Technical Documents on Megaprojects Series

CONSTRUCTION RISKS ASSESSMENT IN LATIN AMERICAN MEGAPROJECTS: A FUZZY CHALLENGE

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Inter-American Development Bank

SERIES: Technical Documents on Megaprojects

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TECHNICAL DOCUMENTS ON MEGAPROJECTS

SERIES

This document belongs to a series called “Technical Documents on Megaprojects.” It is part of a significant research effort developed to study megaprojects in the transport sector in Latin America and the Caribbean. The objective has been to carry out an in-depth analysis of particularly relevant issues concerning the planning, appraisal, and delivery of these endeavors.

For each issue studied, different views proposed by academics and practitioners are illustrated and one position is advocated. It is not the spirit of this series to generate a consistent message around every matter analyzed in the different documents, but to stimulate the discussion and a research environment on this topic. The series can be used as input in those countries that wish to face the challenge involved in developing a megaproject in the transport sector.

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INTRODUCTION

The academic literature usually studies megaprojects separately due to their special characteristics in relation to their size, uncertainty, ambiguity, complexity and integration, and important political and external influences. These special characteristics are related, for example, to a complex set of construction risks, which is difficult to analyse and measure.

On that subject, a probabilistic approach is sometimes suggested to assess construction risks in megaprojects. This approach deals with the estimation of the likelihood and impact of risk factors, based on historical numeric data, and understands risks as estimated variances. It allows combining events or risk conditions using their probability distributions to estimate how risky the project as a whole is. The process for developing such an analysis involves: estimating probabilities of occurrence of adverse events, establishing assumed limits and associated uncertainty, and measuring the potential impact. Basically, risks are estimated based on what has happened in the past, assuming that the risk factors of the project under study can be compared with those in other cases. This may be reasonable for a subset of quantitative well-defined variables such as exchange rate, inflation, rainfall, etc.

However, not all information regarding uncertainty factors in construction projects is numerical, and the aggregation of different risks becomes impossible. In megaprojects, the imprecision, complexity, and vagueness of several of the problems that developers face is the norm. Furthermore, this kind of projects can be considered as one-time projects and it may be unreasonable to assess the risk factors by studying what has happened in cases developed in the past, or in different regions, countries, and cities.

This reality implies an unfailingly subjective assessment of risks. Probability-based techniques cannot deal with ill-defined (vague) risk factors such as "involvement of many decision-making bodies" or "political indecision" or "lack of transparency and corruption". The abovementioned techniques do not consider the subjectivity associated with the corresponding human judgement assessing risk factors, which is context dependent, related to the time and space when and where the project is developed.

As a consequence, other approaches to construction risks assessment have emerged in the last decades. Particularly, the application of Fuzzy Set Theory (FST) minimizes the inherent imprecision, inconsistency, vagueness and uncertainty that linguistic information imposes, and thus give the greatest possible objectivity to an inherently subjective analysis. It mathematically represents the subjectivity of the words used by those who assess risk and, therefore, is useful to analyse the abovementioned ill-defined risks. Under this approach, construction risks are understood as megaproject attributes, not estimated variances. Assessment of these attributes is developed considering the intuition, personal experience and individual judgments of decision makers of the particular megaproject which is studied, who depend on their social and cultural environment to do so.

In this context, the objective of this document is to use FST to assess the construction risks of three megaprojects in Latin America and illustrate the relative importance of ill-defined risk factors in megaprojects of the region. The three cases studied were: Ferroanel Norte of São Paulo, Brazil; Central Railway of Uruguay; and Metro Line 1 of Bogotá, Colombia. The exercise here presented has allowed to list the most relevant construction risk factors for each case, and shows the relative importance of ill-defined variables. Furthermore, it has helped to calculate the contribution of the following risk dimensions: social, technical, environmental, economic and political. On this basis, the document concludes on the usefulness of this approach for megaproject construction risk assessments.

With this purpose, section 2 presents a summary of the literature associated with risk analysis, going through general theoretical risk perspectives, which are then related to relevant issues to the topic here discussed regarding risk in project management and megaprojects. Subsequently, it concludes on the reasonableness of the use of the proposed methodology, and on a set of construction risk factors to be considered for megaprojects.

Section 3, then, justifies the use of a multiple case study in this research process, to meet the proposed study objective. Afterwards, section 4 shows the results obtained and presents a discussion. This document concludes that it is especially useful to resort to this methodology continuously, from the development of basic design studies onwards, to improve the assessment of construction risks, and their subsequent management, in highly complex one-time projects.

2

THEORETICAL BACKGROUND

Risk, in general terms, can be studied using different theoretical standpoints: a sociocultural perspective and a scientific perspective. Firstly, this section succinctly explores this issue to lay the foundations and study how is risk understood in project management. Specifically, it is used to explore the evolution of risk assessment in construction project management.

Subsequently, this section shows that megaprojects have unique characteristics that influence megaproject construction risks' definition and assessment. Considering that, it builds a list of construction risks that should be included in megaproject risk assessment and it theoretically makes the case that FST is a good approach to deal with this issue. Lastly, a methodology for the application of FST for megaproject construction risk assessment is presented.

2.1. RISK PERSPECTIVES

2.1.1. THE SOCIOCULTURAL PERSPECTIVE

The sociocultural perspective analyses the role of risk given social relationships and their subjectivities. Lupton (1999) suggests that there are three approaches to the topic using this perspective: the cultural / symbolic approach; that of the risk society; and the one that deals with governmentality. They share similar concerns, foci, and epistemological underpinnings in their work.

The cultural/symbolic approach refers to the study of risk with an anthropological lens, from which it is asserted that risk is a collective construction, emanating from different levels of social organization. The authors who defend this position, such as Douglas and Wildavsky (1982), suggest that reality cannot be separated from the individuals themselves. The problem cannot be divided between objectively calculated physical risks and subjective and biased perceptions of individuals. The intuition is very simple: regarding several relevant issues, the level of risk can be very high for some individuals and very low for others. As noted by Douglas (1985), risk is a consequence of perception, moral associations, conventions and expectations.

The second approach, that of the "risk society", refers to a sociological approach to this topic. One of the main authors is Beck (1999), who suggests that risk is central to the definition of individual identity. In his opinion, this has varied in history, and in the current post-industrial era, risk is understood as an intrinsically human responsibility, both in its production and management. Again, the authors who defend this position argue that risk is not a purely objective phenomenon.

The third and last of these approaches, with a political lens, refers to the one that deals with the link between risk and "governmentality". This last concept is associated with Foucault's work (See for example Focault, 1991). Under this point of view, risk serves to reinforce, strengthen and protect certain knowledge and associated institutions. Risks can be understood as a possible government strategy so that the general population and individuals are monitored and managed. According to Lupton (1999), risks, in this framework, would be nothing more than a deviation from a certain norm that feeds power systems. Dean (1999, p. 132) explains that risk is understood as one component of the various practices, techniques and rationalities that are associated with how we govern in our society.

This socio-cultural perspective of risk emphasises some relevant points, common to the three previous approaches, which are highlighted below.

Firstly, the materialization of a risk can be a consequence of a human error, and also a consequence of a bet. A higher risk may have a higher level of potential associated profit. Thus, risk appetite becomes a particularly relevant issue. According to this vision, propensity to take risks varies according to individuals and circumstances, their idiosyncrasy and culture. Furthermore, the potential return for risk taking may not be monetizable; it can also be associated with power, glory, love, respect, and even the feeling of adrenaline. Adams (1995) suggests, therefore, that risk is not always the consequence of a mistake, and it is not evident in all cases that its minimization is necessary.

At the same time, another issue that adds complexity, with this perspective, is that the measurement of a potential risk can affect the risk that is intended to be measured. That is why, again, an important part of the academy considers them as a subjective phenomenon, because it depends on a perception, and not on an unobjectionable reality. This is something that is expected to happen in the future. By definition, in their opinion, it depends on who is waiting for it and it is not a static phenomenon.

Finally, another particularly noteworthy point is the following. In any case, the risk comes from some type of uncertainty. Under this approach, this suggests a particular nature of the human being, a state of consciousness, which arises from imperfect knowledge, and is by definition a human construction. Therefore, risk, according to the authors who defend this perspective, is also a human construction. It implies, under any conceptual framework, the commitment of assignment, or the assignment itself, of some type of resource to obtain an objective whose achievement, at the time of said assignment, is uncertain.

2.1.2. THE SCIENTIFIC PERSPECTIVE

The socio-cultural perspective is contrasted with the technical-scientific perspective, used by some currents of engineering and economics, among several other disciplines. In these cases, risk is understood as an objective phenomenon. The study of risk under the assumption of rationality usually has different purposes: identification; cause mapping; generation of predictive models; and response. As noted by Lupton (1999, p. 2), this rational approach focuses on generating a scientific measurement and calculation of the phenomenon in question.

The dichotomy, regarding the social-cultural vision, has been resolved differentiating the supposedly objective risks from the subjective risks. With this criterion, the first ones are those that can be modelled with a statistical logic, and the second ones refer to the different perceptions in the population regarding how individuals anticipate future events. Objective and measurable risk is usually defined as a measure composed of the probability of occurrence and the magnitude of an adverse effect.

This rational vision is usually criticized by the social-cultural vision, seen previously, alleging that probability and potential impact are inherently subjective variables. Slipping on ice can be a game for a child and a fatal accident for an older person, and therefore the perception of impact is not independent of the individual who analyses it. The probability of occurrence, in parallel, can be influenced by how individuals perceive this probability (Adams, 1995, p. 9).

However, the answer that a defender of the scientific perspective could give is that the example of slip on ice presents two different phenomena. One refers to the risk in children and the other in older people. Yet, the counter argument is that if only children are grouped together, children with different characteristics will also be found. So: what is the acceptable level of similarity of children's characteristics which makes the slip in the ice the same phenomenon?

Using an economic lens, the dominant position of the academy has been to treat agents as rational actors who make decisions regarding certain alternatives. Risky decisions, using this framework, can be divided into two. First, there are those decisions in which the probability of occurrence and the possible results are known. This would be an objective risk under the previous definition. Second, there are uncertainty scenarios, when the probabilities of occurrence or the possible results are not known (Knight, 1921; Tversky and Kahneman, 1992).

According to this approach, when the probabilities or the possible results of the decision are not known, the agents generate ideas or beliefs about it and subsequently make decisions. Again, as noted by (Zinn, 2004), with this approach risk is considered as an objective phenomenon, about which more or less information is available. If it is not possible to form expectations on both variables, then, with this economic perspective, the decision is made in ignorance.

This rational view of agents has been particularly useful for modelling and predicting scenarios in some situations, such as auctions or the outcome in competitive markets. However, it shows problems in explaining other situations, such as coordination when there is collective action in social dilemmas. Therefore, a so-called heterodox part of the economic academia has started studying the norms, habits, and personal characteristics around decision-making (see for example Ostrom, 1990, 2005, 2015). This view of the relationship between individuals and reality has become a current of analysis in which the economy begins to pay attention to formal and informal rules of the game, inherent in the decision-making agent, which are more associated with the subjective risk logic mentioned above.

2.2. RISK IN PROJECT MANAGEMENT

The most orthodox perspective from project management is to adopt the following definition: a risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on project objectives (Project Management Institute, 2009). Uncertainty is described based on the probability of occurrence, and the effect considering the expected potential impact. PMI (2009) notes that possible positive effects are understood as opportunities and negative effects are understood as threats.

This vision differentiates specific risks from the global risk of a project. The former refers to those specific events or conditions that may affect one or more objectives. The second represents more than the sum of the different individual risks, and refers to the exposure of the different stakeholders to variations in the impact of the project. It is associated with the strategic decision-making process, project governance and priority setting, among others (Project Mangagement Institute, 2009).

So far, the logic presented by orthodoxy in project management can be analysed within the social-cultural theoretical framework and the scientific method. In this regard, PMI (2009) specifies that it is necessary to contemplate the attitude towards risk of the different stakeholders, because it defines the relevance of individual risks and global risk. This attitude can be linked to how much the project impacts the activities of the different groups, to the commitment assumed by the developer regarding the objectives, and to their sensitivity to specific factors such as environmental impact, relationships, among others, especially linked to idiosyncratic factors. The prioritization of some objectives over others is usually the result of the attitude towards the different risks (Project Mangagement Institute, 2009).

In this general project management framework, construction project management has focused on the study of risk under the same probability-impact model mentioned above. Furthermore, risk is usually analysed based on the potential variation in the initially estimated cost or time, as objectives of the construction project itself. These are usually useful for adopting a single scale for measuring risks of different nature (Taroun, 2014).

In this regard, there have been different methodologies to measure risk in construction projects, generally adopting a negative view of the phenomenon. As noted by Latham (1994), under this view, project risks can be managed, minimized, shared, transferred or accepted. In construction projects, risks are usually associated with those events or environmental conditions that can generate cost overruns, delays, or changes in scope and quality, with respect to the planning carried out.

Thus, the first methodologies for estimating risk in construction projects, which were developed in the 60s, 70s and 80s, were based on probability theory, and are referred in this document as the "probabilistic approach". This allows combining events or risk conditions using their probability distributions to estimate how risky the project as a whole is, in terms of cost overruns and delays. The process for developing such an analysis involves: estimating probabilities of occurrence of adverse events, establishing assumed limits and associated uncertainty, and measuring the potential impact. First analyses in this direction started using statistical methods for their development, from which the literature concentrated on Monte Carlo simulations. Explicitly, as noted by Edwards and Bowen (1998) it involves understanding risk as an estimated variance of project cost or duration. This methodology is especially associated with the scientific perspective presented above.

However, since the late 1980s, the specialized literature has shown significant disadvantages of the previous methodology. For example, Kangari and Riggs (1989) note that not all information regarding uncertainty factors in construction projects is numerical, and the aggregation of different risks becomes impossible. Furthermore, construction projects are usually one-time projects, and it is not always reasonable to draw conclusions regarding some risks considering what happened in other projects, as explained by Flanagan and Norman (1993). In parallel, in construction projects, the imprecision, complexity, and vagueness of several of the problems that developers face is the norm. This reality implies an unfailingly subjective assessment of risks. Thus, the specialized literature has changed the perspective when analysing construction risks. Although it has maintained the previous definition of risks, and used the definition of probability and impact, it has been inclined to try to capture the subjectivity behind this phenomenon, adapting to its inherent complexity.

Thus, other methodologies have emerged, such as the application of fuzzy set theory, and analytic hierarchy process, for the assessment and management of risks in construction projects. The conceptualization of fuzzy set theory was first developed by Zadeh (1975), and was proposed for the analysis of risks in construction projects by Kangari & Riggs (1989). It considers the imprecision and vagueness of the construction risk factors when numerically representing the subjectivity of the words used by those who assess risk based on linguistic variables and membership functions. In simple terms, fuzzy sets (uncertain sets) are like sets whose elements have degrees of membership (this is explained in detail in section 2.4). Besides, the conceptualization of the second, analytic hierarchy process, was developed by Saaty (1980) and applied to project risk management for the first time by Mustafa & Al-Bahar (1991). It is used to structure a complex decision-making process, systematizing relative priorities among criteria.

Since the 2000s these two developments have been the main approaches in academic settings to study risks in construction projects. Most publications adopt risk as an attribute of projects, and not as an estimated variance. Gradually, the academy has converged on the idea that human factors, intuition, personal experience, and individual judgments are essential in risk assessment (for a detailed analysis of this subject see Taroun, 2014). Laryea & Hughes (2008) suggests that the academic literature, regarding the vision of construction risks, has shown a paradigm shift, going from "classicism", focused on probability theory and simulation tools, to a "conceptualism", using analytical techniques. In this document, the first of the above is selected: the application of FST. It does so as the vast majority of applications of AHP use crisp data, and data in many real applications, such as risk assessment in megaprojects, are not crisp, given the ill-defined nature of risk factors.

Obviously, neither of them is an infallible methodology. As suggested by Taroun (2014), when using a probability-impact model, based on individual assessments, interdependencies between risks, changes due to the complexity of the context, and the experience of the risk analyst, among others, are not always taken into account. This is particularly relevant in the case of megaprojects. Specifically, in this regard, from the construction management literature, it is shown that, from its beginning to its conclusion, the construction process in these cases is complex, characterized by much uncertainty and different interactions. This results in unbalanced subjective beliefs regarding risk and uncertainty, and strong difficulties in controlling and managing risks at different moments in time. FST, if applied periodically, may be particularly useful to deal with these issues.

To understand the special complexity in dealing with risk in megaprojects, the following section delves into this topic. Subsequently, a list of construction risks that can be useful in the use of the selected methodology is proposed.

2.3. MEGAPROJECTS UNIQUE CHARACTERISTICS

2.3.1. MEGAPROJECT COMPLEXITY

Megaprojects are exceptionally complex projects; this complexity is associated with a particular decision-making process, which is different from that of smaller projects. Complex systems are made up of several components, and their behaviour cannot be inferred from the behaviour of their components (Bar-Yam, 1997). A given project can be understood as a complex system if there are multiple structural elements which interact and change as the different phases advance (Whitty and Maylor, 2009).

According to Remington and Pollack (2011), megaprojects are typical examples of complex systems. These authors propose an analysis framework in which they specify four dimensions of complexity: structural, technical, directional and temporal. The first one is derived from the many interrelated and interdependent activities that generate a form of non-linear feedback between the organizational structures in charge of implementing the project. Technical complexity, on the other hand, refers to the design challenge, which may create problems for which there is no solution within the required framework. Directional complexity is the result of objectives (or the means to reach them) that are ambiguous or which are not commonly shared by the different participants in the project. Finally, temporal complexity is the complexity given by the sensitivity of the project to unforeseeable changes in the context, whether internal or external, throughout its development (Remington and Pollack, 2011).

Brockmann & Girmscheid (2007) characterize the complexity of megaprojects, by dividing it in three layers: complexity of the task, social complexity and cultural complexity. The first layer is associated with the density of activities within the spatial and temporal framework of the project. Social complexity refers to the number and diversity of stakeholders involved in the project, who communicate and work together. The third level of complexity, the cultural dimension, is linked to the history, experience and way of reasoning of the stakeholders involved in the project.

Likewise, De Bruijn & Leijten (2008) state that megaproject management is dependent on two factors: technical and social complexity. The former has to do with the nature of the project, and the latter with its implementation. The complexity inherent to the nature of the project is related to its potential to create a robust design, and to use proven technology, to the divisibility of the project itself, to the degree of association between the different components, to there being available options that generate redundancy, to the degree of multifunctionality of the project, and to how progressive its implementation is. On the other hand, social complexity comes from the dependence of the user's decision-making, from the wide variety and dynamism of said preferences, from the blocking power of the third parties, from the degree of social impact of the project, and its implementation time.

2.3.2. MEGAPROJECTS AS ORGANIC PHENOMENA

Given the above-mentioned complexity, megaprojects are also characterized as organic phenomena that evolve together with their context and are thus undergoing a process of continuous transformation in terms of their goals and aims (Lehtonen, 2014). Megaprojects should not be regarded only as engineering devices. As demonstrated by Dimitriou et al. (2014), megaprojects change over time and space, inasmuch as they affect—from the moment they are designed and implemented—the territories, economies, and societies they serve. This makes it difficult to establish their scope from a very early stage (see Wysocki, 2014). This is why some authors suggest that it is particularly difficult to assume that it is possible to effectively foresee every single aspect of the development of a megaproject in its gestation period.

Using a holistic success paradigm, megaprojects can be understood as successful when they meet the proposed objectives in terms of outputs and outcomes (see Alberti, 2019). In terms of outputs, when analysing the construction project itself, success of the project is obtained when the project is carried out without cost overruns, delays, and with the expected scope. In terms of intermediate outcomes it depends on the particular sector. It may have to do with reducing travel times for users, reducing travel costs, and lowering emissions or accidents, among others. Regarding the final outcomes, the megaproject may affect the level of efficiency of the transport system as a whole, or that of equity, or have a focus on specific regional or urban development due to its iconic value, in addition to having clear consequences from the electoral-political point of view. When analysing these differences, Samset (2008) refers to operational success, tactical success and strategic success.

The complexity in the decision-making process, and the organic nature of the megaprojects, imply that the achievement of the proposed objectives, in terms outputs and outcomes, is absolutely uncertain, given the social, technical, environmental, economic and political contexts.

2.3.3. INTERDEPENDENCE OF RISK

Considering that risks can be understood as uncertain events or conditions that have effects on project objectives, megaprojects are usually especially risky. This occurs for many reasons, which are usually related to the fact that they are complex and organic, trying to meet objectives at different levels, and in all of them there is uncertainty (Alberti & Pereyra, 2018). In this section, four considerations that emerge from the previous statement are especially considered.

The first consideration that must be made is that megaprojects present a special complexity due to the trade-off that may appear between the different objective levels in terms of outputs and outcomes/impacts, and that said trade-off depends on uncertain events or conditions.

Regarding outputs, megaproject usually have a high risk of presenting cost overruns, delays or differences in scope, in relation to what was originally planned. Regarding risk in terms of outcomes and impact, megaprojects have a high risk of lower economic viability than usual. Furthermore, they present a particularly high risk of negative environmental and social impact. Due to their complexity and size, both the probability and potential magnitude of an environmental impact are usually high. To the previous risks, furthermore, these projects usually add a high political risk, which changes the possibilities of obtaining financing and being carried out. In this context, megaprojects require preinvestment, investment and start-up periods that are, many times, greater than those of government cycles. This fact alone introduces a greater political risk, understood as the risk that the project will not finally be executed because the incoming administration no longer has an interest (Alberti and Pereyra, 2018).

The first noteworthy consideration then, regarding risk in megaprojects, is that risk management at one level (for example the aforementioned political risk - associated with outcomes), may require to accept greater risks in terms of outputs. For example, incomplete pre-investment studies can be carried out, resulting in greater subsequent cost overruns. The same happens in the opposite direction: to reduce the risk of delays, a greater risk of environmental or social impact can be accepted. For example, necessary precautions to diminish negative impacts to the affected communities may not be taken. Countless scenarios can be imagined using this logic (for more information see Alberti and Pereyra, 2018).

The second consideration is that some variables that impact one level also impact other levels. An unexpected increase in costs has obvious impacts in terms of cost overruns, but also in terms of the economic efficiency of the project and the efficiency of public transport policy itself. For example, incomplete or incorrect site/soil studies have a double risk. First, at the output level, it is likely that cost overruns will be generated, understood as the difference between what was initially projected and what was actually spent. At the same time, a larger investment may also imply that the difference between the social benefits and costs is smaller. It is possible to imagine a scenario where this could imply that the project is not, any more, the best project alternative to develop.

The third consideration is that the objectives themselves, of different nature, are developed under conditions of uncertainty. As an example, in terms of outputs, cost overruns can be associated with risks inherent in any complex construction process. For example, they may arise due to bets on the conditions on the site, or to macroeconomic variables beyond the control of the developers, or to the lack of capacities to technically estimate the costs of a project of this nature. In terms of outcomes, they can arise from changes in the interests of interest groups, and must respond to the change in priorities, which is also not a priori controllable.

The fourth and last of the considerations here highlighted, but not least, is that risks are dynamic and interdependent. For example, the risk of unexpected changes in economic variables (i.e. a recession), may be associated with the risk of political instability, and more opposition from the affected community. The management of these risks is usually made separately, but that does not mean that there is no feedback between them.

2.3.4. MEGAPROJECT CONSTRUCTION RISKS

Given the previous characteristics of megaprojects, there is no consensus in the specialized literature on construction management, specifically in the case of large-scale projects, when it comes to risk identification. Different concepts and approaches appear that generate a range of terminology, definitions and explanations about risk factors and dimensions. In addition, it is common to find theoretical analyses, much more than statistical studies that test hypotheses. There is no consolidated risk identification model for megaprojects. On the contrary, as demonstrated by Sanchez-Cazorla & Alfalla-Luque (2016), there is a large number of variables and tools analysed and used.

Considering that success in megaprojects can be evaluated in terms of outputs and intermediate/final outcomes, the first question that must be answered is what is the potential result that would be affected by the materialisation of a particular risk, in order to develop a list of risk factors. The purpose of this document is summarized in the introduction. The aim here is to carry out an analysis of construction risks in megaprojects. At the time of implementation, once the project to be developed has been defined, the objectives of the decision makers are focused on outputs.

Thus, although recognising that outputs may be contingent on and influenced by objectives in terms of outcomes, the focus of this document is the study of the risks associated with achieving output (construction) objectives. Considering the construction contract, to be developed or already signed, it is expected that the project will be executed with the desired scope, at the scheduled time and within the projected cost. It is especially important, using this framework, to study the perception of decision makers, because it is there where all the previous complexity is synthesized.

Even if the previous restriction is used, the consolidation of a comprehensive group of construction risks is difficult because the literature shows differences regarding the dimensions that may be used to classify the different risk factors. Discretionary, this document uses the social, technical, environmental, economic and political dimensions (STEEP), proposed by Boateng, Chen, & Ogunlana (2017), because it is presented as a more intuitive division, in the opinion of the author of this document, than the rest of the options presented in the academic literature.

Obviously, as Boateng et al. (2017) explain, there are interdependencies in these risk factors, and it is part of the complexity of working on this issue with this division. Thus, gathering the construction risks in megaprojects proposed by the literature, a list is proposed based on STEEP axes, but including a comprehensive group of risk factors found in the literature. The following table illustrates which of the risk factors are ill-defined in nature, and which of them are quantifiable using traditional statistical methods.

Table 1 – Risk Factors and Dimensions

Risk Factor	Risk Dimension	Source	Ill-defined in Nature	Quantifiable by traditional statistical methods
Impossibility of obtaining land and access rights	Social	Boateng et al. (2017); Hilber and Robert-Nicoud (2013); Turner, Henryks, and Pearson (2011); Funderburg et al. (2010)	No	No
Compensations higher than expected	Social	Boateng et al. (2017); Hilber and Robert-Nicoud (2013); Turner, Henryks, and Pearson (2011); Funderburg, Nixon, Boarnet, and Ferguson (2010)	No	No
Protests and interference by residents	Social	Samantra et al. (2017); Kou and Lu (2013); Dey (2001); Baloi and Price (2003)	Yes	No
Legal actions of the affected community	Social	Boateng et al. (2017); Funderburg, Nixon, Boarnet, and Ferguson (2010)	No	No
Claims by third parties	Social	Boateng et al. (2017); Galloway (2009)	Yes	No
Costs of contractual disputes with contractor	Social	Boateng et al. (2017)	No	No
Threats to the safety of personnel or assets	Social	Boateng et al. (2017); Jones and Brinkert (2008); Alinaitwe et al. (2007)	No	No
Vandalism	Social	Boateng et al. (2017); Bourne and Walker (2006); Olander and Landin (2005); Winch (2000); Miller and Lessard (2001)	No	No
Involvement of many decision-making bodies	Social	Boateng et al. (2017); Jones and Brinkert (2008); Alinaitwe et al. (2007); Al-Momani (2000)	Yes	No
Inappropriate design due to lack of technical capabilities	Technical	Samantra et al. (2017); Renuka et al (2014); Kou and Lu (2013); Tah and Carr (2000); Dey (2001)	Yes	No
Measurement errors on the site	Technical	Samantra et al. (2017); Bunni (2003); Shen et al. (2001); Zeng et al. (2007)	No	Yes
Conflicting interfaces between work items	Technical	Samantra et al. (2017); Kou and Lu (2013); Iyer and Jha (2005)	No	No
Special conditions on the site	Technical	Renuka et al (2014); Shahbodaghlou and Samani (2013)	No	Yes
Insufficient site inspections	Technical	Samantra et al. (2017); Bunni (2003); Shen et al. (2001); Zeng et al. (2007)	Yes	No
Changes in project scope requirements	Technical	Renuka et al (2014); Tamhain (2013)	No	No

Risk Factor	Risk Dimension	Source	Ill-defined in Nature	Quantifiable by traditional statistical methods
Changes in technology or in industry use standards	Technical	Youjie (2004)	No	No
Other changes in the engineering design of the project	Technical	Boateng et al. (2017); Choo, Hammond, Tommelein, Austin, and Ballard (2004); Ghosh and Jintanapakanont (2004)	Yes	No
Inaccurate estimates of project cost	Technical	Boateng et al. (2017); Nielsen and Randall (2013)	No	No
Poor quality construction plan / poor allocation of time and resources	Technical	Samantra et al. (2017); Kou and Lu (2013); Dikmen et al. (2007); Youjie (2004); Shen et al. (2001)	Yes	No
Insufficient capacities in construction work	Technical	Samantra et al. (2017); Wang and Yuan (2011); Zayed et al. (2008); Zou et al. (2007)	Yes	No
Fall in the supply chain / unstable supply of construction materials	Technical	Boateng et al. (2017)	No	No
Poor quality of local materials	Technical	Shahbodaghlou and Samani (2013)	No	Yes
Bad suppliers	Technical	Shahbodaghlou and Samani (2013)	Yes	No
Obstacles to import	Technical	Shahbodaghlou and Samani (2013)	No	No
Distance between site and materials / suppliers	Technical	Shahbodaghlou and Samani (2013)	No	No
Bad contract enforcement	Technical	Youjie (2004)	Yes	No
Budgetary and cash flow inconsistencies	Technical	Shahbodaghlou and Samani (2013)	No	No
Lack of human resources for the development of the works	Technical	Shahbodaghlou and Samani (2013)	No	No
Technical difficulties and delays in making changes in affected utilities	Technical	Samantra et al. (2017); Kou and Lu (2013); Zayed et al. (2008)	No	No
Insufficient protection of adjacent buildings and facilities	Technical	Samantra et al. (2017); Kou and Lu (2013); Carr and Tah (2001)	No	No
Insufficient worker safety	Technical	Samantra et al. (2017); Kou and Lu (2013); Zayed et al. (2008); Carr and Tah (2001)	No	No
Inefficient protection regarding the surrounding environment	Technical	Samantra et al. (2017); Kou and Lu (2013); Bunni (2003)	Yes	No
Inefficient traffic control and management	Technical	Samantra et al. (2017); Kou and Lu (2013); Carr and Tah (2001)	Yes	No
Changes in funding vehicles	Economic	Boateng et al. (2017); Frick (2009); Sturup (2009); Hodge (2004); Haynes (2002)	No	No
Changes in the taxes	Economic	Boateng et al. (2017); Hodge (2004); Frimpong et al. (2003)	No	No
Multinational sanctions	Economic	Shahbodaghlou and Samani (2013)	No	No
General inflation	Economic	Boateng et al. (2017); Renuka et al (2014); Frimpong et al. (2003);	No	Yes
Wage inflation	Economic	Boateng et al. (2017); Frimpong et al. (2003);	No	Yes
Changes in prices of construction materials	Economic	Samantra et al. (2017); Zou et al. (2007); Dey (2001); Tah and Carr (2000);	No	Yes
Changes in the cost of energy	Economic	Boateng et al. (2017); Smith (2010)	No	Yes
Exchange rate	Economic	Boateng et al. (2017); Ghosh and Jintanapakanont (2004)	No	Yes

Risk Factor	Risk Dimension	Source	Ill-defined in Nature	Quantifiable by traditional statistical methods
Economic recession	Economic	Boateng et al. (2017); Frick (2009) Sturup (2009); Haynes (2002)	No	Yes
Economic effects of an environmental catastrophe	Economic	Boateng et al. (2017); Flyvbjerg et al. (2003)	No	Yes
Legislative or regulatory changes in financing	Economic	Youjie (2004)	No	No
Underground water filtrations	Environmental	Samantra et al. (2017); Kou and Lu (2013); Zayed et al. (2008); Ghosh and Jintanapakanont (2004)	No	No
Affectation of flora and fauna	Environmental	Boateng et al. (2017)	No	Yes
Heavy rain	Environmental	Samantra et al. (2017); Carr and Tah (2001); Kou and Lu (2013); Dey (2001) Kou	No	Yes
Windstorms	Environmental	Samantra et al. (2017); Kou and Lu (2013); Dey (2001); Carr and Tah (2001)	No	Yes
Earthquake	Environmental	Samantra et al. (2017); Kou and Lu (2013);Carr and Tah (2001); Dey (2001)	No	Yes
Political instability	Political	Shahbodaghlou and Samani (2013)	Yes	No
Lack of political support / Political indecision	Political	Boateng et al. (2017); Wu and Pojani (2016); Sturup (2009); Frick (2009); Flyvbjerg et al. (2003)	Yes	No
War or regional conflicts	Political	Shahbodaghlou and Samani (2013)	No	No
Opposition or political interference	Political	Boateng et al. (2017); Wu and Pojani (2016); Plotch (2015);	Yes	No
Government discontinuity	Political	Boateng et al. (2017); Hertogh and Westerveld (2011); Flyvbjerg et al. (2003)	No	No
Changes in the funding policy	Political	Boateng et al. (2017); Renuka et al (2014); Sturup (2009); Frick (2009); Kain (2004); Hodge (2004); Haynes (2002)	No	No
Delays in obtaining approvals and permits	Political	Boateng et al. (2017);	No	No
Lack of transparency and corruption	Political	Shahbodaghlou and Samani (2013)	Yes	No
Protectionism	Political	Boateng et al. (2017)	Yes	No
Lack of regulatory adaptation	Political	Boateng et al. (2017); Greiman (2013); Youjie (2004)	Yes	No
Other unexpected legislative or regulatory changes.	Political	Youjie (2004)	Yes	No

2.4. RISK ASSESSMENT USING FUZZY SET THEORY

Precisely, many of the above risks are not plausibly estimated statistically, based on what happened in other cases. The typical probabilistic approach to risk analysis focuses on the probability and the impact of any given risk, based on historical numerical data. Popular probability-based techniques include sensitivity analysis, decision tree analysis, Bayesian network analysis, and Monte Carlo simulation approach, among others. These tools facilitate risk analysis for construction projects. However, the limitation of probability theory is that it cannot deal with important aspects of project uncertainty, which may arise due to the existence of uncertain and vague risk factors, such as many of the above, during the assessment phase. For example, this may happen with “involvement of many decision-making bodies” or “political indecision” or “lack of transparency and corruption”, among others. Although different people can say that one of the above risks is very probable or its potential effect is very high, they could be eventually thinking differently, because those risks are difficult to numerically define.

However, according to what is mentioned in section 2.1.3., there are other ways of estimating the probability and impact of a given risk. One of them consists of generating linguistic measures and transforming them into a mathematical logical base. Here we propose the use of FST, within the framework that this computational intelligence paradigm can provide.

Computational intelligence has been consistently used by the academy with the aim of assisting in decision-making when using a multi-criteria approach. With this objective, three paradigms have been especially useful according to Doumpos & Zopounidis (2013): statistical learning and data mining; metaheuristics; and fuzzy modelling. Data mining requires large amounts of data and is generally used to find unexpected relationships and summarize variables. Metaheuristics is usually used in multi-objective optimization, without making assumptions about the problem being studied. The third is the one proposed in this document, in the context of the analysis of multiple construction risks.

This methodology has the capacity to minimize the inherent imprecision, inconsistency, vagueness and uncertainty imposed by linguistic information. Several authors have worked on this approach, including Zadeh, (1975), who introduced it, but also Kaufmann & Gupta (1991), Zimmermann (1991), Chan, Chan, & Tang (2000), Yang & Hung (2007) and Chen & Chen (2009).

Regarding its use in this particular sector, fuzzy set theory has recently been used in the analysis of construction risks. For example, Pinto (2014) develops such a model to estimate occupational safety risk in construction projects, Nasirzadeh, Khanzadi, & Rezaie (2014) also uses fuzzy set theory to treat the natural uncertainty of several risk factors , Kuo & Lu (2013) use a fuzzy multi-criteria decision-making approach to assess risks in the construction of a subway, Tamosaitiene, Kazimieras Zavadskas, & Turkis (2013) compare the risks of three construction projects using fuzzy logic, Idrus, Fadhil Nuruddin, & Arif Rohman (2011) develop a model for estimating contingent costs by calculating construction risks based on fuzzy systems, Nieto-Morote & Ruz-Vila (2011) use fuzzy numbers to characterize different construction risks that do not are quantifiable and Xu et al., (2010) develop a risk assessment model for PPP projects in China based on fuzzy logic, among others. This work proposes the use of the methodology selected by Samantra, Datta, & Mahapatra (2017), for reasons that are developed below.

Unlike traditional set theory, where the set is considered a collection of distinct and well-defined objects, fuzzy subset theory implies a fuzzy boundary between sets, and each object is associated with each subset to a certain degree of association. With this theory, uncertainty and imprecision can be represented mathematically, and formal tools can be provided to deal with the subjectivity inherent in any decision-making process.

Therefore, these authors consider appropriate to estimate the degree of severity of all risks factors of megaprojects using fuzzy set theory. By using it, it is possible to effectively explore the subjectivity associated with the uncertain (vague and poorly defined) characteristics of risk factors and the corresponding human judgment when assessing it. In this way, the imprecision, inconsistency and vagueness of risk analysis in megaprojects can be dealt with in an orderly manner, with the support of computational intelligence.

The proposed approach involves the following steps (see for example Samantra et al. (2017).

Figure 1 – Steps for risk assessment using FST

1 Identification of potential factors
2 Selection of lingustic scales for assessing likelihood of occurrence of impact of risk
3 Collection of decision making data from key stakeholders
4 Transformation of linguistic data into appropriate fuzzy numbers representation
5 Aggregation of multiple decision makers' opinion
6 Computation of fuzzy risk extent
7 Estimation of crisp ratings against various risk factotrs

Step 1 was detailed in section 2.2.4. of this document, based on an extensive bibliographic review. The linguistic scale proposed in this study, following Samantra et al. (2017) is the following.

Table 2 – Linguistic Scales

Linguistic scale for quantifying likelihood of occurrence	
Likelihood of occurrence	**Linguistic Variable**
Expected to occur with absolute certainty	Absolutely certain (AC)
Much frequent to occur	Very Frequent (VF)
Likely to occur frequently	Frequent (F)
Likely to occur several times in the life of the operation	Probable (P)
Likely to occur sometime in the life of the operation	Occasional (O)
Unlikely but possible to occur sometime in the life of the operation	Rare (R)
So unlikely that it can be assumed that the possibility of occurrence is negligible	Very Rare (VR)
Linguistic scale for quantifying risk impact	
Impact of risk	**Linguistic Variable**
Very High	VH
High	H
Moderate	M
Low	L
Very Low	VL

Given the above definition, considering steps 1 and 2 have been taken, the following questionnaires can be used to develop step 3.

Table 3 - Questionnaires

Please tick [√] in any one rating that you feel appropriate for each item. (Refer to Table 1)

		LIKELIHOOD OF OCCURRENCE						
		AC	VF	F	P	O	R	VR
Risk Dimension	Risk Factors Under Specific Dimensions							
D1	SOCIAL							
	Impossibility of obtaining land and access rights							
	Compensations higher than expected							
	Protests and interference by residents							
	Claims by third parties							
	Costs of contractual disputes with contractor							
	Threats to the safety of personnel or assets							
	Vandalism							
	Involvement of many decision-making bodies							
D2	TECHNICAL							
	ENGINEERING DESIGN							
	Inappropriate design due to lack of technical capabilities							
	Measurement errors on the site							
	Conflicting interfaces between work items							
	Special Conditions on the site							
	Insufficient site inspections							
	Changes in project scope requirements							
	Changes in technology or in industry use standards							
	Other changes in the engineering design of the project							
	Inaccurate estimates of project cost							
	CONSTRUCTION MANAGEMENT							
	Poor allocation of time and resources							
	Insufficient capacities in construction work							

		LIKELIHOOD OF OCCURRENCE						
		AC	VF	F	P	O	R	VR
	FALL IN THE SUPPLY CHAIN							
	Poor quality of local materials							
	Bad suppliers							
	Obstacles to import							
	Distance between site and materials / suppliers							
	Bad contract enforcement							
	Budgetary and cash flow inconsistencies							
	Lack of human resources for the development of the works							
	Technical difficulties in making changes in affected utilities							
	SAFETY IN CONSTRUCTION							
	Insufficient protection of adjacent buildings and facilities							
	Insufficient worker safety							
	Inefficient protection regarding the surrounding environment							
	Inefficient traffic control and management							
D3	**ECONOMIC**							
	Changes in funding vehicles							
	Changes in the taxes							
	Multinational sanctions							
	General inflation							
	Wage inflation							
	Changes in material costs							
	Changes in the cost of energy							
	Exchange rate							
	Economic recession							
	Economic effects of an environmental catastrophe							
	Legislative or regulatory changes in financing							
D4	**ENVIRONMENTAL**							
	ENVIRONMENTAL RISKS DUE TO CONSTRUCTION							
	Underground water filtrations							
	Affectation of flora and fauna							
	UNFAVOURABLE WEATHER CONDITIONS							
	Heavy rain							

		LIKELIHOOD OF OCCURRENCE						
		AC	VF	F	P	O	R	VR
	Windstorms							
	Earthquake							
D5	POLITICAL							
	Political instability							
	Lack of political support / Political indecision							
	War or regional conflicts							
	Opposition or political interference							
	Government discontinuity							
	Changes in funding policy							
	Delays in obtaining approvals and permits							
	Lack of transparency and corruption							
	Protectionism							
	Lack of updating or regulatory adaptation							
	Other unexpected legislative or regulatory changes							

Please tick [√] in any one rating that you feel appropriate for each item. (Refer to Table 2)

		IMPACT OF RISK				
		VH	H	M	L	VL
Risk Dimension	Risk Factors Under Specific Dimensions					
D1	SOCIAL					
	Impossibility of obtaining land and access rights					
	Compensations higher than expected					
	Protests and interference by residents					
	Claims by third parties					
	Costs of contractual disputes with contractor					
	Threats to the safety of personnel or assets					
	Vandalism					
	Involvement of many decision-making bodies					
D2	TECHNICAL					
	ENGINEERING DESIGN					
	Inappropriate design due to lack of technical capabilities					

		IMPACT OF RISK				
		VH	H	M	L	VL
	Measurement errors on the site					
	Conflicting interfaces between work items					
	Special Conditions on the site					
	Insufficient site inspections					
	Changes in project scope requirements					
	Changes in technology or in industry use standards					
	Other changes in the engineering design of the project					
	Inaccurate estimates of project cost					
	CONSTRUCTION MANAGEMENT					
	Poor allocation of time and resources					
	Insufficient capacities in construction work					
	FALL IN THE SUPPLY CHAIN					
	Poor quality of local materials					
	Bad suppliers					
	Obstacles to import					
	Distance between site and materials / suppliers					
	Bad contract enforcement					
	Budgetary and cash flow inconsistencies					
	Lack of human resources for the development of the works					
	Technical difficulties in making changes in affected utilities					
	SAFETY IN CONSTRUCTION					
	Insufficient protection of adjacent buildings and facilities					
	Insufficient worker safety					
	Inefficient protection regarding the surrounding environment					
	Inefficient traffic control and management					
D3	**ECONOMIC**					
	Changes in funding vehicles					
	Changes in the taxes					
	Multinational sanctions					
	General inflation					
	Wage inflation					
	Changes in material costs					

		IMPACT OF RISK				
		VH	H	M	L	VL
	Changes in the cost of energy					
	Exchange rate					
	Economic recession					
	Economic effects of an environmental catastrophe					
	Legislative or regulatory changes in financing					
D4	**ENVIRONMENTAL**					
	ENVIRONMENTAL RISKS DUE TO CONSTRUCTION					
	Underground water filtrations					
	Affectation of flora and fauna					
	UNFAVOURABLE WEATHER CONDITIONS					
	Heavy rain					
	Windstorms					
	Earthquake					
D5	**POLITICAL**					
	Political instability					
	Lack of political support / Political indecision					
	War or regional conflicts					
	Opposition or political interference					
	Government discontinuity					
	Changes in funding policy					
	Delays in obtaining approvals and permits					
	Lack of transparency and corruption					
	Protectionism					
	Lack of updating or regulatory adaptation					
	Other unexpected legislative or regulatory changes					

This methodology facilitates a quantitative analysis of the contribution of the different construction risk factors to the general probability that the selected megaprojects will obtain the results expected by government decision makers at the construction stage.

Step 4 of this methodology refers to a computation of fuzzy preferences using fuzzy aggregation rules. Following Chen (2000) and Samantra et al. (2017), assuming a group of expert interviewees (E_t, $t = 1, \dots, k$), who are responsible for assessing the risks of n risk influencing factors ($F_{i,j}$, $j = 1 \dots, n$), under m risk dimensions (D_i, $i = 1, \dots, m$), the aggregated fuzzy preference of each risk influencing factors ($\tilde{F}_{ij}$), both for the probability of occurrence (P) and the potential impact (I), can be computed as follows:

$$\tilde{F}_{ij} = \frac{1}{k}\left[\tilde{F}_{ij1} \oplus \tilde{F}_{ij2} \oplus \dots \oplus \tilde{F}_{ijk}\right]$$

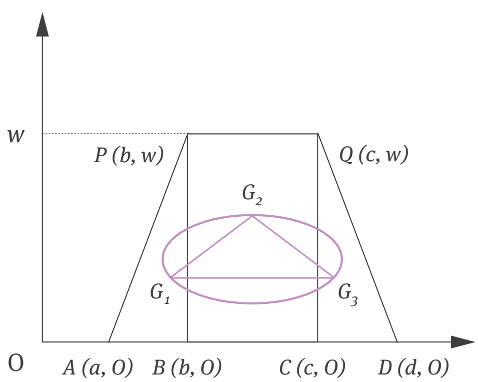
Then, the corresponding fuzzy risk rating of each individual risk factor can be obtained as follows:

$$\text{Fuzzy risk rating} = (\tilde{F}_{ij})_P \otimes (\tilde{F}_{ij})_I$$

For the subsequent step 5, referred to the use of a methodology to calculate sharp values, in this case the methodology proposed by Rao & Shankar (2011), adjusted by Samantra et al. (2017), is used for the assessment of construction risks. To order the fuzzy numbers, the method proposed by these authors is the circumcenter of centroids. The method provides a mathematical formulation for ranking the fuzzy numbers based on their crisp score.

Considering a trapezoidal fuzzy number, firstly, the trapezoid is split into three plane figures like a triangle, a rectangle, and then a triangle again. Then the centroids of these plane figures are calculated followed by the calculation of the Circumcenter of these centroids, which is considered as the reference point to define the ranking of generalized fuzzy numbers.

Figure 2 - Circumcenter of Centroids



Considering a generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d; w)$, the centroids of the three plane figures are the following:

$G_1=((a+2b)/3, w/3)$

$G_2=((b+c)/2, w/2)$

$G_3=((2c+d)/3, w/3)$

Equation of the line $\overleftrightarrow{G_1G_3}$ is $y = w/3$ and G_2 does not lie on the line $\overleftrightarrow{G_1G_3}$. Consequently, G_1, G_2 y G_3 are non-collinear and they form a triangle.

Let us define the Circumcenter $S_{\tilde{A}}(\tilde{x}_0, \tilde{y}_0)$ of the triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d; w)$ as:

$$S_{\tilde{A}}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{a+2b+2c+d}{6}, \frac{(2a+b-3c)(2d+c-3b)+5w^2}{12w}\right)$$

As a special case, for triangular fuzzy number $\tilde{A} = (a,b,c,d; w)$, that is, $c = b$ the Circumcenter of centroids is given by:

$$S_{\tilde{A}}(\tilde{x}_0, \tilde{y}_0) = \left(\frac{a+4b+d}{6}, \frac{4(a-b)(d-b)+5w^2}{12w}\right)$$

The ranking function of the trapezoidal fuzzy number $\tilde{A} = (a,b,c,d; w)$ which maps the set of all fuzzy numbers to a set of real numbers is defined as:

$$R\left(\tilde{A}\right) = \sqrt{\bar{x}^2{}_0 + \bar{y}^2{}_0}$$

$R(\tilde{A})$ is the Euclidean distance from the Circumcenter of the centroids and the original point. This distance serves as a measure of the combined crisp risk rating between the interviewed agents.

3

METHODOLOGY - MULTIPLE CASE STUDY

In this research process, a multiple case study was developed to apply the proposed analysis, with the aim of assessing a comprehensive list of construction risk factors in megaprojects in Latin America and illustrating the relative importance of ill-defined risk factors in megaprojects of the region. In order to study the above, and draw valuable conclusions, a multiple case study has been rigorously structured. If “ill-defined” risks factors are usually assessed as relatively important in all cases, it could be presumed that a numerical probabilistic approach to risk assessment would be incomplete.

According to Yin (2014), the design of a multi-case study involves the specification of five components: questions; propositions; units of analysis; logic to relate data and propositions; and criteria for interpreting results. The question expected to be answered by this paper is: how important are those risk factors, related to construction objectives (cost, time and scope), which are ill-defined (vague) and are not plausibly studied with a probabilistic approach?

Propositions, on the other hand, should direct the attention of the study. They are answers, based on theory, to the previous question. Case studies should be used to corroborate whether they are met. In this study, the selected proposition arises from the theoretical framework proposed in section 2 of this document. There it is presented that construction risks in megaprojects are related to different dimensions, tied to its complex nature. The risk dimensions here included are: social, technical, environmental, economic and political. It is here alleged that it is usually neither possible nor reasonable to develop a numerical, probability-based, analysis about them, because several risk factors that form these risk dimensions are ill-defined and related to the cultural context in which they are carried out. Furthermore, due to their complex nature, it is expected that the most relevant factors and dimensions will not be quantifiable by means of traditional statistical methods.

The corroboration of this proposition from the analysis here presented would represent an analytical generalization and not a statistical generalization. A theory should not be statistically generalized with this methodology because cases should not be read as samples of a population. Cases here should be understood as opportunities to associate theory with practice in a difficult problem. In any case, it is reasonable to assume that more cases that corroborate the chosen proposition imply greater robustness.

Third, the unit of analysis can be people, groups, decisions, programs, events or, as in this case, megaprojects. The hypothesis chosen is that in each megaproject there are social, technical, environmental, economic and political dimensions of risk specific to its environment, which by their nature are not modellable with a probabilistic approach, and which may be more relevant than those that are. Later, at this stage, the question that had to be answered was: How many megaprojects are necessary in this study? A single case analysis can serve to criticize a theory, for being unusual or common, but revealing. Multiple cases, on the other hand, have a logic of replication. The intuition of multiple cases is that they are useful to analyse whether or not the propositions are replicated, in different contexts, to increase the robustness of the fit of the hypothesis to the propositions. Indeed, this research process works on the second option, multiple case studies, to reinforce the results obtained. Each case should be considered as a study in itself, where evidence is sought regarding the propositions and conclusions are drawn. Among cases, the extent of the replication sought should be analysed (Yin, 2014). This is done in section 4.2 of this document.

However, this does not determine the number of megaprojects that should be analysed. The answer to this question is discretionary. It is not possible to use the logic usually chosen to find a sample of a population. The object of analysis is precisely difficult to quantify, and therefore a power analysis to determine the sample size is not possible. Discretionarily, three megaprojects were chosen in this study, as three cases were understood as sufficient to consider that an acceptable replication of the hypotheses has been obtained.

These megaprojects needed to meet certain conditions. Ideally, megaprojects had to be developed in different contexts, to assess the replicability of the mentioned proposition under different conditions. In parallel, in order for the construction risks to be reasonably known, but not yet materialized, the developers of the megaprojects must have achieved a minimum basic design, and not have made substantial progress in construction. Following this logic, the following cases were selected: Ferroanel from São Paulo in Brazil; Central Railway of Uruguay; and Line 1 of the Bogotá Metro in Colombia. These megaprojects needed to be advanced enough as to have had a detailed risk analysis of the construction phase completed, but not so advanced as the team knows which risks have become realities.

By using the above-mentioned cases, megaprojects were studied in different countries. In addition, at the time of conducting the research (2019-2020), the three were at different moments of the project life cycle, within the specified time window. Ferroanel from São Paulo had the complete basic design studies, as well as the environmental and social assessment, but decision-makers had not resolved to advance to the contracting stage. For Line 1 of the Bogotá Metro, on the other hand, decision-makers had resolved to move forward to the contracting stage, and was about to award the project at the moment the questionnaire was deployed. Finally, in the case of the Central Railroad of Uruguay, the project was awarded and contracted, and the final design and construction stage was developing its first steps. The three megaprojects can be seen as a natural experiment to study the issue proposed in this document, considering that they all refer to the rail transport subsector, and thus technical variability between cases is reduced.

Besides, the logic for relating data and propositions can be chosen from an available pool that includes (Yin, 2014): pattern matching; construction of explanations; time series; cross-case synthesis; logical models, among others. In this study, fuzzy logic was used to study and compare the results obtained in the cases. Section 2.3 summarizes how this approach can be applied with the help of computational intelligence. This will show how important are those risk factors, related to construction objectives, which are ill-defined (vague) and are not plausibly studied with a probabilistic approach. Finally, the criterion for interpreting results, in this document, refers to the analysis of contrary explanations. A greater robustness of the conclusions will be achieved as other options are considered and ruled out.

4

RESULTS AND DISCUSSION

4.1. RESULTS

The questionnaires proposed in section 2.3 were completed by 8 experts working on the development of Ferroanel Norte from São Paulo, 8 experts working on the development of the Central Railway Project of Uruguay, and 11 experts in the case of Line 1 of the Metro of Bogota (this is step 3). Experts were identified by IDB specialists and project counterparts, at each one of the countries, considering their experience in construction project management, and their familiarity with the characteristics of the project. Tables in Annex 1 summarise the data obtained. The results of the mathematical analysis presented in 2.3, steps 4 to 7 are presented below.

4.1.1. FERROANEL FROM SÃO PAULO, BRAZIL

Following the proposed methodology, the results of this case are presented below.

Table 4 – Ferroanel Sao Paulo - Aggregated Fuzzy Preferences, computed fuzzy risk rating and corresponding 'crisp' score.

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
SOCIAL																	**14,9%**
Impossibility of obtaining land and access rights	0,30	0,39	0,46	0,55	0,31	0,40	0,50	0,60	0,09	0,16	0,23	0,33	0,20	0,40	0,45	25	3,74
Compensations higher than expected	0,53	0,63	0,68	0,78	0,33	0,43	0,53	0,63	0,17	0,27	0,35	0,48	0,32	0,40	0,51	6	
Protests and interference by residents	0,41	0,51	0,53	0,63	0,25	0,35	0,45	0,55	0,10	0,18	0,24	0,34	0,21	0,41	0,46	21	
Claims by third parties	0,39	0,49	0,55	0,64	0,23	0,33	0,43	0,53	0,09	0,16	0,23	0,33	0,20	0,40	0,45	24	
Costs of contractual disputes with contractor	0,38	0,48	0,53	0,63	0,28	0,38	0,48	0,58	0,10	0,18	0,25	0,36	0,22	0,40	0,46	20	
Threats to the safety of personnel or assets	0,15	0,24	0,28	0,38	0,16	0,25	0,35	0,45	0,02	0,06	0,10	0,17	0,08	0,41	0,42	52	
Vandalism	0,30	0,39	0,43	0,53	0,16	0,25	0,35	0,45	0,05	0,10	0,15	0,24	0,13	0,41	0,43	48	
Involvement of many decision-making bodies	0,64	0,74	0,79	0,86	0,38	0,48	0,58	0,68	0,24	0,35	0,45	0,58	0,40	0,39	0,56	2	
TECHNICAL																	
ENGINEERING DESIGN																	16,2%
Inappropriate design due to lack of technical capabilities	0,20	0,29	0,34	0,44	0,28	0,38	0,48	0,58	0,06	0,11	0,16	0,25	0,14	0,41	0,43	45	4,07
Measurement errors on the site	0,16	0,25	0,30	0,40	0,25	0,35	0,45	0,55	0,04	0,09	0,14	0,22	0,12	0,41	0,43	49	
Conflicting interfaces between work items	0,28	0,36	0,41	0,51	0,33	0,43	0,53	0,63	0,09	0,15	0,22	0,32	0,19	0,41	0,45	27	
Special Conditions on the site	0,29	0,38	0,40	0,50	0,29	0,38	0,48	0,58	0,08	0,14	0,19	0,29	0,17	0,41	0,44	30	
Insufficient site inspections	0,23	0,31	0,39	0,49	0,38	0,48	0,58	0,68	0,08	0,15	0,22	0,33	0,19	0,40	0,45	28	
Changes in project scope requirements	0,34	0,44	0,49	0,59	0,38	0,48	0,58	0,68	0,13	0,21	0,28	0,40	0,25	0,40	0,47	17	
Changes in technology or in industry use standards	0,35	0,45	0,51	0,61	0,38	0,48	0,58	0,68	0,13	0,21	0,29	0,41	0,26	0,40	0,48	15	
Other changes in the engineering design of the project	0,24	0,34	0,40	0,50	0,31	0,40	0,50	0,60	0,07	0,14	0,20	0,30	0,17	0,41	0,44	33	
Inaccurate estimates of project cost	0,34	0,44	0,49	0,59	0,38	0,48	0,58	0,68	0,13	0,21	0,28	0,40	0,25	0,40	0,47	16	
CONSTRUCTION MANAGEMENT																	**19,4%**
Poor allocation of time and resources	0,25	0,35	0,39	0,49	0,30	0,40	0,50	0,60	0,08	0,14	0,19	0,29	0,17	0,41	0,44	31	4,87
Insufficient capacities in construction work	0,25	0,35	0,39	0,49	0,30	0,40	0,50	0,60	0,08	0,14	0,19	0,29	0,17	0,41	0,44	31	
Fall in the supply chain	0,25	0,35	0,39	0,49	0,37	0,47	0,57	0,67	0,09	0,17	0,22	0,33	0,20	0,41	0,45	23	
Bad contract enforcement	0,24	0,34	0,36	0,46	0,30	0,40	0,50	0,60	0,07	0,14	0,18	0,28	0,16	0,41	0,44	34	
Budgetary and cash flow inconsistencies	0,25	0,35	0,39	0,49	0,43	0,53	0,63	0,73	0,11	0,18	0,24	0,35	0,22	0,41	0,46	19	
Lack of human resources for the development of the works	0,18	0,26	0,29	0,39	0,33	0,43	0,53	0,63	0,06	0,11	0,15	0,24	0,14	0,41	0,43	41	

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Technical difficulties in making changes in affected utilities	0,35	0,45	0,48	0,58	0,40	0,50	0,60	0,70	0,14	0,23	0,29	0,40	0,26	0,40	0,48	12	
Insufficient protection of adjacent buildings and facilities	0,18	0,28	0,31	0,41	0,20	0,30	0,40	0,50	0,04	0,08	0,13	0,21	0,11	0,41	0,43	50	
Insufficient worker safety	0,11	0,20	0,24	0,34	0,28	0,38	0,48	0,58	0,03	0,08	0,11	0,19	0,10	0,41	0,42	51	
Inefficient protection regarding the surrounding environment	0,18	0,28	0,35	0,45	0,33	0,43	0,53	0,63	0,06	0,12	0,18	0,28	0,16	0,41	0,44	38	
Inefficient traffic control and management	0,18	0,28	0,31	0,41	0,30	0,40	0,50	0,60	0,05	0,11	0,16	0,25	0,14	0,41	0,43	44	
ECONOMIC																	**20,0%**
Changes in funding vehicles	0,29	0,39	0,43	0,53	0,48	0,58	0,68	0,78	0,14	0,22	0,29	0,41	0,26	0,40	0,48	14	5,04
Changes in the taxes	0,23	0,31	0,35	0,45	0,38	0,48	0,58	0,68	0,08	0,15	0,20	0,30	0,18	0,41	0,45	29	
Multinational sanctions	0,08	0,14	0,19	0,29	0,31	0,40	0,50	0,60	0,02	0,06	0,09	0,17	0,08	0,41	0,42	53	
General inflation	0,19	0,29	0,34	0,44	0,25	0,35	0,45	0,55	0,05	0,10	0,15	0,24	0,13	0,41	0,43	47	
Wage inflation	0,25	0,35	0,39	0,49	0,28	0,38	0,48	0,58	0,07	0,13	0,18	0,28	0,16	0,41	0,44	35	
Changes in material costs	0,31	0,41	0,48	0,58	0,50	0,60	0,70	0,80	0,16	0,25	0,33	0,46	0,30	0,40	0,50	7	
Changes in the cost of energy	0,30	0,40	0,45	0,55	0,40	0,50	0,60	0,70	0,12	0,20	0,27	0,39	0,24	0,40	0,47	18	
Exchange rate	0,35	0,45	0,48	0,58	0,40	0,50	0,60	0,70	0,14	0,23	0,29	0,40	0,26	0,40	0,48	12	
Economic recession	0,34	0,44	0,49	0,59	0,53	0,63	0,73	0,83	0,18	0,27	0,35	0,48	0,32	0,40	0,51	4	
Economic effects of an environmental catastrophe	0,14	0,20	0,28	0,38	0,40	0,50	0,60	0,70	0,06	0,10	0,17	0,26	0,14	0,41	0,43	46	
Legislative or regulatory changes in financing	0,16	0,25	0,30	0,40	0,35	0,45	0,55	0,65	0,06	0,11	0,17	0,26	0,15	0,41	0,43	39	
ENVIRONMENTAL																	
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION																	8,9%
Underground water filtrations	0,28	0,38	0,40	0,50	0,23	0,33	0,43	0,53	0,06	0,12	0,17	0,26	0,15	0,41	0,44	37	2,23
Affectation of flora and fauna	0,35	0,45	0,51	0,60	0,25	0,35	0,45	0,55	0,09	0,16	0,23	0,33	0,20	0,40	0,45	26	
UNFAVOURABLE WEATHER CONDITIONS																	
Heavy rain	0,45	0,55	0,60	0,69	0,33	0,43	0,53	0,63	0,15	0,23	0,32	0,43	0,28	0,40	0,49	8	
Windstorms	0,29	0,38	0,40	0,50	0,24	0,33	0,43	0,53	0,07	0,12	0,17	0,26	0,15	0,41	0,44	36	
Earthquake	0,01	0,03	0,11	0,21	0,36	0,43	0,53	0,63	0,00	0,01	0,06	0,13	0,05	0,41	0,42	55	
POLITICAL																	**20,7%**
Political instability	0,15	0,25	0,30	0,40	0,35	0,45	0,55	0,65	0,05	0,11	0,17	0,26	0,14	0,41	0,43	40	5,21
Lack of political support / Political indecision	0,49	0,59	0,64	0,74	0,50	0,60	0,70	0,80	0,24	0,35	0,45	0,59	0,41	0,39	0,56	1	
War or regional conflicts	0,08	0,10	0,19	0,29	0,33	0,40	0,50	0,60	0,02	0,04	0,09	0,17	0,08	0,41	0,42	54	

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Opposition or political interference	0,34	0,44	0,49	0,58	0,43	0,53	0,63	0,73	0,14	0,23	0,30	0,42	0,27	0,40	0,48	10	
Government discontinuity	0,36	0,46	0,50	0,60	0,41	0,50	0,60	0,70	0,15	0,23	0,30	0,42	0,27	0,40	0,49	9	
Changes in funding policy	0,36	0,46	0,54	0,64	0,48	0,58	0,68	0,78	0,17	0,27	0,36	0,49	0,32	0,39	0,51	5	
Delays in obtaining approvals and permits	0,31	0,41	0,48	0,58	0,45	0,55	0,65	0,75	0,14	0,23	0,31	0,43	0,27	0,40	0,48	11	
Lack of transparency and corruption	0,38	0,48	0,53	0,63	0,48	0,58	0,68	0,78	0,18	0,27	0,35	0,48	0,32	0,40	0,51	3	
Protectionism	0,31	0,41	0,44	0,54	0,33	0,43	0,53	0,63	0,10	0,18	0,23	0,34	0,21	0,41	0,46	22	
Lack of updating or regulatory adaptation	0,24	0,34	0,40	0,50	0,23	0,33	0,43	0,53	0,05	0,11	0,17	0,26	0,15	0,41	0,43	42	
Other unexpected legislative or regulatory changes	0,24	0,34	0,40	0,50	0,23	0,33	0,43	0,53	0,05	0,11	0,17	0,26	0,15	0,41	0,43	42	
TOTAL															**25,16**		

The following table shows the 10 most relevant risk factors in the case of the Ferroanel from São Paulo in Brazil.

Table 5 – Ferroanel São Paulo – TOP 10 Risk Factors

TOP 10 Risks	Risk Ranking
Lack of political support / Political indecision	1
Involvement of many decision-making bodies	2
Lack of transparency and corruption	3
Economic recession	4
Changes in funding policy	5
Compensations higher than expected	6
Changes in material costs	7
Heavy rain	8
Government discontinuity	9
Opposition or political interference	10

The following tables show the most relevant dimensions with different aggregations. The logic behind each one of them is detailed in the discussion section.

Table 6 – Ferroanel São Paulo – Risk Dimensions

UNRELATIVIZED DIMENSIONS	VALUE	%
SOCIAL	3,74	14,9%
TECHNICAL	8,94	35,5%
ECONOMIC	5,04	20,0%
ENVIRONMENTAL	2,23	8,9%
POLITCAL	5,21	20,7%

Table 7 – Ferroanel São Paulo – Risk Dimensions

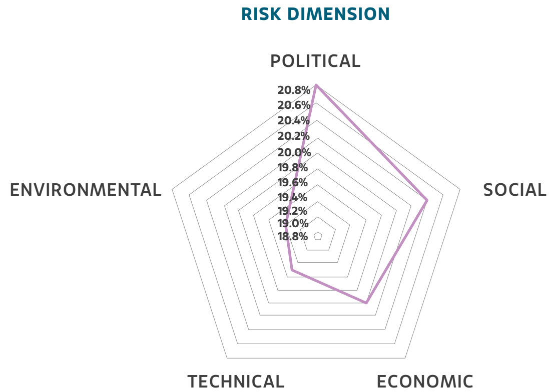
DIMENSIONS WITH ANOTHER AGGREGATION	VALUE	%
SOCIAL-ENVIRONMENTAL	5,97	23,7%
POLITICAL	5,21	20,7%
ECONOMIC	5,04	20,0%
TECHNICAL – ENGINEERING DESIGN	4,07	16,2%
TECHNICAL – CONSTRUCTION MANAGEMENT	4,87	19,4%

Table 8 – Ferroanel São Paulo – Risk Dimensions (relativized by number of factors)

RELATIVIZED DIMENSIONS BY NUMBER OF FACTORS	VALUE	%
POLITICAL	0,474	20,7%
SOCIAL	0,468	20,4%
ECONOMIC	0,458	20,0%
TECHNICAL	0,447	19,5%
ENVIRONMENTAL	0,445	19,4%

Considering the interrelation between risks, it is here suggested plotting the relativized dimensions by amount of factors:

Figure 3 – Percentage of contribution of risk dimensions in Ferroanel São Paulo.



4.1.2. CENTRAL RAILWAY PROJECT, URUGUAY

Following the proposed methodology, the results of this case are presented below.

Table 9 – Central railway Project Uruguay - Aggregated Fuzzy Preferences, computed fuzzy risk rating and corresponding 'crisp' score.

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
SOCIAL																	**14,7%**
Impossibility of obtaining land and access rights	0,13	0,18	0,26	0,36	0,58	0,68	0,78	0,88	0,07	0,12	0,20	0,32	0,17	0,40	0,44	28	3,57
Compensations higher than expected	0,36	0,46	0,50	0,60	0,25	0,35	0,45	0,55	0,09	0,16	0,23	0,33	0,20	0,41	0,45	18	
Protests and interference by residents	0,38	0,48	0,53	0,61	0,28	0,38	0,48	0,58	0,10	0,18	0,25	0,35	0,22	0,40	0,46	9	
Claims by third parties	0,31	0,41	0,48	0,56	0,21	0,30	0,40	0,50	0,07	0,12	0,19	0,28	0,16	0,41	0,44	27	
Costs of contractual disputes with contractor	0,34	0,44	0,49	0,59	0,30	0,40	0,50	0,60	0,10	0,18	0,24	0,35	0,22	0,40	0,46	10	
Threats to the safety of personnel or assets	0,08	0,15	0,18	0,28	0,31	0,40	0,50	0,60	0,02	0,06	0,09	0,17	0,08	0,41	0,42	49	

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Vandalism	0,19	0,28	0,35	0,45	0,16	0,25	0,35	0,45	0,03	0,07	0,12	0,20	0,10	0,41	0,42	46	
Involvement of many decision-making bodies	0,53	0,63	0,64	0,73	0,25	0,35	0,45	0,55	0,13	0,22	0,29	0,40	0,26	0,40	0,48	2	
TECHNICAL																	
ENGINEERING DESIGN																	16,8%
Inappropriate design due to lack of technical capabilities	0,23	0,33	0,34	0,44	0,48	0,58	0,68	0,78	0,11	0,19	0,23	0,34	0,21	0,41	0,46	7	4,08
Measurement errors on the site	0,21	0,30	0,36	0,46	0,38	0,48	0,58	0,68	0,08	0,14	0,21	0,31	0,18	0,41	0,44	22	
Conflicting interfaces between work items	0,34	0,44	0,45	0,55	0,28	0,38	0,48	0,58	0,09	0,16	0,21	0,32	0,19	0,41	0,45	17	
Special Conditions on the site	0,21	0,31	0,35	0,45	0,38	0,48	0,58	0,68	0,08	0,15	0,20	0,30	0,18	0,41	0,45	20	
Insufficient site inspections	0,18	0,26	0,33	0,43	0,40	0,50	0,60	0,70	0,07	0,13	0,20	0,30	0,17	0,41	0,44	24	
Changes in project scope requirements	0,39	0,49	0,55	0,64	0,35	0,45	0,55	0,65	0,14	0,22	0,30	0,41	0,27	0,40	0,48	1	
Other changes in the engineering design of the project	0,40	0,50	0,58	0,66	0,28	0,38	0,48	0,58	0,11	0,19	0,27	0,38	0,24	0,40	0,46	5	
Changes in technology or in industry use standards	0,15	0,25	0,30	0,40	0,21	0,30	0,40	0,50	0,03	0,08	0,12	0,20	0,10	0,41	0,42	45	
Inaccurate estimates of project cost	0,31	0,40	0,45	0,54	0,38	0,48	0,58	0,68	0,12	0,19	0,26	0,36	0,23	0,40	0,47	4	
CONSTRUCTION MANAGEMENT																	20,4%
Poor allocation of time and resources	0,21	0,31	0,35	0,45	0,45	0,55	0,65	0,75	0,10	0,17	0,23	0,34	0,21	0,41	0,46	13	4,93
Insufficient capacities in construction work	0,23	0,33	0,38	0,48	0,46	0,55	0,65	0,75	0,10	0,18	0,24	0,36	0,22	0,40	0,46	8	
Fall in the supply chain	0,25	0,35	0,39	0,49	0,37	0,47	0,57	0,67	0,09	0,17	0,22	0,33	0,20	0,41	0,45	14	
Bad contract enforcement	0,21	0,31	0,35	0,45	0,38	0,48	0,58	0,68	0,08	0,15	0,20	0,30	0,18	0,41	0,45	20	
Budgetary and cash flow inconsistencies	0,14	0,24	0,28	0,38	0,50	0,60	0,70	0,80	0,07	0,14	0,19	0,30	0,17	0,41	0,44	23	
Lack of human resources for the development of the works	0,24	0,34	0,40	0,50	0,45	0,55	0,65	0,75	0,11	0,19	0,26	0,38	0,23	0,40	0,46	6	
Technical difficulties in making changes in affected utilities	0,28	0,38	0,44	0,54	0,36	0,46	0,56	0,66	0,10	0,17	0,24	0,35	0,21	0,40	0,46	12	
Insufficient protection of adjacent buildings and facilities	0,18	0,28	0,31	0,41	0,50	0,60	0,70	0,80	0,09	0,17	0,22	0,33	0,20	0,41	0,45	16	
Insufficient worker safety	0,09	0,16	0,20	0,30	0,55	0,65	0,75	0,85	0,05	0,11	0,15	0,26	0,14	0,41	0,43	33	
Inefficient protection regarding the surrounding environment	0,13	0,23	0,25	0,35	0,38	0,48	0,58	0,68	0,05	0,11	0,14	0,24	0,13	0,41	0,43	34	
Inefficient traffic control and management	0,21	0,31	0,35	0,45	0,33	0,43	0,53	0,63	0,07	0,13	0,18	0,28	0,16	0,41	0,44	25	
ECONOMIC																	**19,7%**
Changes in funding vehicles	0,10	0,19	0,21	0,31	0,50	0,60	0,70	0,80	0,05	0,11	0,15	0,25	0,14	0,41	0,43	32	4,76
Changes in the taxes	0,08	0,15	0,18	0,28	0,43	0,53	0,63	0,73	0,03	0,08	0,11	0,20	0,10	0,41	0,42	43	

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Multinational sanctions	0,05	0,10	0,15	0,25	0,43	0,53	0,63	0,73	0,02	0,05	0,09	0,18	0,08	0,41	0,42	50	
General inflation	0,13	0,21	0,26	0,36	0,38	0,48	0,58	0,68	0,05	0,10	0,15	0,24	0,13	0,41	0,43	37	
Wage inflation	0,13	0,23	0,25	0,35	0,38	0,48	0,58	0,68	0,05	0,11	0,14	0,24	0,13	0,41	0,43	34	
Changes in material costs	0,20	0,30	0,33	0,43	0,40	0,50	0,60	0,70	0,08	0,15	0,20	0,30	0,18	0,41	0,45	19	
Changes in the cost of energy	0,13	0,23	0,25	0,35	0,35	0,45	0,55	0,65	0,04	0,10	0,14	0,23	0,12	0,41	0,43	38	
Exchange rate	0,29	0,39	0,43	0,51	0,33	0,43	0,53	0,63	0,09	0,16	0,22	0,32	0,20	0,41	0,45	15	
Economic recession	0,16	0,26	0,33	0,43	0,35	0,45	0,55	0,65	0,06	0,12	0,18	0,28	0,15	0,41	0,44	30	
Economic effects of an environmental catastrophe	0,11	0,16	0,24	0,34	0,43	0,53	0,63	0,73	0,05	0,09	0,15	0,24	0,13	0,41	0,43	41	
Legislative or regulatory changes in financing	0,10	0,18	0,23	0,33	0,43	0,53	0,63	0,73	0,04	0,09	0,14	0,24	0,12	0,41	0,43	40	
ENVIRONMENTAL																	
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION																	8,9%
Underground water filtrations	0,16	0,26	0,29	0,39	0,33	0,43	0,53	0,63	0,05	0,11	0,15	0,24	0,14	0,41	0,43	31	2,16
Affectation of flora and fauna	0,06	0,11	0,18	0,28	0,25	0,35	0,45	0,55	0,02	0,04	0,08	0,15	0,07	0,41	0,42	51	
UNFAVOURABLE WEATHER CONDITIONS																	
Heavy rain	0,31	0,41	0,44	0,54	0,34	0,43	0,53	0,63	0,11	0,18	0,23	0,34	0,21	0,41	0,46	11	
Windstorms	0,24	0,33	0,38	0,48	0,29	0,38	0,48	0,58	0,07	0,12	0,18	0,27	0,16	0,41	0,44	29	
Earthquake	0,00	0,00	0,10	0,20	0,63	0,73	0,83	0,93	0,00	0,00	0,08	0,19	0,06	0,41	0,41	55	
POLITICAL																	**19,5%**
Political instability	0,03	0,05	0,13	0,23	0,45	0,55	0,65	0,75	0,01	0,03	0,08	0,17	0,07	0,41	0,42	53	4,71
Lack of political support / Political indecision	0,13	0,20	0,28	0,38	0,40	0,50	0,60	0,70	0,05	0,10	0,17	0,26	0,14	0,41	0,43	36	
War or regional conflicts	0,03	0,04	0,14	0,24	0,55	0,65	0,75	0,85	0,01	0,02	0,10	0,20	0,08	0,41	0,41	54	
Opposition or political interference	0,16	0,25	0,30	0,40	0,43	0,53	0,63	0,73	0,07	0,13	0,19	0,29	0,17	0,41	0,44	26	
Government discontinuity	0,09	0,13	0,20	0,30	0,39	0,48	0,56	0,65	0,03	0,06	0,11	0,20	0,10	0,41	0,42	48	
Changes in funding policy	0,09	0,15	0,21	0,31	0,43	0,53	0,63	0,73	0,04	0,08	0,13	0,23	0,11	0,41	0,43	42	
Delays in obtaining approvals and permits	0,29	0,38	0,39	0,48	0,45	0,55	0,65	0,75	0,13	0,21	0,25	0,36	0,23	0,41	0,47	3	
Lack of transparency and corruption	0,03	0,05	0,13	0,23	0,55	0,65	0,75	0,85	0,01	0,03	0,09	0,19	0,08	0,41	0,42	52	
Protectionism	0,06	0,13	0,16	0,26	0,43	0,53	0,63	0,73	0,03	0,07	0,10	0,19	0,09	0,41	0,42	47	
Lack of updating or regulatory adaptation	0,11	0,21	0,23	0,33	0,38	0,48	0,58	0,68	0,04	0,10	0,13	0,22	0,12	0,41	0,43	39	
Other unexpected legislative or regulatory changes	0,13	0,20	0,28	0,38	0,29	0,38	0,48	0,58	0,04	0,08	0,13	0,22	0,11	0,41	0,42	44	
TOTAL															**24,20**		

The following table shows the 10 most relevant risk factors in the case of the Central Railway Project of Uruguay.

Table 10 – Central Railway Project, Uruguay – TOP 10 Risk Factors

TOP 10 Risks	
Changes in project scope requirements	1
Involvement of many decision-making bodies	2
Delays in obtaining approvals and permits	3
Inaccurate estimates of project cost	4
Other changes in the engineering design of the project	5
Lack of human resources for the development of the works	6
Inappropriate design due to lack of technical capabilities	7
Insufficient capacities in construction work	8
Protests and interference by residents	9
Costs of contractual disputes with contractor	10

The following tables show the most relevant dimensions with different aggregations.

Table 11 – Centrail Railway Project – Risk Dimensions

UNRELATIVIZED DIMENSIONS	VALUE	%
TECHNICAL	9,01	37,2%
ECONOMIC	4,76	19,7%
POLITICAL	4,71	19,5%
SOCIAL	3,57	14,7%
ENVIRONMENTAL	2,16	8,9%

Table 12 – Central Railway Project – Risk Dimensions (with different aggregation)

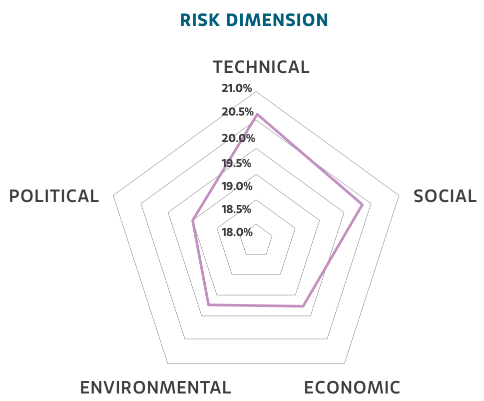
DIMENSIONS WITH ANOTHER AGGREGATION	VALUE	%
SOCIAL-ENVIRONMENTAL	5,72	23,7%
TECHNICAL – CONSTRUCTION MANAGEMENT	4,93	20,4%
ECONOMIC	4,76	19,7%
POLITICAL	4,71	19,5%
TECHNICAL – ENGINEERING DESIGN	4,08	16,8%

Table 13 – Central Railway Project – Risk Dimensions (relativized by number of factors)

RELATIVIZED DIMENSIONS BY NUMBER OF FACTORS	VALUE	%
TECHNICAL	0,450	20,6%
SOCIAL	0,446	20,4%
ECONOMIC	0,433	19,8%
ENVIRONMENTAL	0,432	19,7%
POLITICAL	0,428	19,6%

Considering the interrelation between risks, it is here suggested plotting the relativized dimensions by amount of factors.

Figure 4 – Percentage of contribution of risk dimensions in Central Railway Project Uruguay



4.1.3. LINE 1 METRO OF BOGOTÁ, COLOMBIA

The results of this case are presented in the following table.

Table 14 – Metro Line 1, Bogotá, Colombia - Aggregated Fuzzy Preferences, computed fuzzy risk rating and corresponding 'crisp' score

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
SOCIAL																	**4,01**
Impossibility of obtaining land and access rights	0,27	0,35	0,44	0,55	0,54	0,64	0,75	0,85	0,15	0,23	0,33	0,47	0,29	0,39	0,49	20	15,1%
Compensations higher than expected	0,40	0,50	0,56	0,67	0,41	0,51	0,62	0,73	0,16	0,25	0,35	0,49	0,31	0,39	0,50	16	
Protests and interference by residents	0,53	0,64	0,67	0,78	0,42	0,53	0,64	0,75	0,22	0,34	0,43	0,58	0,39	0,39	0,55	6	
Claims by third parties	0,47	0,58	0,65	0,75	0,35	0,45	0,56	0,67	0,16	0,26	0,36	0,51	0,32	0,39	0,51	14	
Costs of contractual disputes with contractor	0,45	0,56	0,61	0,72	0,40	0,51	0,62	0,73	0,18	0,29	0,38	0,52	0,34	0,39	0,52	9	
Threats to the safety of personnel or assets	0,21	0,31	0,37	0,48	0,22	0,31	0,42	0,53	0,05	0,10	0,16	0,25	0,13	0,41	0,43	52	
Vandalism	0,28	0,38	0,44	0,55	0,28	0,38	0,49	0,60	0,08	0,15	0,21	0,33	0,19	0,40	0,45	44	
Involvement of many decision-making bodies	0,61	0,72	0,75	0,85	0,38	0,49	0,60	0,71	0,23	0,35	0,45	0,60	0,41	0,39	0,56	4	
TECHNICAL																	
ENGINEERING DESIGN																	4,42
Inappropriate design due to lack of technical capabilities	0,17	0,25	0,32	0,43	0,69	0,80	0,91	1,02	0,12	0,20	0,29	0,44	0,26	0,40	0,47	29	16,7%
Measurement errors on the site	0,20	0,30	0,35	0,46	0,64	0,75	0,85	0,96	0,13	0,22	0,30	0,45	0,27	0,40	0,48	27	
Conflicting interfaces between work items	0,31	0,40	0,45	0,55	0,53	0,64	0,75	0,85	0,16	0,25	0,33	0,47	0,30	0,40	0,50	17	
Special Conditions on the site	0,43	0,54	0,58	0,68	0,49	0,60	0,71	0,82	0,21	0,32	0,41	0,56	0,37	0,39	0,54	7	
Insufficient site inspections	0,25	0,35	0,42	0,53	0,47	0,58	0,69	0,80	0,12	0,20	0,29	0,42	0,25	0,40	0,47	31	
Changes in project scope requirements	0,25	0,35	0,42	0,53	0,55	0,66	0,77	0,88	0,14	0,23	0,32	0,46	0,28	0,39	0,49	22	
Changes in technology or in industry use standards	0,22	0,32	0,39	0,50	0,60	0,71	0,82	0,93	0,13	0,23	0,32	0,46	0,28	0,39	0,48	26	
Other changes in the engineering design of the project	0,19	0,28	0,35	0,45	0,44	0,55	0,65	0,76	0,08	0,15	0,23	0,35	0,20	0,40	0,45	42	
Inaccurate estimates of project cost	0,30	0,39	0,45	0,56	0,67	0,78	0,89	1,00	0,20	0,31	0,40	0,56	0,36	0,39	0,53	8	
CONSTRUCTION MANAGEMENT																	**5,13**
Poor allocation of time and resources	0,23	0,34	0,37	0,48	0,58	0,69	0,80	0,91	0,13	0,23	0,30	0,44	0,27	0,40	0,4844	25	19,3%

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Insufficient capacities in construction work	0,19	0,30	0,33	0,44	0,53	0,64	0,75	0,85	0,10	0,19	0,24	0,37	0,22	0,40	0,46	35	
Fall in the supply chain	0,20	0,28	0,34	0,44	0,40	0,50	0,60	0,70	0,08	0,14	0,21	0,31	0,18	0,41	0,44	45	
Bad contract enforcement	0,25	0,35	0,38	0,49	0,55	0,65	0,76	0,87	0,14	0,23	0,29	0,43	0,27	0,40	0,4845	24	
Budgetary and cash flow inconsistencies	0,16	0,25	0,32	0,43	0,55	0,65	0,76	0,87	0,09	0,17	0,24	0,37	0,21	0,40	0,45	39	
Lack of human resources for the development of the works	0,20	0,30	0,35	0,46	0,47	0,58	0,69	0,80	0,09	0,17	0,24	0,37	0,22	0,40	0,46	37	
Technical difficulties in making changes in affected utilities	0,26	0,36	0,40	0,51	0,55	0,65	0,76	0,87	0,14	0,24	0,31	0,44	0,28	0,40	0,49	19	
Insufficient protection of adjacent buildings and facilities	0,17	0,26	0,31	0,42	0,42	0,53	0,64	0,75	0,07	0,14	0,20	0,31	0,18	0,41	0,44	47	
Insufficient worker safety	0,15	0,24	0,28	0,39	0,53	0,64	0,75	0,85	0,08	0,15	0,21	0,33	0,19	0,41	0,45	43	
Inefficient protection regarding the surrounding environment	0,21	0,30	0,33	0,44	0,45	0,56	0,67	0,78	0,10	0,17	0,22	0,34	0,20	0,41	0,45	40	
Inefficient traffic control and management	0,33	0,42	0,45	0,56	0,53	0,64	0,75	0,85	0,17	0,27	0,34	0,48	0,31	0,40	0,51	15	
ECONOMIC																	**5,24**
Changes in funding vehicles	0,21	0,29	0,34	0,45	0,49	0,60	0,71	0,82	0,10	0,17	0,24	0,36	0,22	0,40	0,46	36	19,8%
Changes in the taxes	0,31	0,41	0,46	0,56	0,42	0,53	0,64	0,75	0,13	0,22	0,30	0,42	0,26	0,40	0,48	28	
Multinational sanctions	0,12	0,22	0,25	0,35	0,47	0,58	0,69	0,80	0,06	0,13	0,17	0,28	0,16	0,41	0,44	49	
General inflation	0,32	0,43	0,47	0,58	0,45	0,55	0,65	0,76	0,14	0,23	0,31	0,44	0,28	0,40	0,4870	21	
Wage inflation	0,22	0,31	0,35	0,45	0,41	0,51	0,62	0,73	0,09	0,16	0,21	0,33	0,19	0,41	0,45	41	
Changes in material costs	0,35	0,45	0,53	0,64	0,44	0,55	0,65	0,76	0,15	0,25	0,35	0,49	0,30	0,39	0,4971	18	
Changes in the cost of energy	0,27	0,38	0,44	0,55	0,40	0,51	0,62	0,73	0,11	0,19	0,27	0,40	0,24	0,40	0,47	33	
Exchange rate	0,45	0,56	0,64	0,74	0,53	0,64	0,75	0,85	0,24	0,36	0,47	0,63	0,42	0,38	0,57	3	
Economic recession	0,24	0,35	0,45	0,55	0,55	0,65	0,76	0,87	0,13	0,23	0,34	0,48	0,29	0,39	0,49	23	
Economic effects of an environmental catastrophe	0,18	0,28	0,32	0,43	0,60	0,71	0,82	0,93	0,11	0,20	0,26	0,40	0,24	0,40	0,47	32	
Legislative or regulatory changes in financing	0,12	0,21	0,25	0,36	0,53	0,64	0,75	0,85	0,06	0,13	0,19	0,31	0,17	0,41	0,44	48	
ENVIRONMENTAL																	**2,18**
Underground water filtrations	0,17	0,28	0,32	0,43	0,41	0,51	0,62	0,73	0,07	0,14	0,20	0,31	0,18	0,41	0,44	46	8,2%
Affectation of flora and fauna	0,05	0,06	0,15	0,26	0,28	0,36	0,47	0,58	0,01	0,02	0,07	0,15	0,06	0,41	0,42	55	
Heavy rain	0,30	0,40	0,47	0,58	0,40	0,51	0,62	0,73	0,12	0,20	0,29	0,42	0,26	0,40	0,47	30	
Windstorms	0,07	0,14	0,19	0,30	0,28	0,36	0,47	0,58	0,02	0,05	0,09	0,17	0,08	0,41	0,42	54	
Earthquake	0,07	0,14	0,19	0,30	0,56	0,67	0,78	0,89	0,04	0,09	0,15	0,27	0,13	0,41	0,43	53	
POLITICAL																	**5,55**
Political instability	0,31	0,41	0,46	0,57	0,55	0,65	0,76	0,87	0,17	0,27	0,35	0,50	0,32	0,40	0,51	13	21%

RISK DIMENSIONS / Risk Factors	LIKELIHOOD				IMPACT				FUZZY RISK RATING				x	y	CRISP RATING	RANKING ORDER	RISK PERCENTAGE
Lack of political support / Political indecision	0,37	0,46	0,52	0,63	0,47	0,58	0,69	0,80	0,18	0,27	0,36	0,50	0,32	0,40	0,51	12	
War or regional conflicts	0,15	0,23	0,26	0,37	0,35	0,44	0,55	0,65	0,05	0,10	0,14	0,24	0,13	0,41	0,43	51	
Opposition or political interference	0,44	0,55	0,60	0,70	0,54	0,64	0,75	0,85	0,23	0,35	0,45	0,60	0,40	0,39	0,56	5	
Government discontinuity	0,51	0,62	0,69	0,78	0,50	0,60	0,71	0,82	0,25	0,37	0,49	0,64	0,44	0,38	0,58	1	
Changes in funding policy	0,25	0,33	0,38	0,49	0,48	0,58	0,69	0,80	0,12	0,19	0,26	0,39	0,24	0,40	0,47	34	
Delays in obtaining approvals and permits	0,40	0,50	0,56	0,67	0,62	0,73	0,84	0,95	0,25	0,36	0,47	0,64	0,43	0,39	0,57	2	
Lack of transparency and corruption	0,30	0,40	0,45	0,55	0,58	0,69	0,80	0,91	0,17	0,28	0,36	0,50	0,32	0,40	0,51	11	
Protectionism	0,16	0,25	0,30	0,41	0,36	0,47	0,58	0,69	0,06	0,12	0,17	0,28	0,15	0,41	0,44	50	
Lack of updating or regulatory adaptation	0,35	0,45	0,51	0,61	0,51	0,62	0,73	0,84	0,18	0,28	0,37	0,51	0,33	0,39	0,51	10	
Other unexpected legislative or regulatory changes	0,24	0,34	0,40	0,51	0,40	0,51	0,62	0,73	0,09	0,17	0,25	0,37	0,22	0,40	0,46	38	
TOTAL															**26,52**		

The following table shows the 10 most relevant risk factors in the case of the Line 1 of Metro of Bogota, Colombia.

Table 15 – Metro Line 1, Bogotá, Colombia – TOP 10 Risk Factors

TOP 10 Risks	
Government discontinuity	1
Delays in obtaining approvals and permits	2
Exchange rate	3
Involvement of many decision-making bodies	4
Opposition or political interference	5
Protests and interference by residents	6
Special Conditions on the site	7
Inaccurate estimates of project cost	8
Costs of contractual disputes with contractor	9
Lack of updating or regulatory adaptation	10

The following tables show the most relevant dimensions with different aggregations:

Table 16 – Metro Line 1, Bogotá, Colombia – Risk Dimensions

UNRELATIVIZED DIMENSIONS	VALUE	%
TECHNICAL	9,55	36,0%
POLITICAL	5,55	20,9%
SOCIAL	4,01	15,1%
ECONOMIC	5,24	19,8%
ENVIRONMENTAL	2,18	8,2%

Table 17 – Metro Line 1, Bogotá, Colombia – Risk Dimensions (with different aggregation)

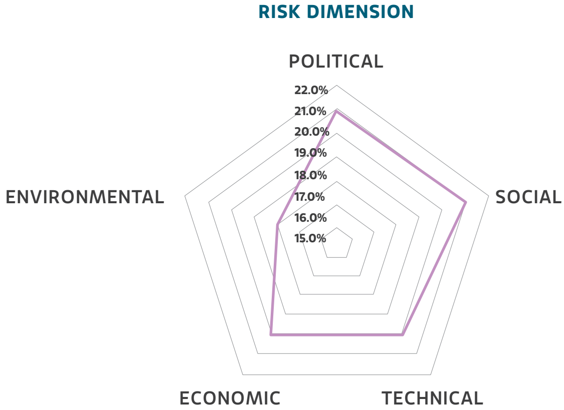
DIMENSIONS WITH ANOTHER AGGREGATION	VALUE	%
SOCIAL ENVIRONMENTAL	6,19	23,3%
POLITICAL	5,55	20,9%
ECONOMIC	5,24	19,8%
TECHNICAL – CONSTRUCTION MANAGEMENT	5,13	19,3%
TECHNICAL – ENGINEERING DESIGN	4,42	16,7%

Table 18 – Metro Line 1, Bogotá, Colombia – Risk Dimensions (relativized by number of factors)

RELATIVIZED DIMENSIONS BY AMOUNT OF FACTORS	VALUE	%
POLITICAL	0,505	21,1%
SOCIAL	0,501	20,9%
TECHNICAL	0,477	19,9%
ECNOMIC	0,476	19,9%
ENVIRONMENTAL	0,436	18,2%

Considering the interrelation between risks, it is here suggested plotting the relativized dimensions by amount of factors:

Figure 5 – Percentage of contribution of risk dimensions in Metro Line 1 Bogotá



4.2. DISCUSSION

The use of fuzzy logic for risk assessment in each of the selected megaprojects presents a picture of the experts' opinion on this matter in a consistent way. It gives objectivity and comparability to the process of risk assessment using a comprehensive list of risks factors in each of the projects studied, considering the selected dimensions: social, technical, environmental, economic and political. In this regard, the following messages can be extracted from the exercise, given this document's objective.

4.2.1. RISK FACTORS

First, regarding risk factors, Ferroanel Norte from São Paulo shows a higher prevalence of the political dimension in the 10 most relevant risk factors. The first 5 include: political indecision; lack of transparency and corruption; and a change in the Government's funding policy. The list of the first 5 is completed with the following two risk factors: the involvement of many decision-making bodies (of the social dimension); and economic recession (of the economic dimension).

In the case of the Central Railway of Uruguay, on the other hand, there is a higher prevalence of technical risks in the first 10, as assessed by the experts included in this research process. Within the first 5, there are: changes in project scope requirements; inaccurate estimates of project cost; and changes in the engineering design of the project. The first five of the list is completed with: involvement of many decision-making bodies (from the social dimension); and delays in obtaining approvals and permits (from the political dimension).

In the case of Line 1 of the Bogotá Metro, finally, there is a higher prevalence of political risks, again, and within the first 5 the following risk factors are included: government discontinuity; delays in obtaining approvals and permits; and opposition and political interference. This list of first 5 is completed with: exchange rate (of the economic dimension); and involvement of many decision-making bodies (from the social dimension).

The comparative results between cases show that the recurring risk factor is "involvement of many decision-making bodies". This is consistent with the propositions stated in section 3: it is not possible to assess some of the most relevant risks of megaprojects with historical numeric data. This risk factor is an "ill-defined" and complex problem which involves subjectivity. Besides, as much as it actually occurs in all projects, this factor is especially associated with the specific bureaucracy of each country and is probably dependant on the time and spatial context where the megaproject is developed.

At the same time, in terms of the dimensions corresponding to the most important factors, politics prevails in two of the cases. Again, within this dimension, the most relevant risk factors cannot be reliably studied by using the typical numeric statistical methodologies.

In the case of Ferroanel Norte, political indecision, lack of transparency, and changes in funding policy, and in the case of Line 1 of the Bogotá Metro, the discontinuity of the Government, delays in obtaining permits and opposition or political interference, all refer to factors that are ill-defined and context specific. They would be at least very difficult to model with a probabilistic approach.

On the other hand, in the case of the Central Railway of Uruguay, the dimension to which the most relevant factors correspond is the technical one, and includes changes in scope requirements, and changes in engineering design, both especially tied to the inaccurate estimates of the cost of the project. Although the risk factor "inaccurate estimates of project costs" is central in the probabilistic approach, this picture shows that it may be especially associated with changes that arise from changes in scope and design priorities, after the start of construction. This is expected to arise from the change in preferences of objectives in terms of outputs and outcomes, due to the organic nature of the project itself. Again, it refers to issues that are context specific, in spatial and temporal terms. A probabilistic approach, using megaprojects of different nature in different countries, can lose sight of this particularly relevant characteristic of megaprojects, which influences the decision-making process.

4.2.2. RISK DIMENSIONS

In terms of risk dimensions, it is necessary to make a comment regarding the methodology proposed in this research process. Without delving into the data, it gives equal weight to all factors, regardless of the dimension to which they belong, and how many factors make up the dimension. Thus, by construction, if one risk dimension is constructed using more risk factors than another, it is extremely likely that the first represents a higher level of total risk.

In the proposed model, the technical dimension has 20 factors, and the environmental dimension 5. With this methodological framework, the technical dimension is expected to be the most relevant, and the environmental dimension the least important. That is not exactly a wrong proposition, inasmuch as the complexity of a megaproject involves a large number of technical risks. That is what the first table of results shows on the dimensions in each of the cases in section 3. In the case of the Ferroanel Norte from São Paulo, the technical dimension as a whole would thus represent 35.5% of the project risk, while on the Central Railroad of Uruguay it would be 37.2% and on Line 1 of the Bogotá Metro it would be 36%.

However, this aggregation strongly simplifies the analysis. Firstly, it adds risk factors of different nature, and secondly, it does not consider interdependencies between risks. To capture this, the numbers can be further analysed to give more information, and that is why the subsequent tables (figures x, y and z) are constructed in each case.

First, technical risks associated with engineering design and construction management can be separated. In addition, environmental and social risks can be associated, which are usually managed together. That is what the second table of results by dimension shows in each case. With this aggregation, in all three cases the environmental and social becomes more relevant. The relevance that is usually given to this dimension as a whole is confirmed, with specific evaluations and plans.

Likewise, by construction, the same relative weight can be assumed per dimension, adjusting that each one had the same number of risk factors. That is what is presented in the third table (tables 8, 13 and 18), and in the graph (figures 3, 4 and 5), in each one of the cases. Thus, it is shown that, in order of importance, the risk dimensions in each case are as follows:

- Ferroanel Norte from São Paulo: political, social, economic, technical and environmental.

- Central Railway of Uruguay: technical, social, economic, environmental and political.

- Line 1 of the Bogotá Metro: political, social, technical, economic and environmental.

This illustrates that each megaproject, within each country, and at each moment of time, has a complex, notoriously specific risk structure.

At the time of developing this study, Ferroanel Norte from São Paulo was a project that had the basic engineering designs completed, but its contracting had not yet been resolved. In this framework, and considering the transparency problems that arose in Brazil in previous years, it is logical that political issues were the most relevant, especially political indecision.

The project of the Central Railroad of Uruguay, on the other hand, was already contracted at the time of this analysis. However, Uruguay is a country with little recent railway developments and culture, with little technical capacity. It was reasonable, then, that the technical topics were the most relevant.

Finally, regarding line 1 of the Bogotá metro, the analysis was made before the award of the contract, before the change of government. It was expected that political issues would then be the most important, especially those related to the discontinuity of the Government and political opposition.

4.2.3. CONCLUSIONS

This study illustrates that it does not seem reasonable to make a numeric, probability-based analysis, based on historical data, to analyse the probability and impact of a comprehensive list of construction risk factors in megaprojects in Latin America. It does so by showing, in cases in different contexts, that the most relevant risk factors and dimensions are ill-defined and not quantifiable by statistical methods. A probability-based methodology can only compare quantitative variables for which there is historical information (exchange rate, inflation, rainfall, etc.), removing others that may are ill-structured but usually more important in megaprojects (political indecision, opposition or political interference, change in project scope requirements, etc.).

Furthermore, it sounds especially reasonable to use a methodology that incorporates specific perceptions of the spatial context, of the country and / or city where the project is developed, because it defines the institutional environment: cultural; normative and regulatory. Likewise, it is particularly relevant that the methodology considers the exact moment in which the analysis is carried out. It is expected that this same exercise done 6 months before or after will have a different result in all cases. The set of construction risks of a megaproject is an inherently dynamic phenomenon. In both senses, both the spatial and temporal context, the fuzzy logic risk assessment methodology presented in this document, when trying to capture the perceptions of a group of decision makers, seems to be more accurate than a probabilistic analysis.

Once the risks have been effectively assessed, using this methodology, it is possible to carry out a continuous and improved risk management process. In this sense, this study proposes a methodology that adjusts to the latest theoretical trends. It allows a joint analysis of accumulated perceptions, which capture the knowledge and impressions of different relevant agents.

In this regard, it is a flexible methodology, in that it allows discretionary grouping of the different risk factors assessed, to study the weight of different dimensions. This grouping can be done with a theoretical perspective, as in the case presented here, but also following, for example, fixed risk management structures of the megaproject developers.

In summary, this document presents a consistent methodology, relatively simple and practical, that can shed some light when assessing construction risks in megaprojects. FST minimizes the inherent imprecision, inconsistency, vagueness and uncertainty that linguistic information imposes, and thus improves objectivity and comparability in an inherently subjective analysis. It mathematically represents the subjectivity of the words used by those who assess risk and, therefore, is useful to analyse al risk factors, including ill-defined (vague) risks. This is particularly relevant as ill-defined risks are of substantial importance when developing megaprojects, as it was shown with the 3 Latin American cases studied.

The paper theoretically justifies the use of FST, and illustrates its advantages with a multiple case study in Latin America. This document promotes the continuous use of this methodology from the development of basic design studies onwards. General practice, usually focused on the probabilistic approach, should be adapted and include FST in order to improve risk assessment and risk management in megaprojects in this region.

5

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6

ANNEX 1 – QUESTIONNAIRES COMPLETED

FERROANEL SÃO PAULO

The complete questionnaire with the perceptions of 8 experts in the case of the Ferroanel Norte of São Paulo are summarised as follows. First, the table below shows the individual ratings of each expert (E1, E2,…, and E8) on the probability of occurrence.

	E1	E2	E3	E4	E5	E6	E7	E8
SOCIAL								
Impossibility of obtaining land and access rights	AC	O	O	O	VR	R	P	F
Compensations higher than expected	VF	F	P	F	P	F	F	VF
Protests and interference by residents	P	O	P	P	R	VF	P	VF
Claims by third parties	P	O	F	P	R	AC	O	F
Costs of contractual disputes with contractor	P	R	F	P	O	P	F	F
Threats to the safety of personnel or assets	O	R	O	VR	R	R	R	P
Vandalism	O	P	P	VR	P	R	P	F
Involvement of many decision-making bodies	VF	VF	VF	F	F	AC	P	AC
TECHNICAL								
ENGINEERING DESIGN								
Inappropriate design due to lack of technical capabilities	P	R	P	VR	R	O	O	O
Measurement errors on the site	P	VR	O	R	R	O	R	O
Conflicting interfaces between work items	F	VR	P	R	R	F	O	P
Special Conditions on the site	P	VR	P	R	P	F	R	P

	E1	E2	E3	E4	E5	E6	E7	E8
Insufficient site inspections	O	VR	O	O	O	F	R	P
Changes in project scope requirements	P	R	F	O	P	P	O	F
Changes in technology or in industry use standards	P	R	O	O	F	VF	O	F
Other changes in the engineering design of the project	P	R	O	O	R	O	O	F
Inaccurate estimates of project cost	O	R	O	P	P	F	O	VF
CONSTRUCTION MANAGEMENT								
Poor allocation of time and resources	P	R	O	R	O	P	P	O
Insufficient capacities in construction work	P	R	O	R	O	O	P	P
FALL IN THE SUPPLY CHAIN								
Poor quality of local materials	O	VR	R	O	R	R	R	P
Bad suppliers	O	VR	O	O	O	F	R	F
Obstacles to import	O	R	R	F	R	P	R	VF
Distance between site and materials / suppliers	O	VR	R	P	O	R	R	P
Bad contract enforcement	O	R	R	O	P	P	R	P
Budgetary and cash flow inconsistencies	P	R	O	O	P	O	R	P
Lack of human resources for the development of the works	F	VR	R	R	R	R	R	P
Technical difficulties in making changes in affected utilities	P	O	P	P	P	P	R	F
SAFETY IN CONSTRUCTION								
Insufficient protection of adjacent buildings and facilities	R	O	R	F	R	O	R	R
Insufficient worker safety	O	VR	R	R	R	O	R	R
Inefficient protection regarding the surrounding environment	O	O	O	R	O	O	R	O
Inefficient traffic control and management	O	R	O	R	R	P	R	O
ECONOMIC								
Changes in funding vehicles	O	O	P	R	O	VF	R	P
Changes in the taxes	O	P	O	P	VR	P	R	R
Multinational sanctions	R	VR	O	R	VR	VR	R	R
General inflation	O	O	O	P	R	R	R	O
Wage inflation	P	O	O	P	R	O	R	P
Changes in material costs	O	O	O	P	P	F	R	F
Changes in the cost of energy	P	O	P	P	P	O	O	O
Exchange rate	P	R	P	P	P	P	O	F
Economic recession	P	O	P	O	O	P	O	VF
Economic effects of an environmental catastrophe	R	O	O	O	VR	VR	VR	P
Legislative or regulatory changes in financing	R	O	O	O	P	VR	R	R

	E1	E2	E3	E4	E5	E6	E7	E8
ENVIRONMENTAL								
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION								
Underground water filtrations	O	R	O	R	R	VF	R	VF
Affectation of flora and fauna	R	O	O	VF	O	AC	R	F
UNFAVOURABLE WEATHER CONDITIONS								
Heavy rain	P	F	O	P	P	AC	P	F
Windstorms	R	R	O	P	P	VF	VR	P
Earthquake	R	VR	VR	VR	VR	VR	VR	VR
POLITICAL								
Political instability	R	R	R	O	R	O	O	O
Lack of political support / Political indecision	P	VF	O	F	VF	VF	O	F
War or regional conflicts	VR	VR	VR	VR	VR	P	O	VR
Opposition or political interference	R	VF	P	R	O	AC	O	O
Government discontinuity	R	VF	P	P	O	VF	O	O
Changes in funding policy	O	F	P	P	F	F	O	O
Delays in obtaining approvals and permits	O	O	P	R	F	P	O	F
Lack of transparency and corruption	P	O	P	P	F	P	O	F
Protectionism	P	R	P	P	F	R	O	P
Lack of updating or regulatory adaptation	O	O	O	P	R	O	O	P
Other unexpected legislative or regulatory changes	O	R	O	P	O	O	O	P

The following table shows the results of the opinion of the 8 experts (E1, E2,...,E8) regarding the potential impact of the risks.

	E1	E2	E3	E4	E5	E6	E7	E8
SOCIAL								
Impossibility of obtaining land and access rights	VH	VL	M	L	L	VH	L	H
Compensations higher than expected	H	L	M	M	L	M	M	VH
Protests and interference by residents	M	L	M	L	M	L	M	H
Claims by third parties	M	L	M	L	M	L	M	M
Costs of contractual disputes with contractor	M	L	M	M	M	M	M	M
Threats to the safety of personnel or assets	M	L	L	VL	L	M	M	L
Vandalism	L	L	M	VL	L	L	H	L
Involvement of many decision-making bodies	M	M	H	L	H	M	M	VH

	E1	E2	E3	E4	E5	E6	E7	E8
TECHNICAL								
ENGINEERING DESIGN								
Inappropriate design due to lack of technical capabilities	H	M	M	L	L	M	M	M
Measurement errors on the site	M	M	L	L	L	H	L	H
Conflicting interfaces between work items	H	H	H	L	M	M	L	M
Special Conditions on the site	M	M	M	VL	M	M	M	H
Insufficient site inspections	VH	VH	M	L	M	L	M	H
Changes in project scope requirements	H	M	H	H	M	M	M	M
Changes in technology or in industry use standards	H	M	H	M	H	M	M	M
Other changes in the engineering design of the project	H	M	H	H	M	VL	M	L
Inaccurate estimates of project cost	H	VH	M	H	L	M	M	M
CONSTRUCTION MANAGEMENT								
Poor allocation of time and resources	VH	M	L	L	L	M	M	H
Insufficient capacities in construction work	H	H	L	L	L	H	L	H
FALL IN THE SUPPLY CHAIN								
Poor quality of local materials	VH	H	L	M	L	H	L	M
Bad suppliers	H	VH	L	M	L	H	L	H
Obstacles to import	M	M	L	H	M	L	L	VH
Distance between site and materials / suppliers	L	M	M	L	L	L	L	L
Bad contract enforcement	M	H	L	H	M	M	L	M
Budgetary and cash flow inconsistencies	H	VH	M	H	M	H	L	H
Lack of human resources for the development of the works	M	H	L	H	L	H	L	H
Technical difficulties in making changes in affected utilities	H	H	H	H	L	H	L	H
SAFETY IN CONSTRUCTION								
Insufficient protection of adjacent buildings and facilities	M	M	L	L	L	H	L	L
Insufficient worker safety	M	VH	L	H	L	M	L	L
Inefficient protection regarding the surrounding environment	H	VH	M	H	L	L	L	M
Inefficient traffic control and management	H	H	L	H	L	M	L	M
ECONOMIC								
Changes in funding vehicles	H	H	H	H	M	VH	M	H
Changes in the taxes	H	VH	H	M	M	M	M	L
Multinational sanctions	H	H	M	H	VL	H	L	L
General inflation	H	H	L	L	L	L	M	M
Wage inflation	M	H	M	L	L	M	M	M

	E1	E2	E3	E4	E5	E6	E7	E8
Changes in material costs	H	VH	M	H	M	VH	H	H
Changes in the cost of energy	M	H	M	H	M	H	M	H
Exchange rate	M	M	M	H	H	M	M	VH
Economic recession	H	VH	H	H	M	VH	M	VH
Economic effects of an environmental catastrophe	VH	H	L	H	L	H	L	VH
Legislative or regulatory changes in financing	M	H	H	H	L	M	L	H
ENVIRONMENTAL								
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION								
Underground water filtrations	H	L	L	L	L	L	L	VH
Affectation of flora and fauna	H	L	L	L	L	M	L	VH
UNFAVOURABLE WEATHER CONDITIONS								
Heavy rain	M	H	L	M	M	VH	L	M
Windstorms	M	L	L	M	M	M	VL	H
Earthquake	VH	L	VL	VH	VL	VH	VL	VH
POLITICAL								
Political instability	H	H	L	H	L	M	M	H
Lack of political support / Political indecision	H	H	H	H	H	VH	M	H
War or regional conflicts	VH	VL	L	H	VL	M	M	VH
Opposition or political interference	M	H	H	H	M	M	H	H
Government discontinuity	M	H	H	M	VL	H	H	VH
Changes in funding policy	M	H	H	H	M	VH	H	H
Delays in obtaining approvals and permits	H	L	H	H	H	VH	H	M
Lack of transparency and corruption	H	M	H	VH	M	VH	M	H
Protectionism	M	L	H	H	M	L	M	H
Lack of updating or regulatory adaptation	L	L	M	M	L	M	M	M
Other unexpected legislative or regulatory changes	M	L	L	M	L	M	M	M

CENTRAL RAILWAY PROJECT OF URUGUAY

The complete questionnaire with the perceptions of 8 experts in the case of the Central Railway Project are summarised as follows. First, the table below shows the individual ratings of each expert (E1, E2,…, and E8) on the probability of occurrence.

	E1	E2	E3	E4	E5	E6	E7	E8
SOCIAL								
Impossibility of obtaining land and access rights	VR	O	VR	O	R	VR	VR	F
Compensations higher than expected	P	F	O	P	O	R	VF	P
Protests and interference by residents	P	P	P	O	R	O	AC	F
Claims by third parties	O	P	O	R	R	O	AC	F
Costs of contractual disputes with contractor	O	P	P	R	O	O	VF	F
Threats to the safety of personnel or assets	VR	R	R	R	R	R	VR	R
Vandalism	R	F	O	O	O	R	VR	O
Involvement of many decision-making bodies	R	VF	VF	R	VF	P	AC	VF
TECHNICAL								
ENGINEERING DESIGN								
Inappropriate design due to lack of technical capabilities	R	O	R	R	P	R	P	P
Measurement errors on the site	O	O	R	R	P	VR	O	F
Conflicting interfaces between work items	O	P	P	R	P	R	P	VF
Special Conditions on the site	P	O	O	R	R	R	O	P
Insufficient site inspections	O	O	O	R	R	VR	O	P
Changes in project scope requirements	O	F	O	O	P	R	AC	VF
Changes in technology or in industry use standards	O	F	O	P	P	O	AC	F
Other changes in the engineering design of the project	R	O	O	R	R	R	O	O
Inaccurate estimates of project cost	VR	P	R	O	O	R	AC	VF
CONSTRUCTION MANAGEMENT								
Poor allocation of time and resources	R	P	O	R	R	R	O	F
Insufficient capacities in construction work	O	O	R	R	R	O	P	F
FALL IN THE SUPPLY CHAIN								
Poor quality of local materials	O	O	O	R	P	R	P	VF
Bad suppliers	O	P	R	O	P	R	O	VF
Obstacles to import	O	R	R	R	F	O	P	R
Distance between site and materials / suppliers	P	O	O	R	O	R	R	P
Bad contract enforcement	R	O	O	R	R	O	R	VF

	E1	E2	E3	E4	E5	E6	E7	E8
Budgetary and cash flow inconsistencies	O	O	R	R	O	R	R	R
Lack of human resources for the development of the works	O	P	R	O	O	R	O	F
Technical difficulties in making changes in affected utilities	O	O	O	R	P	O	P	F
SAFETY IN CONSTRUCTION								
Insufficient protection of adjacent buildings and facilities	R	R	O	O	R	R	R	F
Insufficient worker safety	O	R	R	R	VR	VR	R	R
Inefficient protection regarding the surrounding environment	R	O	R	O	R	R	R	R
Inefficient traffic control and management	O	O	R	P	O	R	R	P
ECONOMIC								
Changes in funding vehicles	R	O	R	R	R	R	VR	R
Changes in the taxes	R	VR	R	R	R	VR	R	R
Multinational sanctions	R	VR	R	R	R	VR	VR	VR
General inflation	O	O	R	R	R	O	R	VR
Wage inflation	O	R	R	R	O	R	R	R
Changes in material costs	O	O	R	R	P	R	R	P
Changes in the cost of energy	O	O	R	R	R	R	R	R
Exchange rate	O	P	R	R	P	O	R	AC
Economic recession	O	O	R	O	O	R	O	R
Economic effects of an environmental catastrophe	VR	VR	R	O	F	VR	VR	R
Legislative or regulatory changes in financing	O	R	R	O	VR	VR	R	R
ENVIRONMENTAL								
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION								
Underground water filtrations	R	O	O	R	R	R	R	P
Affectation of flora and fauna	VR	O	R	R	VR	VR	R	VR
UNFAVOURABLE WEATHER CONDITIONS								
Heavy rain	R	P	O	R	F	R	P	VF
Windstorms	R	P	O	R	F	VR	P	O
Earthquake	VR	VR	VR	VR	VR	VR	VR	VR
POLITICAL								
Political instability	R	VR	VR	R	VR	VR	VR	VR
Lack of political support / Political indecision	R	O	O	O	R	VR	VR	O
War or regional conflicts	VR	VR	VR	O	VR	VR	VR	VR
Opposition or political interference	O	P	R	O	R	VR	R	O
Government discontinuity	P	O	VR	R	VR	VR	VR	VR

	E1	E2	E3	E4	E5	E6	E7	E8
Changes in funding policy	O	R	VR	O	R	VR	VR	R
Delays in obtaining approvals and permits	O	P	R	R	VF	R	AC	VF
Lack of transparency and corruption	VR	VR	VR	R	VR	R	VR	VR
Protectionism	R	R	VR	R	R	VR	VR	R
Lack of updating or regulatory adaptation	R	O	R	R	R	R	R	R
Other unexpected legislative or regulatory changes	VR	O	R	R	O	VR	O	O

The following table shows the results of the opinion of the 8 (E1, E2,...,E8) experts regarding the potential impact of the risks.

	E1	E2	E3	E4	E5	E6	E7	E8
SOCIAL								
Impossibility of obtaining land and access rights	VH	H	VH	M	VH	M	VH	VH
Compensations higher than expected	H	L	H	L	L	L	M	M
Protests and interference by residents	M	M	H	M	L	M	M	L
Claims by third parties	M	M	H	L	L	L	M	VL
Costs of contractual disputes with contractor	M	M	H	L	M	L	M	H
Threats to the safety of personnel or assets	M	VH	H	L	L	L	VH	VL
Vandalism	M	L	M	L	VL	L	M	L
Involvement of many decision-making bodies	L	M	M	M	M	L	L	H
TECHNICAL								
ENGINEERING DESIGN								
Inappropriate design due to lack of technical capabilities	VH	H	H	H	M	M	M	VH
Measurement errors on the site	H	H	H	M	M	L	M	H
Conflicting interfaces between work items	M	M	M	M	L	L	M	H
Special Conditions on the site	M	H	M	H	H	L	M	H
Insufficient site inspections	H	H	M	H	H	L	M	H
Changes in project scope requirements	M	M	M	H	H	L	L	VH
Changes in technology or in industry use standards	M	M	M	M	L	L	L	VH
Other changes in the engineering design of the project	M	H	M	M	L	VL	L	L
Inaccurate estimates of project cost	H	H	H	M	H	L	L	H
CONSTRUCTION MANAGEMENT								
Poor allocation of time and resources	H	H	H	H	H	L	H	H
Insufficient capacities in construction work	H	H	VH	H	H	VL	H	H

	E1	E2	E3	E4	E5	E6	E7	E8
FALL IN THE SUPPLY CHAIN								
Poor quality of local materials	H	H	H	M	H	L	M	VH
Bad suppliers	H	H	VH	H	M	L	M	H
Obstacles to import	M	H	H	M	M	M	M	H
Distance between site and materials / suppliers	M	M	H	H	L	L	L	L
Bad contract enforcement	M	M	VH	H	M	L	M	H
Budgetary and cash flow inconsistencies	H	H	VH	M	M	M	VH	VH
Lack of human resources for the development of the works	H	H	H	M	M	M	H	VH
Technical difficulties in making changes in affected utilities	H	N/C	M	M	H	L	M	H
SAFETY IN CONSTRUCTION								
Insufficient protection of adjacent buildings and facilities	H	H	VH	M	NC	M	VH	H
Insufficient worker safety	H	VH	VH	H	M	M	VH	VH
Inefficient protection regarding the surrounding environment	M	VH	VH	M	L	M	H	L
Inefficient traffic control and management	M	H	H	M	L	L	H	M
ECONOMIC								
Changes in funding vehicles	H	H	VH	H	M	L	VH	VH
Changes in the taxes	H	M	VH	H	M	L	VH	M
Multinational sanctions	M	VH	VH	H	M	L	VH	L
General inflation	M	H	VH	M	L	M	VH	L
Wage inflation	M	M	VH	M	M	M	VH	L
Changes in material costs	H	M	H	M	H	M	M	H
Changes in the cost of energy	H	M	H	M	H	L	M	M
Exchange rate	L	H	H	L	M	M	L	VH
Economic recession	H	VH	H	H	L	L	L	M
Economic effects of an environmental catastrophe	H	VH	VH	M	L	L	VH	M
Legislative or regulatory changes in financing	H	H	H	VH	M	M	L	H
ENVIRONMENTAL								
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION								
Underground water filtrations	M	M	M	M	M	L	H	H
Affectation of flora and fauna	M	M	M	M	L	L	H	L
UNFAVOURABLE WEATHER CONDITIONS								
Heavy rain	M	M	M	M	H	M	VL	VH
Windstorms	M	H	L	M	H	L	VL	H
Earthquake	VH	VH	VH	H	VH	M	VH	VH

	E1	E2	E3	E4	E5	E6	E7	E8
POLITICAL								
Political instability	H	M	VH	M	H	L	H	VH
Lack of political support / Political indecision	H	H	H	M	M	L	H	H
War or regional conflicts	VH	VH	VH	H	H	L	H	VH
Opposition or political interference	VH	H	H	M	M	L	H	H
Government discontinuity	M	M	VH	NC	H	L	H	VH
Changes in funding policy	M	H	VH	H	M	L	H	H
Delays in obtaining approvals and permits	H	H	H	H	H	L	H	H
Lack of transparency and corruption	VH	VH	VH	M	H	L	VH	VH
Protectionism	M	M	VH	M	M	L	VH	VH
Lack of updating or regulatory adaptation	H	M	H	M	M	L	H	H
Other unexpected legislative or regulatory changes	M	H	H	M	M	L	VL	M

LINE 1 METRO BOGOTÁ COLOMBIA

The complete questionnaire with the perceptions of 11 experts in the case of the Line 1 of Metro Bogota are summarized as follows. First, the table below shows the individual ratings of each expert (E1, E2,..., and E11) on the probability of occurrence.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
SOCIAL											
Impossibility of obtaining land and access rights	F	VF	O	O	VR	O	O	P	VR	VR	P
Compensations higher than expected	F	VF	R	O	VR	F	F	P	P	R	F
Protests and interference by residents	VF	VF	O	P	P	P	F	F	P	P	VF
Claims by third parties	P	F	O	P	P	O	F	F	F	P	VF
Costs of contractual disputes with contractor	P	F	O	P	P	O	F	P	P	P	VF
Threats to the safety of personnel or assets	O	P	O	O	R	R	O	O	R	VR	P
Vandalism	O	VF	R	O	P	O	R	F	O	VR	P
Involvement of many decision-making bodies	F	VF	P	F	P	P	VF	VF	AC	R	AC
TECHNICAL											
ENGINEERING DESIGN											
Inappropriate design due to lack of technical capabilities	F	O	O	O	VR	VR	R	R	R	VR	P
Measurement errors on the site	O	O	P	O	R	VR	O	R	R	R	P

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Conflicting interfaces between work items	VF	P	P	P	VR	R	O	O	P	VR	P
Special Conditions on the site	VF	P	P	R	F	O	P	O	AC	O	P
Insufficient site inspections	O	O	P	O	P	R	O	R	O	VR	F
Changes in project scope requirements	F	O	O	R	O	VR	O	R	P	R	F
Changes in technology or in industry use standards	F	O	O	R	R	VR	R	O	O	O	F
Other changes in the engineering design of the project	R	O	F	O	O	VR	R	O	R	VR	P
Inaccurate estimates of project cost	P	O	F	P	VR	O	P	O	O	VR	P
CONSTRUCTION MANAGEMENT											
Poor allocation of time and resources	P	O	R	R	R	O	R	F	O	R	P
Insufficient capacities in construction work	O	O	P	R	R	R	R	P	R	R	O
FALL IN THE SUPPLY CHAIN											
Poor quality of local materials	R	O	R	R	R	VR	R	R	R	VR	O
Bad suppliers	O	O	O	O	R	VR	O	O	O	VR	P
Obstacles to import	F	O	P	O	VR	R	O	O	O	VR	P
Distance between site and materials / suppliers	VF	O	P	O	O	VR	R	F	P	VR	F
Bad contract enforcement	VF	O	O	R	R	VR	R	P	P	R	P
Budgetary and cash flow inconsistencies	R	R	R	O	VR	VR	O	O	O	R	P
Lack of human resources for the development of the works	O	O	R	P	R	R	R	O	F	VR	O
Technical difficulties in making changes in affected utilities	VF	O	R	O	O	R	R	P	P	VR	P
SAFETY IN CONSTRUCTION											
Insufficient protection of adjacent buildings and facilities	R	R	P	O	VR	R	R	P	O	VR	O
Insufficient worker safety	R	R	P	P	VR	VR	R	O	R	VR	O
Inefficient protection regarding the surrounding environment	O	R	P	P	VR	R	R	P	R	VR	P
Inefficient traffic control and management	P	P	P	P	VR	R	P	F	O	VR	P
ECONOMIC											
Changes in funding vehicles	VR	R	R	O	VR	O	P	P	P	VR	R
Changes in the taxes	R	R	AC	O	F	O	P	O	R	VR	P
Multinational sanctions	R	R	VR	O	R	R	R	R	R	R	O
General inflation	R	R	F	P	O	R	P	O	P	O	F
Wage inflation	VR	P	F	R	R	R	R	R	P	VR	F
Changes in material costs	O	F	F	P	P	R	O	O	O	P	F
Changes in the cost of energy	VR	R	P	R	O	R	O	F	O	P	F
Exchange rate	O	R	AC	P	P	O	F	VF	F	O	F

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Economic recession	O	O	O	O	O	O	O	F	O	R	O
Economic effects of an environmental catastrophe	R	R	O	O	P	O	R	R	R	VR	P
Legislative or regulatory changes in financing	R	R	R	R	VR	R	O	O	R	VR	R
ENVIRONMENTAL											
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION											
Underground water filtrations	O	O	R	R	R	O	R	R	O	R	P
Affectation of flora and fauna	VR	VR	VR	VR	VR	VR	VR	R	VR	VR	P
UNFAVOURABLE WEATHER CONDITIONS											
Heavy rain	F	O	P	P	O	VR	O	O	R	P	F
Windstorms	VR	R	VR	R	R	VR	R	R	VR	VR	O
Earthquake	R	R	R	R	VR	R	VR	VR	VR	R	O
POLITICAL											
Political instability	P	F	O	P	O	P	O	VF	R	VR	R
Lack of political support / Political indecision	O	F	F	P	O	VR	P	VF	P	VR	P
War or regional conflicts	VR	P	VR	R	R	R	R	P	VR	VR	P
Opposition or political interference	O	F	P	VF	P	O	O	VF	P	R	AC
Government discontinuity	P	F	AC	P	P	O	F	AC	F	R	F
Changes in funding policy	VR	R	R	O	VR	O	P	F	P	VR	P
Delays in obtaining approvals and permits	F	P	P	F	F	O	O	P	P	VR	VF
Lack of transparency and corruption	VR	P	R	F	P	P	O	O	R	P	P
Protectionism	O	P	R	P	O	VR	R	O	VR	VR	R
Lack of updating or regulatory adaptation	P	P	O	O	P	R	F	O	R	VR	AC
Other unexpected legislative or regulatory changes	O	P	O	O	O	VR	O	R	R	R	VF

The following table shows the results of the opinion of the 11 experts (E1, E2,...,E11) regarding the potential impact of the risks.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
SOCIAL											
Impossibility of obtaining land and access rights	M	H	VH	VH	VL	VH	H	VH	H	VH	L
Compensations higher than expected	M	H	H	H	VL	M	H	M	L	H	H
Protests and interference by residents	H	M	VH	M	H	M	M	M	L	M	VH
Claims by third parties	L	M	H	M	H	M	M	M	L	L	VH
Costs of contractual disputes with contractor	L	M	H	M	M	H	M	H	H	L	VH

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Threats to the safety of personnel or assets	VL	L	M	H	H	L	L	L	VL	M	M
Vandalism	L	M	M	VH	M	L	L	L	VL	H	H
Involvement of many decision-making bodies	L	M	M	H	H	M	M	M	M	M	VH
TECHNICAL											
ENGINEERING DESIGN											
Inappropriate design due to lack of technical capabilities	VH	VH	H	VH	VH	VH	H	H	VH	VH	VH
Measurement errors on the site	H	VH	H	VH	VH	H	H	H	H	VH	VH
Conflicting interfaces between work items	M	H	H	H	H	H	H	H	VH	M	H
Special Conditions on the site	VH	H	H	H	M	H	M	H	M	VH	M
Insufficient site inspections	M	H	H	H	H	VH	M	M	M	H	H
Changes in project scope requirements	H	H	H	VH	M	VH	M	VH	M	VH	N/H
Changes in technology or in industry use standards	M	H	H	VH	H	VH	H	VH	H	H	VH
Other changes in the engineering design of the project	M	H	H	M	M	M	H	H	L	H	H
Inaccurate estimates of project cost	H	VH	VH	VH	H	H	H	VH	VH	VH	VH
CONSTRUCTION MANAGEMENT											
Poor allocation of time and resources	H	H	H	VH	VH	H	M	VH	H	VH	H
Insufficient capacities in construction work	H	H	H	VH	M	H	H	H	M	VH	M
FALL IN THE SUPPLY CHAIN											
Poor quality of local materials	M	H	H	VH	H	VH	M	M	M	VH	M
Bad suppliers	M	M	M	H	H	VH	H	M	M	VH	M
Obstacles to import	L	M	H	H	VH	H	M	M	M	VH	M
Distance between site and materials / suppliers	L	M	L	H	M	M	M	L	L	VH	H
Bad contract enforcement	VH	M	VH	M	VH	H	H	L	L	VH	VH
Budgetary and cash flow inconsistencies	M	H	H	H	VH	VH	H	M	M	VH	H
Lack of human resources for the development of the works	M	M	H	H	H	H	H	M	M	VH	M
Technical difficulties in making changes in affected utilities	VH	M	M	H	H	VH	H	H	M	VH	H
SAFETY IN CONSTRUCTION											
Insufficient protection of adjacent buildings and facilities	L	M	M	H	M	VH	M	M	M	VH	H
Insufficient worker safety	L	M	H	VH	VH	VH	H	M	L	VH	VH
Inefficient protection regarding the surrounding environment	L	M	H	H	H	VH	H	L	L	H	VH
Inefficient traffic control and management	H	M	H	H	VH	H	H	M	M	H	VH
ECONOMIC											
Changes in funding vehicles	M	H	VH	H	VH	H	H	L	H	L	H

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Changes in the taxes	L	M	H	H	M	VH	H	M	L	VH	L
Multinational sanctions	L	M	H	VH	VH	VH	H	L	M	VH	L
General inflation	VL	H	H	VH	H	H	H	M	L	H	M
Wage inflation	VL	H	H	M	H	H	H	M	L	H	M
Changes in material costs	M	H	H	H	H	H	H	H	L	L	M
Changes in the cost of energy	L	M	H	H	M	H	H	H	L	M	M
Exchange rate	L	H	VH	H	H	M	VH	VH	M	M	H
Economic recession	L	M	VH	H	VH	H	VH	M	L	VH	VH
Economic effects of an environmental catastrophe	H	H	VH	VH	H	VH	H	H	L	VH	VH
Legislative or regulatory changes in financing	L	H	H	VH	VH	VH	H	M	M	VH	M
ENVIRONMENTAL											
ENVIRONMENTAL RISKS DUE TO CONSTRUCTION											
Underground water filtrations	H	M	M	H	M	H	H	VL	M	M	H
Affectation of flora and fauna	VL	M	VL	L	M	H	M	L	VL	VH	H
UNFAVOURABLE WEATHER CONDITIONS											
Heavy rain	M	M	M	H	M	M	H	L	L	VH	H
Windstorms	VL	M	VL	L	M	M	H	L	VL	VH	M
Earthquake	H	H	VH	VH	VH	H	H	L	H	VH	M
POLITICAL											
Political instability	L	H	VH	H	VH	VH	H	H	H	M	H
Lack of political support / Political indecision	L	H	H	H	VH	M	H	H	M	L	VH
War or regional conflicts	VL	H	VL	H	VH	VH	M	L	M	VL	H
Opposition or political interference	M	H	H	VH	VH	VH	H	H	M	VL	VH
Government discontinuity	L	H	H	VH	VH	H	H	H	H	VL	H
Changes in funding policy	VL	H	VH	H	VH	H	H	M	H	M	M
Delays in obtaining approvals and permits	H	H	VH	VH	VH	VH	H	H	M	H	VH
Lack of transparency and corruption	H	H	H	VH	VH	M	VH	M	M	H	VH
Protectionism	L	H	M	M	H	M	H	M	L	M	M
Lack of updating or regulatory adaptation	M	H	H	VH	VH	M	VH	M	M	L	H
Other unexpected legislative or regulatory changes	L	H	H	H	H	L	H	M	L	M	H

Inter-American
Development Bank