of the project: engineering and construction. Although there are people with great skills capable of operating in both spheres, the engineering manager will clearly bear a critical weight in the first stage, while for the second it will be the construction manager. The smooth flow between each of these stages will depend on the leadership skills of the Project Manager and his/her relationship with the company's Board of Directors, the party which is ultimately responsible for success.

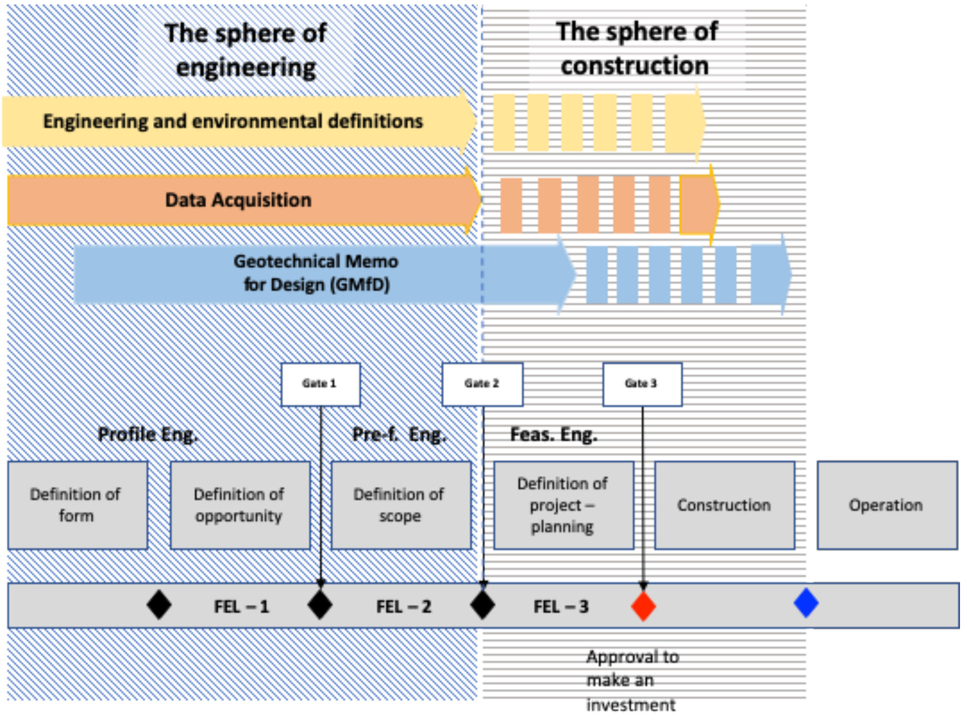


Figure 17: Project construction and engineering spheres (Merrow, 2011; modified by J. Pedrals).

This section highlights the need to create an organization that goes beyond the recruitment of a Project Manager; an organization that assures the success of this new effort. This organization is expected to read the Dynamic Complexity of our times. Below are some of the specific tasks of project governance starting from conceptualization up to the feasibility stages:

– Assure a shared reading of the context in which the project will be developed, offering the strategic definitions for main stakeholders, financial aspects, early strategic purchases, and/or others, as required.
– Assure key definitions for the project, both from the point of view of the goals and methods as well as of their consequences.
– Assure the establishment of an organization and key systems for financial control and project progress.
– Support the organization and particularly the Project Manager, in key strategic decisions to better capture opportunities and mitigate threats. This issue is often associated with taking certain risks and financial exposures.
– Finally, but not least important, assure alignment between the Project Manager and shareholders' interests, particularly in matters related to the appetite for risk (Enrione, 2014) and certain key shareholders' values.

Early in the project, there is a need to shape the organization in charge of its management. Definitions are required with regards to the selection of the Project Manager or general manager, who will be the visible face and project leader. This manager is expected to have all the skills required to lead people in complex environments.

Each of the tasks mentioned above cannot be assured only by the manager and the project team. A complementary entity is also required that can generate a healthy stress within the project team, and which can also secure a critical viewpoint and with it, project success.

Figure 18 below shows four entities: The company's Board of Directors, the sponsor (only when there is a running company in the vicinity), a Technical Committee, and the Project Manager with his/her work team. The lines that connect these entities (with three hierarchy levels) show the most important relationships among them, so as to secure success and avoid weakening the roles and actions of the Project Manager.

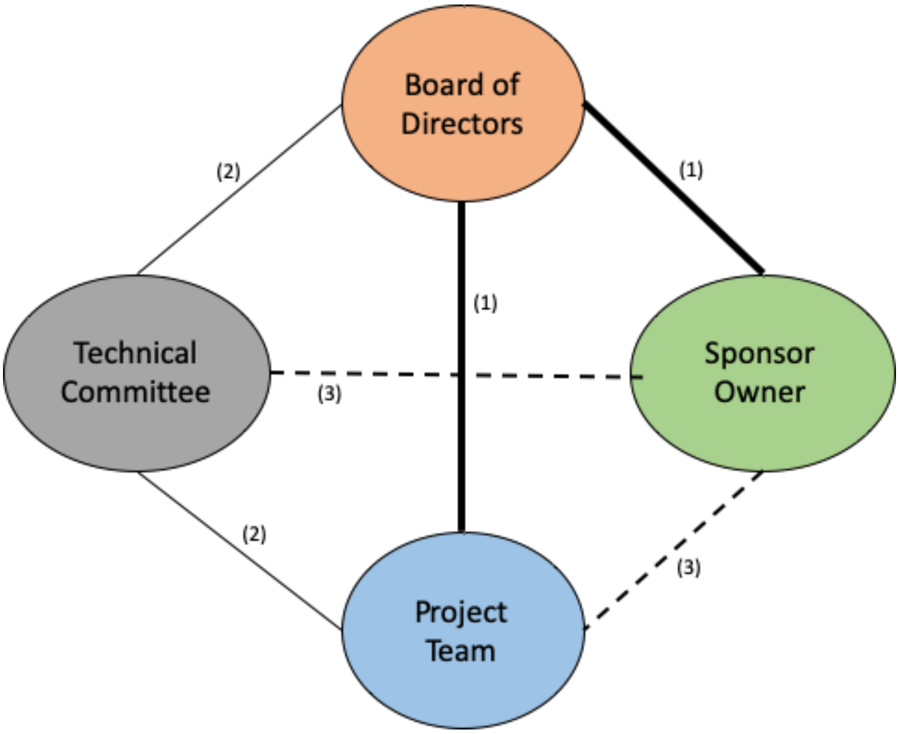


Figure 18: Entities involved in the project

In large corporations, the Board of Directors may be represented by a Committee headed by the CEO and part of his/her key staff. In such a case, the Board of Directors is still required to be duly informed, in particular regarding the definitions of appetite for risk –a task impossible to be delegated.

The Technical Committee, made up of professionals with vast experience in topics related to the project, should be established as soon as possible. It can take the form of a peer review (on an ongoing basis) –changing its shape and/or composition– as the project is been built. The existence of this Committee is required in addition to the revision process suggested by the IPA for each FEL 1, 2 y 3. This will support quality discussions at costs that are irrelevant for what is finally at stake. The composition of the Committee should be as diverse as possible to ensure expertise, independence, and discussions regarding crucial issues, with views from inside and outside the company.

The Technical Committee's main tasks are:

i. Support the project through all its stages, with particular emphasis on the approval phases of each of the FEL 1, 2, and 3, assuring a solid project.
ii. Pay special attention to the preparation of GMfD and S&EMfD, questioning the assumptions, starting with the mental models of the team members, and demanding the creation of a map of potential uncertainties, in addition to traditional risks analyses.
iii. Assure a discussion to review progress in Data Acquisition, validating the work underway related to this topic. All of this takes place based on the preparation of the first GMfD and S&EMfD drafts.
iv. Look over at the project development from a technical perspective, with regular but not excessive work meetings. Progress should be regularly informed to the Board of Directors, along with discussions with the manager and the project team.

5. SUMMARY

This paper reviews a number of definitions made by the academia and/or consulting firms concerning projects, goals and targets, complexity, uncertainties and risks, to apply them to the management of mining projects, from conceptualization to construction. This revision explains the meaning of Dynamic Complexity, both from the standpoint of the learning process as well as from the relationship among different aspects of a project. The concept of uncertainties is redefined –linking it with the learning process– and from there, a definition of Dynamic Complexity is provided for mining projects. In these projects, the definitions of complexity made by Williams (2002), and Darnall and Preston (2010) are used.

Based on the author's experience –with more than 30 years holding management positions in different types of companies, in addition to 10 years devoted to the construction of high complexity mining projects– recommendations are made regarding three topics. First, the concept of Site Investment in the early stages of a project is defined. Site Investment helps manage uncertainties, which are understood as (Perminova and others, 2008) those facts that may occur in a project but which are beyond the "facts and beliefs" in the mental models of those involved. The second issue is related to the use of the Geotechnical Baseline Report (Essex, 2007), a concept used in the international sphere of underground works construction. The main goal of the GBR is to define the responsibilities between the principal and the constructor. However, this article goes beyond this to capture a Bank of Key Assumptions (BKA) that can provide the project team with a tool to manage uncertainties as an objective variable (both in terms of the characterization of the rock mass as well as from a social-environmental standpoint).

Finally, the article suggests that while using the industry's best standards provides greater certainty for the proper completion of a project, the role of the Board of Directors in the definition of the appetite for risk (Enrione, 2014), along with the introduction of a Technical Committee that creates a healthy stress between the Project Manager and the Board of Directors as the ultimately responsible party, can be the best mechanism to support large-scale projects and ensure success.

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