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# MANAGING UNCERTAINTY IN PROJECTS: A REVIEW, TRENDS AND GAPS

## ABSTRACT

Nowadays an increasing number of projects are being developed in high complexity and uncertainty environment, requiring different approaches for project management: less rigid and more flexible. Thus, the purpose of this paper is to present a framework for managing uncertainties, through a systematic literature review. The developed framework, based on the contingency theory, suggests that approaches for uncertainty management are, in part, determined by the characteristics of the existing uncertainties. The responses for uncertainty can be driven by the cause or consequence of the uncertainties and those are chosen according to the ability to influence the cause, which is higher for internal uncertainties and lower for external uncertainties. The flexibility of the project management approach, in its turn, is impacted by the uncertainty degree.

**Keywords:** Uncertainty; Risk; Project Management; Contingency Theory.

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## 1. INTRODUCTIO

Risk management is a widely discussed topic, and the discussion is a longtime one. The discussions range from topics such as techniques and tools for risk management (Kumar, 2002; del Cano and de la Cruz, 2011; Cox, 2008; Wang and Chou, 2010; Dey and Ogunlana, 2004; Zwikael and Sadeh, 2004) to risk factors (Ropponen and Lyytinen, 2000; Han and Huang, 2007; Baccarini et al., 2004; Bannerman, 2008; Sicotte et al., 2006). Several studies also address the issue of risk and uncertainty.

Perminova et al. (2008) assert that uncertainties are present, to a greater or lesser intensity, in all the projects. The risks may also arise from decisions of strategic investments, market competition, uncertainties regarding the performance of new technologies, and other factors (Linsmeier; Pearson, 1996). However, when dealing with risk and uncertainty, understanding the two constructs is important.

The classical definition stated in the literature for risk and uncertainty distinguishes the ability to numerically measure the probability of occurrence of events, which is the case for risks (Perminova et al., 2008; Migilinskas and Ustinovicius, 2008; Kerzner, 2011; Carvalho and Rabechini, 2011). This definition leads to the conclusion that risk and uncertainty are mutually exclusive events.

The 4th edition of the PMBoK (PMI, 2008) defines risk as being an uncertain event that, if it occurs, affects the project goals. This definition, in addition to not conceptualizing uncertainty, might lead the reader to conclude that risk and uncertainty are synonyms (Perminova et al., 2008). The classical literature on project management does not clearly distinguish the difference between risk and uncertainty (Lechler et al., 2012), and in many works, the two concepts overlap. Huchzermeier and Loch (2001), for example, used the terms uncertainty and variability as synonyms, although subsequently, Meyer, Loch, and Pich (2002) distinguished between four types of uncertainty, ranging from variability to chaos. In this typology, risk is understood to be a synonym of variability.

Uncertainty, in turn, can be defined as a situation in which there is not a single and complete understanding of the system to be managed (Brugnach et al. apud Raadgever et al., 2010). Uncertainty is the negative result of project complexity (Vidal and Marle, 2008) and may be rooted in the unpredictability of the project system, in the absence of complete knowledge, or even in ambiguity (Raadgever et al., 2011). Thus, at least two factors that define uncertainty are noted: complexity and ambiguity.

Several studies address uncertainty and complexity, as well as how to manage these factors. From the view of contingency theory, different contexts require different ways of managing the project, and the success of the project depends on the fit between the project management and the environment (Howel et al., 2009).

In this context, Pich et al. (2002) utilize the instructionism, learning, and selectionism approaches. Meyer et al. (2002) demonstrate how to manage the four types of uncertainty that they have proposed. Sommer and Loch (2004) discuss learning and selectionism, choosing the approach based on the cost of each one of these factors. Lenfle (2011) describes selectionism (also called the parallel approach). From a dense source of citations, Raadgever et al. (2011) classify the following strategies for managing uncertainty: ignoring, knowledge generation, interaction, and coping strategies. Howel et al. (2010) propose a framework defining strategies according to the uncertainty level and its impacts. Loch, Solt, and Bailey (2008) demonstrate how to use instructionism, learning, and selectionism based on two variables: complexity and the level of unpredictable uncertainty due to gaps in knowledge.

The literature, however, relates uncertainty management to risk management, although there is a relationship between risk and uncertainty. The work by Ward and Chapman (2003) proposes transforming risk management into uncertainty management. However, within the presented concept, uncertainty is related to having not only negative but also positive project impacts because, according to the authors, risk carries a connotation of threat, whereas uncertainty may be presented both as a threat and an opportunity—although Hillson (2001) had already contributed to the definition of risk as having negative or positive effects.

A more recent work that involves risk and uncertainty management is presented by Thamhain (2013). Whereas Loch, Loose, and Bailey (2008) propose managing uncertainties considering the level of uncertainty and complexity, Thamhain (2013) adds a new dimension to manage risks: the consequence or impact of the event.

Another method for dealing with risks and uncertainties is associated with the contingency theory (Barki et al., 2001; Howel et al., 2010), in which the practical improvement of

management is associated with the context in which the project is inserted.

Pich et al.'s (2002) instructionism is an analytical approach that assumes the knowledge of the state of the world, and in this context, classic risk management (with identification, analysis, response planning, and risk monitoring and control) can be framed as an instructionist approach. According to the authors, managing unpredictable uncertainties necessitates learning and selectionism approaches. Works such as those by Rice et al. (2008) and Lenfle (2011) separately describe the two approaches for uncertainty management. Other works additionally discuss flexible management (Thomke, S; Reinertsen, D, 1998; Biazo, S, 2009).

Although there are various frameworks for risk management and some few for uncertainty management, the literature does not explicitly provide an integrated framework of how to manage both simultaneously, according to the characteristics of the uncertainty. Within this context, we intend to answer the following research question: What should be the management approach in different situations of uncertainty? The main objective of this paper is to propose a framework on how to manage uncertainties.

This paper is structured as follows. In Section 2, the research methods are presented. In Section 3, the results and discussions and in Section 4 the main insights and conclusions.

## 2. RESEARCH METHODS

To answer the research question, a systematic literature review (SLR) of the subject of risk and uncertainty in project management field was conducted. This research methodological approach was selected following the steps and recommendation of the literature, concerning transparent and replicable procedures (Carvalho et al., 2013, Littell et al., 2008, Tranfield et al., 2003).

### 2.1. Sampling Process

The search procedures were performed in the ISI Web of Science database. The first search applied the strings - topic (risk) AND topic ("project management"), resulting in 716 articles, and the second search applied the topic (uncertaint*) AND topic ("project management"), resulting 430 articles. We used just type of documents (articles and reviews) as a filter, because of the peer review process, and the period of analysis was from 1900 to 2015. The intersection among the two searches was 321 articles, resulting in an initial sample of 825 articles.

These articles were then screening to verify if the articles are indeed related to this research objective. The most cited articles were analyzed based on the premise that authors cite the articles that most influence their research (Carvalho et al. 2013, Ramos-Rodriguez and Ruiz-Navarro, 2004). Appendix 1 lists the most cited articles their respective subjects within the risk and uncertainty areas.

### 2.2. Data Analysis

Data analysis was based on content analysis. The surveyed articles were classified and coded as suggested by the literature (Carvalho et al., 2013, Duriau et al 2007). The most frequent mentioned codes in the content analysis are shown in Table 1. Appendix 1 presents the results of this analysis for the most cited articles.

The main codes considering the number of articles were Risk Management (RM) and Strategies for managing uncertainties (SMU). As expected, a considerable number of articles describe traditional risk management, focusing on predictable and identifiable risks (variability). The second most frequent code were Strategies for managing uncertainties (SMU), with articles discussing uncertainty management approaches, particularly the following approaches are predominant: learning or "trial and error," selectionism (also called parallel approaches) (Pich et al., 2002; Sommer and Loch, 2004; Loch et al, 2008; Chun, 1994; Lenfle, 2011; Rice et al., 2008), and managerial flexibility (Huchzermeier and Loch, 2001; Thomke and Reinertsen, 1998; Santiago and Bifano, 2005; Biazzo, 2009; Wang and Yang, 2012). Instructionism (an approach in which decisions are made a priori) and the hybrid approach between flexible and rigid management are also cited (Olausson and Berggren, 2010).

**Table 1 –** Most frequent codes in the content analysis

| Core Subject | Code | Full Name | Description | # articles |
|---|---|---|---|---|
| R | RM | Risk management | Describe traditional risk management, focusing on predictable and identifyed variabilities. | 33 |
| R | T&T | Tools and techniques | Present the techniques and tools that can be used for each step of the risk management process. | 19 |
| R | RF | Risk factors | Describe the implementation in specific context suh as IT and construction projects. | 19 |
| R | IRM | Implementation of risk management | Application of risk management and propose frameworks. | 19 |
| R | DM | Decision making | Present models that support decision-making, under uncertainty and risk. | 17 |
| R | QRA | Quantitative risk analysis | Refers to the risk analysis and propose models to quantify risks exposure. | 15 |
| U | SMU | Strategies for managing uncertainties | Discuss how to management uncertainties environments. | 25 |
| U | SBU | Scheduling and/or budgeting under uncertainty | Present methods to evaluate uncertainties related to time and cost. | 21 |
| U | CU | Categories of uncertainties | Discuss specific uncertainties categories and propose categories. | 20 |
| R | PRT | Risk perception and tolerance | Explore which factors influence risk perception and tolerance. | 4 |
| U | PM | Portfolio management | Manage uncertanties of project portfolios. | 6 |
| U | KM | Knowledge management | Explore learning and knowledge management along the project risk management and for further projects. | 4 |
| U | EU | Effects of uncertainty | Address the impacts of uncertainties according to the consequence severity. | 3 |

After coding, we performed the synthesis with the key insights emerging from the content analysis were condensed in the integrative framework aligned to the goal of the work, through an inductive process (see Fig.1).

Using the insights obtained from reading the articles, a framework was built, which represents the answer to the research question.

## 3. RESULTS AND DISCUSSION

The concept of risk in the project literature tends to address the greater frequency of this concept related to variability, seeking to shape the likelihood of occurrence and to investigate the potential impacts on the project goals. Meyer et al. (2002) propose four types of uncertainty: variability, foreseen uncertainty, unforeseen uncertainty, and chaos. Variability refers to random, predictable, and controllable variations, which are predominant in the literature of the studied sample.

The search based on the uncertainty related search strings reveals that several articles retrieved from the search are on "risk," suggesting a relationship between risk and uncertainty. In addition, when analyzing the publications, it is noticeable that there are articles that, although they have "uncertainty" as one of the keywords, discuss "risk" as a synonym of variability (see Appendix 1).

One of the key aspects of the discussion scenario is based on the idea of the contingency theory.

Several investigations have revealed that the majority of projects are not successful, without meeting deadlines or costs, satisfying the customers' needs, or even meeting the company's expectations. To investigate this phenomenon, several studies of the critical factors for project success have been developed, which, despite their popularity, have had a low impact on the improvement of management processes (Sauser et al., 2009).

Facing this failure, project management has recently and increasing used the theory of contingency as a basis (Hanisch and Wald,

2012). The contingency theory states that the effectiveness of an organization is related to its "fit" with the environment (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Perrow, 1967, cited by Howell et al., 2009). Translating this theory into the context of project management means that different conditions require different ways of organizing the project and that the project success depends on how appropriate the project organization is, relative to the prevailing conditions (Howel et al., 2009).

The idea that no single method to manage projects exists has been exploited by several authors. Sauser et al. (2009) listed 15 authors and their contributions to the management of projects based on the contingency theory. Each of the authors proposes factors or contingencies that may characterize the project, leading to different methods of managing it.

Thus, uncertainty is also a contingency that is fairly considered in projects and using the contributions of academic literature, the framework presented in Fig. 1 was built.

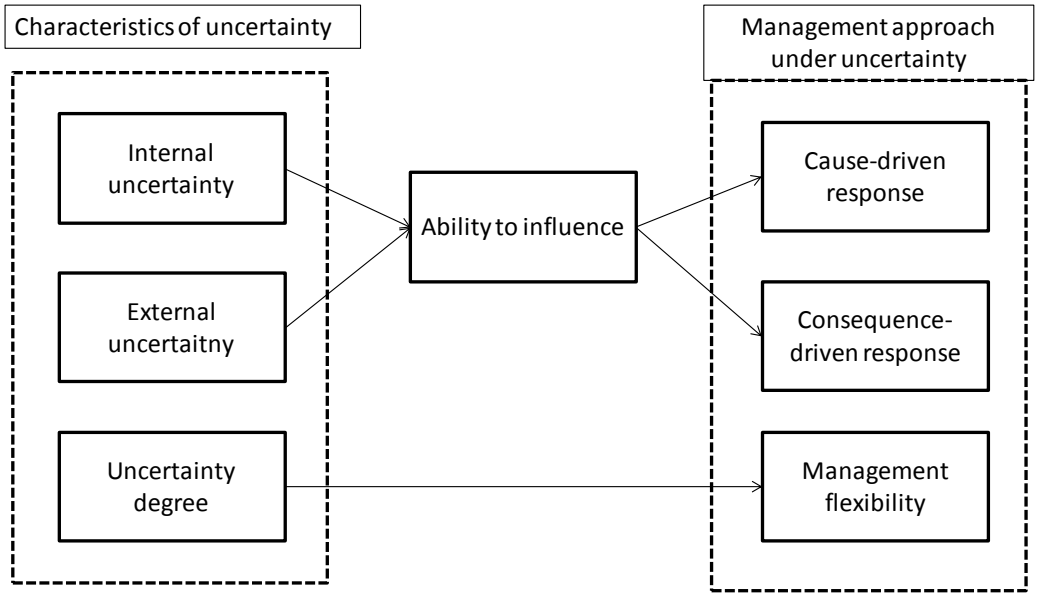


**Fig. 1** - Conceptual Model

The following sections explain the relations presented in the framework.

### 3.1. Sources of uncertainty

Several studies explore the sources of uncertainty (i.e., where it comes from) and classify it into categories. Rice et al. (2008) identify four types of uncertainty associated with technical, market, organizational, and resource innovations. Technical uncertainties comprise those related to the completeness of scientific knowledge regarding the problem, the reliability of the manufacturing process, whether the technical specifications may be applied, and other factors.

Technological uncertainties are widely cited as a category of uncertainties. Shenhar (2001) classify four degrees of technological uncertainties: low, medium, high, and super high. Lechler et al. (2012) also state that even with rigidly planned technical specifications, projects are subject to unpredictable uncertainties (*unknown-unknowns*). Moreover, regarding technological uncertainties, Sicotte and Bougault (2008) raise the uncertainty of the platform, defined as the degree of uncertainty that exists in a specific solution of the project, which can affect changes in the original project.

Market uncertainties are related to the customers' needs, the types of sales/distribution, and the project team's understanding of the relationship between their product and those of their competitors (Rice et al., 2008). The difficulty in understanding the customers' needs and translating them into functional and symbolic characteristics of the product generates market uncertainty (Biazzo, 2009). Song et al. (2001) suggest that the greater the market or technical uncertainty, the greater the complexity and turbulence of the external environment will be. The relationship between market uncertainty and the form of management is exploited by Maccormack and Verganti (2003).

Organizational uncertainties are associated with the dynamics of the organization. These types of uncertainty may manifest as organizational resistance, lack of continuity or persistence, inconsistencies in expectations and metrics, changes in strategies, or changes in internal or external partners. This category of uncertainties is also identified by Lechler et al. (2012). Resource uncertainties refer not only to financial resources but also to all types of skills.

Other sources of uncertainty are also identified in the literature as follows: lack of communication integration and "project language," low professional qualifications, lack of clarity in the delegation of responsibilities (Migilinskas and Ustinovicius, 2008), inadequate practices or tools for management (Lechler et al., 2012), and others factors.

Any of these sources of uncertainty can be reclassified into broader categories, as identified by Sicotte and Bougault (2008): external uncertainty, internal uncertainty (organizational interdependence), and characteristics of activity. External uncertainties correspond to the lack of information related to external factors that may affect the project performance. These external factors may be political situations, local infrastructure, local culture, nature, or economic stability (Kolltveit, 2004). External uncertainties can also be classified into uncertainties of state, effect, or response (Milliken, 1987 apud Sicotte and Bougault, 2008). Uncertainties of state occur when there is a failure to understand how the components of the environment are changing. Uncertainties of effect are those in which it is not possible to predict how a future state will affect the environment. Uncertainties of response occur when the available options for responding to uncertainty, or the cost of the response, are not known.

The characteristics of the activity assume two dimensions: variety and analyzability. The first dimension is caused by the non-ordinary characteristic of activities, namely, research and development activities. Analyzability is defined as the degree to which a well-structured process can be used to develop problem solutions. Fig. 2 presents the sources of uncertainty and how they interrelate.

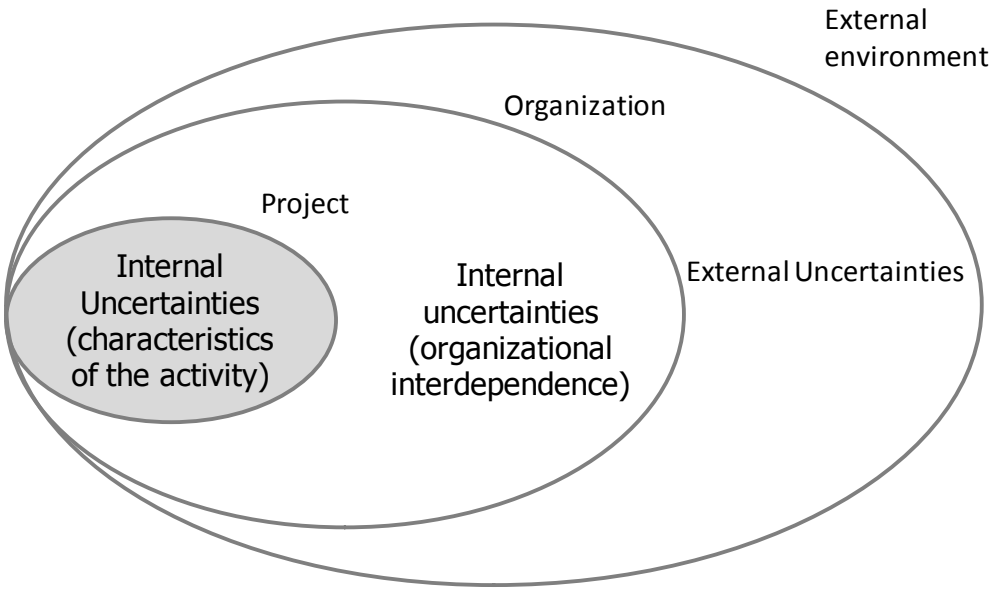


**Fig. 2 -** Classification of the sources of uncertainties

### 3.2. Guidelines for responses to uncertainty

As Milliken (1987) reports, uncertainties may involve the state or effect; Reyman et al. (2013) also state that uncertainties may be related to the cause, and in this case, the uncertainty is called unpredictability or, concerning the consequences, uncontrollability.

Kezner (2011) posits that risk control does not attempt to eliminate the source of the risk but seeks a way to reduce its consequence or likelihood of occurrence. Borrowing such concepts, the actions for managing uncertainties can be oriented to the cause (source) of the uncertainty or to the effect of the uncertainty, i.e., it is possible to attempt to control either the causes or the effects of uncertainty.

Cause-oriented actions are common even in traditional risk management, to the extent that the PMBoK recommends the technique of root-cause analysis as a method to identify risks and to allow the development of a response plan (PMI, 2008). Techniques that involve a causal analysis (using fishbone diagrams, for example) are also highly utilized in the quality control area.

However, if the cause of uncertainty is highly complex, such that an individualized action by the project team only or by high business direction may not be sufficient to eliminate the cause of uncertainty (i.e., there is a relatively low ability to influence the cause of uncertainty), then actions geared toward managing the cause may not be more efficient in circumventing the effects of uncertainty. Thus, certain mitigating actions are performed to minimize the effects of uncertainty without dealing with the cause. An example of this situation is the hiring of *hedges* for protection from fluctuations in the financial market.

Thus, several hypotheses are derived from these observations.

With respect to the source of uncertainty:

- The more internal the uncertainties are to the project, the greater the ability to influence the source of uncertainty.
- The more external the uncertainties are to the project, the smaller the ability to influence on the source of uncertainty.

Regarding the uncertainty response:

- The greater the ability to influence the source of uncertainty, the more intense the actions are oriented to the cause of uncertainty.
- The smaller the ability to influence the source of uncertainty, the more intense the actions oriented to the consequence of uncertainty.

To understand the ability to influence the source of uncertainty, the following classification is proposed: high, moderate, or low ability to influence. Situations with a high ability to influence correspond to those in which an effective and efficient action to manage the uncertainty can be internally applied to the project. In situations with a moderate ability to influence, the involvement of the organization's senior management (responsible for the project) or other external stakeholders is required. When the action requires the articulation of various *stakeholders*, including those indirectly involved in the project, a situation with a low ability to influence exists. Fig. 3 presents the concept of the ability to influence.

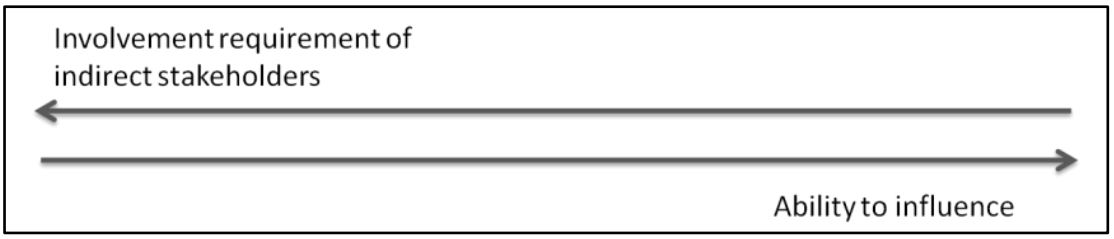


**Fig. 3 -** Ability to influence the source of uncertainty

### 3.3. Uncertainty degree

The adopted concept of the uncertainty degree relates to the ability to statistically describe uncertain phenomena, using the definitions of Walker et al. (2003) and Meyer, Loch, and Pich (2002). Uncertainties can be of four types: variability or statistical uncertainty, predictable uncertainty or scenarios, unpredictable or recognized uncertainty, and chaos or total ignorance.

Variability is caused by various influences, which are numerous and small enough so that it is difficult to control and monitor each of them individually, thereby yielding a range of values for a particular activity. In such cases, the sequence of activities, their nature, and their objectives are clear, but the schedule and costs may vary from the baseline. Despite not being able to control each of the influences individually, it is possible to control the variations resulting from these influences. Walker et al. (2003) call this situation statistical uncertainty because it is possible to describe the uncertainty in the form of stochastic expressions.

According to Meyer et al. (2002), predictable uncertainties are identifiable and understood influences, but it is not possible to

know whether they will occur. The difference between uncertainty and predictable variability is that whereas in variability, it is not possible to control each of the influences individually, in predictable uncertainty, the influences are monitored with the elaboration of several alternative plans. Additionally, Walker et al. (2003) state that in uncertainty scenarios, the manager or the decision maker is able to construct the possible scenarios of how a system or the forces that direct it will behave in the future, without knowing, however, the probability of their occurrence.

Unpredictable uncertainties, as the name suggests, are influences that are not possible to identify beforehand, and consequently, there are no a priori mitigation plans. These cases are also called *unk-unks* or *unknown unknowns* (Meyer, Pich, and Loch, 2002). The mechanisms and functional relations of the system being studied are unknown, which makes both the determination of stochastic expressions and the construction of future scenarios impossible. This category of uncertainty can be still divided into reducible and irreducible ignorance, i.e., in first, it is possible to reduce the uncertainty through the deepening of the surveys, whereas, in the second, this reduction is not possible (Walker et al., 2003).

In the three types of previously described uncertainty, the project has a relatively stable objective and assumptions. For projects subject to chaos, this is not true. In these projects, even the project plan is uncertain (Meyer, Pich, and Loch, 2002) and reflects a situation in which the project team does not even know what is unknown.

### 3.4. Management flexibility

The most basic approach to project management is defined by Pich, Loch, and Meyer (2002) as instructionism. The policies that guide the project are determined either a priori or as the project is executed, determining what activities are to be performed in response to a signal. For example, typical instructionist activities include the preparation of an activity schedule and risk management. Considering the context of new product development, the traditional approach is "specifications-oriented," requiring that the specifications are all complete, and only then is it possible to "freeze" the project engineering (Thomke and Reinertsen, 1998).

The consecrated methodology of *stage-gates* is extremely rigid. The basic concepts and propositions must be defined during the initial stage of planning and frozen as soon as they pass through the first gate (Biazzo, 2009).

This management approach is effective in situations where uncertainties are moderate and stable but, for most turbulent environments, may not be the most appropriate approach (Biazzo, 2009). In this context, Pich, Loch, and Meyer (2002) identify two other approaches: learning and selectionism.

Selectionism can be regarded as an extension of instructionism; the project team improves the project model to improve its policy. Thus, the team depends on its ability to identify the optimal policy (Pich, Loch and Meyer, 2002). In other words, this approach consists of identifying multiple paths for the problem and observing a posteriori which of the paths yields better results for the project.

Selectionism is a well-established approach, also called the "parallel approach," which disappeared in the 1960s but returned to a management practice (Lenfle, 2011). The author also states that this approach can be used in two ways: first, by selecting only a single path as the solution to the uncertainty problem and second, by combining the solutions of several parallel paths.

The learning approach is simply a situation in which the project team realizes that the signals emitted by the project's environment (i.e., its "world") do not match the initial premises that were the basis for defining all the activities; facing this divergence, the team is prepared to make changes that suit the reality (Pich, Loch and Meyer, 2002).

Both the selectionism and learning approaches require the flexibility of design (to recognize and accept the necessity of making changes or to adopt more than one solution option) and the agility in responding to changes.

Flexibility is defined by Thomke and Reinertsen (1998) as a function of the incremental cost of modifying a product in response to external or internal changes so that the higher the cost of change, the less flexibility exists. Wang and Yang (2012) define flexibility as the ability to introduce new products to the market with minimal disruptions when the market and technology change rapidly.

Considering the concept of flexibility and the degree of uncertainty, the following hypothesis is derived:

- The greater the degree of uncertainty, the more flexible the project management should be.

## 4. CONCLUSIONS AND LIMITATIONS

The performed bibliographic research demonstrates that the concepts of uncertainty and risk are relatively vague—so much so that they often overlap, and the terms are used as synonyms. Thus, in this study, the terms were used as two different phenomena, in which uncertainty is more comprehensive and risk is a type of uncertainty (Meyer et al., 2002).

It was also determined that when dealing with uncertainties, various typologies are explored, and two types of uncertainty that are highly utilized are market uncertainty and technological uncertainty, in addition to the concept of internal uncertainty and external uncertainty. This typology was used as the basis for constructing a conceptual model, in which the concept of the ability to influence the cause of uncertainty was also introduced, which should guide the response to uncertainty by acting on the cause or on the effect.

Another method to classify uncertainties is the ability to describe events in the form of stochastic expressions (Walker et al., 2003), which indicates the degree of uncertainty for the event. The work suggests that the degree of uncertainty directly influences the project management approach, varying between two extremes: from the most rigid, corresponding to instructionism (Pich et al., 2002), to the most flexible, corresponding to learning and selectionism (Thomke and Reinertsen, 1998).

The work contributes insights into how to better manage projects within the context of numerous and rapid changes by being agile in responding to such changes without compromising the project outcome. The practical implications are the developed framework of Figure 1, which can be used as a guideline to better plan the responses to uncertainties. Although none of the concepts of section 3 are novelties, the paper contributes to the literature by building a relation between those subjects, that are usually treated separately.

As next steps, initially, an empirical proof of the raised hypothesis must be conducted. The present article explored the concept of management flexibility. However, more detailed research on flexibility should be performed. In addition, a recent approach that has emerged is improvisation. To enrich the framework using the approaches of management under uncertainty, the literature regarding improvisation and agile project management must also be explored.

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**Appendix 1.** Content analysis of the most cited articles

| Article | Times cited* | Purpose | Focus on | | Codes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Risk | Uncertainty | T&T | RF | IRM | QRA | DM | PRT | SMU | SBU | CU | RM |
| Herroelen and Leus (2005) | 190 | Reviewing the fundamental approaches for planning (scheduling) projects under uncertainty; discussing the potential of approaches for programming under uncertainty with the evolution structure of deterministic networks | | **X** | | | | | | | | X | | |
| Nidumolu (1995) | 138 | Studying the effects of vertical and horizontal coordination mechanisms in guidelines of risk as uncertainties in projects on the project success | | **X** | | | | | | | | | X | |
| Shenhar (2001) | 127 | Demonstrating how various types of projects are managed in different ways, exploring the domain of the traditional contingency theory in the context of projects | | **X** | | | | | | | | | X | |
| Huchzermeier and Loch (2001) | 124 | Testing the hypothesis that the project value is based on the uncertainties of performance, market, cost, time, and market payoff, with uncertainty, in this case, being a synonym for variability | | **X** | | | | | **X** | | X | | | |
| Pich et al. (2002) | 123 | Developing a model in which the project is defined as a payoff function that depends on the state of the environment and the selection of the action sequence, with three management strategies identified: instructionism, learning, and selectionism—including when each one is used | | **X** | | | | | | | X | | | |
| Tatikonda and Rosenthal (2000) | 105 | Testing the relationship between project complexity and technological novelty in the project success (measured in the technical performance, unit cost, time-to-market, and combination of goals) | | **X** | | | | | | | | | X | |
| Barki et al. (2001) | **93** | Testing the hypothesis that the Performance of software projects is influenced by the Fit, which is defined as the extent to which the risk management profile also matches the risk exposure | **X** | **X** | | | **X** | | | | | | | X |
| Wallace et al. (2004a) | 87 | 1) Exploiting the tendency in the risk dimensions in high-, medium-, and low-risk projects; 2) determining how the characteristics of the project such as the scope, sourcing practice, and strategic orientation of a project affect the risk | | **X** | | | | | | | | | | X |
| Ropponen and Lyytinen, (1997) | 84 | Investigating the impact of the software development practices; examining the following questions: 1) What are the components of software development risks? 2) Which practices and environmental contingencies help to address these components? | **X** | | | | **X** | | | | | | | |
| Mustafa and Albahar(2004) | 82 | Introducing a new approach for project risk management through AHP | **X** | | | | | | **X** | | | | | |
| Thomke and Reinertsen (1998) | 78 | Defining and examining flexibility, including how it can be quantified, how to improve its performance, and how it can be introduced to the organization | | **X** | | | | | | | X | | | |
| Wallace et al. (2004b) | 66 | 1) Identifying the risk dimensions of software projects and developing and validating a tool for measuring these risks; 2) building and testing a model guided by the theory that correlates the dimensions of risk and project performance | | **X** | | | | | | | | | | X |
| Kumar (2002) | 55 | Emphasizing the difference between risks that may be resolved by actions and risks that require hedging; presenting a framework for understanding and hedging risks in IT projects based on real options | **X** | | **X** | | | | | | | | | |
| Sommer and Loch (2004) | 54 | Comparing the payoff performance in the learning and selectionism approaches based on a priori identification of the project characteristics to determine whether there are unpredictable uncertainties, how complex the project is, and how much learning and selectionism cost | | **X** | | | | | | | X | | | |
| Browning et al. (2002) | 46 | Proposing that project progress and added value to the consumer in product development is tantamount to producing information for minimizing performance risks | **X** | | | | **X** | | | | | | | |

* Until 2013

**Appendix 1.** Content analysis of the most cited articles – end.

| Article | Times cited* | Purpose | Focus on | | Codes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Risk | Uncertainty | T&T | RF | IRM | QRA | DM | PRT | SMU | SBU | CU | RM |
| del Cano and de la Cruz (2011) | 37 | Presenting a particularization of the generic process of risk management for construction projects from the viewpoint of the owner and the consultant who supports the owner | X | | X | | | | | | | | | |
| Raz et al. (2002) | 36 | Examining the extent of the use of risk management practices (such as risk identification, probabilistic risk analysis, uncertainty planning, and trade-off analysis), the difference in applications in different projects, and their impact on several dimensions of project success | | X | | | | | | | | | | X |
| Han and Huang (2007) | 35 | Exploring the relationships between software risks and their impact on the project performance | X | | | X | | | | | | | | |
| Drummond (1996) | 33 | Demonstrating the limitations of the premise that risk is quantifiable, predictable, and controllable in complex projects | X | | | | | | X | | | | | |
| Kwak and Stoddard (2002) | 33 | Presenting the lessons learned while implementing risk management in software development environments | X | | | | X | | | X | | | | |
| Nidumolu (1996) | 32 | Determining how to explain the effect of uncertainties in the requirements and standardization in software-development project performance | | X | | | | | | | | | | |
| Baccarini et al. (2004) | 31 | Identifying the more relevant risks of IT projects in terms of probability and impact and the specific strategies to manage these risks | X | | | X | | | | | | | | |
| Santiago and Bifano (2005) | 31 | Describing the practical application of a flexible management approach for developing new products, highlighting the advantages and limitations of this methodology, with a model focusing on uncertainty resolution of the product-development life cycle and addressing technical, market, and cost factors simultaneously | | X | | | | | | | X | | | |
| Cox (2008) | 29 | Presenting the mathematical properties of risk arrays and their limitations | X | | X | | | | | | | | | |
| Benaroch et al (2007) | 29 | Studying the application of option-based risk management and its theoretical perspective and methodology in a big investment problem in the IT field | | X | | | | | | | | | | X |
| Molenaar (2005) | 25 | Presenting a methodology developed by the Washington State Department of Transportation for the validation process of cost estimation | | X | | | | | | | | | | |
| Tavares et al. (1998) | 25 | Studying the risk of projects as a function of the uncertainty regarding the duration of the activities and their costs in accordance with the adopted schedule, which is considered the biggest decision affecting the problem | | X | | | | | | | | | | |
| Wang and Chou (2010) | 24 | Identifying the risks in Taiwanese highway projects; discussing the methods to diversify risks using contractual clauses; analyzing the influence of the type of risk diversification in the contractor's risk management strategies | X | | X | | | X | | | | | | |
| Bannerman (2008) | 24 | Reconsidering the status of risk and risk management in the literature and practice | X | | | X | | | | | | | | |
| Ropponen and Lyytinen(2000) | 24 | Investigating which characteristics of risk management practices and other environmental factors and procedures relate to the performance improvement of software risk management | X | | | X | | | | | | | | |

* Until 2013