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The complexity of projects: an adaptive model to incorporate complexity dimensions into the cost estimation process

The Complexity of Projects: An Adaptive Model to Incorporate Complexity Dimensions into the Cost Estimation Process

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LIST OF ABBREVIATIONS

APM	Association for Project Management
APMBOK	Association of Project Management Body of Knowledge
APMG	Association for Project Management Group
APAC	Asia and Pacific
ATP	Advanced Target Pod
CAS	Complex Adaptive Systems
CAQDAS	Computer Aided Qualitative Data Analysis Software
CEO	Chief Executive Officer
CERs	Cost Estimation Relationships
CFO	Chief Financial Officer
CMM	Capability Maturity Model
COCOMO	Constructive Cost Model
EMEA	Europe, Middle East, and Africa
ECA	Electronic Combat Aircraft
ERP	Enterprise Resource Planning
ET	External Tank
GPS	Global Positioning System
ICCPM	International Centre for Complex Project Management
ISCM	Institute for Strategy and Complexity Management
IPMA	International Project Management Association
LATAM	Latin America
LRE	Launch and Recovery Elements
MCA	Multi-Criteria Analysis
MCE	Mission Control Elements
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration

OLS	Ordinary Least Regression
PERT	Programme Evaluation and Review Technique
PLC	Project Life Cycle
PMBOK	Project Management Body of Knowledge
PMAJ	Project Management Association of Japan
PMI	Project Management Institute
PRINCE2	Projects iN Controlled Environments
PTMS	Power Thermal Management System
QDA	Qualitative Document Analysis
R&D	Research and Development
RII	Relative Importance Index
SMART	Specific, Measurable, Attainable, Realistic, Time-bounded
SIA	Social Impact Assessment
SLIM	Software Life Cycle Management
TPS	Thermal Protection System
USD	United States Dollar
VPM	View Point Model
WBS	Work Breakdown Structure

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DEDICATION

I would like to dedicate this work to my brother, Frederic Herszon, who left us so early, and to my father who is not with us anymore. I think they would be proud of this accomplishment.

DECLARATION OF ORIGINALITY

DECLARATION OF ORIGINALITY – CONDUCT OF ASSESSED WORK

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Name of candidate LEON HERSZON ID number: U1474603

In presenting my PhD Thesis I declare that I have read and understood the University Policy on Academic Misconduct and that:

1. this work is my own;
2. the work of others used in its completion has been duly acknowledged.

While the research was in progress, some research findings were published in refereed conference papers prior to this submission

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ABSTRACT

Most projects fail to deliver the required product, on time, or within the budget; and complex projects have additional challenges due to the impact of complexity factors, henceforth called dimensions. Cost overruns are common occurrences with projects, especially on complex ones, which points to a better understanding of the cost-estimation process. Accordingly, it is important to identify the factors affecting the project complexities and their impact on cost-estimation process. Although project complexities and cost-estimation practices have been discussed in literature, there is a clear gap in the existing body of knowledge regarding how complexity dimensions are linked with cost estimation of project-based industries and how to give due consideration to such complexity dimensions in cost estimation practices. The dynamic nature of complexity calls for a model that considers these dimensions and supports practitioners in the cost estimation process, including guidelines to deal with such complexities.

This research aims to develop a model that incorporates complexity dimensions into the cost-estimation process for complex projects. For that to happen, there is a need to explore the concept of complexity, the dimensions of complexity, and in what context these should be considered in the cost-estimation process. An investigation of how these complexity dimensions impact the cost-estimation process precedes the development of the proposed model.

Philosophically this research is positioned in the middle of the ontological, epistemological, and axiological spectra leaning towards idealism, interpretivism, and subjectivism respectively. Considering the use of survey and case studies as research strategies, the research mode is better positioned as inductive with the research choice based on a mixed method of quantitative and qualitative analysis. Empirical data has been collected from a database of complex projects through documentary analysis, and from a survey and interviews that have been used to develop and enhance the proposed model.

An analysis of the existing literature on project complexity, along with a documentary analysis of 27 complex projects in a database, provided a list of 23 dimensions that are relevant to project complexity. Based on this list, a survey of 54 practitioners was conducted to gather expert views about the complexity dimensions and their impact on project cost estimation. The 23 dimensions were then prioritized using the Relative Importance Index, which revealed that different industries have distinct views on some dimensions and aligned on others.

The survey was followed by a series of 10 in-depth interviews with subject experts. A final analysis of the survey and interviews results helped to eliminate dimensions, reducing the list of complexity dimensions to 15. Once the list of 15 dimensions was established, the model was drafted and divided into an assessment table where practitioners would assess each dimension on a scale of 1 to 4, the mapping of these results on a radar graph for better visualization, and a list of guidelines for cost estimators on how to deal with these complexities.

The contribution to knowledge and society will be that such model could support practitioners on creating awareness for complexity dimensions, which would generate more accurate and reliable cost estimates for complex projects.

CHAPTER 1 - INTRODUCTION

This chapter will provide an overview of the research problem, justification, aim, objectives, contribution to knowledge, and structure of the entire document. After reading this chapter, the reader should have a high-level view of the research and thesis.

1.1. Research Background

Even today most projects fail, despite all the available knowledge and use of best practices. According to a survey of practitioners and organizations, only 32% of all projects surveyed successfully delivered the required product with all its features and functions on time and within budget. Another 44% were delivered late, had cost overruns, or failed to provide all the requirements and functions. The remaining 24% were actually cancelled before completion or were delivered but the product was never used (StandishGroup, 2009). These statistics include all types of projects, complex and not; therefore, it can be argued that for complex projects, unsuccessful results would be even more prevalent (Flyvbjerg, Bruzeluis, & Rothengatter, 2010), due to the nature of complexity that will be addressed further on.

Even though not all mega projects are complex in nature, the majority have underestimated costs, with common cost overruns of 50% to 100% (in real terms), and not so rare cost overruns surpassing 100% as supported by many authors (Altshuler & Luberoff, 2004; Flyvbjerg, 2005; Priemus, Flyvbjerg, & Wee, 2008; Flyvbjerg et al., 2010). Given the predominance of cost overruns, it can be argued that these mega projects might contain dimensions of complexity that are valuable to consider.

A broad range of industries lends themselves to studies of complexity. Construction projects for instance have grown in complexity since World War II and their complexity continues to increase (Baccarini, 1996). However, even though there are many cases of complex projects related to construction in both government and private initiatives, the concept of project complexity is not limited to this industry (Williams, 1999). Furthermore, the concept of complexity is not related only to the size of a project—one of the key characteristics of mega projects—but also to the complexity of the product itself. For instance, the development of a new processor might be considered complex due to the level of effort and innovation involved (Williams, 2002). Several authors have indicated that other industries also contribute to the study of complexity, such as engineering (Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011), information technology (Roberts, Cheney, Sweeney, & Hightower, 2004), and aerospace (Lopez, 2006).

Even though a number of authors shared concepts of project complexity (Baccarini, 1996; Vidal & Marle, 2008; ICCPM, 2012), project-cost estimation (PMI, 2011, 2012; Kerzner, 2013), and project complexity factors (Shenhar & Dvir, 2007; Remington & Polack, 2008; Kerzner & Belack, 2010) on an isolated way, generally there is an obvious lack of literature about the impact of project complexity on the project-cost-estimation process.

Considering this scenario, further research of relevant complexity dimensions and their inclusion in a model that would increase awareness among practitioners could reduce the gap of the actual cost estimations of complex projects.

1.2. Research Problem

Several authors have indicated complexity dimensions as relevant aspects when managing complex projects, and others presented proposed approaches to deal with complexity (Bertelsen & Koskela, 2005; Cicmil, Coke-Davies, Crawford, & Richardson, 2009; Cavanagh, 2011; Cooke-Davies, Crawford, Patton, Stevens, & Williams, 2011; Levin & Ward, 2011; PMI, 2014), but no specific model was found in the literature to support cost estimators when dealing with complexity dimensions that can impact projects.

One model identified complexity as one of the elements of its “Diamond” approach that could support project cost estimation (Shenhar & Dvir, 2007). This model, however, does not specify how various elements of project complexities (hereafter complexity dimensions) may influence project cost estimation and consequently how the estimates can be improved by considering these complexity dimensions..

The problem is the lack of a model that takes into consideration the dimensions of complexity to support practitioners when estimating costs for complex projects.

1.3. Research Justification / Rationale

It is common to find statements about issues that complexity can create in projects, such as overestimation of benefits, underestimation of costs, failure to meet client requirements, misalignment among stakeholders with different and competing views and goals, the lack of appropriate resources to manage the project, and the lack of proper tools to manage complex projects, all leading to overwork and low performance (Hass, 2009; Flyvbjerg et al., 2010;

Cooke-Davies et al., 2011). Similarly, infrastructure projects in a private or public setting could be considered a good source of cases that confirm the tendency for early optimistic cost estimates to end up being greatly underestimated, leaving stakeholders facing the harsh reality (Rolstadås, Hetland, Jergeas, & Westney, 2011).

According to PMI (2012), a project manager has to manage ten project management areas – scope, time, cost, quality, human resources, stakeholders, risks, communications, procurement, and integration. Even though all of them are important, this research is focused on the cost estimation process since there is a large number of references and cases of costs overruns in complex projects (Kern & Formoso, 2004; Baccarini, 2005; Priemus et al., 2008; Olaniran, Love, Edwards, Olatunji, & Matthews, 2015).

Today most projects are estimated using traditional criteria that do not account for complexity factors. For instance, the Project Management Institute recommend the use of several inputs, tools, and techniques to reach an estimate for projects (PMI, 2011). Furthermore, the analogous, parametric, and definitive estimation techniques have been used for decades but still do not consider the dimensions of complexity widely in cost estimations (PMI, 2014).

This research proposes to resolve this problem by exploring the dimensions that determine project complexity; by exploring the cost-estimation process within the context of complex projects; by investigating which are the more and less impactful complexity dimensions to cost estimations; and by proposing a model to support practitioners on improving the cost-estimation process for complex projects by providing awareness of the existence of complexity dimensions and guidelines to be used on these projects.

Complexity has factors or variables (hereafter called dimensions) that can influence projects (Shenhar & Dvir, 2007), and these dimensions can also influence each other (Baccarini, 1996; Williams, 1999). This dynamic state calls for a model that has the capability to consider the impact of these dimensions in the cost-estimation process. Such a model would consider the necessary dimensions to better determine the qualitative degree of project complexity and help improve the cost-estimation process for complex projects by providing awareness and a set of recommendations.

1.4. Research Aim

The aim of this research is to develop a model that incorporates complexity dimensions into the cost-estimation process for complex projects.

1.5. Research Objectives

1. To explore the dimensions that determine the complexity of a project.
2. To explore the characteristics of project cost estimations within the context of complex projects
3. To investigate which complexity dimensions are considered more important than others, eliminate the less relevant, and consolidate the similar ones.
4. To model the links between the complexity dimensions and their impact on the cost-estimation process.
5. To provide recommendations and guidelines for decision making on a better upfront estimate of complex projects.

1.6. Research Contribution to Knowledge

This research is contributing to the existing knowledge by developing a model that incorporates the most relevant complexity dimensions into the cost-estimation process based on the literature, supported by case studies of complex projects, prioritized by survey, and validated by interviews with practitioners. The model also provides an assessment for each dimension, graphical mapping, and guidelines considering the complexity aspects of a project. The overall approach allows a better cost-estimation process for industries in which project complexity is common, including construction.

1.7. Structure of the Research

Chapter One introduces the research justification, aim, problem, objectives, questions, and proposed contribution to knowledge.

Chapter Two comprises the literature review that provides definitions of projects, project management, complexity, project complexity, cost estimation process, and supporting theories. It lists the complexity dimensions, describes the cost estimation process, how it is used in the industry, and what is the impact of complexity on the cost estimation process. It sustains the search for a model that helps estimators to take into consideration dimensions of complexity when estimating costs on their projects.

Chapter Three describes and justifies the methodology used in this research, by using the "nested approach". The research philosophy is presented, followed by the research approach and techniques. Finally, the chapter explains the use of case studies, survey and interviews to obtain the necessary data to support the development of a cost estimation model that considers complexity dimensions.

Chapter Four summarizes the 27 case studies of complex projects used to validate the complexity dimensions and describes new dimensions that could be considered. Each case study depicts the industry and a brief description of the challenges and impact of complexity in that project.

Chapter Five provides details about the survey, in which 54 professionals participated, with a priority rank by industry and a consolidated view. Following this is a description of the results of 10 comprehensive interviews that served to validate the existing dimensions.

Chapter Six brings all the data and information from previous chapters together to serve as a basis for a proposed model that provides awareness for project practitioners when estimating costs of complex projects.

Finally, Chapter Seven shares the conclusions from this research, limitations, and possible future research.

1.7. Chapter Summary

This chapter provided the research background, identified the problem to be solved, explained the justification of this research and its aim and objectives. It also proposed the resulting contribution to knowledge and, finally, described how the research was structured. The next chapter covers the literature review related to projects, project management, and complexity.

CHAPTER 2 - PROJECT MANAGEMENT, COMPLEXITY, AND COST ESTIMATION

2.1. Introduction

This chapter reviews the literature related to the concepts of project management, complexity, and cost estimation. The first step on the literature review was to identify the seminal authors on each field – project management, complexity, and cost estimation. The process to identify the most relevant authors was by checking the articles most referred to by other authors and the textbooks that appeared most frequently as bibliographic references. Search engines like Google Scholar, Scopus, and the University of Huddersfield library were used. Works that appeared just once and not referred by other authors were not considered relevant. The next step was to read the articles, journals, and textbooks with support of the qualitative data analysis tool NVivo that allowed to keep record of the main topics of each source.

This chapter provides an overview of supporting concepts such as complexity theory and complex adaptive systems, multi-criteria analysis and adaptation, and contingency theory, leading to the concept of project complexity and managing complex projects. The chapter also provides the findings related to which complexity factors (hereafter called dimensions). Supported by these foundational concepts, this chapter then explores the cost-estimation process as pertaining to projects; the inputs, outputs, tools, and techniques used to estimate their costs; and how two project-based industries estimate costs. Finally, initial thoughts about a model to support the cost-estimation process are provided.

2.2. Project Management

This section aims to explore the concept of project management. To better understand what project management is, the definition of ‘project’ should be explored. Even though the concept of project is well known, the precise definition varies slightly depending on which project-management institute is the source.

Until 1900, civil engineering projects were generally managed by creative architects, engineers, and master builders. As a discipline, project management developed from several fields of application including civil construction, engineering, and heavy defense activity. Forefathers were Henry Gantt (father of planning and control techniques) and Henri Fayol (creation of the five management functions). Both Gantt and Fayol were students of Frederick

Winslow Taylor's theories of scientific management. The 1950s marked the beginning of the modern project management era where core engineering fields come together to work as one. Followed that the Project Management Institute started its research on project management best practices in 1969.

A comparison of the following definitions from five different organizations might prove useful (Alvarez-Dionisi, Turner , & Mittra, 2016).

- According to the Project Management Institute's (PMI) *A Guide to the Project Management Body of Knowledge (PMBOK Guide),* a project is "a temporary endeavour undertaken to create a unique product, service, or result" (PMI, 2012, p.3).
- The Association for Project Management (APM), in its *APM Body of Knowledge* (APMBOK), defines *project* as "a unique, transient endeavour undertaken to achieve a desired outcome" (APM, 2006, p.150).
- The APM Group (APMG) International defines *project* as "a temporary organization that is created for the purpose of delivering one or more business products according to an agreed Business Case" (Commerce, 2009, p.309).
- The International Project Management Association (IPMA) defines *project* as "a time and cost constrained operation to realize a set of defined deliverables (the scope to fulfil the project's objectives) up to quality standards and requirements" (Association, 2009, p.13).
- The Project Management Association of Japan (PMAJ) defines *project* as "the value creation undertaking based on a specific, which is completed in a given or agreed timeframe and under constraints, including resources and external circumstances" (Japan, 2005, p.15).

Furthermore, a project is defined by Kerzner (2013) as a series of multifunctional activities that have an objective to be achieved with specifications and funding limits, within a time frame, and while consuming resources.

When analysing all these definitions, there are several points of general consensus. Project constraints typically involve scope, time frame, and costs (PMI, 2012). Managing the scope is related to managing what needs to be done, managing time related to assuring the project will be delivered by the proposed deadline, and managing cost related to delivering the project within the approved budget.

The definitions also point out that projects create a unique product, service, result, outcome, or set of deliverables. This uniqueness implies that projects have not been done before with the exact same resources, constraints, objectives, and requirements. All projects have to involve an estimation of costs, normally by analysing the necessary resources, their quantity and for how long they will be needed. In other words, the focus is on the time and budget limits, the need to fulfil an objective, the use of resources, and the uncertainty and uniqueness of the endeavour (Baccarini, 1996; Shenhar & Dvir, 2007; Hendrickson, 2008; Cooke-Davies et al., 2011; ICCPM, 2012).

Even though there was no definition of project that would conflict or contradict the others, some offer other perspectives, such as the focus on value creation as recommended by the Project Management Association of Japan or the need for a business case before the project is launched as proposed by the Association for Project Management. The Project Management Institute (PMI, 2012) actually recognizes that a project manager must go beyond the so-called "triple constraint"—scope, time, and cost. Its recommendation is to also manage the quality of the product to be delivered, the risks to the project, the communication between all people involved, the human resources, the acquisitions and contracts (procurement), and the stakeholders' interactions, while keeping all these areas integrated.

For this research, the definition provided by the Project Management Institute is being used. The reason is that among the articles and books used in this research, the vast majority (over 70%) made reference to the Guide to the Project Management Body of Knowledge (PMBOK). Another reason is that PMBOK is recognized as the world standard for project management (Chin, Yap, & Spowage, 2010).

Once the concept of project is established, the definition of project management follows. Several organizations are dedicated to supporting project managers in their work by providing guidance and sharing approaches and methods to successfully manage projects. Similarly to the concept of project, the following definitions of project management will help clarify how the work of managing a project is viewed in different parts of the world (Alvarez-Dionisi et al., 2016):

- The Project Management Institute defines project management as "the application of knowledge, skills, tools and techniques to project activities to meet the project requirements" (PMI, 2012, p.554).

- The Association for Project Management (APM) defines project management as “the process by which projects are defined, planned, monitored, controlled and delivered so that agreed benefits are realized” (APM, 2006, p.151).
- The APM Group (APMG) International defines project management as “the planning, delegating, monitoring and control of all aspects of the project, and the motivation of those involved, to achieve the project objectives within the expected performance targets for time, cost, quality, scope, benefits and risks” (Commerce, 2009, p.309).
- The International Project Management Association (IPMA) defines project management as “the planning, organising, monitoring and controlling of all aspects of a project and the management and leadership of all involved to achieve the project objectives safely and within agreed criteria for time, cost, scope and performance/quality” (Association, 2009, p.128).
- The Project Management Association of Japan (PMAJ) defines project management as “the professional capability to deliver, with due diligence, a project product that fulfils a given mission, by organizing a dedicated project team, effectively combining the most appropriate technical and managerial methods and techniques and devising the most efficient and effective work breakdown and implementation routes” (Japan, 2005, p.16).

These definitions are aligned with respect to their emphasis on the processes needed for planning, monitoring, and controlling projects, and assuring that the product is delivered as specified (Kerzner, 2013). Similarly to the concept of projects, the definitions of project management only vary by the emphasis on specific areas but they are not in conflict. For instance, both the APM Group International and the International Project Management Association focus on delivering projects within the predetermined scope, time, and cost, and with the expected level of quality or performance, while the Project Management Institute emphasises that this has to be done through knowledge, skills, tools, and techniques. Related to benefits, the Association for Project Management and the APM Group International focuses that this aspect should be considered when managing a project.

Furthermore, it is interesting to note that some of the listed organizations emphasize interpersonal and managerial skills in their definitions of project management. For instance, APMG mentions motivation as an integral part of project management, the IPMA includes leadership, and the PMAJ directly mentions teamwork. Beyond that, focus on safety is proposed by IPMA, and the need for proper due diligence and alignment with the company's mission by the PMAJ.

The American aerospace organization NASA supports the concept that project management cannot consist of only a list of specific steps that should be followed for any and all projects. The concept of 'one size does not fit all' applies to project management as well (Shenhar et al., 2005). In summary, when looking beyond the short definitions provided by each organization all the points above are actually present.

In the next section, a view of complexity will be provided to support the proposed statement that complex projects and the way they are managed should differ from standard projects and approaches. The authors of this research will also propose an original definition of complexity.

2.2. Complexity - Supporting Concepts

This section aims to explore the most referred supporting concepts necessary to understand the definitions of complexity and project complexity.

2.2.1. Complexity Theory and Complex Adaptive Systems

Complexity theory originated from chaos theory in the early 20th century (Levy, 1994; Thiétart & Forgues, 1995; Murphy, 1998; Thomas & Mengel, 2008). Even though complexity theory is more common in mathematics and exact sciences, it has been developed in the social sciences, management, and business as well (Curlee & Gordon, 2011). Edward Lorenz was a meteorologist and is credited as the pioneer in using practical applications for chaos theory in addition to defining the 'butterfly effect' theory. He shared that some things that might not be perceived as being in any order actually were, and that observers of such phenomena were simply incapable of seeing how the elements were connected. A simple example of this is the weather forecast. Why is so difficult to predict the weather with total accuracy? One possible reason is that no one is able to know and control all the possible variables that impact the weather in a given location (Lorenz, 2001).

According to Manson (2001) , complexity theory states that critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties. Considering that the many elements of a system might interact and self-organize, it can be argued that the common approach of breaking down a project into its smaller parts to understand the whole might not be the most appropriate method to deal with complex projects. Once one focuses on a small part in isolation, one loses perspective on how it would interact with the other parts.

An interesting article by Cicmil et al. (2007) provides a good background review of complexity theory and how it relates to project management. According to the authors, the main concepts defining complexity theory are complex adaptive systems, nonlinearity, self-organization, and emergence. Other authors also supports this statement (Baccarini, 1996; Williams, 1999; Remington & Polack, 2007, 2008).

Experience from practitioners suggests that not all parts or components of a project can be controlled. This lack of full control might cause discomfort for project managers and create a sense of uncertainty that is not always welcome. On the other hand, when the project manager and teams embrace the initial 'chaos' as part of the project reality and work towards the resolution of the known parts, there is a tendency to achieve more success considering that all parts will reorganize as time passes. Complexity theory provides a non-common-sense approach since it states that the project manager will not have full control. One recommendation is to be aware that all elements of the project are connected somehow and try to understand the interconnections as much as possible (Curlee & Gordon, 2011). Once this is achieved, the odds of positive results improve. It can be argued that most project managers have a tendency to view the project elements as separate parts or silos instead of trying to understand how they are interconnected.

In 1984, the Santa Fe Institute based in New Mexico, USA, started to study the behaviour of complex adaptive systems (CAS). CAS can be better understood as a framework representing the complexity in natural systems, which would emerge from the interaction of multiple, simple, but adaptive, factors (Murray, 1994; Brownlee, 2007).

Self-Organization is the property of a system self-organizing in an unpredictable way, considering that no external forces act upon that system (Harkema, 1994). Emergence takes into account how diversity and variety arise in order to allow evolution to happen (Cicmil et al., 2007). Nonlinearity takes into account that even small changes in a system may have an unpredictable impact on nonlinear systems, which is one of the aspects of complexity (Aritua, Smith, & Bower, 2009). These references point to the direction that complexity is aligned with the complexity theory and is influenced by the concepts of complex adaptive systems, nonlinearity, self-organization, and emergence. With respect to self-organization, there is no evidence that it can apply to projects because they might have external acting forces, presenting an inherent contradiction to the definition of self-organization.

A complex project is a complex adaptive system (CAS) with the following types of complexity: structural, technical, directional, and temporal. Structural complexity is related to the interrelation and interdependence of the many elements of the project. Technical complexity arises from the challenges of understanding or implementing the project's technical/design requirements. Directional complexity is directly related to unclear or undefined goals, which might be quite common at the early stages of a project. Finally, temporal complexity is the result of the lack of understanding about changes that might occur over time, resulting from internal or external environmental influences (Remington & Polack, 2007).

It can be argued that non-linear behaviour might be a key element of complex projects, which can also be understood as a lack of predictability. If one thinks about complex projects as adaptive systems, there is a need to accept the fact that the project manager, cost estimator, and other stakeholders might not be able to completely understand all the interactions but instead focus on following the system's evolution and adapt to the results as they become apparent. This might seem reactive, but if there is no way to predict all the possible interactions, adaptation to change is crucial for proper management.

The concept behind complex adaptive systems goes beyond being a self-organizing system because the system can learn from its own experience. This learning comes from the adaptation or adjustment to the changing environment. If there are no changes to the environment (rarely on the case in complex projects), there is no need for adaptation, and the less complex the project will be. For a project or any system to be considered a complex adaptive system, it must have the following characteristics (Levin & Ward, 2011):

- It has many elements acting in parallel and without hierarchical control.
- These elements keep changing, creating by consequence multiple levels of organization and structure to support them.
- According to the second law of thermodynamics, the system exhibits entropy and, without additional energy entered into the system, will wind down.
- It allows patterns to be recognized and used to predict future and adaptation to change.

On these grounds, it could be argued that a system that behaves as listed above is considered a complex adaptive system and, therefore, a complex system (Cicmil et al., 2009).

The next section explores the concepts of multi-criteria analysis and the need for adaptation as it pertains to complexity.

2.2.2. The Multi-Criteria Analysis (MCA) and Adaptation

There is a need for a multi-criteria analysis (MCA) to support the decision-making process in complex systems (Baker & English, 2011). The concept and usage of MCA is quite common. According to Baker and English, MCA is used in daily life when people make decisions based on more than one criterion, such as buying a new car. Several criteria could be used during this process; safety, performance, and price, for instance. The same applies to projects where the traditional constraints—scope, quality, time, and cost—are actually criteria for decision-making and estimates, as are profitability and customer satisfaction (Linkov et al., 2006; Marques, Gourc, & Lauras, 2011).

According to the above-mentioned authors, it is clear that a comprehensive set of criteria should be used to better estimate the costs of a complex project, leading by nature to a multi-criteria analysis. The issue with this position according to Diakoulaki & Karangelis (2007) is that there is a natural limitation of the individuals making the decision or assessment related to the level of complexity and uncertainty.

The limited knowledge or experience of these individuals may impact the results of each criterion used. For that matter, the focus would be on criteria that take into consideration the level of competency that the "evaluator" would have during the assessment. The aspect that can hinder the efficiency of an MCA is the amount of information available. This aspect should also be weighted as a risk factor during the decision-making process (Mendoza & Martins, 2006).

The multi-criteria analysis points the practitioner to understand that more than one criterion might be used to manage a project, but also to the fact that one has to adapt to changes. Shenhar and Dvir (2007) introduce an adaptive approach to project management suggesting a multi-dimensional model for the analysis of a project. This adaptive model, also known as "The Diamond Approach," uses four dimensions: complexity, technology, novelty, and pace. Even though the first dimension of this model is called 'complexity', in this research complexity is considered the main topic, not a dimension. For that reason, a more developed multi-dimensional model is proposed in this research, one that includes other aspects that may have a strong impact on a project and on the cost-estimation process. Hence, it is the focus of this research to consider the project complexity factors that will effectively help the estimation process.

The next section will cover the contingency theory, which is closely related to the process of estimating costs and creating contingencies (or buffers).

2.2.3. Contingency Theory

According to Lawrence & Lorsch (1967), the traditional contingency theory states that when external conditions are different they might require different organization characteristics, or in other words the organization might need to adapt to the external conditions to become more effective.. Another way to look into contingency theory is that there are specific situations that can affect the relationships between independent and dependent variables. On the other hand, Shenhar (2001) states that there are ways to support complexity and the management of projects by applying structural contingency theory to today’s project environment. With this in mind, one can argue that there is no perfect way to manage an organization or project unless the internal and external situations are known.

Hence, taking into account that each project has several external conditions that can influence the process of estimating costs and impact its outcome, it can be argued that it is necessary to consider as many conditions as possible. According to Shenhar (2001), the existing project management body of knowledge does not often consider the contingency theory since it proposes the same set of standard characteristics and approaches for any project at any level of complexity or uncertainty. This research found an absence of arguments to contradict the importance of the contingency theory when discussing complexity. With this premise in mind, the “one size does not fit all” argument is quite applicable to projects, and especially complex projects.

The next section brings together the concepts of project management, complexity theory, complex adaptive systems, multi-criteria analysis, adaptation, and contingency theory to contextualize complexity.

2.3. Complexity

This section aims to investigate the concept of complexity, propose a definition to be used during this research, and prepare for the next section that explores project complexity.

Although complexity is a common word, there is not yet a full and commonly accepted explanation of what it is. Different people use complex and complicated in different ways, and there is still a great deal of confusion about them. From the early 20^{th} century to the modern days, there was an increasing development of the concept of complexity. Some authors (Holland, 1995; Kauffman, 1995; Goodwin, 2001; Kurtz & Snowden, 2003; Poli, 2013) invested on clarifying the difference between complicated and complex, whereas others were instrumental to provide a clear view of complexity like Baccarini (1996) and Bar-Yam (2004).

A good start in distinguishing these two words would be to understand their origins. The word "complicated" comes from the Latin *complicatus* (past participle of *complicare*) that means 'to fold together', and is related to projects that have a large amount of parts that are interconnected and interdependent. On the other hand, the word "complex" comes from the Latin *complexus* and *complecti*, which mean 'to entwine', and is related to projects where each individual part can change, and each change might or not affect the other parts (Cooke-Davies et al., 2011).

The table 2.1 below provides an example explaining the difference between simple, complicated, and complex problems (Glouberman & Zimmerman, 2004, p.22):

Table 2.1 – Simple, complicated, and complex problems

Simple: Following a recipe	Complicated: Sending a rocket to the moon	Complex: Raising a child
The recipe is essential.	Formulae are critical and essential.	Formulae have a limited application.
Recipes are tested to assure easy replication.	Sending one rocket increases assurance that the next will be successful.	Raising one child provides experience but not assurance of success with the next.
No particular expertise is required, but cooking expertise increases success rate.	High level of expertise in a variety of fields is necessary for success.	Expertise can contribute but is neither necessary nor sufficient to assure success.

Simple: Following a recipe	Complicated: Sending a rocket to the moon	Complex: Raising a child
Recipes produce standardized products.	Rockets are similar in critical ways.	Every child is unique and must be understood as an individual.
The best recipes give good results every time.	There is a high degree of certainty of outcome.	Uncertainty of outcome remains.

With respect to complexity, the example above illustrates that a step-by-step process can limit project success. Another supporting view is that complexity is not just a matter of size, duration or the number of parts that a specific system has but the fact that the problem does not have an immediate resolution or a specific process to be followed (Bar-Yam, 2004). It can be argued then that there are different possible approaches that would result in failure, but a very limited number (if not only one) that will result in success. The more complex a situation, the harder it is to find the limited options that may lead to success. A consensus view is that complex problems do not have one single approach that can be effectively used, and no author proposed a definitive approach for resolution to complex problems. Rather, each situation might need a different resolution or approach.

Another aspect of complexity pinpointed in Table 2.1 is that neither experience nor expertise/knowledge is enough to assure project success. The claim is that knowledge and understanding will not necessarily eliminate complexity (Cilliers, 2010). The available evidence suggests that the more human knowledge and especially technology advances, the more complex existing systems will become (Bar-Yam, 2004). Organizations are becoming more complex and are dealing with increasingly complex environments. One decision by an individual could impact an entire organization, or a decision of one region may impact the entire world (Rizzo, House, & Lirtzman, 1970). On the other hand, no arguments were found to suggest that knowledge and experience are not a relevant aspect of complexity.

Also present is a definition of complexity related to how difficult (or easy) it is to describe a system. Complexity can be defined as the 'property of a model which makes it difficult to formulate its overall behaviour in a given language, even when given reasonably complete information about its atomic components and their inter-relations' (Edmunds, 1999, p.72). For instance, the amount of effort required to describe a book is much less than what is needed to describe an animal. One can describe something by using words (written or verbal), graphical representations, comparisons, etc. It can be argued that if the understanding of a system is proportional to the understanding of its description, the complexity should be directly related to how well the presenter describes the whole, the parts, and their relationship, but it also depends on the recipient's level of knowledge (Bar-Yam, 2004). For example, how differently would someone describe a chair to a two-year-old child or to an adult? A poor description will create incomplete or faulty understanding, which will directly affect the listener's success in dealing with that system. No further support was found to validate this aspect as relevant to defining complexity.

Complex systems are systems made up of a great number of multiple-interacting components in which it is difficult to understand the behaviour of each individual component and to predict the behaviour of the entire system based on what is known of the starting conditions (Simon, 1996). Complexity can also be seen as a condition between numerous elements in a system and in the numerous ways they can relate to each other (Williams, 2002). Even though Williams (2002) provided a concise definition of complexity, he did not make reference to the interdependence of the elements which is prominent by other authors (Baccarini, 1996; Manson, 2001; Shenhar & Dvir, 2007; Cicmil et al., 2009; Cavanagh, 2011; Cooke-Davies et al., 2011; Curlee & Gordon, 2011). Perhaps a way to deal with complex problems would be to understand the whole by figuring out what each part does. However, this approach rarely works because an important aspect is missing—understanding how each part interacts with the others (Bar-Yam, 2004). The abundance of references about the dependency and interdependency between the elements supports the statement that this condition results in a higher level of uncertainty and difficulty to define, understand, and predict the interaction between the elements and their outcome (Baccarini, 1996; Williams, 2002; Bar-Yam, 2004; Cicmil et al., 2009; Cicmil et al., 2007; Hofkirchner & Schafranek, 2011; Manson, 2001; PMI, 2014).

In conclusion and supported by the references above, the authors of this research put forward for consideration a definition of complexity. The proposed view is that complexity is a dynamic state that has an unknown outcome and an increased level of difficulty since one does not know if or how each part affects or is affected by the other(s).

The next section presents supporting concepts for the definition of project complexity so that the research goes beyond the concept of complexity to prepare the reader to understand the discussions around managing complex projects.

2.4. Project Complexity

This section aims to explore the topics related to complexity in projects and its applicability to manage complex projects. Aligned with the first research objective of exploring the dimensions that determine the complexity of a project, it is necessary to investigate the characteristics that define a complex project.

Baccarini (1996) and Williams (1999) are seminal authors who published articles on complexity that actually serve as a reference to upcoming publications in this area. Some of the reasons for studying and understanding complex projects are: the growing number of projects with some level of complexity and the expectation that this number will continue to grow; how society considers these projects more important than less complex projects; the observation that these projects face great challenges and fail at a greater rate; and the conclusion that not much work has been done on how to deal with them (Merrow, 2011). Supporting the importance of further exploring project complexity, the lack of clear understanding of its meaning might lead project managers to miss the fact that some projects are actually complex systems (Geraldi, 2008). Another argument is that the failure of projects is commonly associated with their complexity (Ivory & Alderman, 2005).

According to the International Centre for Complex Project Management, which is dedicated to developing research and delivering education and support services related to project complexity, complex projects "… are open, emergent and adaptive systems that are characterised by recursiveness and non-linear feedback loops" (ICCPM, 2012, p.6). The concept of adaptation was already discussed in sections 2.2.1 and 2.2.2.

Recursiveness can be understood as the reproduction of sequences of activity and actions or, in other words, doing the same thing several times in order to produce a particular result or effect (Jarzabkowski, 2004). Supporting the significance of emergence and non-linearity, Remington, Zolin, & Turner (2009) indicate that even though complicated projects can be managed using existing processes and best practices, the same approach might not work on complex projects because they exhibit non-linearity and emergent behaviour.

Another aspect to be considered is that project complexity consists of many varied, interrelated, and, hence, unpredictable, parts (Baccarini, 1996). Interrelationship is defined by the way in which two or more elements are connected and affect one another (Dictionary, 2016). The understanding is that several parts of the project are related to others in ways that are known and unknown, hence the complexity. In support of this view, complexity happens when a new property of the system appears from the interaction between its parts, and this property is unknown by the people solving the problem or managing the project (Vidal & Marle, 2008). For instance, it can be argued that in complex projects one might not know what will be the result of an interaction between the elements of that project. In complicated projects, one knows the results of the dependency and interdependency of the elements. The level of difficulty depends on how much is known about the results of these interactions.

Hence, in a systemic view, system complexity is defined as a structural intricacy which takes into account not only the number of parts but also how they are connected, also known as inter-connectedness (Moldoveanu, 2004). Finally, a complex system can be defined as "one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of the parts …" (Simon, 1996, p.183). During the literature review, no arguments existed contrary to the significance of the relationship between the parts and their interrelation and interconnectedness.

Project complexity can also be understood by how much is known about what needs to be done to deliver the product, service, or result. What would be the difference between a complicated and a complex project using this definition? In complicated projects one knows what has to be done, and, by following a specific process, will probably reach the desired result, even though facing some level of difficulty. In complex projects, one does not know what needs to be done (known and unknown unknowns), and even with the use of tools and methods it might not be possible to overcome the existing uncertainties (Cavanagh, 2011).

Aligned with the knowledge of what needs to be delivered by the project, it can be argued that complexity is also associated with the project manager's knowledge and experience. In other words, for a less experienced project manager a project could be considered very complex, but for a more experienced project manager the project could be seen as less complex (Baccarini, 1996). On similar ground, complex projects demand a great deal of management capability, and the use of only traditional approaches developed for non-complex projects is commonly inappropriate (Morris & Hough, 1987). Considering the organization itself, a complex project will only be successful if the capability of the performing organization to deal with complexity is equal to or greater than the complexity of the project itself. In other words, project complexity can be associated with the project manager's or organization's capability to manage that project (Bar-Yam, 2004). These authors point to the importance of knowledge, experience, and capability in managing complex projects from both the individual project manager and the performing organization.

Kerzner and Belack (2010) define five elements of a complex project: size and cost, number and type of interactions, cultural implications, uncertainty, and stakeholders' influence. However, complex projects have to handle other variables, too, like politics, technology, interaction with other organizations' sectors, quantity of information to be managed, existing and new processes to be considered, and project management maturity level (Levin & Ward, 2011). It is proposed by Ivory and Alderman (2005) that there are three distinct aspects of project complexity that need to be considered: the existence of multi-modality (dispersed, fragmented, and not fully understood), the need for bottom-up and top-down intervention by existing stakeholders, and the need for some organizational flexibility ("slack"). As presented before, it can be argued that complex projects involve both linear and non-liner interactions between the human factor (stakeholders) and "process" factors (i.e., technology). Once one is able to separate each of these factors, it becomes easier to identify the main causes of failure. Supporting this view, it is proposed that the concept of project complexity should consider organizational and technological complexity (Baccarini, 1996).

According to the Project Management Institute, "complexity is a characteristic of a program or project or its environment that is difficult to manage due to human behaviour, system behaviour, and ambiguity" (PMI, 2014, p.12). This statement incorporates the significance of human behaviour, with their necessary leadership and interpersonal skills. To manage complex projects, one needs not only to use tools and techniques appropriate to the nature of complexity, but also to develop interpersonal ('soft') skills. These skills also include intuition, holistic thinking, handling competing and sometimes conflicting values or requirements, dealing with internal and external politics, and managing stakeholders (Cicmil et al., 2009).

One common aspect mentioned by the foregoing authors is uncertainty. The Project Management Institute defines a project as "an endeavour undertaken to create a unique product, service, or result" (PMI, 2012, p.3). It can be argued that the uniqueness of a project creates uncertainty because projects will produce something that was never created before with the same resources, constraints, external factors, stakeholders, risks, requirements, and so on. Similarly, it can be reasoned that the ambiguity aspect mentioned by PMI when defining complexity is another factor related to uncertainty (PMI, 2014). Supporting this statement, complex projects could be defined as projects that contain elements of great uncertainty and size (duration and/or budget). Both aspects are being considered since a large project (i.e., several years or USD billions) is not necessarily complex by nature; it may simply be resource intensive. Other projects may have a shorter duration or lower budget but be quite complex (Bar-Yam, 2004).

All these aspects emphasize how complexity dimensions affect projects and the way they should be managed. This is especially important considering that the standard Project Life Cycle (PLC) approach to managing projects presents severe limitations as shown in recent research (Flyvbjerg et al., 2010; Rolstadas et al., 2011).

In summary, the literature does not offer a definitive set of concepts related to complexity, rather different authors have distinct views on this subject. The findings point to a group of complexity factors that appear more often when considering complex projects and will be explored in more detail in the next section.

It is also necessary to explore how to manage complex projects considering the possible challenges in estimating costs. Remington and Polack (2008) examined through a survey the tools and techniques used by people to manage complex projects. They found that the five most important capabilities for people managing complex projects were negotiation skills, flexibility, creativity, communication skills, and relationship management. At the end of the research, the authors contend that there is not one set of specific tools shared by all the successful project managers who manage complex projects, but actually a large variety of tools, techniques, and behaviours. This finding supports the understanding that a successful delivery of a complex project is not related to the tools used. Nevertheless, consideration will be given to which factors may contribute to the successful outcome of complex projects, in particularly those that relate to the estimation process.

The International Centre of Complex Project Management (ICCPM) is focused on studying complex projects and how they can be better managed. The ICCPM partners with several institutions, among them The Institute for Strategy and Complexity Management (ISCM), which created a simulation model called View Point Model (VPM) to 'stress-test' complex projects. The simulation model shows the impact and consequences of decisions made before and during a project. It also helps to identify requirements of expected time and budget. Further, it has a behavioural aspect that is considered important for the future model resulting from this research (ICCPM, 2012).

These approaches deal with parts of the problem but do not provide an integrated model that would necessarily cover the important dimensions and factors needed for the estimation of process. Considering that knowledge is the set of information, ideas, and expertise required to perform a task (Bartol & Srivastava, 2002), it can be argued that a model that provides the information about the potential complexity factors impacting the cost-estimation process would prove to be useful. Such analysis would allow better decision-making by executives and sponsors and provide internal and external groups with the necessary information to support feasible projects or reject unfeasible ones.

The next section provides a further analysis of the most referred complexity factors (hereafter called dimensions) that should be considered when managing complex projects.

2.5. Complexity Dimensions

The findings in the previous section showed that there are several dimensions related to complexity but no analysis was done regarding which dimensions occur more often. Table 2.2 contains 16 complexity dimensions and a summary of the references per dimension.

It can be debated that the absence of dimensions that were referred to only once in the literature is an issue, but considering the large number of potential dimensions, this research is focusing on those with more occurrences. Conversely, a dimension found more often than another is not necessarily more important.

Table 2.2 – Complexity dimensions

Complexity Dimension	Literature Review	
	# References	Authors
1. Dependency and Interdependency	13	(Baccarini, 1996), (Herbemont & César, 1998), (Williams, 2002), (Bar-Yam, 2004), (Remington & Polack, 2007), (Danilovic & Browning, 2007), (Ivory & Aldeman, 2007), (Cicmil et al., 2007), (Vidal & Marle, 2008), (Geraldi, 2008), (Remington, Zolin, & Turner, 2009), (Kerzner & Belack, 2010), (Levin & Ward, 2011).
2. Innovation to Market	8	(Baccarini, 1996), (Herbemont & César, 1998), (Luhmann & Boje, 2001), (Williams, 2002), (Remington & Polack, 2007), (Shenhar & Dvir, 2007), (Vidal & Marle, 2008), (Shenhar, Zhao, Melamed, & Holzmann, 2012).

Complexity Dimension	Literature Review	
	# References	Authors
3. Technology	7	(Baccarini, 1996), (Herbemont & César, 1998), (Williams, 2002), (Shenhar & Dvir, 2007), (Remington & Polack, 2007), (Vidal & Marle, 2008), (Levin & Ward, 2011).
4. Uncertainty	7	(Williams, 2002), (Remington & Polack, 2007), (Danilovic & Browning, 2007), (Shenhar & Dvir, 2007), (Vidal & Marle, 2008), (Remington et al., 2009), (Kerzner & Belack, 2010).
5. External Environment Constraints	6	(Williams, 2002), (Ivory & Alderman, 2005), (Remington & Polack, 2007), (Vidal & Marle, 2008), (Remington et al., 2009), (Cooke-Davies et al., 2011),
6. Political Influence (Politics)	5	(Flyvbjerg, 2005), (Priemus et al., 2008), (Levin & Ward, 2011), (Rolstadås et al., 2011), (Cooke-Davies et al., 2011)
7. Product and Project Size	4	(Vidal & Marle, 2008), (Kerzner & Belack, 2010), (Levin & Ward, 2011).
8. Organizational Capability	4	(Baccarini, 1996), (Herbemont & César, 1998), (Remington & Polack, 2007), (Remington et al., 2009).
9. Time Frame	4	(Herbemont & César, 1998), (Remington & Polack, 2007), (Remington et al., 2009), (Hass, 2009).
10. Stakeholder Interactions	4	(Flyvbjerg, 2005; Remington et al., 2009), (Cooke-Davies et al., 2011).
11. Clarity of Goals	3	(Turner & Cochrane, 1993), (Remington et al., 2009), (Cooke-Davies et al., 2011).
12. Risk	3	(Shenhar & Dvir, 2007), Kerzner & Belack, 2010), (Levin & Ward, 2011).
13. Degree of Trust	2	Muler & Geraldi, 2007), (Geraldi, 2008).
14. Project Management Maturity Level*	2	(Kerzner & Belack, 2010), (Levin & Ward, 2011).
15. Project Description	2	(Bar-Yam, 2004), (Remington et al., 2009).
16. Pace/Speed to Market	2	(Shenhar, 2001), (Shenhar & Dvir, 2007).

Each of the 16 dimensions is explained conceptually below to allow a better understanding of its meaning and applicability. To provide even more clarity, a proposed grading system with levels 1, 2, 3, and 4 is provided. Level 1 would be the best scenario or the lowest possible level of complexity. Level 4 would be the worst scenario of complexity or the highest possible level of complexity. The premise for this approach is that it would be helpful for someone who does not understand the concept but is able to relate when a grading range is presented. This grading system was based on the existing model created by Shenhar and Dvir (2007) where each of the elements had four levels of complexity.

Once the four levels are defined, the next step was to write a description for each level. That description was discussed with the researcher local advisor and pre-validated by three potential participants. Their feedback was used to update the descriptions and then used during the survey. No comments from the 54 survey participants indicated any issues with the description of each dimension levels.

2.5.1. Dependency and Interdependency

One aspect of project complexity is "consisting of many varied interrelated parts," where interdependency is an important part (Baccarini, 1996). Clearly addressing interdependence and dependence of the parts and how each part can affect the others is also necessary. What would happen if one applies change to one or a few parts? Would the entire system be affected? On one hand, there may be changes in some parts that have no or minimal impact on the whole. On the other hand, the opposite is also true: one change could have a great impact on the entire system (Bar-Yam, 2004).

According to the Remington et al (2009), the number and interdependency of elements was one of the five dimensions of complexity identified. The other four were goals, means to achieve goals, timescale of projects, and environment—market, political, and regulatory.

To better understand complexity and complex systems, one must consider the concept of interdependence. It is not just about 'breaking' the "whole" into its "parts", but in how the parts interact with each other. This dimension deals with the relationship between the elements that are part of the project. This relationship can be of dependency (relationship in which some elements are dependent and some are not) and/or interdependency (relationship in which each element is mutually dependent on the others). It also refers to how much integration is needed between the elements of the project. In complex projects, stakeholders might not know what the result of an interaction between the elements of that project will be.

In the grading system described below, Level 1 is the best scenario, whereby any dependency and interdependency between the elements of the project is clearly understood, or in other words the level of complexity is the lowest possible. In the same way, Level 4 would be the worst or most complex scenario, where there is no understanding of the dependency and interdependency between the elements of the project.

Example: The weather forecast, where we don't know how, or if, a specific event occurring in another part of the world will impact the local weather, as in the "butterfly effect" (Lorenz, 2001).

L1. There is complete understanding by the decision maker, project manager, and team of the dependency and interdependency of all elements of the project.
L2. There is partial understanding by the decision maker, project manager, and team of the dependency and interdependency of all elements of the project.
L3. There is very limited understanding by the decision maker, project manager, and team of the dependency and interdependency of all elements of the project.
L4. The decision maker, project manager, and team are not capable of understanding the interdependence or independence of the elements of the project.

2.5.2. Innovation to Market

Recent discussions point to the challenge of innovation in highly complex projects. The authors use the example of the Boeing Dreamliner 787 project, showing how the innovation level was the key reason for the high difficulty and the reason for cost and schedule overruns (Shenhar et al., 2012).

In a study that analyses the tools for complex projects, it is proposed that innovation directly impacts the process of managing complex projects and the effectiveness of the cost-estimation process (Remington & Polack, 2007). The importance of innovation is also linked to organizational and technological complexity (Vidal & Marle, 2008). Both organizational and technological complexity were considered key aspects of complexity according to Baccarini (1996), hence it can be concluded that innovation should also be considered a relevant dimension. This dimension is related to the level of innovation of the product generated by the project. Innovation level impacts market-related activities, time, and effort to define and "freeze" requirements. The higher the innovation level, the more difficult it is to establish and keep the requirements as originally defined (Shenhar et al., 2012).

Example: Releasing an existing product with a new colour involves a lower level of innovation than the launch of Post-it® notes, which no one had used before (Shenhar & Dvir, 2007).

L1. Derivative: The product is an extension or improvement of existing products, with a low level of innovation (e.g., a new colour for an existing product).

L2. Platform: A new generation on an existing product line. The product replaces the previous version of an existing product with a moderate level of innovation (e.g., a new automobile model).

L3. New-to-the-Market: The product, even though existing in other markets, does not exist in the target market, and a high level of innovation is required (e.g., the first personal computer).

L4. New-to-the-World: The product never existed before in the world. It transforms new concepts/ideas into new products, with a very high level of innovation (e.g., the first Post-it® note).

2.5.3. Technology

The term *technology* is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used on a specific project. Normally technology complexity is found in projects that use a new or untried technology (Remington & Polack, 2007). Furthermore, the Diamond framework (Shenhar & Dvir, 2007) divides technology uncertainty into four distinct levels—low, medium, high, and super high tech. Another concept of technology is the transformation process that converts inputs into outputs when utilizing materials, means, techniques, knowledge, and skills (Baccarini, 1996). The complexity in this case would be associated with the number and variation of inputs and possible outputs (which one cannot ascertain). The less the team or performing organization knows or has used that technology, the more complex the project will become.

Example: The Apollo program, which had the objective of landing Americans on the moon and returning them safely to Earth, had to create technologies that were never used before. For this dimension, the Diamond framework will be used to define the four possible levels of technology complexity, or, as Shenhar and Dvir (2007) describe, technology uncertainty.

L1. Low-tech: No new technology is used. The project uses only low-tech technology that is already existent and well established. These technologies normally do not have a significant level of uncertainty or difficulty (e.g., a house).

L2. Medium-tech: Some new technology. The project uses mostly medium-tech technology, which can be characterized as based on existing technologies or a limited use of new technologies (e.g., a new automobile).

L3. High-tech: All or mostly new but existing technology. The project uses many new technologies that have been recently developed. It might use technology for the first time, but that technology was already created (e.g., the satellite).
L4. Super high-tech: Critical technologies do not exist. The project uses or has to develop a technology that never existed before. The level of uncertainty is very high and the outcome cannot be established (e.g., the Apollo program/moon landing).

2.5.4. Uncertainty

Uncertainty presented itself as an important aspect of complexity, since one cannot forecast the outcome of the interactions between elements, which makes managing complex projects very challenging.

Even though complexity is different from uncertainty (Baccarini, 1996), uncertainty can be considered as a dimension that can increase or decrease the level of complexity of a project. Furthermore, looking into where complexity comes from, the statement "Complexity, very generally, is a result of interrelationships and feedback between increasing number of areas of uncertainty and ambiguity" (Remington & Polack, 2007, p.20) shows how important uncertainty is when related to complexity. The Project Management Institute states that uncertainty in programs and projects 'may be described as a lack of awareness and understanding of issues, events, path to follow, or solutions to pursue' (PMI, 2014, p.20).The Cambridge Dictionary (2016) defines the word 'uncertainty' as "a situation in which something is not known, or something that is not known or certain", so it can be concluded that uncertainty is an undesirable effect of project complexity (Vidal & Marle, 2008).

This dimension is related to the level of uncertainty existing, not just in a project but also in the product, or in the development process. Other dimensions can also impact the level of uncertainty, like innovation to market and technology.

Example: Developing a new drug where the side effects are not known. For this research, an adaptation of the work of H. Courtney is used as below (Courtney, 2003).

L1. Low level of uncertainty: While there is confidence on the outcome, there are some key variables for which one does not have precise values. It is possible to make some estimates, or to establish some "most likely lows" and "most likely highs" and then plan for the range.

L2. Medium level of uncertainty: There is a variety of future scenarios, but it is possible to list them, and they are mutually exclusive and exhaustive.
L3. High level of uncertainty: There are scenarios that can be constructed, but they are more illustrative of possibilities rather than an exhaustive listing.
L4. Complete uncertainty: In some cases, it is impossible to even frame scenarios. The understanding is so unstable that any scenario is merely a wish list. It may be years before the possibilities sort themselves out.

2.5.5. External Environment Constraints

The external environment can be a significant factor to influence the level of complexity on a project (Cooke-Davies et al., 2011). Aspects like a change of existing regulations or the dynamism of the market or regulatory environment were also mentioned in articles about this subject (Remington & Polack, 2007). It is also stated that the main determinant for complexity of the project management process includes the market and regulatory context (Ivory & Alderman, 2005). These references support that external influences play an important role in creating additional complexity in projects. It can be argued that some external constraints affect more or less specific projects but nonetheless there was no argument on the contrary.

Summarising, this dimension is related to the existing external environment of an organization (on a local, regional, country, or global level) and how it adds to the complexity of a project. Factors such as changes to existing regulations, the fluctuation of the market, and a shift in the political or regulatory environment are included here (Vidal & Marle, 2008).

Example: A change in taxation can significantly impact the feasibility of a project.

L1. The external environment has no impact on the project.
L2. The external environment has limited or very punctual impact on the project.
L3. The external environment has considerable impact on the project, affecting the capability to perform the work needed to deliver the product.
L4. The external environment has potentially catastrophic impact on the project, which will not allow the project to proceed.

2.5.6. Political Influence (Politics)

The concept of political influence or politics is presented in this research from both internal and external perspectives. Internal political influence means the politics between the organization's stakeholders, for instance but not limited to executives, managers, other departments, and regions. External political influence is related to any stakeholder outside the organization with interest in the project, for instance but not limited to government bodies, regulatory agencies, other organizations, and external investment companies.

Supported by several authors, political influence is one dimension that should be considered when managing complex projects (Flyvbjerg, 2005; Priemus et al., 2008). Generally, the stronger the political influence, the higher the chances for an overestimation of benefits and underestimation of costs, leading to the approval of that project and attending the interests of key stakeholders. It can be reasoned that complexity will occur when people from different interests, cultures, and perspectives, work together to deliver a project, which can also be defined as 'organizational politics' (Cooke-Davies et al., 2011).

In summary, this dimension is related to the level of internal or external political influence involved in the project. If there are political influence and interests to approve a project that might not be feasible, the chances for an overestimation of benefits and underestimation of costs are higher (Jaafari, 2001; Dill & Pearson, 2013).

Example: The Eurotunnel project suffered extensive political influence and after implemented it was confirmed that it was underestimated on costs and overestimated on benefits (Anguera, 2006).

- L1. No political influence or interest with no impact on the project.
- L2. Limited or very punctual political influence or interest, with minimal impact on the project.
- L3. Considerable or spread political influence or interest, with considerable impact on the project.
- L4. Strong and multi-level political influence or interest, with major impact on the project.

2.5.7. Product and Project Size

Product or project size is another proposed dimension for project complexity (Vidal & Marle, 2008). Actually, Corbett and Campbell-Hunt (2002) claim that a project should be over a minimal size to be considered a complex project. This claim could be controversial since there is no clear definition of what is a minimal size and what type of size is being considered—number of parts, duration, budget, number of resources involved, and so on. The challenge is to identify which are the parameters to define a product or project size related to its complexity. Another way to look into this is to define what size of project/product is the company used to managing. For a company that manages projects up to a specific size or type, a larger endeavour would probably be characterized as more complex (Kerzner & Belack, 2010).

For clarification purposes, the premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple endeavour would be to deliver a standard component, followed by subsystem, moving to deliver an entire system, and finally to produce an array or system of systems (Shenhar & Dvir, 2007).

Example: The London Olympics involved many different parts and sub-projects, several years to complete, and a budget on the order of Billion Pounds £ (Flyvbjerg, Holm, & Buhl, 2002).

- L1. Standard: The project objective is to deliver a single component, with minimal amount of work. For example, delivering a standard memory chip.
- L2. Subsystem: The project objective is to deliver a set of components that interact to produce a sub-system, where the amount of work is still within the range of capabilities of the performing organization. For example, assembling a motherboard.
- L3. System: The project objective is to deliver a series of sub-systems that together produce a system, which requires a greater amount of work and interaction between several parts. For example, a new computer.
- L4. Array: The project objective is to deliver an array or series of systems and the work to be performed is beyond the capabilities of the performing organization. For example, a computer network that was not being installed before.

2.5.8. Organizational Capability

This dimension is related to how capable, structurally and technically, an organization is in managing the project and delivering the required product. It is also directly associated with the appropriate selection of project personnel (Remington et al., 2009). Supporting this view, the functions of the organizational structure involve the communication and reporting process, how the responsibilities and authorities are allocated, and how the tasks are assigned

(Baccarini, 1996). It can be argued that any project could be considered complex if the performing organization does not have the proper structure to manage and implement it, or if the organization has limited personnel to deliver the project, or even if the people involved are not properly trained to do the necessary work. The contrary can also be reasoned since the organization might have the capability needed, decreasing the complexity level (Herbemont & César, 1998; Remington & Polack, 2007).

Example: A company that does not have technical employees with experience developing applications on the "cloud" would encounter an extra layer of complexity when they engage in such a project (Cooke-Davies et al., 2011).

- L1. The organization is capable of delivering this type of project with proper structure and technical knowledge to support the management of the project and development of the product.
- L2. The organization has limited capability to deliver this type of project, will need to make some adjustment to the organizational structure, and has proper technical knowledge to support the management of the project and development of the product.
- L3. The organization has very limited capability to deliver this type of project, an inadequate organizational structure, and limited technical knowledge to support the management of the project and development of the product.
- L4. The organization has no capability to deliver this type of project, an inadequate organizational structure, and no technical knowledge to support the management of the project and development of the product.

2.5.9. Time Frame

According to Remington and Pollack (2007), there are four types of complexity dimensions—structural, technical, directional, and temporal. The last one is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. Time is often being described as having a direct effect on how complexity is perceived by project team members and stakeholders (Remington et al., 2009).

Timeframe is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the timeframe of the project, notably with ones that have long durations. The longer the timeframe, the more chances that changes will impact the project, which increases the level of complexity.

Similarly, it is stated that "One of the biggest problems with long-term projects is that so many unforeseen things can happen" (Hass, 2009, p.118).

Example: Building the necessary transportation infrastructure for the 2014 Soccer World Cup was impacted by changes in priorities during the length of the project and ended up not being implemented (Frawley & Adair, 2014).

- L1. There is no change of decision makers, the requirements are stable, and the key relations and project plans remain the same over time.
- L2. The change of decision makers over time is not significant, the key requirements are stable over time, and the key relations and project plans remain almost the same over time.
- L3. There are significant changes of decision makers and the requirements over time, and key relations and project plans are also changing over time.
- L4. The decision makers changed over time and had conflicting interests, the requirements changed, producing a different product, and the key relations and project plans were completely changed.

2.5.10. Stakeholders Interaction

According to PMI, "a stakeholder is an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project" (PMI, 2012, p.563). This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening in the project (Cooke-Davies et al., 2011).

The following situations with stakeholders' interaction might increase the project complexity level: existence of multiple decision makers, customers, and suppliers; unrealistic expectations by senior stakeholders and clients; inappropriate senior level support; and changing requirements by stakeholders (Remington et al., 2009).

Example: Financial managers in the company may look at the budget and meeting schedules, while technical managers may be concerned with the best solution for the customer, and may recommend increasing the budget to overcome unexpected problems, or take advantage of new opportunities (Levin & Ward, 2011).

L1. The key stakeholders are aligned with the project objectives and requirements. Their interaction is effective and the high-level executives provide the necessary support for project success.
L2. Most key stakeholders are aligned with the project objectives and requirements. Their interaction is good but sometimes there is some "noise". Mostly the high-level executives provide the necessary support for project success.
L3. Most of the key stakeholders are not aligned with the project objectives and requirements. Their interaction is not effective and many issues arise due to poor stakeholder interaction. There is very limited support from high-level executives.
L4. The key stakeholders are not aligned with the project objectives and requirements, with common conflicts and re-work. Their interaction is ineffective and there is no support from high-level executives to ensure project success.

2.5.11. Clarity of Goals

This dimension defines how well-defined the goals of the project are and the impact this has on how the project is managed and decisions made. The lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance (Turner & Cochrane, 1993; Remington et al., 2009). This dimension is also referred to as a directional complexity or one that arises as the result of a change in project direction, creating unclear goals. These changes normally appear at the beginning of the project due to technical or environmental changes (Cooke-Davies et al., 2011).

Example: A goal of 'improving the work environment' is vague, not measurable, and not specific, hence different stakeholders may interpret it very differently (Turner & Cochrane, 1993).

L1. The goals are well defined, with a clear understanding of the deliverables and objectives by all stakeholders (project manager, team members, decision makers, customers, suppliers, and partners). The early decisions made during the feasibility study are still valid when the project progresses.
L2. The goals are in most part properly defined, with good understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision makers, customers, suppliers, and partners). The early decisions made during the feasibility study may vary when the project progresses.

L3. The goals are not well defined, with unclear understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision makers, customers, suppliers, and partners). The early decisions made during the feasibility study are mostly invalid.

L4. The goals are not defined at all and there is no understanding of the deliverables or objectives by all stakeholders (project manager, team members, decision makers, customers, suppliers, and partners). The early decisions made during the feasibility study are not being considered any longer.

2.5.12. Risk

Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project (Levin & Ward, 2011). Also it becomes clear that the more risks—especially the unknown ones—the more complex a project might be, since one does not know what can happen or the potential repercussion to the other elements of the project (Kerzner & Belack, 2010).

This dimension defines specifically how much unknown (known-unknowns and unknown-unknowns) risks exist in a project and possible impacts to the management process and delivery of the final product. Managing risks entails implementing processes directed to reduce the impact and/or probability of negative risks (also known as threats), or to maximize the impact and/or probability of positive risks (also known as opportunities) (Shenhar & Dvir, 2007).

L1. The project risks are well known, and the team has experience managing them.

L2. The project does not have a significant amount of unknown risks, and people with previous experience with them can manage the existing ones.

L3. The project has a large amount of unknown risks, and the team has very limited experience managing them.

L4. Almost all risks are unknown, mostly unknown-unknown risks. The team has no experience managing them.

2.5.13. Degree of Trust

This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (i.e., supplier and project team; senior management and project manager). The more trust there is, the less complex the project would be (Muler & Geraldi, 2007). Trust is not forced throughout the organization but earned by the performing team and other stakeholders. Similarly, when there is a lack of trust the chances for issues and increased complexity are greater (Geraldi, 2008).

Example: If a project manager does not trust the team—and for that reason does not share sensitive but important information—there is an additional level of complexity due to the lack of transparency and clear communication (Cavanagh, 2011).

L1. There is trust among all the project stakeholders and they have been working together for a long time.
L2. There might be some trust issues among some stakeholders but nothing that should impact the results of the project.
L3. There is a lack of trust among key stakeholders, which can jeopardize the process of managing the project and delivering the product.
L4. The lack of trust among all stakeholders is evident and the results will probably not be achieved. There is a need for intervention.

2.5.14. Project Management Maturity Level

This dimension addresses the degree of relative maturity that the organization has achieved in project management. There are several models that measure project management maturity levels but all of them are based on the five-level original Capability Maturity Model (CMM) first described in the book *Managing the Software Process* (Humphrey, 1989).

The assumption is that more mature organizations will be better able to manage complex projects and deliver the products (Levin & Ward, 2011). Just to serve as a reference, the Kerzner Project Management Maturity Model will be used, where Level 1 is the existence of common language; Level 2 is when there are common processes to manage projects; Level 3 is when a project management methodology is implemented; Level 4 when the organization starts doing benchmark with others; and Level 5 is when the organization achieves a state of continuous improvement (Kerzner, 2005). It can be debated that the dimensions of organizational capability and project management maturity level are similar and could be consolidated. This discussion will be conducted in Chapter 6.

Example: A company like IBM, which has a more mature project management level, will be better equipped to manage the adaptive nature of complex IT projects than a company that is still working to get a common project management language implemented (Kerzner & Belack, 2010).

L1. The organization has achieved a project management maturity level 4 or 5.
L2. The organization has achieved a project management maturity level 3.
L3. The organization has achieved a project management maturity level 2.
L4. The organization is immature in project management or is only at level 1.

2.5.15. Project Description

This dimension focuses on the level of difficulty encountered when describing the project, including all of its elements (Bar-Yam, 2004). Even though this might be influenced by how much knowledge or experience one has with a specific type of project, it is not the same as the dimension knowledge and experience. It is possible to have knowledge and experience about a project but be challenged when describing the project and its scope, interactions, and components (Remington et al., 2009).

Example: Describing a project to create new software to manage the stock market for an audience that has no financial literacy (Cicmil et al., 2009).

L1. The project can be easily described with all its components and all the stakeholders can understand it.
L2. The project can be easily described with most of its components and all the key stakeholders can understand it.
L3. It is not easy to describe the project with all its components and not all the stakeholders can understand it.
L4. It is not possible to describe the project with all its components and the stakeholders have a limited understanding of it.

2.5.16. Pace / Speed to Market

This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the project be aligned with the market demands (Shenhar, 2001). The Diamond framework by Shenhar and Dvir will be used a reference. The pace will be defined as regular, fast, time-critical, or blitz.

The less time to manage a project and deliver a product, the more layers of complexity can be added.

Example: Responding to a catastrophe (i.e., 2005 Hurricane Katrina, 2010 Gulf of Mexico oil spill) with limited time to plan and execute is much more complex than implementing a frequently executed type of project (Shenhar & Dvir, 2007).

L1. Regular: The time to deliver (pace) the product is not critical to the success of the organization.
L2. Fast: The time to complete the project is important for competitive advantage, and not delivering on time might have a negative impact on the organization.
L3. Time-critical: The time to deliver the product is critical for project success and delays can be reflected as failure of the project.
L4. Blitz: Not only is the time to deliver critical, but is considered as a crisis; therefore delivery cannot be delayed for any reason.

After covering the concepts of project, project management, complexity, and the complexity dimensions in the previous five sections, the upcoming three sections will explore the cost-estimation process, provide some examples of cost estimation on project-based industries, and describe the impact of complexity in cost estimates.

2.6. The Cost-Estimation Process

Drawing on the project management and complexity concepts presented in the previous chapter, this section will explore the cost-estimation process as pertaining to projects.

The Project Management Institute (PMI) started presenting project management concepts in 1969 and one of the main areas was cost estimation process in projects. Through many publications of its Guide to the Project Management Body of Knowledge (PMBOK) – years 1996, 2000, 2004, 2008 and 2012, PMI has shared the improvements on how project managers should manage costs more effectively.

To successfully manage a project, the following areas have to be properly addressed: scope, time, cost, quality, human resources, risks, communications, procurement, stakeholders, and integration (PMI, 2012). One of them is cost management, which includes the cost estimation of all activities and effort necessary to deliver the project. Cost estimation is not just an exclusive process used in projects but an on-going operation (not temporary or repetitive) in areas like manufacturing (Ozbayrak, Akgun, & Turker, 2004), banking (Ferrier & Lovell, 1990), and education (Duncombe, Ruggiero, & Yinger, 1995), just to name a few.

As supported by several authors, it is common to observe cost overruns on projects, especially those that are considered complex (Flyvbjerg et al., 2002; Baccarini, 2005; Olaniran et al., 2015). The reason for that may vary from unrealistic timeframe, uncontrolled changes of scope (also known as scope creep), novelty, technology level, or speed to market (Shenhar & Dvir, 2007), but another view consolidates all these factors under the name 'complexity'. Under this argument, complexity carries a strong influence over several aspects of the project, notably cost management (Kaming, Olomolaiye, Holt, & Harris, 1997).

Even though cost overruns are commonly associated with misrepresentation of the reality of that project with the objective of getting that project approved (Flyvbjerg, 2005), a confronting view argues that this is not necessarily the case. Factors mentioned in the previous paragraph related to scope, time, stakeholders, and other might be the main cause for a faulty estimate (Shane, Molenaar, Anderson, & Schexnayder, 2009).

Another way to consider the cost-estimation process is to look into the cause-effect relationship. The recommendation is to consider each event that can cause effect on the project (a.k.a. the butterfly effect) and estimate the cost. Once another event (or episode) occurs or is known, an update of the cost estimate should be done. This will mitigate the creation of a rigid estimate, which normally does not produce the best results (Overman & Loraine, 1994).

The project-management processes presented by the Project Management Institute (PMI, 2012) are divided into Inputs (what needs to be considered for each process to be executed), Outputs (the expected results or deliverables of that process), and Tools & Techniques (how to transform the Inputs into Outputs). The representation of the cost-estimation process follows the same approach as represented in Figure 2.1 below.

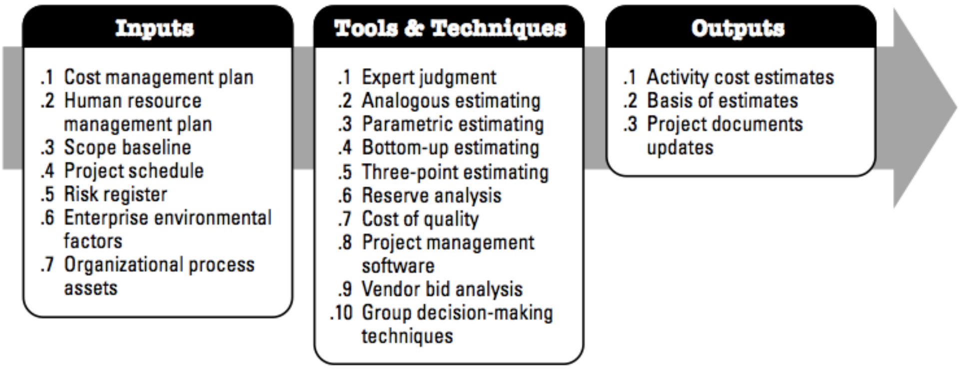


Figure 2.1 – PMI cost-estimation process (PMI, 2012, p.200)

Similarly, the Practice Standard for Project Estimating published by the Project Management Institute (PMI, 2011) describes the estimation approach as presented in Figure 2.2 below:

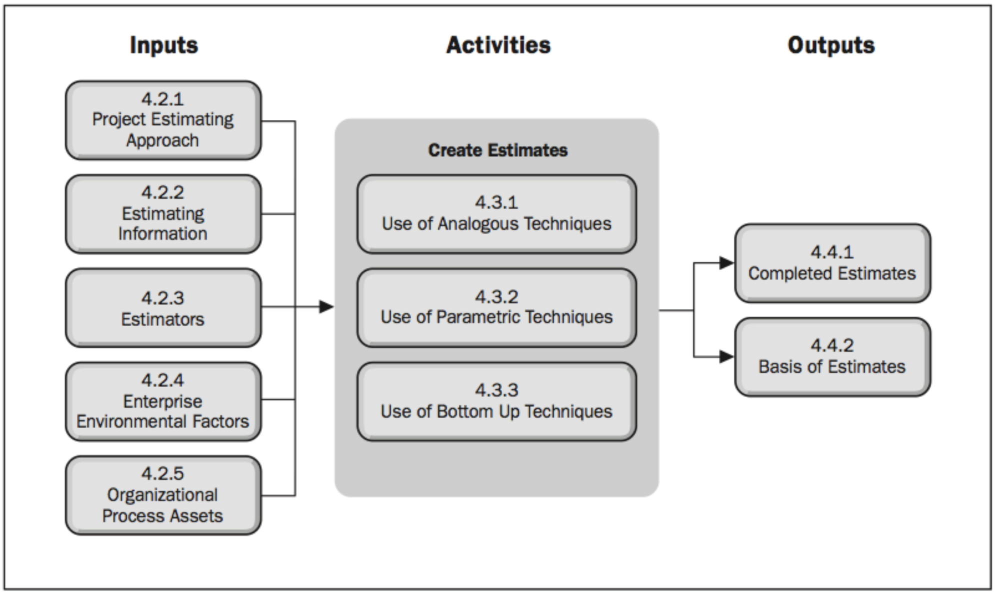


Figure 2.2 – Create estimates process (PMI, 2011, p.26)

2.6.1. Inputs for Cost Estimation

According to the Project Management Institute (PMI, 2011, 2012) and described by figures 2.1 and 2.2, the following Inputs are listed:

The project estimating approach is a document that registers which approach(es) will be used to estimate the project. It will explain also the tools and techniques to be used, assumptions, constraints, and directive to perform the estimates.

The estimating information is part of the sources for the estimation, like historical information from similar projects, benchmarks, industry best practices, lessons learned, and any existing information pertaining to the actual project.

The estimators are the people involved in estimating the costs. They are critical for the success of the cost estimate since their knowledge and experience could prove invaluable to the accuracy of the estimate. The best estimators are the ones who are going to be involved in the work to be delivered, and the difference between the best and the worst estimators could be 10:1 (Sackman, Erikson, & Grant, 1968).

The cost-management plan is a plan that describes how the cost is going to be managed in that project. It can contain techniques to be used, frequency of meetings, usage of a specific tool, etc.

The human resource management plan is similar to the cost-management plan since it describes how human resources will be managed. This is important considering that a great deal of project costs can come from human resources.

The scope baseline refers to the use of the scope statement and the work breakdown structure (WBS), both crucial to the proper understanding of the scope of the project and scope of the product.

The project schedule contains all the activities that need to be performed by the organization, with reference to resources and durations. Both aspects are directly linked to the cost of the project.

The risk register contains all the identified risks for the project. A risk has a probability and an impact and can influence the cost-estimation process, since practitioners have a tendency to add more costs ('buffer') when dealing with negative risks. This is the only aspect that is listed in the complexity dimensions found in this research.

The enterprise environmental factors are considered conditions that can influence, constrain, or direct the project but where the project team has no immediate control (PMI, 2012, p.539). Some enterprise (organizational) factors can influence the cost estimates. An example could be market conditions, since they define which products are available in the market and what are the limitations associated with them (e.g., regional or global supply).

The organizational process assets might include the plans, policies, existing methodologies and templates, previous experience (historical information), and lessons learned database that could influence the cost-estimation process.

The inputs listed were not disputed by other authors, which supports the argument that they are necessary before one starts to estimate costs. It can be argued that less prior information (or inputs) would result in a less accurate cost estimate. The next section will cover the tools and techniques used to estimate costs.

2.6.2. Cost-Estimation Tools and Techniques

The process of estimating costs is well documented, even though not necessarily emphasizing projects. This section will explore some of the most recurrent tools and techniques used when estimating costs for projects and summarize the findings.

The main estimating techniques used in project management for decades are analogous (top-down), parametric, and bottom-up (definitive) as presented in Figure 2.3 (PMI, 2011).

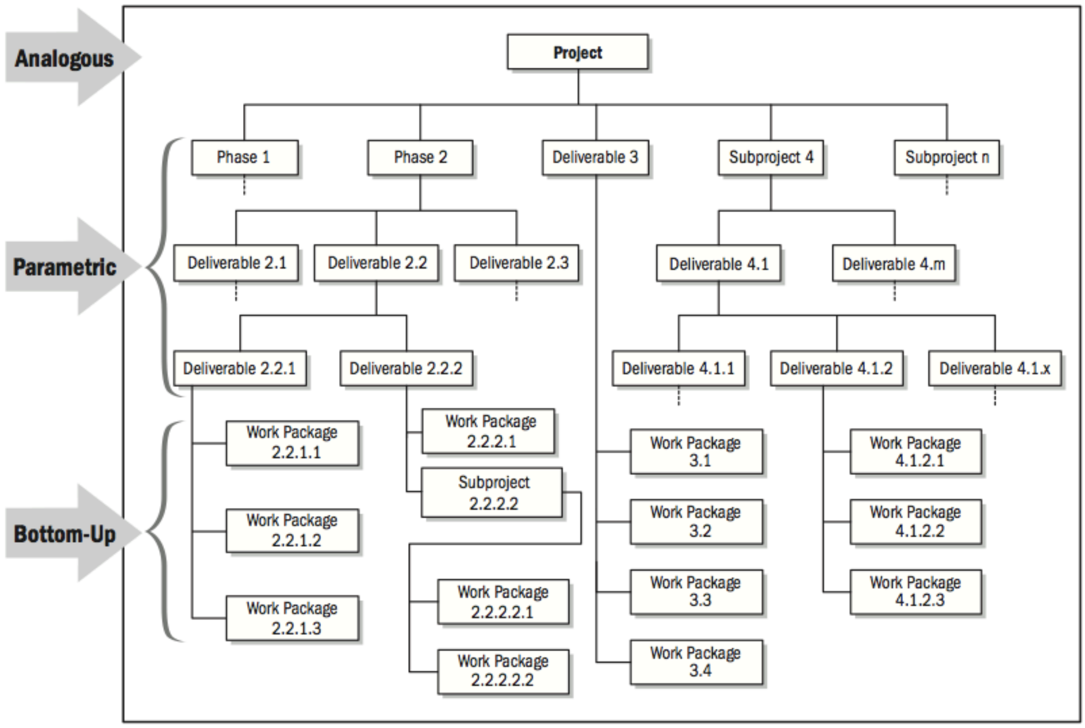


Figure 2.3 - Types of estimating techniques in the context of decomposing a WBS (PMI, 2011, p.28)

Another view is provided below in Table 2.3 with four estimation techniques (Kerzner, 2013). Even though the names are different, three of them are similar—engineering estimates are the same as bottom-up; parametric estimates and scaling are considered as parametric; and the equipment/subsystem analogy estimates are the same as analogous estimates. The last one listed is expert judgment which is normally considered a resource used in different estimation techniques (Jorgensen, 2004) but is also listed by the Project Management Institute as one of the estimating techniques (PMI, 2012).

Table 2.3 – Estimating methods (PMI, 2012, p.578)

Estimating technique	Application	Advantages	Disadvantages
Engineering estimates (empirical)	Reprocurement Production Development	- Most detailed technique - Best inherent accuracy - Provides best estimating base for future program change estimates	- Requires detailed programs and product definition - Time-consuming and may be expensive - Subject to engineering bias - May overlook system integration costs
Parametric estimates and scaling (statistical)	Production Development	- Application is simple and low cost - Statistical database can provide expected value and prediction intervals - Can be used for equipment or systems prior to detailed design or program planning	- Requires parametric cost relationships to be established - Limited frequently to specific subsystems or functional hardware of systems - Depends on quantity and quality of the data - Limited by data and number of independent variables
Equipment/ subsystem analogy estimates (comparative)	Reprocurement Production Development Program Planning	- Relatively simple - Low cost - Emphasizes incremental program and product changes - Good accuracy for similar systems	- Requires analogous product and program data - Limited to stable technology - Narrow range of electronic applications - May be limited to systems and equipment built by the same firm
Expert opinion	All program phases	- Available when there is insufficient data, parametric cost relationships, or program/product definition	- Subjected to bias - Increased product or program complexity can degrade estimate - Estimate substantiation is not quantifiable

Analogous estimating

Analogous estimating is also known as top-down estimating, which means that one does not have a lot of information about the project and/or does not have enough time to develop a more detailed estimate or limited information is available (i.e., early stages of a project or during the feasibility analysis period). This type of estimate makes a comparison between the project to be estimated and a previous similar one. The use of historical information and experts is frequently required. The use of experts is advisable since they have more experience with projects of that nature, which will reduce the chances of under- or over-estimation. The most common analogous approaches are ratio, range, and PERT (three-point) estimating (PMI, 2011, 2012). When analysing recent and future trends in cost estimation for product development, analogous estimating was identified as one of the techniques used and some of the shortcomings identified, like a lower level of accuracy and dependence on previous information from similar projects (Layer et al, 2002).

The ratio-estimating approach is also known as a capacity factor. This technique assumes that there is a direct relationship between the total cost of the project and some (one or more) of its deliverables (PMI, 2011). An example from the construction industry would be a project whose cost was equal to two times the cost of materials. Another view is shared by, but not limited to, the software development industry, where ratio is one of the continuous variables together with interval and absolute scale. This analogous estimation approach has some vulnerability considering the reliability of the ratio for a specific project. In other words, a ratio might work properly for one project and not for another (Shepperd & Schofield, 1997).

The range-estimating approach is simply providing a variation range for the estimate. Instead of using a single amount, the estimate is provided through a range of values. To improve reliability, the cost estimator should not only provide the most likely estimate but a range that considers different scenarios (PMI, 2011). For instance, the project will cost USD 500,000 ± 10%, or the project will cost between USD 450,000 and USD 550,000. It is pointed out that there are limitations in using range-cost estimation in the construction industry. The range estimation process is based on breaking down the project into smaller parts and defining ranges for each work package using statistical analysis (i.e., Monte Carlo simulation). The main difficulties are to define values for subjective data and the number of necessary simulations. One recommendation is to rely more on experts for input to possible costs for the work to be done (Shaheen, AbouRizk, & Fayek, 2007).

The PERT (Programme Evaluation & Review Technique) is also known as a three-point estimate, which is also a type of range-estimation approach. It uses a weighted average between three possible estimates: the optimistic (when everything goes as planned), the pessimistic (when everything that can go wrong will go wrong and you have to do it all over again), and the most likely (your best guess). This approach is used when there is great uncertainty in estimating the cost of an activity, work package, or the entire project (PMI, 2011, 2012).

The most used common formula for PERT uses the Beta distribution, where one adds the optimistic estimate (O), the pessimistic estimate (P), and four times the most likely estimate (ML), dividing the result of this sum by 6.

$$PERT = (O + P + 4 \times ML)/6$$

Another formula for PERT uses the Triangular distribution, where one adds the optimistic estimate (O), the pessimistic estimate (P), and the most likely estimate (ML), dividing the result of this sum by 3.

$$PERT = (O + P + ML)/3$$

Parametric estimating

Parametric estimating uses the relationship between variables to estimate the cost necessary to perform the work of the project. These variables are also called parameters. Parametric estimation is useful when more information is available for the estimator. Normally a parameter is used to estimate the first levels of the work breakdown structure (e.g., floor area in construction, function-points in software development). When a parametric estimation is applied, one has to create or use a model that uses the parameter(s) and enter the necessary information to obtain the values for cost, number of resources, or any other relevant information (PMI, 2011, 2012).

Parametric estimation has independent variables that are a function of size, productivity, and complexity, and dependent variables as the effort. That points to the possibility of using parametric estimation when dealing with complexity. This estimation process includes several steps like data gathering, normalization, defining what the author calls 'cost estimation relationships' (CER) through statistical analysis, a testing hypothesis, and using the model itself (Cooke-Davies et al., 2011).

Even though there are many parametric estimation models on the market, one can create his or her own. Another key aspect when dealing with the estimation process is the need to develop a business case. Business cases are not exactly an easy task for technical people but are necessary when presenting the return of investment (ROI), or any other financial measurement of added value for that matter, to top executives. There is a tendency for estimators to be overly optimistic when they estimate, even when they try to be pessimistic. The use of experts, with previous knowledge and experience about that specific project, can mitigate the effects of cost underestimation.

Parametric estimation can be used as a successful approach to define an early stage project budget when a good case study is available, together with reliable historical information.

These are estimates based on previous projects, historical data, and previous experience from cost estimators and project managers. The more experience the estimator has with that type of project, the greater the expected accuracy. The opposite is also true; a lack of knowledge and experience with similar projects was considered as one of the complexity dimensions.

An adaptation of the parametric estimation process (Cooke-Davies et al., 2011) is presented in Figure 2.4 below:

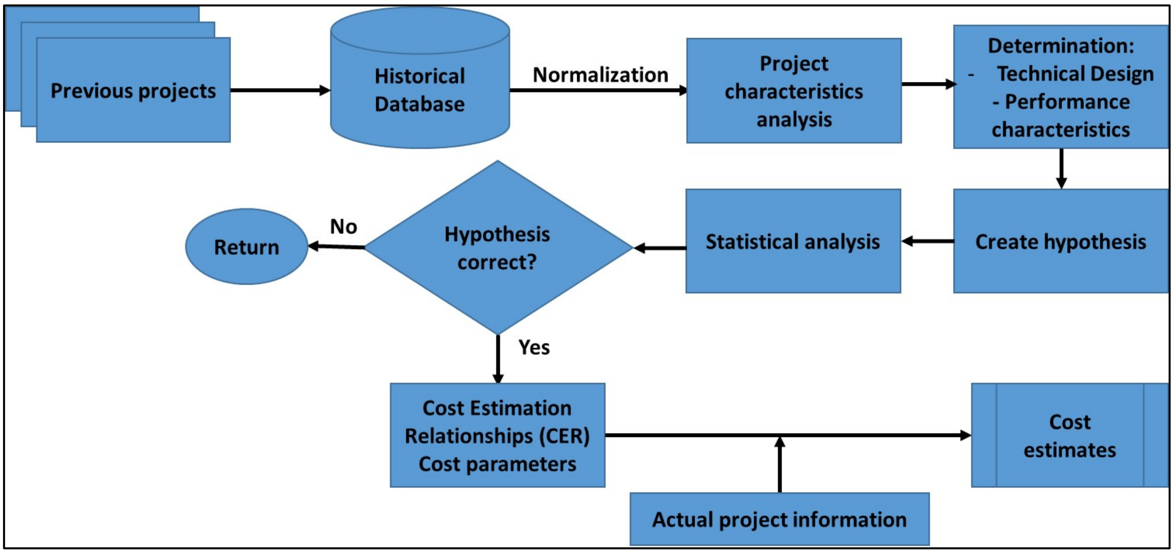


Figure 2.4 – Parametric estimation process

The process starts with a database of previous projects and estimates that will be normalized for proper use. The characteristics of the actual project are then analysed to determine the technical design and desired performance. When this is done, a hypothesis is created and has to be tested. The result of this testing is a group of cost-estimation relationships (CERs) that not only represent the database of previous projects, but actually will serve as parameters for the actual project and future projects.

The following steps would serve any organization willing to build its own parametric model (Cooke-Davies et al., 2011):

Step 1: Determine the requirements for the parametric cost model and indexes to be considered (i.e., ROI, NPV, IRR).

Step 2: Define boundaries and assumptions.

Step 3: Gather historical data from previous projects that have accurate cost estimates and supporting information.

Step 4: Assure the data is relevant to the organization environment (normalization)—currency, inflation (present value), measurement unit (metric x imperial), production rate, etc.

Step 5: Identify the cost drivers that will serve as independent variables.

Step 6: Formulate a hypothesis about the independent and dependent variables.

Step 7: Test the hypothesis statistically.

Step 8: Document the cost-estimation relationships (CERs) for future use.

Parametric estimation is not pessimistic or optimistic by nature, it is just a representation of the past projects estimates that could be use for a new project. Obviously if the content of the database is based on optimistic estimates, the resulting parameters used for future projects will also be optimistic. Ideally, the historical database should be updated with the actual results of the past projects so assure they are realistic – not optimistic nor pessimistic.

One question might come to mind: how accurate is the parametric estimation process? Can it be trusted? There are many parametric models in the market today and they are being used by many organizations, so it can be argued that they are considered useful and trustworthy.

Besides assuring that more accurate cost estimates are part of the historical database, which might not be easy to implement, what else can be done? Often the project managers focus on investing effort in requirements definition/clarification. This is a good approach and should be implemented but the project manager has to confirm that the requirements or expected design reflects the desired product and create steps to check if changes occur during the project. On the other hand, any existing techniques that do not consider the complexity dimensions and their impact on the project might produce unrealistic estimates.

Out of several estimation techniques, the parametric showed to be most effective at the early stages of a project (Cooke-Davies et al., 2011). The main challenge is that this type of information is rarely complete or accurate when dealing with complex projects.

Definitive Techniques

The definitive estimation technique is also known as bottom-up, which means that the estimate is done from the activity level, going up to the work packages, and moving upward on the WBS. According to the PMBOK, the WBS is a “hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables” (PMI, 2012, p.567).

This approach is more accurate and provides a more transparent view of the cost per activity (Activity Based Costing). It provides a summation of all the work that needs to be done on that project, at any level one wants to analyse. On the other hand, it takes more time due to the necessary effort to perform and is normally done when the project already started (Jorgensen, 2004).

The one-point or three-point (PERT) estimates can also be used during the definitive estimation approach. The three-point estimate is normally used when the estimator does not have enough information, experience, or knowledge about the work to be done (PMI, 2012).

Like the previously mentioned estimation techniques, bottom-up does not consider other complexity dimensions beyond risks and uncertainties. For that reason, a model that allows project managers to include such dimensions will be useful and provide a more realistic estimate of costs.

Other Techniques

According to the Project Management Institute (PMI, 2012), there are other estimating techniques that might be considered as well. A summarised list of what was not covered is provided below.

Contingency Reserves

The use of reserve analysis is recommended when there are risks or uncertainties in the project, which leads to the use of contingency reserves. They usually cover the 'known-unknowns' during the cost estimate and can be applied to a specific task, a work package, a set of deliverables, or the entire project. On example of 'known-unknowns' is the knowledge that some rework would be needed (the known part), but the extent of that rework and how much more it might cost is not available (the unknown part) (PMI, 2012).

Other research presents conflicting views about the understanding and use of proper project cost contingency by project practitioners. The issue is the lack of best practices to support the estimation of project-cost contingencies, reinforced by poor management. Another issue is that once the contingency is established, there is limited monitoring and controlling of these numbers throughout the project life cycle. The result is a lower level of accuracy of the proposed contingencies (Baccarini, 2005).

Cost of Quality

The cost of quality is related to possible costs for assuring quality of the product and implementing quality control processes. These costs are typically incurred during quality planning, quality control, and quality assurance. Another aspect to consider is the cost of non-conformance, which is the cost of not delivering what was expected by the client —rework, warranty, waste, loss of market; and reputation (PMI, 2012).

Supporting this view, Love and Irani (2003) analysed the quality costs in construction projects. By using a prototype project management quality cost system, the authors analysed the costs and causes of rework concluding that it would be useful to have a system to point out the shortcomings in project-related activities and propose actions to improve the cost estimation.

2.6.3. The Outputs of Cost Estimation

The output or result of the cost-estimation process is an estimate of how much it will cost to do the project and deliver the product, service, or result. They are by nature quantitative assessments of the possible cost to do the necessary work. The estimates cover everything from labour to materials, equipment, installations, services, technology, fees, etc. (PMI, 2012).

The estimates would later be adjusted to the real cost of the project and serve as a reference for future and similar projects (historical information).

2.7. Cost Estimation in Project-Based Industries

This section explores two main project-based industries where cost estimation is used more often, construction and information technology/software development, with emphasis on the construction industry.

There are certainly other project-based industries that have to estimate costs such as defence, aviation, and energy but none of them had as many references in the literature. As far as cost estimations are concerned in other industries' complex projects, cost overruns are a common issue. If considering public work, costs are underestimated in nine out of 10 public projects (Flyvbjerg et al., 2002). Similarly, Mackenzie states (as cited by Olaniran et al., 2015) that average cost overruns of hydrocarbon projects are 90.75% in Europe.

2.7.1. Construction

According to Bertelsen & Kostela (2005), construction projects are considered as part of production. Due to its nature, production can be classified as mass production or project production. Mass production is a specialised process of a well-defined and specialised product, whereas project production is the creation of a unique product or service, which is naturally more complex. Generally, complex projects involve many professionals from different disciplines working together, as it is uneconomical to handle all the work while achieving specialisation. This leads to organizational complexity for many projects. However, complexity is a necessary part of a flexible and responsive industry. Therefore, improving the ability of project management to deal with these complexities is essential for the growth of the industry.

Construction can be considered as complex systems (Bertelsen, 2004). This is not necessarily only an outcome of technological complexity of construction projects (number of elements and their interdependencies). Another dimension of the idea of complexity is 'uncertainty', which refers to the degree of uncertainty of goals and the degree of uncertainty of methods to achieve the goals of the project (Williams, 1999). In comparison, unlike other industries, construction industry projects are usually complex as they are vulnerable to external weather conditions which may influence or alter the cost estimates, design, contracts, and production planning (Kern & Formoso, 2004). Among the factors that are largely influenced by uncertainties, cost estimates are critical because the cost estimate is one of the essential cost documents for a construction contract as well as throughout the process.

Estimated construction cost is defined as budgeted or forecasted construction cost at the time of decision to build (Flyvbjerg et al., 2002). As complex projects contain elements of high uncertainty and size, achieving accuracy in cost estimation is often challenging. Traditionally, construction cost estimations are made based on the quantification of building elements such as walls (m^2), concrete (m^3), and windows (units) (Kern & Formoso, 2004). However, there can be flow activities/waste activities, which do not add value to the project, yet highly impact the financial cost of the project. These activities are not often taken account in the cost-estimation process. Furthermore, poor forecasting, level of available information, and likely changes in design, scope, duration, and ground conditions could result in cost overruns (Elfaki, Alatawi, & Abushandi, 2014). Bertelsen and Kostela (2003) identified a number of case studies of complex construction projects that experienced a higher percentage of cost overruns, including Sydney Opera House and Cumberland Infirmary.

Cost underestimation of capital incentive projects cannot always be explained by errors, rather it can be explained as strategic misrepresentation (Flyvbjerg et al., 2002). This shows that the cost overrun issue is rather common in all complex projects regardless of industry. However, the nature of construction projects is unique according to the three-dimensional model of Bertelsen and Kostela (2005), as it is a unique and material-sensitive product, and the customer is usually an individual. Therefore, it can be assumed that the degree of importance given to the factors, which affects the cost-estimation accuracy, could vary across the disciplines.

Considering the construction industry for instance, engineers are normally involved in the initial estimation process and their input is used in the business case for a decision of Go-No Go. If the cost estimator is optimistic, which happens quite often (Flyvbjerg, 2005), the result might be an underestimated project. Another aspect to consider is that these same optimistic individuals might be the ones in charge of estimating the cost of the project. If that happens, there is a greater chance that complexity dimensions will be overlooked. Emphasizing this point of view, estimates are normally performed by technical people (i.e., engineers), which by nature are optimistic (Cooke-Davies et al., 2011). They normally think that the work can be done, that a solution can be found, even though there are several complexity factors such as interdependency of elements, uncertainty, innovation, and politics. Also it is emphasized that delays on project will cause direct impact on cost performance (Aibinu & Jagboro, 2002).

Further analysis of the construction industry show that the issues are not limited to specific regions. For instance, research was done in countries including Saudi Arabia, Nigeria, Hong Kong, Thailand, Jordan, Ghana, and others pointing to a consistent delay in delivery. When projects are delayed, they are normally accelerated or extended, which causes direct cost overruns (Sambasivan & Soon, 2007). According to the authors, the research pointed to a set of eight main causes for delay, which can be considered additional complexities on the project. These eight causes, listed below in order of importance, had the main effect of delaying the project and causing cost overruns:

1. Contractor related (subcontractors, site management, construction methods, improper planning, mistakes during construction, inadequate contractor experience)
2. Material related (quality of materials, shortage of materials)
3. Labour and equipment related (labour supply, labour productivity, equipment availability and failure)
4. Client related (finance and payment, owner interference, slow decision-making, unrealistic expectations)
5. Contract relationship related (major disputes and negotiations, inappropriate organizational structure, lack of communication)
6. Contract related (changes to orders, mistakes on contract documents)
7. Consultant related (contract management, preparation and approval of drawings, quality assurance and control, waiting time for approval)
8. External related (weather, regulations, problems with neighbours, unforeseen site conditions)

There is a consensus about the challenges of estimating costs, including aspects like knowledge and experience of the cost estimator, amount of information available, pressure from key stakeholders, technique used, type of contracts, external factors, materials used, and so on, just to name a few. As important as the technique used, the optimistic nature of the cost estimator also plays a role in the possible underestimation of costs. Furthermore, the phase of the project is also directly related to the level of accuracy; the earlier the stage and the less information available, the less accurate the estimate will be.

2.7.2. *Software Development*

Looking into the software development industry, several cost-estimation approaches have been used since the late 1960's. Three of the most common models are function points with neural networks, case-based reasoning, and regression. Recent studies point out that regression models normally do not perform well when dealing with the complex aspects of software development, but neural networks and case-based reasoning perform better (even though not a great deal) when providing estimates. The main conclusion is that when applying artificial intelligence to the model, the results are much better (Finnie, Wittig, & Desharnais, 1997).

A recent article points to a high rate of cost overruns in the software development industry (Ramasubbu & Balan, 2012). Additional study finds a group of approaches that can also be used. They are listed below in order of appearance, beginning in the 1960's to more recent dates (Boehm, Abts, & Chulani, 2000).

- Model-based: SLIM, COCOMO, Checkpoint
- Expertise-based: Delphi, Rule-based
- Learning-oriented: Neural, Case-based
- Dynamics-based: Abdel, Hamid, Madnick
- Regression-based: OLS, Robust
- Composite: Bayesian, COCOMO II

The authors Boehm, Abts, and Chulani (2000) propose that the learning-oriented and dynamics-based models are less mature than the others, but all of them have issues when confronted by the high pace of change in the software development industry.

Software development is part of the information technology industry and as such under the same challenges that projects share—competing demands and the need for accurate estimates to increase chances of success. Evidence shows that bottom-up estimates provide more realistic results than parametric estimating techniques because they improve predictability. Predictability is directly linked with project success but it is also a challenge for an industry that changes so rapidly. Finally, analogous estimating proved to be less accurate and only recommended by less experienced project managers as a way to generate some level of predictability (Henry, McCray, Purvis, & Roberts, 2007).

It can be argued then that no single model would be appropriate for all projects and situations but a necessary analysis is recommended to find the best option.

These are just a few techniques; the analysis was not intended to be exhaustive. The techniques presented are based on the best practices of cost estimation but do not consider the influence of complexity dimensions. Further details are provided in the next section, where the impact of complexity on the cost-estimation process will be explored.

2.8. Impact of Complexity on the Cost-Estimation Process

Complex projects are often characterized by underestimated costs and overestimated benefits, which do not materialize in the end. Previous studies have quantified the impacts and described the main causes of such variations, yet offered no viable solution.

Even when the project would not realize the presented benefits and stay within the unrealistic cost estimates, the fact that it was "sold" as a feasible initiative does not change the reality when it was implemented: higher than estimated costs, lower benefits, and lack of expected revenues. To support that statement, a list of several complex projects that had similar performance is provided. These numbers reinforce the statement that a model that can increase predictability and help decision-making is desirable.

Recent statistics by Rostadäs, Hetland et al. (2011) state that the original estimate made in 2003 for required facilities for the London Olympics was £ 4 billion. It was revised in 2007 to a sum of £ 9.3 billion, and actually needed another £ 5 billion for associated transport projects. Furthermore, the author mentions the Shell Sakhalin II project (original estimate of USD 10 billion and latest estimate of over USD 28 billion).

Similarly, the Eurotunnel (between UK and France) was delivered 80% over budget for construction and 140% for financing. The International Space Station had a USD 5 billion cost overrun. Boston's Central Artery-Tunnel project was 275% and USD 11 billion over budget. The Denver International Airport was 200% and USD 5 billion over budget. The Bangkok Skytrain cost USD 2 billion and did not realize half of its estimated benefits (Flyvbjerg, 2005).

These statistics show the reality of how the traditional cost-estimation process fails when dealing with complexity and complex projects. None of the processes presented consider complexity or its possible dimensions as inputs for the cost-estimation process. The only dimensions of complexity present are risk and uncertainty, which has been an aspect of traditional project management for several decades.

At the moment that a cost estimate is created based on a standard 'one-size-fits-all' approach, the chances for that estimate to be accurate are quite low as can be proved by all the complex project budget overruns (Shenhar, 2001).

Which techniques would be more effective when estimating costs for complex projects and at which stage of the project they should be used are relevant questions. Estimates can be done before the project exists to support the decision to move forward or not with a project. They can be done at the beginning of the project, when initial requirements are refined or confirmed with the client and other stakeholders. Cost estimates can also be performed during the project life cycle and adjusted as the scope or other elements of the project change. Finally, cost estimates can be confirmed and revised when the project approaches the end.

Before the project starts is when the organization has to analyse how feasible it is. Terms like Return of Investment (ROI), Internal Rate of Return (IRR), Net Present Value (NPV), Opportunity Cost, Impact measures (for non-for-profit), and so on are often used to define if a potential project should be implemented or not. More often than not, a business case is built where the costs are compared with the benefits and a decision is made. Normally, the decision-makers would prefer a project where the benefits are higher than the costs, so it is important to ensure that the cost estimates are not underestimated and the benefits overestimated (Cooke-Davies et al., 2011).

The use of a business case is pertinent for both public and private sectors. Both have to provide enough information for the decision-makers to establish whether the project is feasible or not, and whether the project should be implemented at that time, postponed, or even cancelled. Another aspect that might add a challenge is that in most organizations there is one group of people who are optimistic and willing to implement the project, and another group that plays a more sceptical role. The second group, normally represented by the decision-makers or top executives, might start with the assumption that no project with underestimated costs and overestimated benefits is feasible. They became sceptical by witnessing many projects that supposedly were supposed to provide great return to their organizations, but in the end became great failures (due to cost overruns, delays, and loss of market-share, just to mention a few issues). The responsibility to prove the accuracy or reliability of both estimates falls on the first group (Flyvbjerg et al., 2002).

As a conclusion, it can be argued that project complexity has a direct impact on the cost estimates, not only on the final result (budget) but also on the necessary steps needed to produce an estimate with a level of accuracy that is acceptable by key stakeholders or decision-makers. Which dimensions of complexity have more or less impact on the cost-estimation process is a subject for upcoming chapters, so the focus now will be on how complexity impacts the cost estimates.

2.9. Preliminary Discussion about the Complexity Model Supporting Cost Estimation

After conducting a review of the literature, and aligned with the fourth research objective to model the links between the complexity dimensions and their impact on the cost-estimation process, there is a need to integrate the findings into such a model. The proposed model should be used to support practitioners (i.e., project managers and cost estimators) in estimating costs for complex projects, taking into consideration the more relevant complexity dimensions, supporting an initial assessment, and providing guidelines to address the complexities.

The model is represented in Figure 2.5, with the following elements:

Element 0 – Project: This element describes the project itself, objectives, scope and other constraints (time, budget, quality), stakeholders, external environment, acceptance criteria, technological level required, and so on. This is the description of the project where the cost estimation is needed.

Element 1 – Complexity dimensions: This element is divided into two parts:

> Definitions: A detailed definition of each complexity dimension is provided to the user, assuring proper understanding.
>
> Levels of complexity: Defines how the complexity level will be assessed (type of scale used and the number of levels), and the description of each level per complexity dimension.

2 – Assessment of complexity levels: The practitioner will perform an assessment of the complexity level for each complexity dimension according to the parameters defined on element 1 above. The assessment defines the impact that a specific dimension would have on

the project and consequentially on the cost estimation process for that project. It ranges from 1 (lowest impact) to 4 (highest impact). See more details on section 6.2.2.

3 – Graphical mapping of complexity levels: The assessment resulting from element 2 above will then be mapped in a graphical format allowing better visualisation of the results. A definition of the graphical type to be used is necessary.

4 – Guidelines/recommendations for practitioners: For each dimension, a set of recommendations and guidelines will be provided to project managers and cost estimators. These recommendations have the objective to provide steps that can be followed to reduce the impact of that dimension or considerations to be taken into account when estimating costs.

5 – Updates on cost estimation: Once the recommendations are followed and more relevant complexity dimensions taken into consideration, it is expected that the cost estimate will be more accurate.

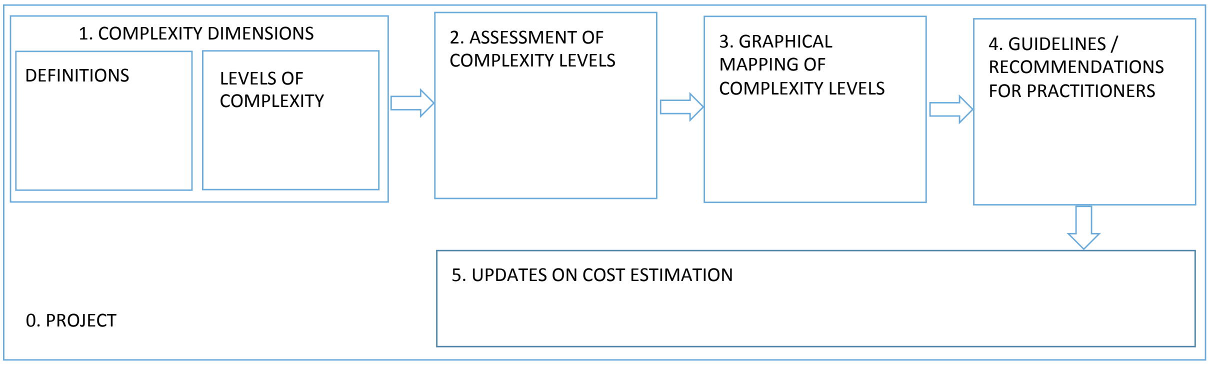


Figure 2.5 – Structure of complexity model supporting cost estimation

The initial results of the literature review provided a list of 16 complexity dimensions that will be considered as part of the model that would help cost estimators improve their estimates by being aware of aspects of the project they otherwise would not be. These dimensions are listed below in alphabetical order.

– Clarity of Goals: This dimension defines how well-defined the goals of the project are and the impact this has on how the project is managed and decisions are made. The lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance (Turner & Cochrane, 1993; Remington et al., 2009).

- Degree of Trust: This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (i.e., supplier and project team; senior management and project manager). The more trust there is, the less complex the project will be (Muler & Geraldi, 2007).
- Dependency and Interdependency: This dimension deals with the relationship between the elements that make up the project (Baccarini, 1996). This relationship can be one of dependency (in which some elements are dependent on one another, and some are not) and/or interdependency (in which each element is mutually dependent on others). In complex projects, stakeholders might not know what the result of an interaction among the elements of that project will be.
- External Environmental Constraints: The external environment can be a significant factor in influencing the level of complexity on a project (Cooke-Davies et al., 2011). This dimension is related to the existing external environment of an organization (on a local, regional, national, or global level) and how it adds to the complexity of a project. Factors such as changes to existing regulations, the fluctuation of the market, and a shift in the political or regulatory environment are included here.
- Innovation to Market: This dimension is related to the level of innovation of the product generated by the project. Innovation level impacts market-related activities, time, and effort to define and "freeze" requirements. The higher the innovation level, the more difficult it is to establish and keep the requirements as originally defined (Shenhar et al., 2012).
- Organizational Capability: This dimension is related to how capable—structurally and technically—an organization is in managing the project and delivering the required product. It is also directly associated with the appropriate selection of project personnel (Remington et al., 2009).
- Pace or Speed to Market: This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the product be aligned with market demands (Shenhar, 2001).
- Political Influence (Politics): This dimension is related to the level of internal or external political influence involved in the project. If political influence and interests lead to the approval of a project that might not be feasible, the chances of an overestimation of benefits and underestimation of costs increase (Jaafari, 2001; Dill & Pearson, 2013).

- Product and Project Size: Product or project size is another proposed dimension for project complexity (Vidal & Marle, 2008). Actually, Corbett and Campbell-Hunt (2002) claim that a project should be over a minimal size to be considered a complex project. The premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple would be to deliver a standard component, followed by subsystem, moving to delivering an entire system, and finally to producing an array or system of systems (Shenhar & Dvir, 2007).
- Project Description: This dimension focuses on the level of difficulty encountered when describing the project, including all of its elements (Bar-Yam, 2004). Even though this might be influenced by how much knowledge or experience one has with a specific type of project, it is not the same as the dimension knowledge and experience. It is possible to have knowledge and experience about a project but be challenged when describing the project and its scope, interactions, and components (Remington et al., 2009).
- Project Management Maturity Level: This dimension addresses the degree of relative maturity that the organization has achieved in project management. The assumption is that more mature organizations will be better able to manage complex projects and deliver the products (Levin & Ward, 2011).
- Risks: Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project (Levin & Ward, 2011). This dimension defines specifically how much unknown (known-unknowns and unknown-unknowns) risks exist in a project and possible impacts on the management process and delivery of final product.
- Stakeholders' Interaction: This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening in the project (Cooke-Davies et al., 2011).
- Technology: The term *technology* is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used in a specific project. Normally technology complexity is found in projects that use a new or untried technology (Remington & Polack, 2007). The complexity in this case would be associated with the number and variation of inputs and possible outputs. The less the team or performing organization knows or has used that technology, the more complex the project will become.

– Time Frame: Time is often referred as having a direct effect on how complexity is perceived by project team members and stakeholders (Remington et al., 2009). Timeframe is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the timeframe of the project, notably with ones that have long durations. The longer the timeframe, the more chances that changes will impact the project, which increases the level of complexity.
– Uncertainty: The Cambridge Dictionary (2016) defines *uncertainty* as "a situation in which something is not known, or something that is not known or certain". This dimension is related to the level of uncertainty existing not just in a project, but also in the product or the development process. Even though complexity is different from uncertainty (Baccarini, 1996), uncertainty can be considered a dimension that can increase or decrease the level of complexity of a project.

Considering only the number of references found in the literature (Section 2.5), the most referred to dimensions are Dependency & Interdependency, Innovation to Market, Technology, Uncertainty, and External Environment Constraints. A point can be made that the number of references found in the literature does not represent the level of importance of a specific complexity dimension, but simply the fact that it was found more often by the researcher and several authors might have used the same initial reference (Braun, 2003). For that reason, the 16 complexity dimensions will be considered equally important.

This initial list could be extended by further analysing cases of complex projects to find if there are other complexity dimensions that should be considered impactful. This is presented in Chapter 4.

The next step would be to discover which dimensions would be more relevant, and this information can be obtained by a survey with practitioners. Input from a survey and interviews would provide more rigour to the process of defining which complexity dimensions should be considered. A further aspect for discussion would be to define if there should be a limit on the number of dimensions represented in the model (Doyle & Hughes, 2000). It is important to point out that aligned with the objective of this research, the complexity dimensions to be considered should be the ones that would impact the cost estimates. On the other hand, since cost is part of the triple constraint (scope, time, and cost) of any project (PMI, 2012) cost becomes an intrinsic part of the project itself, so it can be observed that any complexity dimension that impacts a project would have some level of impact on the cost estimates, in a more or less significant way.

During a survey, one aspect to consider is how representative the sample should be of different industries. When a great number of participants are from a specific industry, there is a possibility that the results will reflect the behaviour or pattern of that industry. The researcher should, as much as possible, have an evenly distributed sample of industries. When this is not possible, clear reference of which industries are represented and their percentages of the total should be presented. Supported to many authors, it can be concluded that the same rationale can be used for other demographics such as regions of the world, as cultural aspects or external influences might influence the way practitioners estimate costs (Gummesson, 2000; Easterby-Smith, Thorpe, Lowe, & Jackson, 2008; Creswell, 2009; Saunders, Lewis, & Thornhill, 2009; Marshall & Rossman, 2011).

There are many ways to enter information into a model, and one key aspect is whether the information is quantitative or qualitative in nature. Considering the subjective nature of complexity (Baccarini, 2005), it would be more appropriate to use a qualitative approach to enter the level of complexity for each dimension. This research will use a four-level scale, from the least possible impact a dimension would have on the cost estimates (level = 1) to the most impact (level = 4). The input template could be a simple spreadsheet (i.e., MS Excel).

Once the information is included in the model, it would be necessary to define how the model shows the results (output) and guides the user to make decisions based on these results. There are many acceptable formats to map the results, which will be discussed in further chapters.

Finally, the need for the model to provide recommendations to practitioners on how to deal with the complexities must be addressed. Once again, this topic will be discussed in upcoming chapters. One of the benefits of the model proposed in Chapter 6 is that it would lead estimators to evaluate several complexity dimensions and provide guidelines for the cost estimators. The model would make people stop and think about these other dimensions, consider what they may be missing, and get more information about the parts that are not clear, resulting in estimators being confronted with facts that they cannot ignore and end up with more accurate estimates. At this stage, the model will look like Figure 2.6 below. Further versions of the model will be provided throughout this research in upcoming chapters.

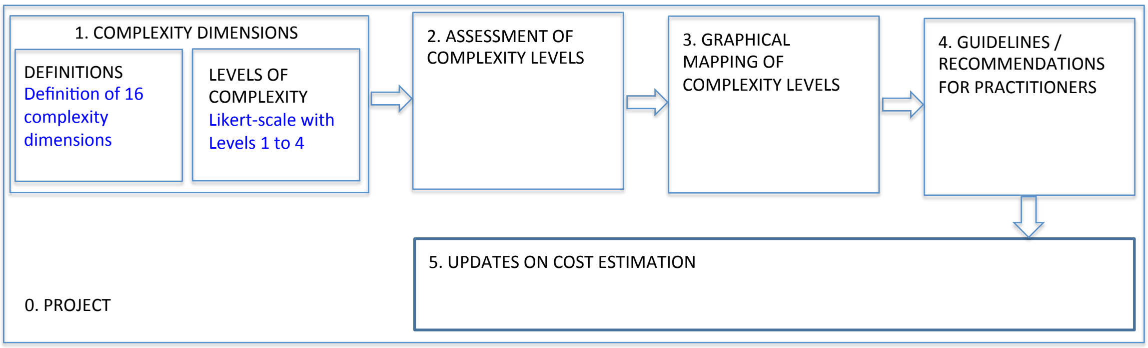


Figure 2.6 – Updated model view

2.10. Chapter Summary

A review of the literature was described in this chapter together with a synthesis of the findings. The initial concepts of project, project management, and complexity created the basis to understand project complexity. Once project complexity was understood, the literature review revealed 16 complexity dimensions and a description of each one was provided. The chapter ended with a discussion of key questions around the construction of a model that takes into consideration complexity dimensions to support the cost-estimation process.

This chapter also contains the literature review related to the cost-estimation process with emphasis on the project-management area of knowledge. It presents the recommended inputs, tools and techniques, and outputs of the cost-estimation process as per the Project Management Institute. A view of the construction and information technology process of estimating costs was also provided, pointing to the similarities and differences between these two industries. Another aspect discussed was the impact of complexity on the cost-estimation process in general, finalizing with further development of the questions supporting the development of the model.

The next chapter will cover the methodology used to support this research and supporting details.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1. Introduction

The previous chapters covered the research background, aim, objectives, and problem, together with an analysis of the existing literature about project management, complexity, and cost estimation. This chapter discusses the philosophical and operational aspects of the research design and justifies the methodology used for this research.

In order to achieve the aim of developing a model that incorporates complexity dimensions into the cost-estimation process for complex projects, a research methodology needs to be defined to support the efforts to analyse what already exists, search for possible dimensions of complexity, and propose an improved model for cost estimation with recommendations and guidelines for cost estimators. The methodological elements are explained based in the nested model (Kagioglou et al., 1998). The research philosophies are presented and discussed, followed by the research approach used, and subsequently the research techniques used are explained and justified. These discussions will provide the basis for the overall methodological framework for this research. Furthermore, discussions will cover generalizability, reliability, and, at the end of the chapter, validity issues.

A summary of the research plan is presented in Figure 3.1.

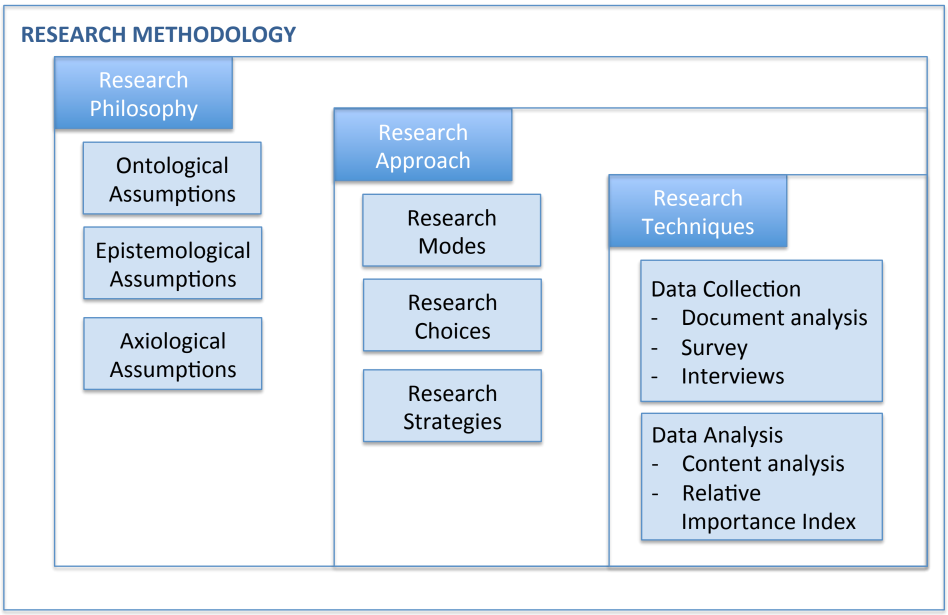


Figure 3.1 – Research plan

The next section will provide a view of which methodological framework will guide this research and clarify the reasons for that choice.

3.2. Methodological Framework

As described in Chapter 1, this research addresses the creation of a model that assists the cost estimation of complex projects, taking into consideration factors (hereafter called dimensions) directly associated with project complexity. The justification of this research is that such a model was not directly proposed before in the literature.

Research is done to help people discover things, which by result increases their knowledge. Methodology in the context of this thesis could be understood as the theory of how the research should be undertaken. With that said, research methodology can be considered as the process to develop the research that people apply in order to find out things or support ideas in a systematic way, thereby increasing their knowledge about the subject (Kerlinger, 1979; Saunders et al., 2009).

The selection of the appropriate research methodology is necessary to explain how the development of the research will be done and issues resolved. The elements that compound the methodology, according to the Nested Model by Kagioglou et al. (1998), are research philosophy, research approach, and research techniques. As presented in Figure 3.2, the Nested Model indicates that the research philosophy governs the research approach, and that the research approach governs the research techniques.

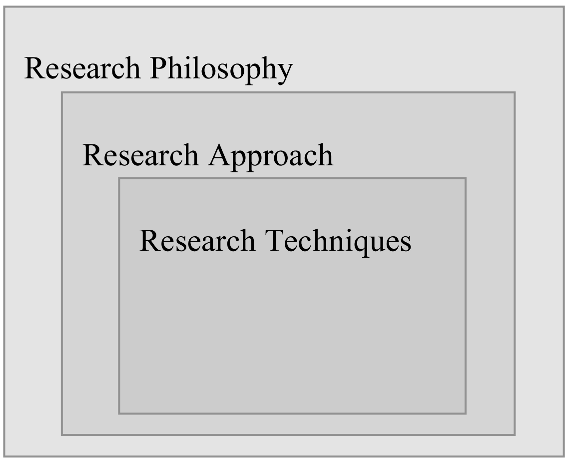


Figure 3.2 – The Nested model (Kagioglou et al., 1998)

The Research ‘Onion’ (Saunders et al., 2009) model provides more details than the three layers presented by the Nested model, so it is being considered as well. The Research ‘Onion’ presents extra layers between the research techniques and the research philosophy that the researcher has to investigate. The most internal layer is related to the research techniques, and the most external layer addresses the research philosophies. What would be the research approach in the Nested model is actually broken down into approaches, strategies, choices, and time horizons. The Research 'Onion' model is presented in six layers: Philosophies, Approaches, Strategies, Choices, Time Horizons, and Techniques and Procedures, according to Figure 3.3 below.

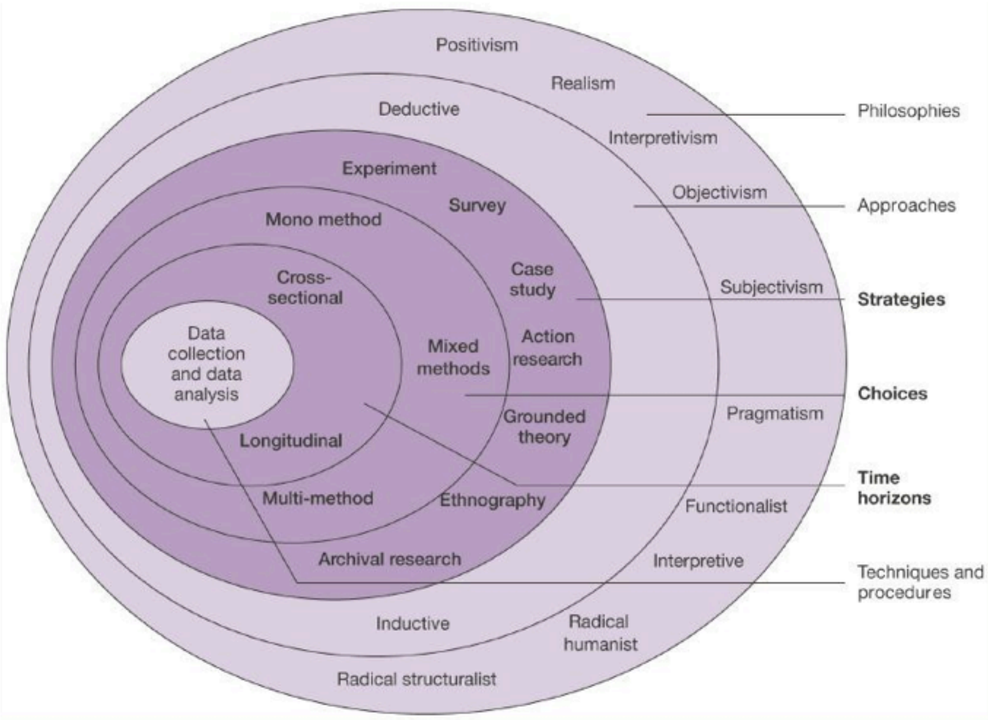


Figure 3.3 – The Research Onion (Saunders et al., 2009)

Comparing these two research models, Figure 3.4 depicts the interaction of the three research aspects of the Nested model (research philosophy, research approach, and research techniques) with the six research layers of the Research 'Onion' (philosophies, approaches, strategies, choices, time horizons, and techniques and procedures).

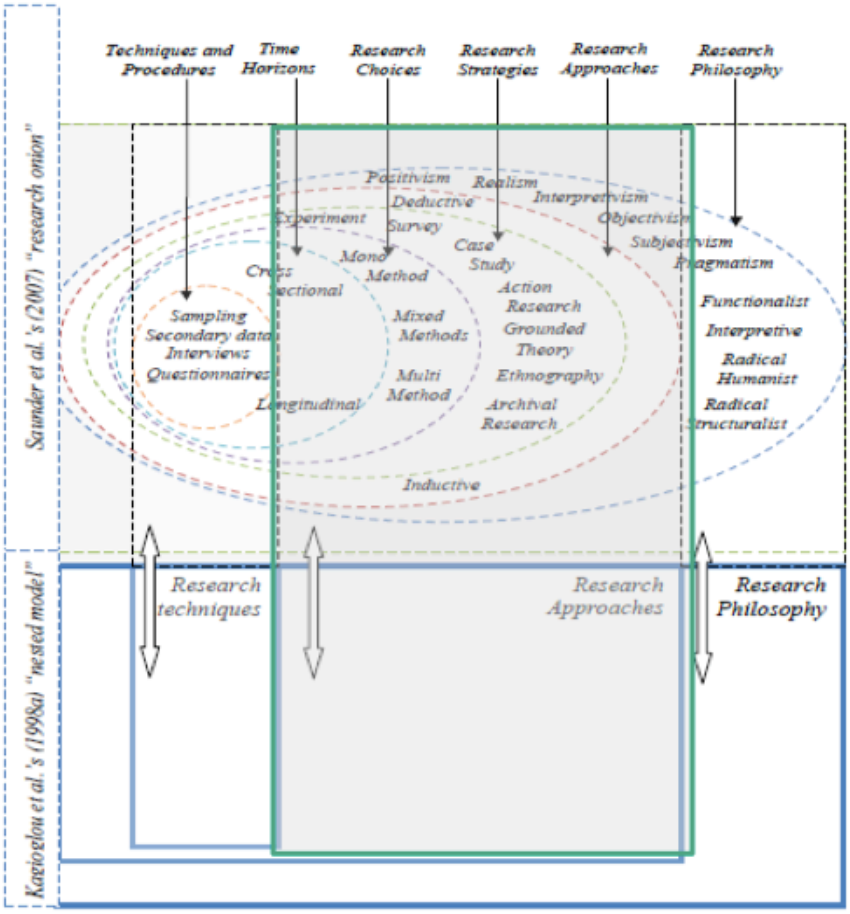


Figure 3.4 – Comparison between the Research Onion and the Nested model (Keraminiyage, 2014)

Even though both models cover the necessary information, due to simplicity this research will use the Nested model as a basis but expand the research approach into more detail, following the Research Onion topics as depicted in Table 3.1 below.

Table 3.1 – Comparison between the Nested model and the Research 'Onion', adopted from Keraminiyage (2009)

Nested Model	Research Onion	Examples
Research Philosophy	Research Philosophy	e.g. Positivism / Interpretivism
Research Approach	Research Strategies	e.g. Case studies / Experiments
	Time Horizons	e.g. Cross sectional / Longitudinal
	Research Choices	e.g. Quantitative / Qualitative Multi-method, Mono-method
	Research Approaches	e.g. Inductive / Deductive
Research Techniques	Techniques and Procedures	e.g. Interviews, Questionnaire, Surveys

The next section will provide a view of the research philosophies that will guide and support this research.

3.3. Research Philosophies

According to Saunders (2009), the term research *philosophy* is related to the development and nature of knowledge. It is through the adoption of a research philosophy that the researcher states the assumptions that will underpin the chosen research strategies and methods to be used. In other words, it represents the way the researcher views the world and reality. Supporting this view, Easterby-Smith et al. (2008) proposes three main reasons to establish and understand the research philosophy: to clarify the research design; to identify which research designs will and won't work under given circumstances; and to help in identifying and creating research designs beyond the researcher's knowledge and experience.

Considering that different authors may use different terms to represent the same concept, this research will be based on Sexton's classification as described in Figure 3.5. This figure presents an overview of the philosophies and choice variation spectrum.

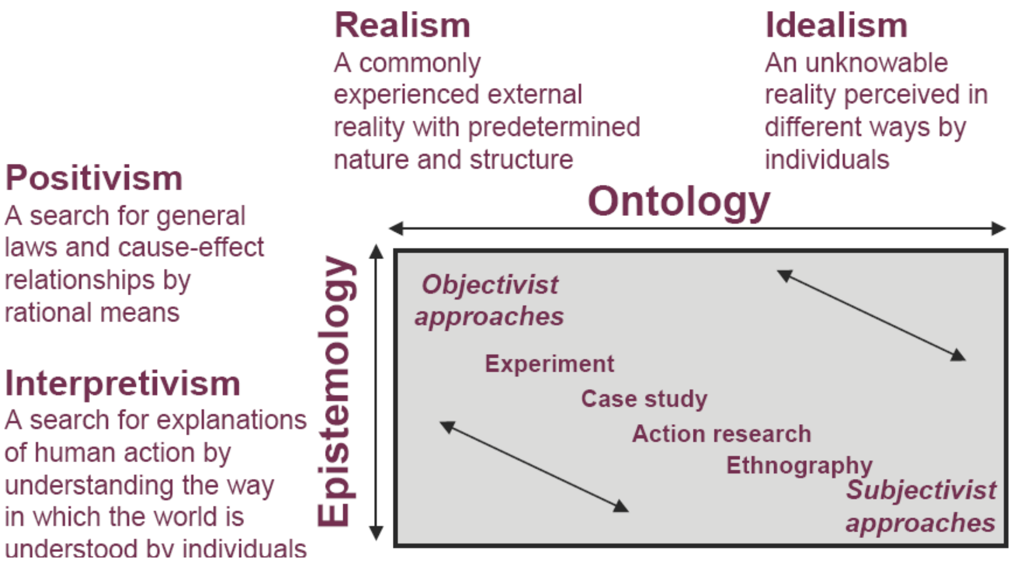


Figure 3.5 – Summary of research philosophies (Sexton, 2003)

The philosophical assumptions are summarised below (Steup, 2009):

Ontology: The focus is on the researcher's view of the nature of reality and being. This is quite important since it explains the researcher's understanding of how the world works and is the basis of assumptions described in the research document.

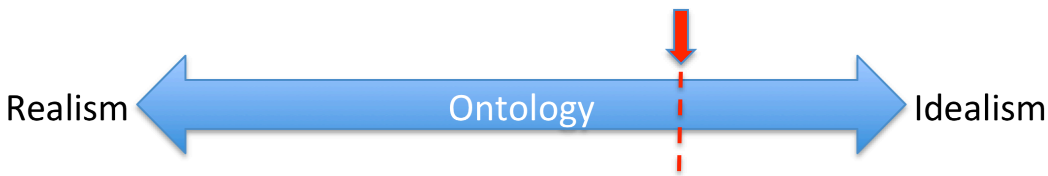
Epistemology: The focus is to answer how we know what we know, how we differentiate justified belief from a point of view, and to define the assumptions of how knowledge should be obtained and accepted.

Axiology: The focus is on the researcher's values and how they will impact the research. The possible assumptions would be if reality were value free or value laden.

3.3.1. Ontological Assumptions

When analysing the two ontological assumptions of realism and idealism, this research will fall closer to idealism since it considers that reality is a product of one's own mind and each person may have a different view of reality. Idealism considers external, multiple views chosen to best enable answering of a research question (Gummesson, 2000). In idealism, either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. The focus is on practical applied research, which integrates different perspectives to help interpret the data (Saunders et al., 2009). This approach is more aligned with the subjective nature of the research, considering that each project manager or cost estimator might have a different perspective of which complexity dimensions are more relevant and how they might impact the cost-estimation process.

Conversely, realism exists independently of human thoughts and beliefs or knowledge of their existence (realism), but is interpreted through social conditioning (critical realism). Realism is when observable phenomena provide credible data and facts (Easterby-Smith et al., 2008). Insufficient data means inaccuracies in sensations (direct realism). Alternatively, phenomena create sensations, which are open to misinterpretation (critical realism). The focus is on explaining within a context or contexts (Saunders et al., 2009). It does not provide the appropriate assumption since it states that reality exists independently of the perception of the external world.



Considering that the concept of complexity and how complex a project can be varies from individual to individual, that variation of perception is more aligned with subjectivism than objectivism. Objectivism states that reality does not depend on one's perception or social factors, which is not the case for this research.

3.3.2. Epistemological Assumptions

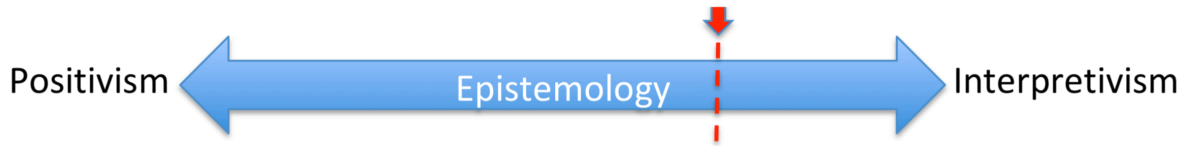
Epistemologically, this research is closer to the assumption that knowledge is socially constructed and subjective (interpretivism). The research analyses and proposes a model to support the cost-estimation process for complex projects, and that people (social players) have different levels of knowledge about complexity. Interpretivism is related to subjective meaning and social phenomena. The focus is upon the details of a situation, a reality behind these details, and the subjective meanings motivating actions. Interpretivism is socially constructed and subjective.

In opposition, positivism is considered when only observable phenomena can provide credible data and facts. It considers external and objective observation, and it is independent of social actors (Saunders et al., 2009). Table 3.2 provides additional support to the choice that this research is closer to interpretivism than positivism.

Table 3.2 - Contrasting implications of Positivism and Interpretivism (Easterby-Smith et al., 2008)

Item	Positivism	Interpretivism
The observer	Must be independent	Is part of what is being observed
Human interests	Should be irrelevant	Are the main drivers of the science
Explanation	Must demonstrate causality	Aim to increase general understanding of the situation
Research progress through	Hypothesis and deductions	Gathering rich data from which ideas are induced
Concepts	Need to be operationalised so that they can be measured	Should incorporate stakeholder perspectives
Units of analysis	Should be reduced to simplest terms	May include the complexity of "whole" situations
Generalisation through	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

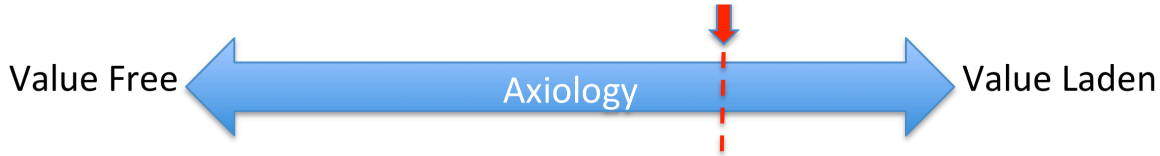
Taking into consideration the Table 3.2 above, the aim of the research is to improve the understanding about the topic of complexity and how its dimensions affect the cost estimation process. Also supporting the proximity to interpretivism instead of positivism, this researcher (or observer) is external to the projects being analysed but this is not an absolute need. For instance, the observer is part of the project described on section 6.3. Human interests are relevant to the research and it incorporates the perspective of several players (stakeholders), since each project manager might have a different view and understanding of what complexity dimensions are more important and how they impact the cost estimation process. Furthermore the use of data from the survey is a key component of this research so to validate which complexity dimensions are more relevant, which again tends towards interpretivism. Positivism would require a more statistical analysis of the results, which is not the case for this research that only used a mathematical approach to rank the survey data. Finally, to support the epistemological assumption of interpretivism, the sampling process was limited to a small number. The use of 27 case studies was also limited to find additional complexity dimensions.



3.3.3. Axiological Assumptions

Axiologically, this research is value laden and subjective. "Value laden" means biased by worldviews, cultural experiences, and upbringing. Value plays a large role in interpreting results, whereas objective and subjective points of view are being adopted. Conversely, value-free considers that the research in undertaken in a value-free way, independent from the data, and the objective stance is maintained (Saunders et al., 2009).

Considering the ontological and epistemological assumptions, the complexity dimensions and their impact on cost estimation are interpreted within a subjective, not objective, context. Furthermore, the researcher has theoretical and practical experience in the field of study which is considered valuable, and the researcher's views and conclusions are based on this knowledge (Easterby-Smith et al., 2008).



3.3.4. *Research Philosophies Summarised View*

Considering the objectives of this research in building a model to support project management practitioners when estimating costs for complex projects, the nature of the research is more exploratory. This points to an ontological assumption of idealism, epistemological stance of social constructivism (interpretivism), and axiological view of value laden. In summary, an overall view of where the research stands on the research philosophies continuum is presented in Figure 3.6 below.

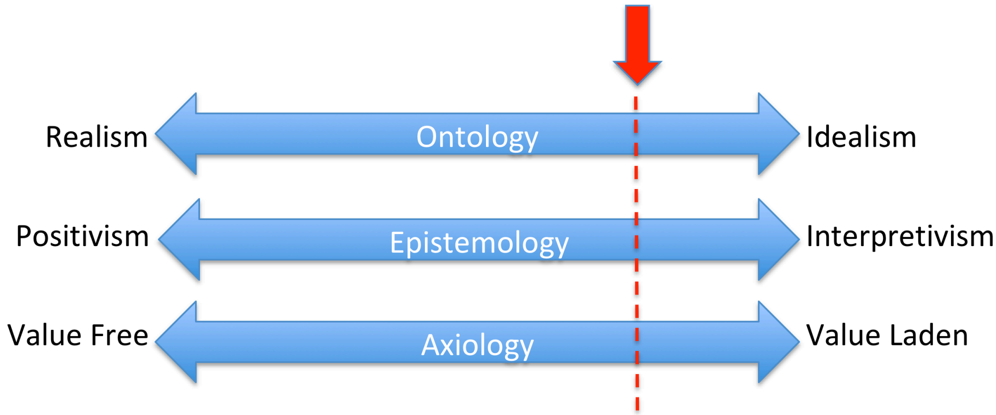


Figure 3.6 – This research position on the research philosophy continuum

The next section will explore what research approach is more appropriate to achieve the research's aim and objectives.

3.4. Research Approach

3.4.1. *Research Modes*

Research involves the definition of a theory, and research approaches are normally divided into how this theory will be built and how the conclusions will be presented. The two types of research approaches are deductive and inductive (Saunders et al., 2009). The presence of both deductive and inductive approaches is known as abductive.

Deductive research contemplates the definition of a theory first followed by tests to confirm or refute its validity, a method commonly associated with scientific research. Deductive research can be broken down into five stages as described by Robson (2002): deducing a hypothesis from the theory; expressing the hypothesis in operational terms; testing the operational hypothesis; examining the specific outcome of the inquiry; and, if necessary, modifying the theory. In its initial phase, this research will use the deductive approach to establish the theory that there is a need to include complexity dimensions in the cost-estimation process and to determine which dimensions are relevant.

Inductive research is based on building a theory, with the objective to understand what is happening and what is the nature of the problem. Once data is gathered and analysed, a theory can be formulated, or in other words the theory will follow the data (inductive), not the other way around (deductive) (Saunders et al., 2009). Even though the deductive approach for research was born in natural sciences, there is a need to address the social sciences, which is more appropriate for the research of potential dimensions of complexity that can influence the cost-estimation process.

Furthermore, considering that this research started as deductive mode with a general theory that complexity factors impact the cost estimation process and moved to an inductive mode with the analysis of the context of complexity within the cost-estimation process and the analysis of a smaller sample of cases with more emphasis on qualitative data, the research mode used is abductive.

3.4.2. Research Choices

Starting with research design, there are three types to be considered—quantitative, qualitative, and mixed methods. This research will use a mixed research choices with quantitative and qualitative methods.

Qualitative research is a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem. The process of research involves emerging questions and procedures, data typically collected in the participant's setting, data analysis inductively building from particulars to general themes, and the researcher making interpretation of the meaning of the data (Creswell, 2009). Since the research proposes to build a model to help the cost-estimation process for complex projects, qualitative data analysis is recommended.

On the other hand, quantitative research can be described as a means for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, so that numbered data can be analysed using statistical procedures (Creswell, 2009).

For that reason, a mixed methods research is indicated since it combines or associates both qualitative and quantitative forms.

3.4.3. Research Strategies

The main objective of a research strategy is to allow a response to the research question(s) and solve the proposed problem(s) to meet the research objective(s). Each of these strategies can be used for explanatory, exploratory, or descriptive research (Yin, 2009).

According to Figure 3.7 below, there are five main research strategies as identified in the Nested model (also known as research strategies by the Onion model): experiment, survey, case study, action research, and ethnography (Sexton, 2003).

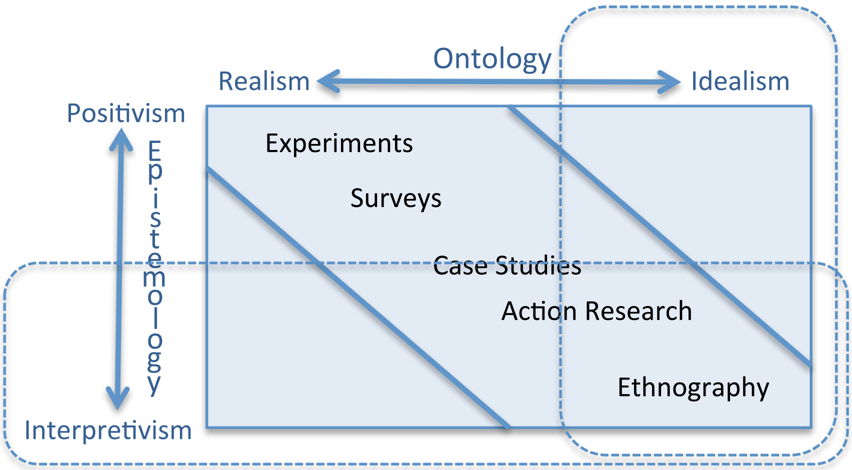


Figure 3.7 – Research strategies continuum (Adopted from Sexton, 2003)

Based on the aforementioned research strategies continuum, experiments and surveys are recommended for an epistemological stand of realism and an ontological stand of positivism. On the other hand, action research and ethnography are recommended for an epistemological stand of interpretivism and an ontological stand of idealism. It can be argued that case studies are close to the middle of both extremes and might be proved useful for both scenarios.

Considering this research's ontological assumption is close to idealism and the epistemological assumption closer to interpretivism, it would be expected to use ethnography or action research as a research strategy. Ethnography has the purpose of describing and explaining the social world the subjects live in and is limited to the way they understand it, which takes a long period of time to do successfully (Saunders et al., 2009) and won't be applicable to this research since the focus is not on explaining the social world over a long period of time. Action research can be summarised as research in action instead of research about action. In other words, the researcher is included in the problem environment with the objective of influencing or changing it through influencing the participants (Saunders et al., 2009), which also is not recommended due to the fact the researcher is not part of the problem environment.

A case study focuses on bringing light to a decision or decisions by defining why the decisions were taken, how they were implemented, and what were the expected results. It is "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2009, p.18). This will be the selected strategy since it provides an actual view of the phenomenon through a database of complex projects, each of them acting as case studies that will be used to support the results obtained by the survey.

Experiment is a research strategy associated to objectivism and more aligned with realism (ontological assumption) and positivism (epistemological assumption), neither of which is related to this research. The main purpose of an experiment is to select a variable and see whether and how it affects another dependent variable (Saunders et al., 2009).

To put the research questions into context, the focus is on answering "what" complexity dimensions exist in the literature, "what" are the characteristics of project-cost estimation within the context of project complexity, "what" are the relevant dimensions and the less relevant, and "how" to create a model that incorporates complexity dimensions with recommendations and guidelines for practitioners. The research objectives do not require answering "why" questions.

Considering that the research questions do not require an analysis of participants' behavioural patterns through a long period of time, the ethnographic strategy should not bring benefits. Even though the events are contemporary in nature, there is no need to control the variables of the environment, which makes action research less attractive.

Conceptually, case study is a strategy that involves empirical investigation of a contemporary phenomenon in a real-life context and using multiple sources of evidence. This strategy has the ability to answer 'why' questions, and also 'what' and 'how', even though the last two are more common on survey strategies (Saunders et al., 2009). This strategy is particularly useful where a priory construct exists and needs validation through iterative data collection and confirmation from case studies.

To achieve the research objectives, there may be a need to use more than one research strategy. This research will use a documentation analysis of existing case studies to support the findings from the literature review. Furthermore, considering the inductive nature of this research, a survey will be beneficial to allow the researcher to gather some qualitative data and address objective #1. It will be used to validate the top dimensions that project management practitioners consider when managing complex projects and specifically when estimating costs.

Finally, to fulfil the need for qualitative data and to address objectives #2 and #3, the researcher will use interviews to validate the complexity dimensions obtained up to that point and eliminate redundancies. The interviews will also provide the necessary input for the model and validation of the recommendations and guidelines to practitioners, fulfilling then objectives #4 and #5.

A different view is provided by Yin (2009) in the form of Table 3.3 below, which represents the recommended research methods based on three questions: what is the form of the research question?; does the research require control of behavioural events?; and, is the focus of the research on contemporary events?

Table 3.3 – Relevant situations for different research methods (COSMOS Corporation, 1983, cited in Yin, 2009)

Method	Form of Research Question?	Requires Control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case Study	How, why?	No	Yes

Yin's view also points out that 'what, who, where, how many, how much' questions are more exploratory in nature, whereas 'how' and 'why' questions are explanatory. This research will make use of both explanatory and exploratory questions and, as described previously, address 'what', 'how', and 'why' questions. For that reason, it will apply different research methods through literature review, survey, document review of existing case studies, and interviews.

3.4.4. Time Horizons

The key question is to define how time is going to influence the research. Would the results change over a period of time? Are the findings a representation of a specific time or a variety of time segments? According to Saunders (2009), time horizons could be divided into two options:

- Cross-sectional: The phenomenon does not change over the period of time and the results are a representation of a specific time (also called "snapshot").
- Longitudinal: The phenomenon changes over a period of time and the results are presented showing the variation over this time.

Considering that this research looks to find the dimensions that can influence the cost-estimation process for complex projects, there is no need for an analysis extending several periods of time; therefore, the selected time horizon is cross-sectional.

In summary, this research mode would be inductive, using a mixed method of qualitative and quantitative data analysis, with the research strategy of case study supporting a survey and use of interviews as validation of the data collected, through a cross-sectional time horizon. The next section will explore in more detail the research techniques to be used.

3.4.5. Operational Aspects

The operational aspects of this research are based on the interpretation of the results obtained through the literature review, analysis of case studies, survey, and interviews. The term *interpretation* means "an explanation or opinion of what something means" (Dictionary, 2016) or, in other words, something that might have several different and even conflicting points of view.

The concept of what is real or not and the level of subjectivity when analysing a phenomenon is dependent on the criteria used by the researcher to explain and model it (Sheridan, 1999). It can be argued then that an interpretation is a matter of one's perspective or perception. How real is one's perception? According to Gibson (1976), perceptions are true and drive actions or behaviours. A contrary argument can be made that one's perspective does not define reality. For instance, if a colour-blind person sees the sky as green, it does not make it so. A counter-argument can also be made that for that individual, the sky is actually green, and so reality would be defined by what is real for each person.

With this in mind, this research has to find a way to mitigate the impact of individuals' perspectives when collecting input about how the complexity dimensions affect the cost-estimation process for projects. Considering that ontologically speaking this research is closer to idealism and that the epistemological stand is closer to interpretivism, there is a need to deal with the subjective nature of the input from practitioners. For that reason, this research will use several strategies to address the aim and objectives as described in Figure 3.8 below.

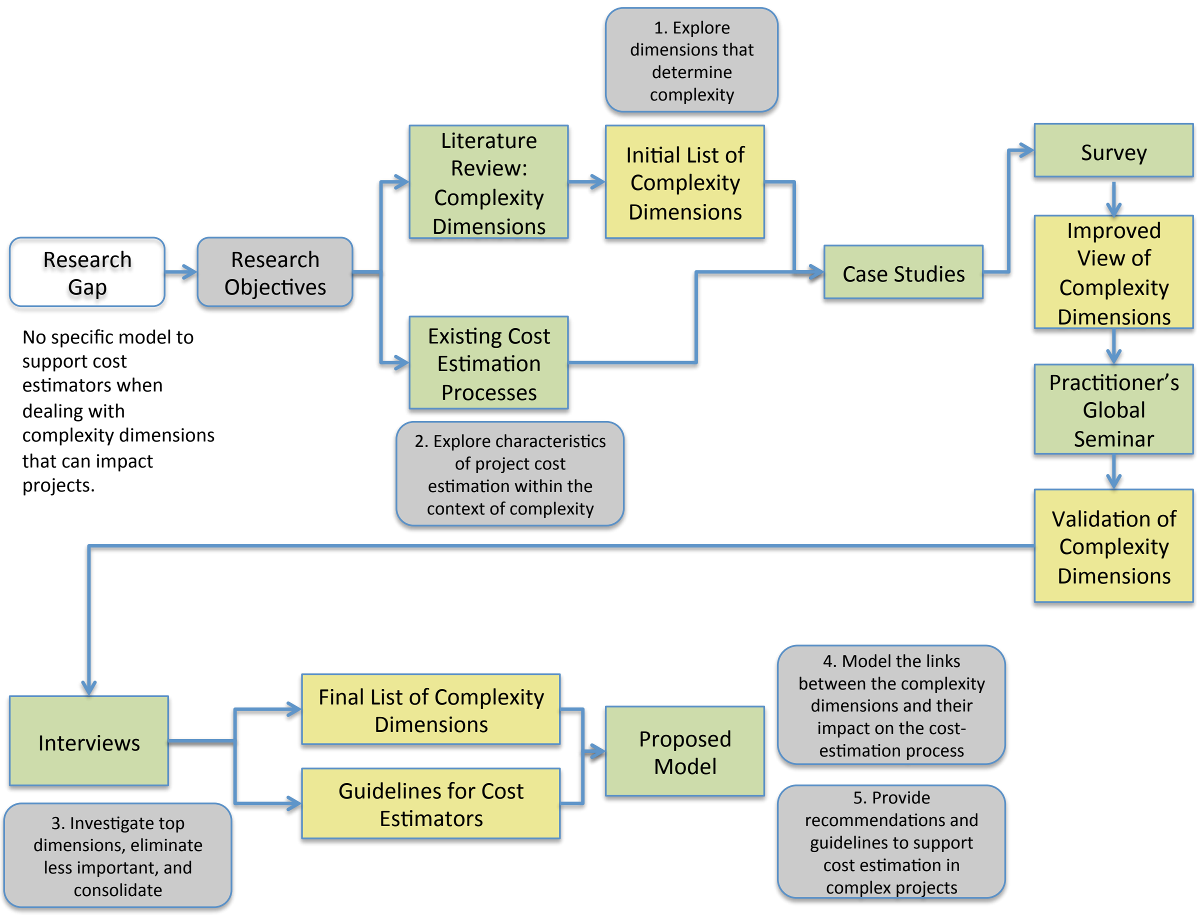


Figure 3.8 – Step-by-step research process

The entire process starts with the previous knowledge and understanding of the topic by the researcher. This would be called pre-understanding and is represented by Figure 3.9 below (Gummesson, 2000).

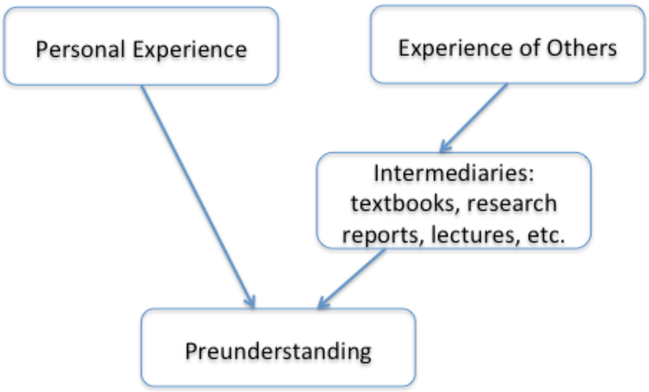


Figure 3.9 – Sources for pre-understanding – adopted from (Gummesson, 2000)

As the research process moves forward, the knowledge and understanding acquired by the results of the previous steps becomes understanding and consequentially pre-understanding for the next step, and so on. Figure 3.10 depicts the hermeneutical spiral.

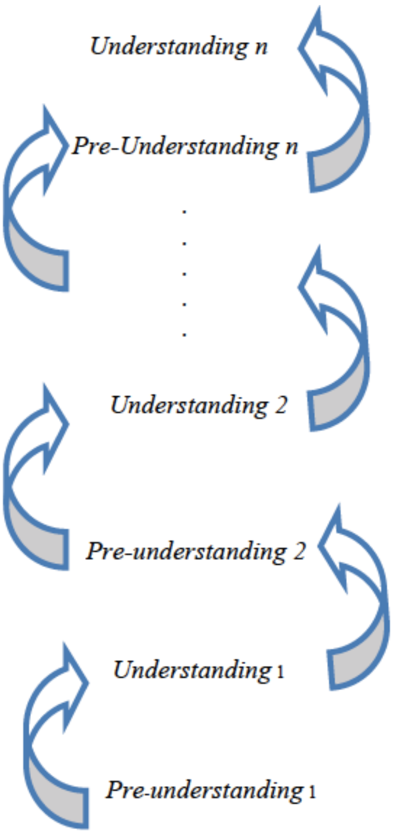


Figure 3.10 – The hermeneutical spiral – adopted from Gummesson (2000)

The researcher's pre-understanding is based on more than 20 years as a practitioner involved in complex projects and cost estimation. The starting point for this research was the researcher's pre-understanding that cost estimation for complex projects should be managed in a different way than recommended by traditional project management (PMI, 2012).

Starting with the definition of the research objectives, a review of the literature generated a group of 16 dimensions based on how many times it occurred during the searching process. That list was then validated through a document review of 27 case studies of complex projects. New dimensions were added, totalling 23 complexity dimensions. These results added to the researcher's pre-understanding and became understanding for the next step.

A further survey with 54 participants was used to prioritize the dimensions with more influence on the cost-estimation process for complex projects, and the Relative Importance Index (RII) was used to rank the results (Faridi & El-Sayegh, 2006). Once a list of dimensions was produced, these results were presented in a paper during a global congress with real-time input from over 50 practitioners.

An interview with 10 people was then built to explore the characteristics of the cost-estimation process within the context of complexity and to investigate which dimensions were more relevant and which should be eliminated from the list to generate a consolidated list. The interview also gathered recommendations and guidelines for cost estimators when estimating costs for complex projects. The results of the previous steps allowed the researcher to propose a model with 15 complexity dimensions on a radar graph format with guidelines for cost estimators.

3.4.6. The Case Study Design

According to Yin (2009), case study research is a linear but iterative process that can be represented by Figure 3.11. The aforementioned author also states that case study is a preferred method when the researcher has to answer the questions 'how' and 'why', has little or no control over the events to be studied, and the focus is on actual real-life events.

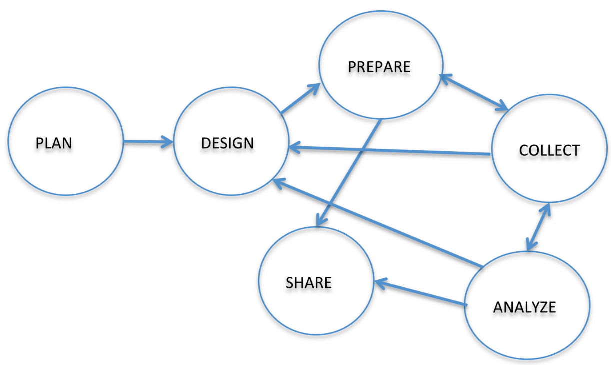


Figure 3.11 – Process of doing case study research

As explained in sections 3.4.3 and 3.4.5 of this research, more than one research method will be applied to answer the research methods, including a document review of 27 case studies of complex projects.

It is recommended that whether the case study design will be based on a single case study or multiple case studies be defined, and whether it will use a single unit of analysis (holistic) or multiple units of analysis (embedded) (Yin, 2009). Figure 3.12 represents these options on a 2 x 2 matrix.

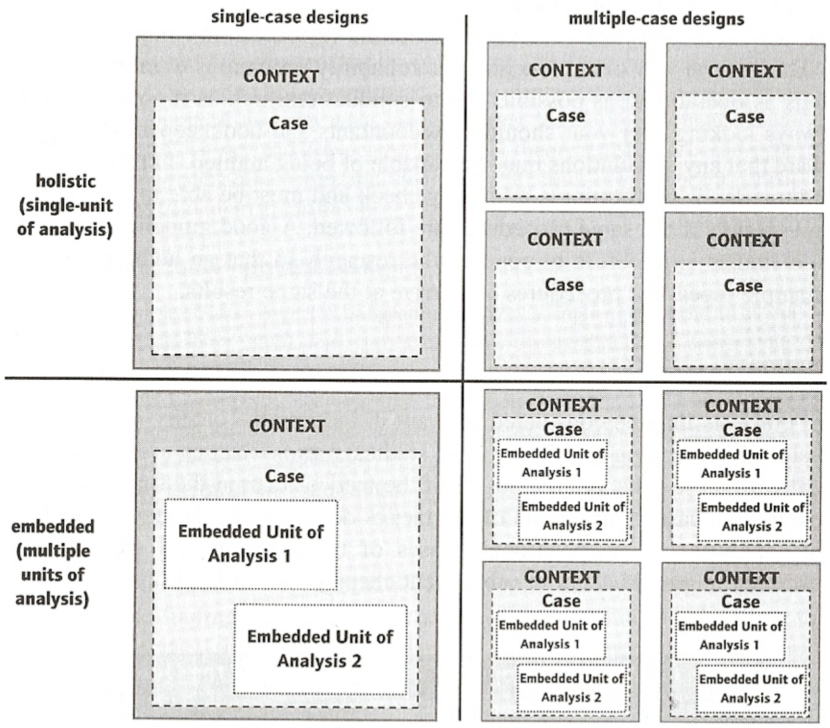


Figure 3.12 – Basic types of design for case studies (COSMOS Corporation, 1983, cited in Yin, 2009)

The use of single case studies can be summarised into five rationales. The first one is when a single case study represents a well-formulated theory and that when meeting all conditions of the theory can confirm, deny, or expand the theory. The second rationale is when the case study represents a unique case that can rarely be found. The third rationale is when the case study represents a typical or commonplace situation that in turn represents many similar ones. The fourth rationale is when the researcher has a chance to observe and analyse a phenomenon that was not accessible previously. The fifth and final rationale to use a single case study is related to the longitudinal time horizon, or, in other words, when the researcher analyses the same case study in two or more different points in time (Yin, 2009).

When deciding whether or not to perform a single case study, the researcher needs to be cognizant that one case might not be a good representation of the phenomenon and that there is a possibility of misrepresentation. This research does not fit any of the characteristics described that point to performing a single-case study—critical, unique, representative, revelatory, or longitudinal. For that reason, it will not use a single case study but rather a document review of 27 different case studies of complex projects. The multiple case study design allows identifying commonalities between the different case studies and, with that, recognising the complexity dimensions that occur more often in these cases. The next question to be asked is whether the single case study would analyse one or more units. Holistic design (one unit of analysis) is recommended when no subunits are considered or when the nature of the case study is holistic (Yin, 2009).

The process to select the case studies started by accessing a database of 136 cases of complex projects (refer to section 3.5.1.2 for more details). Each of these cases had a section VII.5. named "Other complexities" where the project manager described complexity factors that influenced that project. The researcher read all 136 cases, specifically the "other complexities" section to look for complexity dimensions that were not part of the initial 16 dimensions found during the literature review. The number of cases with additional complexity dimensions were 27. Once these cases were selected, the researcher read each of the 27 cases and used the computer-aided qualitative data analysis software (CAQDAS) named NVivo version 11 for Windows to register the new complexity dimensions. The result of this process is described in details on section 4.3.

This research considers the project as the main unit of analysis, but the questions are directed to determine which complexity dimensions would impact the project and, most directly, the cost-estimation process. Cost estimation is a sub-unit of the project and each possible dimension is an embedded unit of analysis of that project. It can be argued then that this research will use a multiple case study design with multiple units of analysis. Furthermore, and considering the selection of a multiple case study design, it allows the use of replication logic as the mode of analytical generalisation instead of the use of theories.

The next section will explore the research techniques to be used to reach the research objectives, specifically during the data collection and analysis processes.

3.5. Research Techniques

As explained in the previous sections, this research will use a series of approaches involving survey, case studies, and interviews. The research techniques are divided into data collection techniques (section 3.5.1.) and data analysis techniques (section 3.5.2.). The data analysis technique used is content analysis.

3.5.1. Data collection techniques

According to Yin (2009), to support the conclusions obtained from the data collected, using multiple sources is recommended. These sources could be documentation, archival records, interviews, direct observation, participant observation, and physical artefacts. Table 4.4 presents the strengths and weaknesses of each source of evidence.

Table 3.4 – Six sources of evidence: strengths and weaknesses (Yin, 2009, p.102)

Source of Evidence	Strengths	Weaknesses
Documentation	- Stable: can be reviewed repeatedly - Unobtrusive: not created as a result of a case study - Exact: contains exact names, references, and details of an event - Broad coverage: long span of time, many events, and many settings	- Retrievability: can be difficult to find - Biased selectivity, if collection is incomplete - Reporting bias: reflects (unknown) bias of author - Access: may be deliberate
Archival records	- [same as those of documentation] - Precise and usually quantitative	- [same as those of documentation] - Accessibility due to privacy reasons
Interviews	- Targeted: focused directly on case study topics - Insightful: provides perceived causal inferences and explanations	- Bias due to poorly articulated questions - Response bias - Inaccuracies due to poor recall - Reflexivity: interviewee responds with what interviewer wants to hear

Source of Evidence	Strengths	Weaknesses
Direct observations	- Reality: covers events in real time - Contextual: covers context of "case"	- Time-consuming - Selectivity: broad coverage difficult without a team of observers - Reflexivity: event may proceed differently because it's being observed - Cost: hours needed by human observers
Participants' observations	- [same as above for direct observations] - Provides insight into interpersonal behaviour and motives	- [same as above for direct observations] - Bias due to participant-observer's manipulation of events
Physical artefacts	- Provides insight into cultural features - Provides insight into technical operations	- Selectivity - Availability

Of great importance will be the initial crafting of instruments and protocols and the combined qualitative and quantitative data. The data collection will come from the following areas: literature review (section 3.5.1.1.) supported by a document review of 27 case studies (section 3.5.1.2.); survey to validate dimensions of complexity (section 3.5.1.3.); feedback from project managers during a global congress in 2014 (section 3.5.1.4); and interview with practitioners managing complex projects (section 3.5.1.5.).

3.5.1.1. Literature review

The initial data was collected through documentation via literature review of complexity dimensions and the cost-estimation process. The complexity dimensions were tabulated based on the number of occurrences from the most referred dimensions to the least.

The literature review on the cost-estimation process focused on exploring which approaches are used more often to estimate costs when managing projects. The conclusion is that actual cost-estimation processes do not take into consideration the possible impact of complexity dimensions on the estimates. Figure 3.13 represents the areas covered during the literature review.

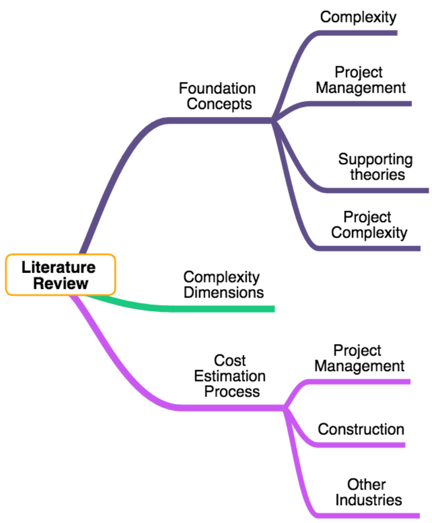


Figure 3.13 – Areas covered through the literature review

3.5.1.2. Document review of case studies

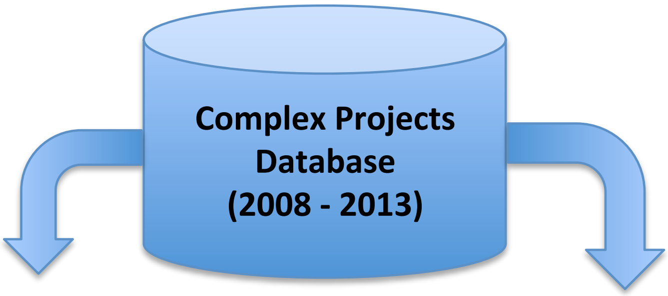
Furthermore, Yin (2009) states that the researcher can maximize the benefits of the aforementioned sources of evidence by following three main principles. The first one is the use of multiple source of evidence, which was already discussed. The second is to create a case study database, which was not necessary for this research since a database of 136 cases of complex projects was already created, as described in Table 3.5. The third and final principle is to maintain a chain of evidence, which is based on the same principle as forensic investigations. In other words, it allows the person investigating to follow the process from the moment the questions were posed to the conclusions.

Table 3.5 – Number of complex project cases

Year	Number of projects
2008	17
2009	23
2010	21
2011	23
2012	24
2013	28
Total	136

This research used a document review of existing case studies. The document review technique is simpler than other techniques and often considered a secondary approach to increase the reliability of the collected data. Nevertheless, this research will consider the document review as a primary technique because all documents were available to the researcher and the case studies contained clear information about complexity dimensions. The source of the case studies was the Aviation Week Network's Program Excellence Initiative as part of the Aerospace Industry Programme Excellence award process, which analyses several case studies of complex projects per year. The timeframe of analysis was six years, from 2008 to 2013.

The database was used to validate the dimensions found during the literature review and to check for new dimensions that were not mentioned in the literature review. For each project presented, there is a 10-page report detailing the areas described in Figure 3.14.



I. Program Overview	1. Program name
	2. Leader
	3. Category
	4. Backgroud
II. Value Creation	1. Value
	2. Excellence & Uniqueness
III. Strategic: Organizational Processes / Best Practices	1. Opportunity Management
	2. Supply Chain & Cost Effectiveness Mgmt
	3. Operational Integration & Systems Engineering
IV. Operational: Organizational Processes / Best Practices	1. Planning, Monitoring & Controlling
	2. Supply Chain & Logistics Mgmt
	3. System Integration, testing & Reviews
	4. Risks & Opportunity Management

V. Team Leadership	1. Team Culture & Motivation
	2. Lessons Learned & Knowledge Mgmt
	3. Leadership Development
VI. Best Practices	1. Unique best practices
VII. Adapting to Complexity	**1. Market Uncertainty**
	2. Technological Uncertainty
	3. System Complexity
	4. Pace & Urgency
	5. Other Complexities
VIII. Metrics	1. Customer
	2. Performance
	3. Preparing for the Future
	4. Team
	5. Unique Metrics

Figure 3.14 – Complex projects database

The researcher then filtered all cases that had 'Other Complexities' listed in the case study documentation, which corresponds to item VII.5 in the previously mentioned structure. Another view is provided in Figure 3.15 below.

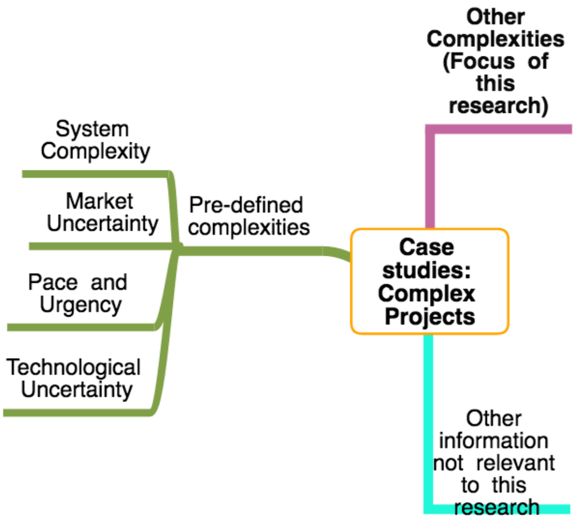


Figure 3.15 – Case studies document review

These selected cases were not limited to North America, but included participation from South America and European organizations, which makes the representation less region-centric. The resulting 27 cases represent 20% of all cases from the database and cover a varied range of industries (Nations, 2016) as presented in Table 3.6.

Table 3.6 – Dispersion of cases per industry*

Industry*	Number of Occurrences	Cases
Information and Communications (Telecommunications, Information Technology)	12	#3, 4, 6, 7, 10, 12, 14, 16, 18, 20, 23, 25
Transportation (Avionics, Logistics)	9	#2, 5, 9, 13, 17, 21, 22, 26, 27
Construction and Engineering	9	#2, 5, 15, 16, 17, 19, 20, 21, 22
Defence and Aerospace	8	#1, 11, 13, 15, 16, 20, 26, 27
Professional & Technical Services (Electronics)	7	#3, 4, 8, 11, 17, 18, 19

Industry*	Number of Occurrences	Cases
Support Services (Maintenance, Security, Environment)	3	#1, 9, 25
Education	1	#24

(*) Industry classification according to the United Nations Statistics Division (Nations, 2016)

Once the literature review was finished and supporting details provided through the case studies document review, the data collected next was from a survey to gather input from practitioners on which dimensions were more relevant.

3.5.1.3. Surveying

The next step was to design a survey to gather additional data with the purpose of validating the literature review and prioritizing the existing 23 dimensions. The survey was divided into two distinct parts: Demographics (region and industry), and classification of the level of impact each dimension has on projects. The level of impact used the Likert scale and varied from 1–No Impact, to 5–Extreme Impact. Figure 3.16 contains a graphical representation of the survey.

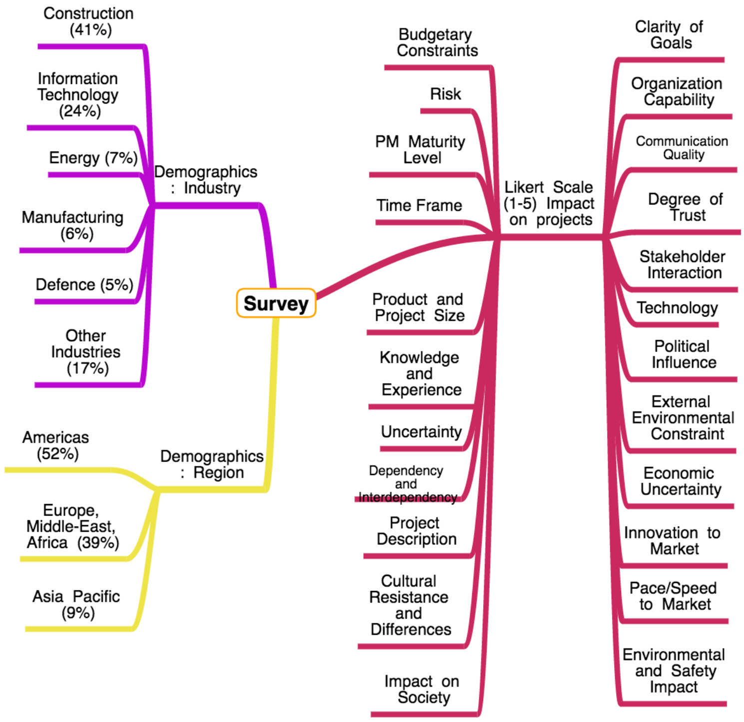


Figure 3.16 – Survey structure

To ensure consistency in the responses, a definition of each dimension was provided together with an example. The survey also asks to provide a rough estimate of the cost overrun and the main causes of complexity. The content of the survey can be found in Appendix A.

The following steps were used to obtain a prioritized list of dimensions that would support the upcoming survey:

Step 1 – Define the percentage of respondents that selected each level (1-5) per dimension.

Step 2 – Create a weighted average using only extreme impact (5) and significant impact (4).

Step 3 – Obtain a priority list by complexity dimensions with a higher weighted average.

The analysis of the data from the survey also used the Relative Importance Index (RII), which considers the sum of all responses from that specific dimension divided by the product of the maximum rate (5) and number of respondents. Since the objective was to obtain a list of the most impactful dimensions and to limit the number of dimensions, the researcher considered dimensions with RII equal to or over 0.70 as more relevant (Faridi & El-Sayegh, 2006). The formula for the RII method is provided below:

$$RII = \frac{\sum W}{A \times N} \; (0 \leq \text{RII} \leq 1)$$

W = Weighting given to each factor

A = Highest weight

N = Number of respondents

Not all results from the RII technique were similar to the weighted average. The main differences were related to the rank of the dimensions when considering each approach, but most of the lowest ranked dimensions were similar. Considering that the RII technique is better supported by many authors and that the differences were not highly significant, this research will use the Relative Importance Index. More details on the specific results of both approaches are presented in Chapter 5.

3.5.1.4. Feedback from project managers during global congress

The researcher published a paper on October 27, 2014, entitled "Dimensions of Project Complexity: The Impact on the Cost-Estimation Process" during the 2014 Project Management Institute Global Congress in Phoenix, Arizona (USA). The results of the research thus far were presented to an audience of over 50 participants, and during the presentation the researcher asked the project managers for their input on possible complexity dimensions that would impact the cost-estimation process. Details of the data collected can be found in section 5.4 of this research. Figure 3.17 contains a graphical representation of the dimensions from the research and the input received from practitioners.

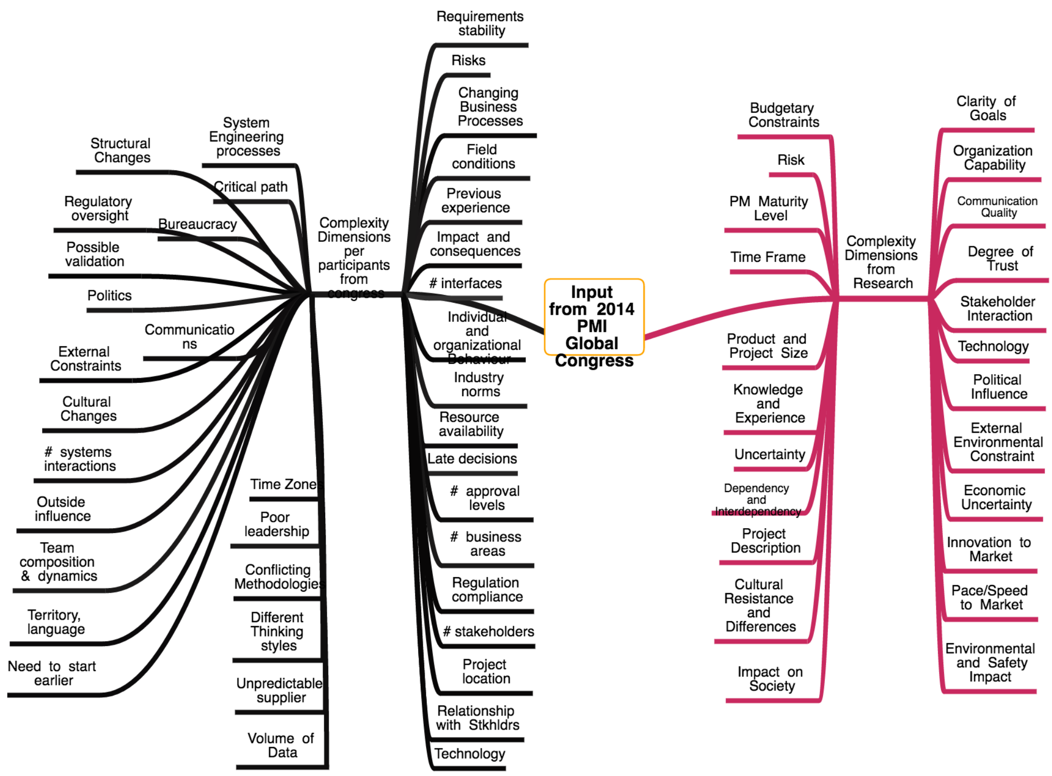


Figure 3.17 – 2014 PMI Global Congress input

3.5.1.5. Interviews

Interviews can be valuable means of gathering valid and reliable data to answer research questions. They can be structured, semi-structured, or unstructured (Saunders et al., 2009). Another way to classify interviews is as standard or non-standard (Healey & Rawlinson, 1993). Finally, a third typology involves distinguishing between respondent interviews and informant interviews (Robson, 2002). To select the most appropriate type of interview, one might consider the association between the interview type and the research category presented in Figure 3.18.

	Exploratory	Descriptive	Explanatory
Structured		✓✓	✓
Semi-structured	✓		✓✓
Unstructured	✓✓		

✓✓ = more frequent, ✓ = less frequent.

Figure 3.18 – Use of different types of interviews in each of the main research categories (Saunders et al., 2009, p.323)

Structured interviews are more useful when there is a standardized and predetermined set of questions (Saunders et al., 2009), which is not the case for the type of questions being asked for this research since each interviewee was at liberty to add comments and variations to the initial questions. Unstructured interviews are informal and do not contain a predetermined set of questions (Saunders et al., 2009), which again is not the case for this research since some questions were predetermined.

This research will focus more as an explanatory study since it looks to understand the relationship between several variables. On the other hand, it can be argued that this research has a less prominent but still existent exploratory aspect. Considering both exploratory and explanatory categories, the semi-structured interview type will be selected. Out of the 54 people who responded to the survey, 10 accepted to be interviewed. Table 3.7 provides a demographic view of the interviewees.

Table 3.7 – Demographic view of interviewees

Participant ID	Experience	Region	Industry Background
Participant 1	Expert/Academia	North America	Other
Participant 2	Expert/Academia	North America	Defence
Participant 3	Practitioner	Europe	Energy
Participant 4	Practitioner	Europe	Other
Participant 5	Practitioner	South America	IT
Participant 6	Expert/Academia	South America	Other
Participant 7	Practitioner	Caribbean	Construction
Participant 8	Practitioner	Middle East	Construction
Participant 9	Practitioner	Europe	Construction
Participant 10	Expert/Academia	North America	Defence

Finally, Figure 3.19 presents a visual representation of the interview structure.

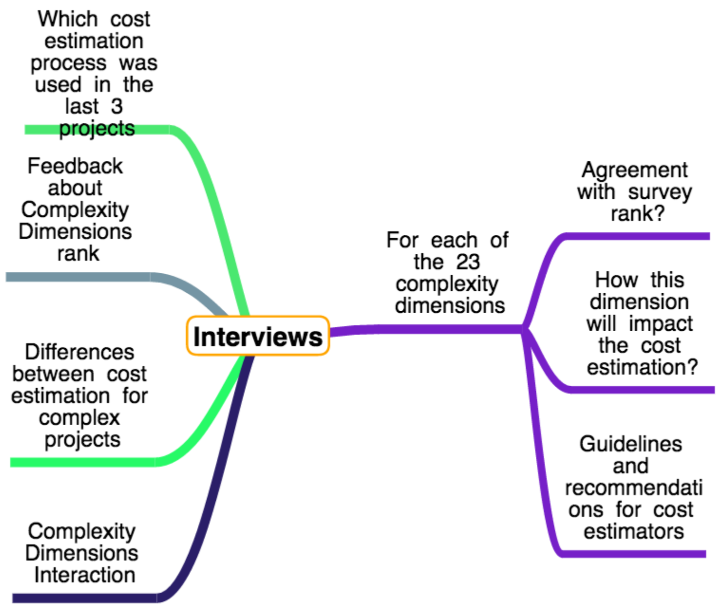


Figure 3.19 – Interview structure

The upcoming section will discuss the data analysis and presentation techniques used during the research.

3.5.2. Data analysis and presentation techniques

This section will discuss how the collected data will be analysed and which presentation techniques will be used to support the reader. Before describing which data analysis technique will be used, the statement below explains how challenging this endeavour could be:

"The analysis of case study evidence is one of the least developed and most difficult aspects of doing case studies. Too many times, investigators start case studies without having the foggiest notion about how the evidence is to be analysed". (Yin, 2009, p.127)

Research could be qualitative or quantitative in nature, so the technique used to analyse the data should consider the distinctions between qualitative data and quantitative data. The survey used during this research is related to quantitative data, which means that the numbers have meaning and the analysis is conducted using diagrams and statistics (i.e., Relative Importance Index). The document review of case studies, feedback from practitioners, and interviews are related to qualitative data. In qualitative data the meaning is based on words and analysis is conducted through the use of conceptualisation (Saunders et al., 2009).

Yin (2009) recommends that the researcher use some of the six analytical manipulations as proposed by Miles and Huberman (1994). These manipulations can help put the evidence in some logical order. The first manipulation is to put information into different arrays; the second is to make a matrix of categories and place the evidence within these categories; the third is to create data displays for better data examination; the fourth is to tabulate the frequency of different events; the fifth is to examine the complexity of these tabulations and their relationship; and the sixth is to put the information in chronological order. Once these steps are completed, the researcher will look for a general strategy to apply.

There are four general strategies that can be used to analyse the data (Yin, 2009). The most preferred strategy is to rely on theoretical propositions. Since these theoretical propositions were used to define the case study objectives and design, the researcher should start with this strategy. The other three strategies are developing a case description, examining rival explanations, and using both qualitative and quantitative data. Both the theoretical propositions and the use of qualitative and quantitative data are going to be used during this research through the use of survey, literature review, case study document review, and semi-structured interviews.

Furthermore, one of five analytical techniques can be used within the above strategies, but the researcher needs to be cognizant that none of them is easy to use and they require significant time to master (Yin, 2009).

- Pattern matching: This analytical technique compares an empirically based pattern with an existing, predicted one. For an explanatory case study, the patterns can be related to both dependent and independent variables. For a descriptive case study, the pattern matching can still be relevant as long as the predicted patterns of the variables are defined prior to the data collection. This research would benefit from using such a technique on both explanatory and exploratory aspects.
- Explanation building: This special type of pattern matching analyses the case study data by building an explanation about the case. This technique is used mainly for explanatory case studies and strengthens the internal validity, so it would be recommended for this research.
- Time-series analysis: As the name states, this technique focuses on examining relevant ‘how’ and ‘why’ questions about the relationship of events over a period of time. It can use single time series or complex time series but neither of them would be

applicable to this research since the time of the analysis is not relevant. The goal is to find the dimensions that impact the cost-estimation process.

- Logic models: This technique stipulates a complex set of cause-and-effect patterns that are analysed over a long period of time. The dependent variable or event from the previous stage becomes an independent variable (causal event) for the next stage. This technique matches empirically observed events with theoretically predicted events.
- Cross-case synthesis: This technique requires multiple cases and cross-references them. Since this research will do a document review of existing case studies instead of building them, the researcher won't use it.

In retrospect, considering that most of the data is qualitative in nature, the technique used for analysis will be content analysis. For that to happen, the researcher made use of available computer-aided qualitative data analysis software (CAQDAS) named NVivo version 11 for Windows.

The process of analysing the data of the semi-structured interviews was to take notes using LiveScribe and record the interviews. Each interviewee provided verbal and written consent to be recorded with the exception of one individual. No recording was made for that person.

The transcripts and recordings were then sent to a professional transcriber who typed the content into a Word document. The identities of all interviewees were kept anonymous. Once the transcription was finished, the researcher input the data in NVivo and generated a series of tables with the results as can be seen in section 5.7. Further diagrams generated by NVivo were also added to improve the presentation of the results. Note that NVivo is not intended to replace the work of the researcher in learning from the data, but to increase the effectiveness and efficiency of this process (Bazeley & Jackson, 2013).

3.6. Research Validation

A key question during a research process is how to ensure that the evidence and conclusions will stand up to scrutiny. There are two areas of research design that have to be emphasised to reduce the chances for errors—reliability and validity (Saunders et al., 2009).

Reliability refers to how consistent the findings are from the data collection techniques used and the analysis process. Reliability can be assessed by answering the following questions: Will the data collection techniques or analysis procedures yield the same results on another occasion? Will other observers reach similar results? Is there transparency of how the conclusions were reached by the raw? (Easterby-Smith et al., 2008, p.109).

According to Robson (2002), there are four main threats to reliability that need to be observed. The first is participant error, which reflects the possibility that a participant provides erroneous information (i.e., lack of understanding of the questions). The second is related to participant bias, which refers to receiving responses that might not be accurate due to an existing bias (i.e., cultural or belief system). The third and fourth are related to errors or bias on the part of the researcher or observer. They have similar explanations as the threats described previously, but from the observer's point of view.

Validity is concerned with whether the findings are an accurate representation of what they appear to be. One of the key questions is whether the relationship between two variables is a correlational relationship or a causal one (Saunders et al., 2009). A correlational relationship states that two variables perform in a synchronized way. One example would be the relationship between ability in math and proficiency in music. If the relationship is true, then the two variables are correlated. In other words, there is no definition of the cause for this relationship, or certainty that one variable causes the other or vice-versa (Trochim, 2006). On the other hand, if one variable causes an effect on another, there is a causal relationship between the variables.

According to Creswell (2009), the validation process has different meanings in qualitative research than in quantitative. This view is supported by Gibbs (2007), who states that qualitative validity indicates that the researcher looks to validate the findings by using specific procedures, and qualitative reliability indicates that there is consistency between the researcher's approach with that of other researchers.

Similarly, Robson (2002) suggests that there are threats to validity that should be considered by the researcher. One of them is related to how history or a past experience can affect the results of a specific study. Another considers the possibility of subjects changing their answers to benefit themselves in some way. The next is related to the effect of participants dropping out of the study, which would be like having nine of the interviewees from this research stating they don't want to participant any longer.

Another way to look into the quality of the research design is proposed by Yin (2009) and is based on four design tests as shown in Table 3.8.

Table 3.8 – Four design tests (Yin, 2009, p.41)

Tests	Case study tactic	Phase of research in which tactics occurs
Construct Validity	– Use multiple sources of evidence – Establish chain of evidence – Have key informants review draft case study report	– Data collection – Data collection – Composition
Internal Validity	– Do pattern matching – Do explanation building – Address rival explanations – Use logic models	– Data analysis – Data analysis – Data analysis – Data analysis
External Validity	– Use theory in single case studies – Use replication logic in multiple case studies	– Research design – Research design
Reliability	– Use case study protocol – Develop case study database	– Data collection – Data collection

Construct validity:

The construct validity test is used to mitigate subjective judgments and help the researcher develop a sufficient set of measures. As described in Table 3.7, this can be accomplished by using multiple sources of evidence, establishing a chain of evidence, and having a review of case study reports by key informants (Yin, 2009). The tactic used in this research was to use multiple sources of evidence, also known as triangulation.

Triangulation refers to the use of different sources of data or data collection techniques to confirm the findings obtained through one source (Saunders et al., 2009). For this research, triangulation will be used to support reliability and validity of the findings through the following sources: literature review, document review of case studies, survey, input from practitioners during a congress, and interviews.

Internal validity:

Internal validity is normally used for explanatory research, when the focus is to answer 'how' and 'why' questions, and to deal with the problem of making inferences (Yin, 2009). An example provided by the aforementioned author related to the first situation is when a researcher is trying to explain that event *x* led to event *y* and proposes a causal effect between these two events without knowing that a third factor, event *z,* may be the cause for event *y.* This logic would not be applicable to studies that are not concerned with the causal relationship (i.e., surveys, case studies). The author further explains that the second situation—inferences occurs every time an event cannot be directly observed.

This research will address internal validity by the selection of the most appropriate research design and technique. The research design used is the modified nested model as described in section 3.2, and research techniques are explained in section 3.5.

External validity:

External validity is concerned with addressing whether the research findings can be generalised beyond the scope of the study. This generalisation could be either statistical, for surveys or other quantitative data collection techniques, or analytical, for case studies, experiments, or other qualitative data collection techniques (Yin, 2009). This research will use generalisation of the findings considering multiple sources of data including validation with practitioners during a global project management congress (sections 3.5.1.4 and 5.4) and interviews (sections 3.5.1.5, 5.6, 5.7, and 5.8).

Additionally, there was a validation by external experts referring the questions of the survey (section 5.2) and the recommendations for practitioners generated during the interviews (section 5.7). The process to gather external validation was similar for both cases:

1- Started with the selection of the experts, whereas the researcher invited three seminal authors in the field of project management, cost estimation and complexity . For both cases, these experts accepted the invite to provide feedback of the survey questions and the recommendations provided during the interviews.
2- The researcher sent the experts the survey questions, got their feedback, and updated the questions prior to starting the survey. Similarly, the researcher sent the experts the recommendations provided during the interviews, updated the recommendation texts, and included on the model.
3- A final review on both cases was done by a proof-reader to assure that no grammatical errors were present.

Reliability:

As described previously, the objective is to assure that a future researcher will be able to reach the same results by following the same process for the same case study (Yin, 2009). Obviously, this process depends on having the same case study or data available. On the other hand, one needs to be aware that there are many factors (i.e., time of research, market conditions, changes in specific industries) that might affect the results; nonetheless, the existence of a repeatable process is necessary to provide reliability to the research (Marshall & Rossman, 2011). This research is using a set of well-documented procedures that can be replicated by further researchers.

3.7. Chapter Summary

This chapter presents the methodology used for this research, starting with the methodological framework used and moving on to the ontological, epistemological, and axiological assumptions. The research approach is also discussed and detailed into the research choices, mode, and strategies. Following, it also covers the time horizons and operational aspects, and presents the case study design. Next, the data collection techniques and data analysis are presented, finalizing with the research validation process through the construct validity, internal and external validity, and reliability. The next chapter will present the results obtained from the document review of the case studies.

CHAPTER 4 – CASE STUDIES

4.1. Introduction

This chapter will analyse the case studies to strengthen understanding of complexity dimensions. The case studies came from a list of complex projects used during Aviation Week Network's Program Excellence Initiative. This initiative is part of the aerospace industry programme excellence award process, which analyses a series of complex projects each year. The timeframe of analysis was six years, from 2008 to 2013, with a total of 136 cases from different parts of the world.

The main reasons for selecting these case studies were as follows:

(1) All projects listed are complex in nature as this was one of the key requirements to apply for the award; and

(2) The content was rich in information and included several different industries, including construction and engineering, information technology, manufacturing, aerospace, and defence.

The focus was to check the records under the 'VII. Adapting to Complexity' section of each case study. In the document template adopted, each case study is divided into several parts as shown in Figure 4.1.

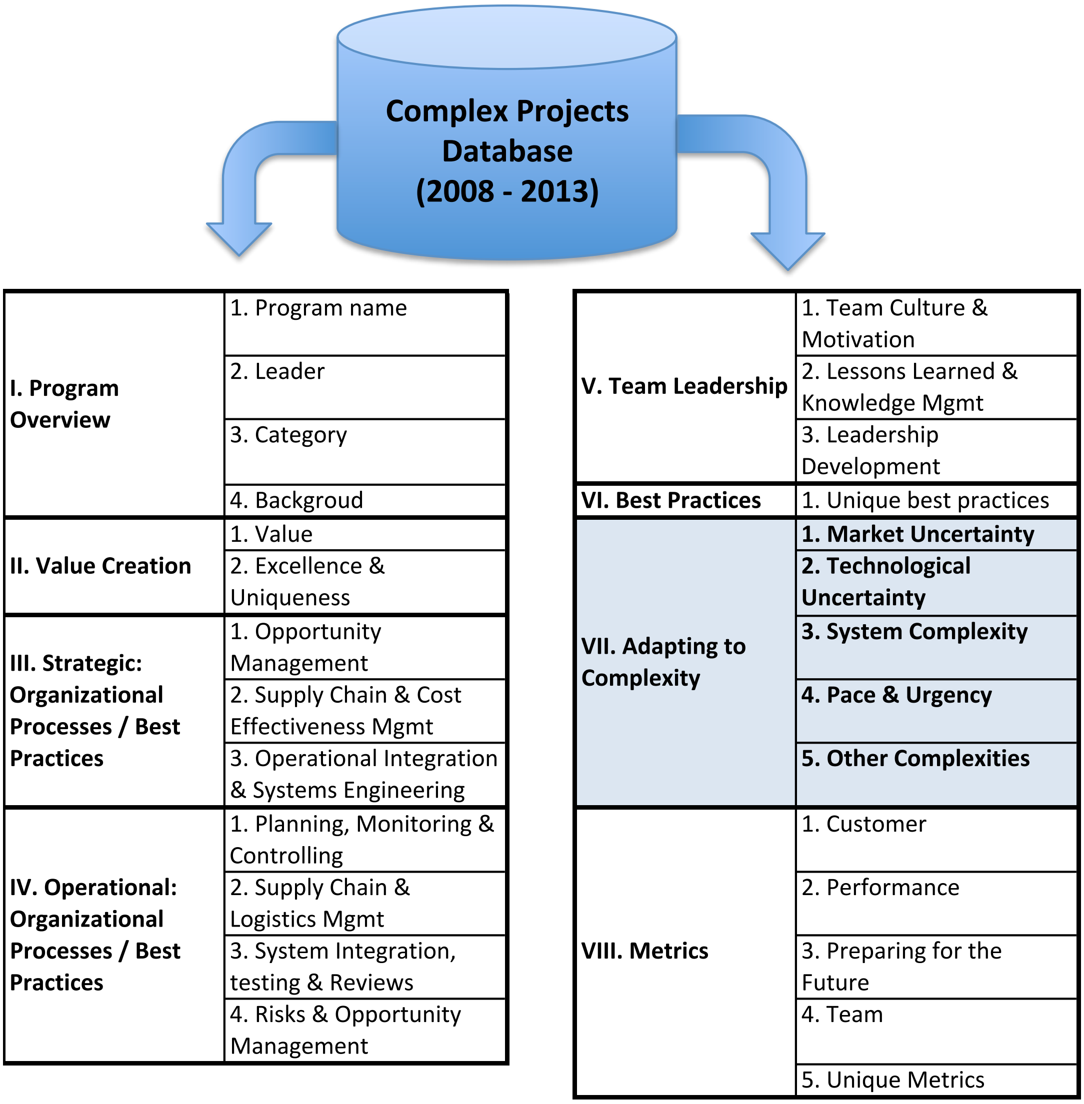


Figure 4.1 – Complex projects database

Note that four common complexity dimensions are considered in all projects in this database: Market Uncertainty, Technological Uncertainty, System Complexity, and Pace. Additionally, there is an opportunity to add any other dimension under “Other Complexities”. The parallel of these four complexity dimensions is described in Table 4.1.

Table 4.1 – Correlation between literature review and case studies

Case Study Dimension	Research Dimension
Market Uncertainty	Uncertainty
Technology Uncertainty	Technology
System Complexity	Product & Project Size (1)
Pace	Pace/Speed to Market

[(1)] The correlation between system complexity and the size of the product or project is defended by Baccarini (1996) when associating these two dimensions as intricate elements of systems' complexity.

Considering the high number of cases, there was a need to limit the number of cases to for the sake of manageability. The number of cases was reduced from 136 to 27 by selecting the cases that had additional complexities described. This information was found by reading the content of section *VII. Adapting to Complexity,* sub-section *5. Other Complexities* of all 136 cases and marking the cases that would provide additional complexity dimensions. The step-by-step process is explained below:

1. Access the database of complex projects available at the Aviation Week Program Excellence Initiative.
2. For each of the 136 cases listed between the years 2008 and 2013, open the document and read section *VII. Adapting to Complexity*, sub-section *5. Other Complexities*, to find any complexity dimensions listed. If complexity dimensions are found, flag the case study for future review. If not, disregard that case study.
3. After reviewing all 136 cases (step 2 above), revisit the flagged cases to perform these steps:
    a. Create a new reference number to maintain confidentiality.
    b. Define which industry the case study refers to.
    c. List the complexity dimension(s) found.
4. Summarise the findings.

Considering that this research also has to analyse data in non-numerical form, the process of content analysis was used as part of the Qualitative Document Analysis (QDA). An analysis of the dimensions found in the Literature Review is evaluated and verified in each case, followed by a further analysis of additional dimensions found in that case.

4.2. Selected Cases

As described in section 4.3, the database is based on complex projects submitted as part of Aviation Week Network's Program Excellence Initiative. The timeframe of analysis was six years, from 2008 to 2013. Table 4.2 shows the number of projects submitted per year:

Table 4.2. – Number of projects submitted per year for AW Program Excellence Initiative

Year	Number of projects submitted
2008	17
2009	23
2010	21
2011	23
2012	24
2013	28
Total	136

Out of the 136 cases analysed, the research focused on 27 case studies that contained the targeted information. Table 4.3 shows the 27 case studies divided by industry [(*)].

Table 4.3 – Dispersion table per industry*

Industry*	Number of Occurrences	Cases
Information and Communications (Telecommunications, Information Technology)	12	#3, 4, 6, 7, 10, 12, 14, 16, 18, 20, 23, 25
Transportation (Avionics, Logistics)	9	#2, 5, 9, 13, 17, 21, 22, 26, 27
Construction and Engineering	9	#2, 5, 15, 16, 17, 19, 20, 21, 22
Defence and Aerospace	8	#1, 11, 13, 15, 16, 20, 26, 27
Professional & Technical Services (Electronics)	7	#3, 4, 8, 11, 17, 18, 19
Support Services (Maintenance, Security, Environment)	3	#1, 9, 25
Education	1	#24

(*) Industry classification according to the United Nations Statistics Division (Nations, 2016)

4.3. Complexity Dimensions from Case Studies

4.3.1. Case # 01

Case reference: 2007-1/7 Year: 2007 Industries: Defence, Support services

The project's objective was to implement an unmanned aircraft to help secure an international border, which could be used for different regions thereafter. Existing manned aircraft and ground agents were already in use but the project added an extra capability that would greatly increase security in that region. The approach was to have daily flights of the unmanned aircraft to report possible threats and help capture, store, and analyse data to support the manned operations, as described in the project report, "Custom and Border Patrol personnel leverage their detection, monitoring and interdiction skills to safeguard our nation from terrorists and terrorist threats, to staunch drug smuggling and illegal drugs, to interdict illegal immigration attempts, and to support criminal investigations".

The use of a new generation of unmanned aircraft to patrol the region brought a level of uncertainty since it has to be adapted to the specific needs of this project as described above. The necessary improvements had to be tested and integrated into operations prior to deployment, with a focus on safety and efficacy. The integration process between the unmanned aircraft operation and the existing customs and border patrol was crucial for the success of this initiative but was also its main challenge.

Technologically, even though the unmanned aircraft already exists, the project could be considered as medium-technology since it is being used for new requirements. This is especially accurate once the patrol covers the northern border, where the climate (ice, snow) can be an important factor in increasing the complexity of the solution.

The project and product size complexity level could be considered as an array since it will use several systems (i.e., local, regional, and central operation centres, diverse systems used to manage each equipment) located across the country to gather, analyse, and consolidate data from all regions into a centralized hub.

The pace or speed to market would bring a lower to medium level of complexity since it can be considered fast competitive—there was great interest in implementing the project as soon as possible due to the described benefits, but there was not an absolute deadline that would impact the entire project.

The fact that no one from the aircrew team has experience operating the new system brings complexity to the project. Due to this lack of knowledge and experience, no feedback can be provided and considered before or during the implementation of the project. Intense training will be needed and adjustments will probably be made to the system once delivered.

During the document analysis, several dimensions were found as presented in Table 4.4.

Table 4.4 – Dimensions for case # 01

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Knowledge and Experience		X

4.3.2. Case # 02

Case reference: 2007-2/7 Year: 2007 Industries: Transportation, Construction and Engineering

This project's objective was to design, develop, test, and produce a new generation of a carrier-based electronic combat aircraft (hereafter called ECA) for the navy of the country where the company is located. The new aircraft was to be built on an existing and operational platform in use since the 1970's but using more technologically advanced features.

The ECA should incorporate the most advanced technology available for this type of aircraft, which would bring tactical advantage to the navy. The program was considered a success with respect to the performance of the new aircraft and in meeting or being ahead of major project milestones while staying on budget, including not using significant management reserves. Not only will the new ECA be less expensive to operate, but it will also allow the older aircraft model to be retired, significantly reducing operation and maintenance costs.

The project team applied rigorous risk and opportunity management by focusing on negative risks (the ones that could negatively affect the project) and analysing their impact on scope, time, cost, and technical performance. This approach to managing risks was also due to lessons learned from other projects where no formal risk-management process was implemented, creating negative consequences.

One consequence of not doing proper risk management was missing the interdependence among all the components of the project. Without a clear picture of the dependence and interdependence of the elements, the chances of making mistakes are much higher, which itself is a risk.

As external environmental constraints, the fact that this project creates a new generation of ECA brings uncertainty regarding how long it will operate before being made obsolete by future technologies; however, this is the nature of advancement. Considering also that budget cuts are possible, the government could also be considered an external environmental constraint.

The integration of mature technology in an existing platform to create a new ECA could be considered as medium technological level. Several tests were performed to assure that any technological issues were covered and addressed.

The product and project size, with the related complexity level, is present in the integration between mission-critical subsystems like communication—radio, jammer, radar, satellite, and displays. The architecture had to be managed through the decomposition of all the requirements and detailed design of the solutions. According to the project report, the approach was as follows: “By properly allocating functionality to the appropriate subsystem, and through careful interface definition and control, complex systems are divided into manageable hardware and software components, with a corresponding team organization to best divide work based on team knowledge and abilities”.

The pace/time to market was considered time-critical since the navy had a firm and challenging deadline to launch the new ECA and replace older models. According to the project manager, meeting the time constraints was one of the key success factors for this project and also one of the major risks.

Even though not found in other cases, transition to production was considered a complexity dimension that impacted this project as the aircraft was built concurrently with all the necessary testing and equipment qualifications. Performing this type of work while one delivers a product adds complexity because when anomalies are discovered and addressed, changes must be made to equipment that was supposed to have been finalized. The fact that these issues happened during the project drives one to conclude that the project team was lacking knowledge and experience.

During the document analysis, several dimensions were found as presented in Table 4.5.

Table 4.5 – Dimensions for case # 02

Complexity Dimension	Literature Review	New from Case Study
Risk	X	
Dependency & Interdependency	X	
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	
Knowledge and Experience		X
Transition to Production		X

4.3.3. Case # 03

Case reference: 2007-3/7 Year: 2007 Industries: Information and Communication, Professional and Technical Services

Military organizations across the globe share the challenge of modernizing their operations. Requirements are more and more aligned with the changing global security environment, and future engagements require more precise and fast responses. This project was to develop a Future Combat System (FCS), which is an integrated system of systems, covering unmanned sensors to support operations on land and air.

The project has several key stakeholders, including the customer (Government Department of Defence), the lead systems integrator, over 20 subcontractors, and more than 600 suppliers. During the system development and demonstration phase, the project met cost, performance, and schedule goals.

A state of uncertainty was created by the limited budget available, leaving some requirements unmet. The need to obtain financial resources for more immediate initiatives created a challenge to a more traditional funding schedule. The approach used to manage this situation involved educating key stakeholders and decision-makers to influence the project execution. This stakeholder interaction was crucial to the success of the project and it required a well-planned and executed communication plan.

The technology level for this project was considered low due to the strategy to reduce risks. Whenever possible, the approach was to use existing, proved, and stable technologies, so the risk of unforeseen issues was reduced. Other parts of the project were considered medium-risk technology, mostly due to the interaction among different segments of the army and the use of some maturing technologies that were still going through acceptance tests before entering production.

According to the project report, the project and product size could be characterized as a system of systems, or described as "a large multidisciplinary, networked, system-of-systems that provides overmatching combat power, situational awareness, sustainability, agility and versatility necessary for the full spectrum of military operations".

The need to produce early spinouts of the technological elements of the project can impose an acceleration of pace or time to market. On the other hand, larger defence contracts are rarely focused on speed during the design and analysis phase: better take time to plan properly than to fix issues afterwards. Overall, the pace can be considered fast since reaching the deadline is important for competitive advantage and delays will have an undesirable impact on the project outcome.

There were several demands from the army for new projects, but not all of them could be implemented due to budgetary constraints. Priorities were set up and some initiatives could not move forward. The same happened with the competing demands for this specific project.

The communication quality had to be centred on direct communication to avoid multiple interpretations of the message. It also had to be aligned with the preferences of each stakeholder, as in what, where, how, and when to communicate.

An aspect that can bring complexity to this project is the geographical distribution of the two main contractors, located in 14 different sites. Furthermore, the project involved several suppliers, partners, and army personnel located in different countries and time zones. The numbers are impressive: a total of 24 first-tier partners and over 600 companies.

During the document analysis, several dimensions were found as presented in Table 4.6.

Table 4.6 – Dimensions for case # 03

Complexity Dimension	Literature Review	New from Case Study
Stakeholder Interaction	X	
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Budgetary Constraints		X
Communication Quality		X
Geographical Distribution		X

4.3.4. Case # 04

Case reference: 2007-4/7 Year: 2007 Industries: Information and Communications, Professional and Technical Services

The project aims to deliver a ground-located system that improves GPS accuracy by providing differential GPS corrections and adjusting the satellites' readings. This system is important for any activity that requires more accurate readings, lack of visibility, greater precision, and better decision-making. One challenging aspect, as described in the project report, is that the system "should have total interoperability and that there should be complete independence between the ground station and the airborne".

Soon after the project started, one of the key stakeholders of this system expressed concerns about integrity monitoring issues, which could impact the accuracy of GPS readings. Due to budgetary constraints, the project had to change from acquisition and development to a research and development project. It took a few years of research with universities and research organizations to address and solve the issue. Once implemented, the system was able to perform as required.

Considering that a GPS system already existed in previous generations, reducing complexity and impact on the project, the uncertainty level was not considered high. As a derivative product of an existing system, the technology complexity could be considered medium to high level, especially considering the new approach for correcting the GPS measurements and accuracy.

The system was comprised of sensors, process, and broadcast subsystems, so the product and project size could be considered a system, which can have some impact on the complexity level of the project.

The company contracted to implement the new system was competing with three other organizations, so the pace and time to market could be considered fast competitive. The faster one has to implement a project, the greater the level of complexity.

As mentioned before, the budgetary constraints directly impacted the performance of the project, limiting the implementation time and requiring a change in direction to a more research and development approach up to when the budget was made available.

During the document analysis, several dimensions were found as presented in Table 4.7.

Table 4.7 – Dimensions for case # 04

Complexity Dimension	Literature Review	New from Case Study
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Budgetary Constraints		X

4.3.5. Case # 05

Case reference: 2007-5/7 Year: 2007 Industries: Transportation, Construction and Engineering

Due to an aging helicopter fleet, there was a need to manufacture new and better-performing engines, capable of working in harsh climates (i.e., high temperatures) and lifting heavier cargos. The only vehicle available for such environmental conditions had an engine with limited power and older technology. One option considered was to upgrade the existing engine, but a feasibility study showed that designing, developing, and manufacturing a new engine was a faster and less costly solution.

The new engine would be a derivative product of the existing one but with 25% more power and new technology. The only uncertainty in this project was related to the timing of the budget release for production of the necessary engines, so the complexity level related to this aspect was low to medium. The technological aspect of this project could be considered medium to high, not necessarily due to the new engine alone but also the electronic control system needed to control it. Once a new engine is developed, a suitable control system should also be created with the best technology available.

When considering the product and project size, a more simplistic view could be that an engine is an assembly, or equipment performing a single function—to generate power. According to the project report, "...with well over 1000 different part numbers, a large gas turbine engine is much more complex. The engine has several sub systems performing the thermodynamic functions of air compression, fuel mixing and combustion, and power extraction. Each of these subsystems is mechanically and aerodynamically complex, requiring high precision design and manufacture for the system to work". That means it should be considered a system with a higher complexity level.

The pace/speed to market could be considered fast competitive, since it would bring an advantage compared with the previous versions of the engine. The complexity level due to this dimension was not considered significant.

A complex budget system associated with a large supply base with over 1,000 parts obtained through dozens of suppliers created a complex situation where each part could impact the entire project. This type of budgetary constraint could only be managed by very close control of every single part of the process and all suppliers and production.

During the document analysis, several dimensions were found as presented in Table 4.8.

Table 4.8 – Dimensions for case # 05

Complexity Dimension	Literature Review	New from Case Study
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Budgetary Constraints		X

4.3.6. Case # 06

Case reference: 2007-6/7 Year: 2007 Industries: Information and Communication.

The project aimed to integrate legacy IT systems and migrate them to a new platform architecture. The existing IT systems were responsible for gathering information (intelligence), planning, and executing military operations, but they were at capacity. The objective of the new system and integration was to allow better decision-making close to real time. As described in the project report, the new system "collects data in real time on coalition and enemy forces, and coordinates Army, Air Force, Navy and Marine systems so war fighters can synchronize and execute battle plans electronically through a secure wide area network". The existing system is being used in over 600 locations worldwide.

The uncertainty level of this project is considered low since it is derived from existing systems and platforms. In other words, it is an evolution of previous systems without any new generation or breakthrough application or functionality.

Even though the uncertainty level does not bring significant complexity to the project, the technology used could be considered medium to high level. The reason for that is the architecture migrated from a client-server model to Enterprise Service Oriented Architecture, which provides web-based information services. There was also the need to adapt this service-oriented architecture to the specific requirements of the military.

The project could be considered a system with many subsystems integrated to produce the final IT product. Besides the integration of all the subsystems, there was a need to consider different environments and end-user requirements, which takes the product and project size complexity a higher level. Dedicated process engineering and personnel were considered key success factors for this project. Interestingly, the method used to manage the complexity of this project is called Integrated Inspection and Quality Point (QP) review process. According to the project report, "The Inspection process ensures the product being inspected is technically sound. The QP process ensures process integrity and that all support organization impacts are addressed. All team members are completely involved in the version development cycle to evaluate the product and provide inputs using the QP review process".

When analysing the pace/speed to market, we could consider this project as having a regular pace, without any extra complexity added due to this dimension. The development and implementation process followed the well-known spiral development approach, which installs new features and applications in short rather than long increments.

An additional significant complexity dimension is related to the stakeholders' interaction. Managing expectations and user requirements from all different branches of the military, contractors, subcontractors, and end users was a challenge, and the complexity level could be considered medium, where not all stakeholders were aligned with the objectives and requirements of the project.

During the document analysis, several dimensions were found as presented in Table 4.9.

Table 4.9 – Dimensions for case # 06

Complexity Dimension	Literature Review	New from Case Study
Technology	X	
Product & Project Size	X	
Stakeholder Interaction	X	

4.3.7. Case # 07

Case reference: 2007-7/7 Year: 2007 Industries: Information and Communication

The project's objective was to optimize the supply chain process for this multidisciplinary research and development organization focused on solving complex national security problems. The supply chain management data analysis covered the product lifecycle phases described in the project report as "the need for the requirement through procurement, delivery of product, movement, fleet, storage, property/asset tracking and reapplication". The utilization analysis started in a small business unit as a pilot, was then extended to 10 more business units within the Materials Management area, and after that extended to other business units.

Given the nature of this project, where a successful pilot of a well-established supply chain management analysis process is implemented, the uncertainty level is quite low.

On the same note, the technology used for this project—mostly related to data extraction and reporting—can be considered low to medium. The reason it is not low is that the required reports were new and never developed before.

The product and project size has medium impact on complexity since it is comprised of several subsystems working together to produce a final analysis, covering the entire supply chain process as described previously.

The speed/pace to market is considered regular because the time to deliver the project is not crucial to success.

The only additional complexity dimension that presented relevance to this project was budgetary constraints, mostly due to limited financial resources available to perform all the necessary tasks.

During the document analysis, several dimensions were found as presented in Table 4.10.

Table 4.10 – Dimensions for case # 07

Complexity Dimension	Literature Review	New from Case Study
Product & Project Size	X	
Budgetary Constraints		X

4.3.8. Case # 08

Case reference: 2008-1/3 Year: 2008 Industries: Professional and Technical Services

The project aimed to develop an unmanned, non-recoverable, and low-cost aerial vehicle that would serve as a decoy and replicates the flight patterns of existing aircraft. It should also serve as a signal jammer and be able to be launched from ground or air. A counter air-operation was needed to protect the aircraft and the invaluable lives of the aircrews. Strong teamwork, simplified processes, and innovation earned this project impressive results during tests, with 95% success for the decoy and 100% for the jammer functionality.

The uncertainty level was high since it was, as described in the project report, "a breakthrough program in technology, modularity and affordability. It is the first low-cost, programmable, non-recoverable air-launched electronic warfare system". The final product will serve as the basis of future and improved versions.

The complexity level due to technology can be considered high, as mentioned above. The aerial vehicle and jammer device used new technology to fulfil the requirements. The decoy capability used medium technology, due to the existence of previous and mature technology.

Because this product is integrated with existing and already operating subsystems and devices, the product and project size can be considered as system, or, in other words, the complexity level is high.

The customer's requirement to be the first in market and the imperative of fast delivery, allied to the need to do all the tests and integration of many different components and subsystems, in various scenarios, increased the complexity level related to pace/speed to market.

Another complexity dimension of significance was the organizational climate due to extensive overtime work to meet the scheduled deadlines and external pressure from key stakeholders. This can be considered an external environmental constraint since it came from outside the project organization and team, and increased the complexity level with direct impact on the team's performance.

During the document analysis, several dimensions were found as presented in Table 4.11.

Table 4.11 – Dimensions for case # 08

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	

4.3.9. Case # 09

Case reference: 2008-2/3 Year: 2008 Industries: Transportation, Support Services

This country's military had the goal of reducing by 20% the operating costs of fast jets by enhancing its military platform from traditional repairs and spares replacement to a contracting process focused on making services and parts available when needed. The focus on improving logistics was key to surpassing the cost reduction goal and extending the approach to other areas of the military.

The uncertainty level could be considered between medium and high due to the change from a "do and charge" procurement principle to "cost per hour". This new approach was not used before between the military and the over 300 suppliers, so the results were not predictable.

Considering that the service to be provided involved building upon existing technology from the aircraft industry, it could be considered low to medium technology (mature technology adaptation). The complexity factor is due to applying the technologies across different organizations with distinct cultures.

There was no model to take into account the scale, availability, and sustainability of the services provided, so a high level of complexity can be considered for the product and project size. An array, or system of systems, would be a better representation of the complexity of the product and project size. The solution required a simulation at strategic and tactical levels to understand the impacts, costs, and implementation approach.

Related to the pace/speed to market, it was driven by the desire to be the first in the market with this approach (fast competitive). This brings a medium complexity level considering the need for innovation and accelerated learning curve.

The fact that this project had over 600 people involved, several different locations and facilities, and over 150 distinct services, created an environment where the cultural resistance and differences were significant, bringing an additional complexity level to the project. As described in on the project report, "Cultural differences and reward and recognition differences add further complexity. Systems that have been developed for commercial enterprise do not readily read across a military environment".

During the document analysis, several dimensions were found as presented in Table 4.12.

Table 4.12 – Dimensions for case # 09

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Cultural Resistance and Differences		X

4.3.10. Case # 10

Case reference: 2008-3/3 Year: 2008 Industries: Information and Communications

This information technology project aims to develop a data system to provide fast, safe, well-coordinated, and effective options for military engagement. As described in the project report, the project "provides the Force Commander with an automated command and control capability that rapidly performs the planning, de-confliction and engagement of surface targets with land, maritime and airborne attack assets while minimizing the risk of fratricide or collateral damage". The development model used innovative solutions and followed the supplier's Six Sigma process. This innovation increases the level of complexity with direct impact on delivering the software versions on time, within budget, and according the requirements.

The uncertainty level of this project is considered very high due to a complete redesign of the previous program into a set of network-enabled services, moving from a system-oriented to a service-oriented approach. In short, it is an evolution of what was working into a new architecture, which had never done before.

The technological aspect brings a high level of complexity due to over 8,000 system requirements that have to be fulfilled during the implementation. Another factor that increases the complexity is that the new system should be able to adapt to new technologies as they become available, which requires the foresight to plan for needed integration.

The level of complexity related to the product or project size could also be considered high. According to the project report, "It contains over 75 separate software processes that fully implement all layers of software necessary to manage, distribute, process and act on information".

A unique challenge that increased complexity on this project was the team's limited knowledge and experience in integrating third-party applications with simulation tools into the software. This was addressed by synchronizing all the schedules involved (i.e., third parties, project team) and by adjusting the simulation and testing tools to the specific requirements of this project.

During the document analysis, several dimensions were found as presented in Table 4.13.

Table 4.13 – Dimensions for case # 10

Complexity Dimension	Literature Review	Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Knowledge and Experience		X

4.3.11. Case # 11

Case reference: 2009-1/6 Year: 2009 Industries: Defence and Aerospace, Professional and Technical Services

One of the military branches decided to move from chemical propellants to electromagnetic launch. This existing technology allows higher velocity and range in the form of an electromagnetic force. One of the challenges was to increase the previous record of energy launch at 8 MJ (mega-joules) to 32 MJ. The product set world records in velocity, and the success of the project is described as follows in the project report: "This program is an example of a successful fast-paced, complex, and first of its kind advanced product development that fully met customer needs and satisfaction. It has provided significant value to our customer, company and shareholders".

The uncertainty level was quite high since it was a breakthrough program, developing a product new to the world. The program provided a revolutionary and significant advantage to the clients, creating a new generation of products for the aerospace and defence industry.

On the technological front, the project can be considered very high due to the use of state-of-the-art technologies to build something completely innovative. The approach used to deal with such a level of technological uncertainty was to work in tandem with industry leaders and academic and government organizations to define, develop, and evaluate possible technologies.

The product and project size itself did not bring a high level of complexity and could be considered low to medium. It could be classified as a subsystem, or fitting within a larger collection of systems. The challenge was the uniqueness of the project or product to be delivered, not its size.

Pace and speed to market were driven by the desire to be the first in the market, but it was not a time-critical or crisis-driven project, so this complexity level could be considered low to medium. The project team used concurrent work to analyse multiple possible solutions in the shortest possible time but without extreme pressure to deliver on a specific deadline.

Another dimension that brought a significant level of complexity was stakeholder interaction due to the client's request to keep a competitive environment between the different players. This created a challenge in deciding what information to keep secret and what would be beneficial to share with competitors.

Finally, another critical aspect was related to external environmental constraints created by the client, who imposed restrictions on using their assets and facilities, which by result impacted the program's efficiency level. The approach used by the project manager was to involve the client during the entire process to allow a better understanding of needs and reduction of the restrictions.

During the document analysis, several dimensions were found as presented in Table 4.14.

Table 4.14 – Dimensions for case # 11

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
External Environmental Constraints	X	
Stakeholder Interaction	X	

4.3.12. Case # 12

Case reference: 2009-2/9 Year: 2009 Industries: Information and Communications

The project's objective was to create a new generation of satellite systems to serve as a 'bridge' between the existing system and a new one, delivering high data rate communication services to the military and allied government worldwide. The approach was to use the commercial best practices already in place and initially implement three satellites, growing to six units, with the possibility of doubling this capacity in the future. One new satellite was able to provide more communication capacity than all the existing satellites combined, while maintaining compatibility with legacy systems.

The uncertainty level was high since this new satellite would provide more than 10 times the communication capability of its predecessors and was considered a product new to the world. As described in the project report, the program "provides unprecedented communication flexibility, capability, and capacity…"

The technology level is considered high or super-high since the project utilized recently developed technology or non-existent technology that needed to be developed during the project. The technology would enable point-to-point, broadcast, and multicast capabilities.

The project and product size could be considered of high complexity, since an entire system was to be built. As stated in the project report, the program "…is a global satellite communications system that includes a constellation of high-power geosynchronous satellites and ground-based command and control elements [….]. Each satellite contains more than 2,000 unit assemblies that are integrated into seven satellite subsystems…".

The pace or speed to market did not bring a high level of complexity since the project was to be delivered as soon as practical. The best way to describe the pace was fast competitive, since there was a desire to be the first to market but no absolute or critical-to-success deadline.

According to the project report, there were year-to-year variations in the funding made available for this project. This possible budgetary constraint creates additional challenges in long-term planning and execution, increasing the complexity level.

During the document analysis, several dimensions were found as presented in Table 4.15.

Table 4.15 – Dimensions for case # 12

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Budgetary Constraints		X

4.3.13. Case # 13

Case reference: 2009-3/6 Year: 2009 Industries: Transportation, Defence and Aerospace

The project aimed to create a modern, utility-purposed helicopter to be used for non-combat environments. The new helicopter would be a military derivative of a commercially successful one. One challenge was the quick transition of production from Europe to the United States, which had local benefits but also increased the complexity level of the endeavour. The project was considered a success, since it was delivered on or ahead of schedule and meeting or exceeding the customer's expectations.

The uncertainty level was quite low since the new aircraft was a derivative of an existing one. The fact that the new product was meant for use both in the U.S. and globally brought some level of complexity, but still a minimal amount.

Similarly, the technology used could be considered low to medium, since existing technology was used to meet new design requirements.

On the other hand, with respect to the product or project size, it was a system comprised of several subsystems with a medium to high complexity level. The four main efforts involved in creating the new product were production, maintenance, site stationing, and delivery with logistical support.

The pace or speed to market was considered time critical, with a critical-to-success deadline due to the need to retire the obsolete helicopters and release the combat-specific aircraft from non-combat missions.

An external environmental constraint that impacted the project considerably was geographical dispersion, with management and implementation teams located in different regions, time zones, and countries.

During the document analysis, several dimensions were found as presented in Table 4.16.

Table 4.16 – Dimensions for case # 13

Complexity Dimension	Literature Review	New from Case Study
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	

4.3.14. Case # 14

Case reference: 2009-4/6 Year: 2009 Industries: Information and Communications

At the onset of this project, air traffic control systems were still based on World War II radar technology, so there was a need to create a more efficient and safe technology that could also be placed where radar could not, allowing greater coverage. According to the project report, the new product "…uses data from the Global Navigation Satellite System and is critical to the […] plan for improving safety in the air and on runways while meeting the predicted tripling of demand in coming years".

The uncertainty level can be considered at least medium because it would create a new generation (based on a previous product) but would require an extensive research and development effort and presentation of its capabilities to the market.

Another aspect that brought additional complexity is the fact that previous attempts to introduce more advanced technology failed. The impact was a slow incorporation of the new technology, since potential users were reluctant to implement before they could consider it stable enough and time-proofed. The technology level could be considered high, or, in other words, recently developed technology.

The product and project size produced a high impact on the complexity level due to the creation of a system of systems. Per the project report, the "...technology incorporates the […] ground infrastructure, aircraft avionics, radar surveillance data, and all […] automation platforms. In addition, the system will impact pilots, controllers, and aviation technicians, requiring new training".

Considering the safety implications and capacity limitations of the existing technology, the pace or speed to market could be considered time critical, which brings the complexity level to high. Another aspect is the fact that other countries are also trying to implement similar technology, which would bring them market advantage. In other words, there was an urgency to be first to market.

Due to recent failures in implementing such technology and the economic impact suffered by the early adopters of the previous attempts, there was a lack of trust. When the degree of trust is low, the complexity level increases significantly because implementation of the new solution might be very slow and even impact the economic feasibility of the entire project.

Lack of confirmed funding year after year created a more complex environment. The budgetary constraints could have severely impacted the project so the team had to frequently meet with the key stakeholders to present the project status and provide assurance of its success.

During the document analysis, several dimensions were found as presented in Table 4.17.

Table 4.17 – Dimensions for case # 14

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Degree of Trust	X	
Budgetary Constraints		X

4.3.15. Case # 15

Case reference: 2009-5/6 Year: 2009 Industries: Construction and Engineering, Defence and Aerospace

The project aimed to create a super lightweight external tank (ET) for NASA's space shuttle. With an objective of reducing 7,500 pounds of weight, through a new aluminium-lithium alloy structure, it would provide extra performance enabling NASA to build and sustain the International Space Station. On a more technical level, according to the project report, "The external tank has three primary components: a Liquid Hydrogen pressure vessel, a Liquid Oxygen pressure vessel, and an unpressurized structural component called the Intertank that splices the pressure vessels together. The ET is covered with various Thermal Protection System (TPS) materials to provide pre-launch conditioning of the propellants, control ice formation, and protect the metal substrate from thermal effects".

The level of uncertainty is low since the new tank is a derivative of previous versions but uses a different material. Similarly, the technology level is low to medium, considering that the technology used evolved from existing technology but was driven by new requirements.

On the other hand, the product and project size brings a medium to high complexity level due to the fact that it is a system (collection of subsystems performing multiple functions). According to the project report, "The ET is a system comprised of structural, electrical, propulsion, and thermal sub-systems, that when integrated, fulfil the roles of the ET within the Space Transportation System".

According to the project report, the pace or speed to market could be considered time critical, which brings a high level of complexity. This can be confirmed by the deadline to complete all space shuttle flights, which was the end of 2010. The team had a hard deadline and intensive pressure to deliver as planned. Failure to deliver on time would have impacted the entire initiative.

Several external environmental constraints highly impacted the project and increased the complexity level as follows:

- Due to the tragic Columbia shuttle accident, manufacturing had to be restarted after the program was shut down. This impacted the retention of knowledge and experience.

- Hurricane Katrina impacted the schedule since workers were not able to return to their jobs.
- The decision to terminate the space shuttle program by the end of 2010 directly impacted the performance of the teams involved.

Furthermore, Hurricane Katrina significantly impacted operations in Louisiana, with loss of time and personnel. This environmental and safety impact could be considered high level. The greater challenge was to retain personnel after the hurricane.

During the document analysis, several dimensions were found as presented in Table 4.18.

Table 4.18 – Dimensions for case # 15

Complexity Dimension	Literature Review	New from Case Study
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraint	X	

4.3.16. Case # 16

Case reference: 2009-6/6 Year: 2009 Industries: Information and Communications, Construction and Engineering

This project objective was to conduct science observations and experiments through the Mars Reconnaissance Orbiter (MRO). It started in 2000, with the orbiter launched in 2005 and operations starting in 2006. The project's main goals, with the overall aim to acquire data needed to prepare for a future exploration of Mars and quoted directly from the project report, were as follows:

- "Characterize Mars' seasonal cycles and daily variations of water, dust & carbon dioxide.
- Characterize Mars' global atmospheric structure, transport and surface changes.
- Search sites for evidence of aqueous and/or hydrothermal activity.
- Characterize in detail the stratigraphy, geology & composition of Mars surface features.
- Characterize the Martian ice caps and the polar-layered terrains.
- Profile the upper crust while probing for subsurface water and ground ice.
- Characterize the Martian gravity field and upper atmosphere in greater detail.
- Identify and characterize many sites for future landed Projects".

The uncertainty level could be considered high since the project could be classified as a new generation, increasing the capabilities of previous orbiters but keeping the same technology.

Even though the project used existing technology, several aspects could be considered medium to high complexity due to the use of cutting-edge instruments, engineering, and software.

The product and project size of the MRO project could be considered a system divided into several subsystems, including Lander/Rover support, Entry, Landing, and so on. All these subsystems bring the complexity level to medium to high. The project is part of the Mars program.

The pace or speed to market ranges from fast competitive to time critical depending on the subsystem in question. The complexity level varies from medium to high as well.

The need for several different stakeholders to interact in five separate science disciplines brought a higher complexity level, considering that the stakeholder interaction had to be managed closely to ensure proper communication and teamwork.

During the document analysis, several dimensions were found as presented in Table 4.19.

Table 4.19 – Dimensions for case # 16

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Stakeholder Interaction	X	

4.3.17. Case # 17

Case reference: 2010-1/6 Year: 2010 Industries: Transportation, Construction and Engineering, Professional and Technical Services

This project's objective is to create a product that integrates environmental and power systems on an aircraft. Eliminating separated systems is an important means of reducing weight. According to the project report, the final product "…uniquely integrates auxiliary power, emergency power, electrical power generation, thermal management and environmental control in a single system which provides the aircraft's power and cooling. Viewed as an enabler, other aircraft systems rely on the PTMS [Power Thermal Management System] to operate optimally".

The uncertainty level of this project is high since the integrated system was never produced before; it could be considered a breakthrough achievement. The team managed the level of uncertainty by building a prototype and performing tests to ensure the required results would be achieved.

The new system has to use recently developed technology (high technology), which is aligned with the high degree of uncertainty as mentioned above. This uncertainty is mostly associated with the turbo-machine and electronic controller. Once again, prototyping was the route chosen to reduce the impacts of using such technology.

The final product is a system, comprised of several subsystems, which had to be tested separately and once working properly as designed, were integrated and tested for performance validation. The product and project size is considered highly complex.

Even thought there was a desire to gain competitive advantage by developing and releasing the product as soon as possible, the pace or speed to market did not have a high impact on complexity since the priority was fulfilling the requirements.

Geographical dispersion could be considered an external environmental constraint and it played an important role in increasing the complexity of the project since the development and testing took place in several different locations. The team had to create a remote testing procedure to allow all parts involved to collaborate and be part of the testing.

During the document analysis, several dimensions were found as presented in Table 4.20.

Table 4.20 – Dimensions for case # 17

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
External Environmental Constraints	X	

4.3.18. Case # 18

Case reference: 2010-2/6 Year: 2010 Industries: Information and Communications, Professional and Technical Services

With the objective of achieving increased performance of targeting capabilities, also known as Advanced Target Pod (ATP), the project encompassed data link capability and advanced sensors improvement. The product would be ideal not only for the military but homeland defence and natural disasters since it covers target, navigation, and surveillance. Another requirement of this product is to allow the simple insertion of new technologies.

The uncertainty level is from low to medium since it is a new generation of an existing product. Similarly the technological level is also low to medium considering that the only advanced technology was related to the inclusion of sensors in the product platform.

The product and project size could be classified as medium according to the project report, which states that the product "… could best be described as a complex sub-system of optical sensors, lasers, electronics, precision pointing gimbal and data link combined together to provide the aircraft pilot the capability to detect, identify, interrogate and transmit and receive information about a target to ensure precision targeting and designation".

Classified as time critical, the pace or speed to market could be considered medium to high. The urgency was based on the need to deliver the product to support immediate military efforts and surveillance needs.

An external environmental constraint is the fact that great distance, time zones, and countries separated the teams. This certainly brings an additional complexity to the project, due to the need to properly manage all people involved.

Other Project Complexity Dimensions from Case Study:

Due to the geographical dispersion of the teams throughout different countries, the communication quality was crucial for the success of the project. An extra level of complexity was brought into consideration since effective communication is already a challenge with only one language and culture, and much more difficult when different countries and cultures are involved.

During the document analysis, several dimensions were found as presented in Table 4.21.

Table 4.21 – Dimensions for case # 18

Complexity Dimension	Literature Review	New from Case Study
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	
Communication Quality		X

4.3.19. Case # 19

Case reference: 2010-3/6 Year: 2010 Industries: Construction and Engineering, Professional and Technical Services

The project aimed to add maritime modes to the existing unmanned aircraft system, dual-band data links, and enhanced electronic support capabilities. The existing system covered air vehicle, launch and recovery, and mission control elements, so the addition was for maritime operations as well. The new system was tested and supported fire fighting efforts in central and northern California, and damage assessment of the Gulf Coast following Hurricane Ike.

The uncertainty level was low since the product is a derivative of an existing and operational one. The addition to maritime capabilities to the existing system was the only aspect that brought uncertainty, since it was something new to the market. Overall the complexity due to uncertainty could be defined as low to medium.

Conversely, the technology used could be considered high technology, so the complexity level would also be high for this dimension. Developing maritime sensors that would provide high-quality images and real-time data to support decision-making was the most challenging aspect of this project.

The product and project size could be defined as a system (collection of subsystems), which would bring the complexity level to medium-high. To give a better sense of the operation's complexity, the project report describes the following: "While the Air Vehicle and LRE [Launch and Recovery Elements] are deployed in the overseas theatre, the MCE [Mission Control Elements] conducts the missions from a location in the Continental U.S., communicating with the aircraft via satellite systems in Europe, processing the imagery and other downlinked data within and disseminating it from a Navy-developed 'Tactical

Auxiliary Ground Station' (located in Maryland) to multiple organizations both in the U.S. and overseas".

Considering the criticality of the deadline due to military requirements, the pace and speed to market complexity level is considered to be high.

The complexity level described in the project report due to geographical dispersion and the need for proper communication among all the stakeholders indicates that communication quality is a significant dimension to consider.

During the document analysis, several dimensions were found as presented in Table 4.22.

Table 4.22 – Dimensions for case # 19

Complexity Dimension	Literature Review	New from Case Study
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
Communication Quality		X

4.3.20. Case # 20

Case reference: 2010-4/6 Year: 2010 Industries: Information and Communications, Construction and Engineering, Defence

This project is part of the defence strategy focused on early warning radar detection against imminent threats. This specific radar is located in an inhospitable location (Artic Circle) where logistics is quite challenging and the environment directly affects operations. The project incorporates manufacturing, integration and test of equipment, development and maintenance of computer systems, and construction of new operation centres.

The uncertainty level is low to medium since it is a new generation of an existing product (equipment and software), but the construction aspect is just a derivative of something existing. Similarly, the technology used is of low complexity since it uses existing technology to meet new requirements. Based on the project report, the pace or speed to market does not have a significant impact on complexity either.

The project and product size can be considered a system and as such has a medium to high complexity level. It comprises the equipment/technology necessary for defence, surveillance, and warning; software development; and construction of the operation centres.

The environmental and safety impact due to the site location increased the complexity level. According to the project report, "The harsh environment at […] and the remoteness of the site provided certain complexities for the program. The radar is located 12 miles from the base, and under storm conditions, non-essential personnel […] are required to leave the site before conditions become more severe. Weather delays were factored into our planning based on historical weather data". In the construction part of the project, the team had to use the summer months to send materials on a cargo ship. This ship was carrying 340,000 pounds of construction materials and was struck by an iceberg, so it had to divert for repairs, causing delays in the construction schedule.

During the document analysis, several dimensions were found as presented in Table 4.23.

Table 4.23 – Dimensions for case # 20

Complexity Dimension	Literature Review	New from Case Study
Product & Project Size	X	
Environmental and Safety Impact		X

4.3.21. Case # 21

Case reference: 2010-5/6 Year: 2010 Industries: Transportation, Construction, and Engineering

The project was created to support the initiative to reduce the amount of manufacturing sources and materials shortages, becoming a key enabler for efficient and cost-effective life-cycle management. The following options were created for the client to choose: Life Time Buy, Last Time Buy, and Product Redesign. These options are compared to support proper decision-making.

There was no significant uncertainty related to this project since is a derivative of an existing product already in place. The readily available software to support the project implies a low technology level, so no significant complexity would be considered for this dimension. In the same fashion, the product and project size does not represent additional complexity considering that it encompasses existing and stable subsystems. The predictive nature of the system developed also does not have any relevant impact on the pace or speed to market.

The communication quality between the project team, suppliers, and customer was an important success factor. This is due to the need for a constant exchange of information to assure reprioritization of on-going efforts, redistribution of internal funding, and reallocation of manpower.

During the document analysis, one dimension was found as presented in Table 4.24.

Table 4.24 – Dimensions for case # 21

Complexity Dimension	Literature Review	New from Case Study
Communication Quality		X

4.3.22. Case # 22

Case reference: 2010-6/6 Year: 2010 Industries: Transportation, Construction and Engineering

This project was to provide advanced avionics components for a new aircraft jet family. According to the project report, the components to be provided were "… state of the art cockpit displays, radio/communications equipment, collision alert & warning sensors, aircraft position transponders, fly by wire & automatic flight controls, integrated flight management system, and aircraft lighting". The reason for implementing these components was to improve safety, reliability, and operational efficiency, all at a low cost, allowing the manufacturer to keep a competitive advantage in the 70- to 110-passenger market niche.

There was no significant uncertainty level considering that all elements of the project were a derivative of existing products. The product and project size was also of low complexity, since it is a subsystem and part of a larger system.

Conversely the technology used for the project could be considered high complexity, or recently developed new technology. Specifically the new technologies used were the Controller-Pilot Data Link Communications and the Display Unit.

The pace or speed to market could be considered a medium to high complexity level due to the need to enter the market before all competitors. If the project is delivered behind schedule, there will be an impact on the business.

A significant dimension that impacted the project is cultural resistance and differences. The manufacturer is from a culture where business is more informal and personal connections are more important than formal agreements. The time commitments are more 'flexible', which affects the supplier's tight schedule and procedures. The challenges were managed by constant meetings, implementation of active change control to avoid deviation from scope, and mentoring/coaching of team members to understand the local culture.

During the document analysis, several dimensions were found as presented in Table 4.25.

Table 4.25 – Dimensions for case # 22

Complexity Dimension	Literature Review	Case Study
Technology	X	
Pace/Speed to Market	X	
Cultural Resistance and Differences		X

4.3.23. Case # 23

Case reference: 2011-1/2 Year: 2011 Industries: Information and Communications

A new multi-band radar development was the objective of this project. The radar had to work on low-frequency radio waves, issue unique signatures, and cover a wide area day or night in all types of weather. According to the project report, the deliverables "… include a radar, a real-time on-board processor, a ground processor, and specialized software that generates output products". The project used spiral and agile methodologies to drive innovation and manage complexity and uncertainty. The key approach principles to assure the project's success were (1) Collaborative Customer Relationship, (2) Supplier and Subcontractor Partnerships, (3) Manage Opportunity and Risk Dynamically, (4) World-Class Multi-Disciplined Team, and (5) Spiral/Agile Development.

Although this is a small project (compared to others described in this section), the uncertainty level is high due to the development of a product new to the world. This uncertainty is natural for research and development initiatives with product and solution unknowns. The project had a clear goal but not a clear solution. The technology follows the same high complexity level since it creates a new technology that did not exist before. According to the project report, "the iterative and adaptive systems engineering processes employed during this effort assured effective management of complexity".

The complexity level related to the product and project size is low because the product is actually a subsystem of an airborne surveillance system. The same applies to the pace or speed to market since there was no criticality to deliver the project in an urgent fashion. One approach to reduce the challenge of R&D is to eliminate work that does not add value to the final solution, which is why the agile approach was selected.

One dimension that impacted R&D projects on a high level was the lack of knowledge and experience. The following sentence from the project report describes the challenge well: "Other complexities and uncertainties dealt with include: the unknown of the specific missions and concept of operations used by the system; funding inconsistencies to support core engineering staff; technological obsolescence; and the lack of firm requirements".

During the document analysis, several dimensions were found as presented in Table 4.26.

Table 4.26 – Dimensions for case # 23

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Knowledge and Experience		X

4.3.24. Case # 24

Case reference: 2011-2/2 Year: 2011 Industries: Education

The project aims to deliver training to the next generation of air traffic control specialists and improve the efficiency and quality of the training materials. This education process is also necessary because 70% of the workforce will retire within the next decade, so there is a need to train over 17,000 people in 315 different locations during this time. According to the project report, "Services provided and products delivered include curriculum analysis, design, delivery (classroom and simulation lab instruction), evaluation, and maintenance. The program provides qualification training to 3,800 new controllers every year while conducting proficiency training for 15,000 certified controllers".

There is minor uncertainty related to this project since it is an improvement of an existing training program. The training materials need to be updated for the new systems but will be based on current procedures and knowledge.

The technology on the other hand has a more significant impact since new generations of employees have different training delivery requirements to keep them engaged. As described in the project report, “The new generation of student has matured in an age of instant multi-mode communications, gaming, etc. Today the student demands engagement; interactivity and variety”.

The product and project size also impacts complexity since the training has to cover different but simultaneously integrated missions, sizes, simulation needs, and scenarios. The training then needs to be stratified into several levels: the national level applicable to all traffic controllers, the type of work to be done (i.e., air traffic control, terminal radar approach control, command centre), and the site-specific needs.

Similarly, the pace or speed to market is considered of high complexity or time-critical. There is an immediate need to train and well prepare the next generation of air traffic controllers before the existing team retires.

A few external environmental constraints can impact the project complexity, one of them being the mandate to retire and replace a large group of very experienced professionals with new employees. Another external constraint is the new system of air traffic control being implemented.

During the document analysis, several dimensions were found as presented in Table 4.27.

Table 4.27 – Dimensions for case # 24

Complexity Dimension	Literature Review	New from Case Study
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	

4.3.25. Case # 25

Case reference: 2012-1/2 Year: 2012 Industries: Information and Communications, Support Services

The objective of project 2012-1/3 was to measure the ocean's salinity level from space to better understand this key climate parameter. The almost decade-long project was a joint effort between two space institutes located in different countries.

Global salinity patterns (a.k.a. Sea Surface Salinity) are connected to several climate occurrences, such as rainfall and evaporation, continental river runoff, and the freezing and melting of ice. Furthermore, it can affect seawater density, which governs ocean circulation and helps regulate climate. The main challenge is that conventional measurements using boats and buoys are too sparse to monitor the enormous area in a short period of time. Actually, in two months this project was able to collect the same amount of measurements as using the conventional process did in 125 years. The project helps answer two proposed questions: (1) How are global precipitation, evaporation, and the cycling of water changing? and (2) How can climate variations induce changes in global ocean circulation?

The dimension of <u>uncertainty</u> appears in this project because this way of measuring salinity levels from space has not been done before. Therefore, it can be characterized as new to the world, indicating a high level of uncertainty.

Even though the project used several existing technologies, the use of some new <u>technology</u> could be considered a significant dimension due to the added complexity of building and implementing something new.

When analysing the <u>project and product size</u>, this dimension also showed to be significant considering not only the complexity of the equipment itself (never built before) but also the fact that it has to interact with seven other types of equipment without interference.

Another dimension that had direct impact on the project complexity was the <u>pace/speed to market</u> as the time to deliver the project was critical to its success and delays would mean failure.

Several occurrences of <u>external environmental constraints</u> could be observed in this project as described below:

The visit of the president of the United States of America is an example of how an external event can impact a project, since several decisions were postponed until after the visit.

Another aspect is related to cultural features—holidays, soccer games, etc.—that are important in Brazil and Argentina and directly impacted the project schedule.

Even though logistics is not listed among the complexity dimensions, it can be considered an external environment constraint that, in this case, had a significant impact on the project, increasing its complexity level.

Beyond the dimensions found in the Literature Review, the following additional dimensions appeared when analysing this project:

There was a budgetary constraint that limited the number of test units to be built, so only one unit was built to be completely functional and ready to use.

The impact on society is related to the request from the project manager in the USA to have local contractors in Brazil working during periods that were not aligned with local cultural norms, creating issues and performance challenges.

This project shows how economic uncertainty can impact a project, as fluctuating exchange rates created economic instability and unpredictability.

During the document analysis, several dimensions were found as presented in Table 4.28.

Table 4.28 – Dimensions for case # 25

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Pace/Speed to Market	X	
External Environmental Constraints	X	
Budgetary Constraint		X
Impact on Society		X
Economic Uncertainty		X

4.3.26. Case # 26

Case reference: 2012-2/2 Year: 2012 Industries: Transportation, Defence and Aerospace

This program's objective was to produce a total of 167 aircraft over a five-year period. Using tilt rotor revolutionary technology, these aircraft would be able to 'short' distances with great speed and autonomy (inflight refuelling). Development continued while production efforts accelerated and upgrades in crew support and all-weather operations were implemented. This project demonstrated the ability of two companies to work together as a team to develop and produce a breakthrough product that exceeded expectations.

The uncertainty level was high considering that the objective was to create a new aircraft with more than three times the range of existing ones. The previous speed, range, and altitude limitations for helicopters were revisited, impacting also the planning process on using them.

At the time of its development, the new aircraft used new technology and the complexity level was high. Many of the technologies used are now common and used not only in the military but also civil industry. Very extensive testing was performed covering everything from aerodynamics to durability.

The level of complexity due to the product and project size could be considered high since it was a system comprised of a collection of subsystems performing multiple functions. This does not only cover the aircraft itself but also maintenance, training, and support systems.

The project had a fast competitive pace or speed to market due to its large scale, so the complexity level is considered low to medium. Knowledge gained and lessons learned from previous projects were used to support the initiative but no critical or absolute deadline was defined.

Considering the need for proper communication among all stakeholders involved—contractors, suppliers, local and international government agencies, and civil organizations—the communication quality was crucial for the success of the project and increased its complexity level.

During the document analysis, several dimensions were found as presented in Table 4.29.

Table 4.29 – Dimensions for case # 26

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Product & Project Size	X	
Communication Quality		X

4.3.27. Case # 27

Case reference: 2013-1/1 Year: 2013 Industries: Transportation, Defence and Aerospace

This project's goal is to build a propulsion system to support three variations of an aircraft with cutting-edge technology to serve the USA and several of its allies including Australia, Canada, Denmark, Italy, Netherlands, Norway, Turkey, and the United Kingdom. According to the project report, the new aircraft's "…advanced airframe, autonomic logistics, avionics, propulsion systems, stealth and firepower ensure the […] is the most affordable, lethal, supportable and survivable aircraft ever to be employed by U.S. and allied war fighters across the globe".

Uncertainty impacted complexity on a high level since several parts of the product were new to the market and used new technologies to achieve reliability, affordability, performance, and supportability objectives. The multi-platform approach also brought an increased level of complexity.

Related to product and project size, the complexity level could be defined as low to medium since it is considered a subsystem (propulsion) of the aircraft. The complexity level of this project is not related to its size but to the technology described previously. Similarly, the pace or speed to market had little impact on project complexity since there was no specific time pressure.

Due to competing demands, sequestration, and an austere budget, one dimension that strongly impacted the project was economic uncertainty. The team did not know if enough financial resources would be available to proceed with the project in upcoming years.

During the document analysis, several dimensions were found as presented in Table 4.30.

Table 4.30 – Dimensions for case # 27

Complexity Dimension	Literature Review	New from Case Study
Uncertainty	X	
Technology	X	
Economic Uncertainty		X

4.4. Additional Complexity Dimensions from Case Studies

After the analysis of the 27 case studies, this research found an additional seven complexity dimensions for further consideration.

4.4.1. Budgetary Constraints

Normally all projects have a limited budget. This dimension is related to how budget constrains the ability to manage the project, which might add to the complexity level. If an organization is able to afford only a limited project cost (i.e., up to USD 100 million), a higher cost (i.e., USD 1 billion) brings a level of complexity to the project. Furthermore, if the available budget is limited, the performing team might need to implement approaches that were not used before, which again creates an increased complexity level.

Example: If a limit is placed on a project's budget, the performing team might need to implement changes that had previously not been considered, such as reduced scope or performance (Kern & Formoso, 2004).

- L1. There is no budget limitation and the cost of the project is within the range the organization is accustomed to managing.
- L2. There is some budget limitation but it does not affect the capability to deliver the product. The cost of the project is no more than 50% above the range of what the organization is accustomed to managing.
- L3. There is a budget limitation that affects the capability to deliver the product. The cost of the project is no more than two times above the range of what the organization is accustomed to managing.
- L4. There is an extreme budget limitation for the size of the project, which will not allow the project to deliver the product. The cost of the project is at least five times above the range of what the organization is accustomed to managing.

4.4.2. Cultural Differences and Resistance

In today's world, team members and stakeholders might come from various parts of the world and have different cultural backgrounds. Cultural differences can impact a project and create resistance around tasks that need to be performed. As cultural clashes increase, the more complexity is added to interactions between stakeholders.

Example: The Airbus A380 project was done by five different countries and faced confusion in work coordination due to country-specific cultural practices (Gummesson, 2006).

L1. There is no cultural resistance to the project-management process and the interaction between stakeholders is seamless.
L2. The existing cultural resistance is limited to parts of the project that will not affect the final result or the interaction between stakeholders.
L3. The existing cultural resistance is significant and involves several key stakeholders, which can jeopardize the final results.
L4. The existing cultural resistance does not allow the project to be managed nor the product to be delivered.

4.4.3. Economic Uncertainty

This dimension is related to the existing economic environment in an organization (on a local, regional, national, or global level) and the challenges that an unstable and uncertain economic environment presents to a project. Economic uncertainty can result in a lack of predictability with regard to many variables that might affect the project.

Example: Times of economic crisis (i.e., the 2008 global financial crisis) have an impact on most organizations and consequently add complexity to existing projects (Baker, Bloom, & Davis, 2012).

L1. The economic environment is stable and has no impact on the project.
L2. The economic environment is mostly stable and has limited or very brief impact on the project.
L3. The economic environment is uncertain and has considerable impact on the project, affecting the capability to perform the work needed to deliver the product.
L4. The economic environment is uncertain and has a potentially catastrophic impact on the project, which will not allow the project to proceed.

4.4.4. Environmental and Safety Impact

This dimension is associated with the degree to which a project may have an impact on the environment and/or safety of those within the organization and community. Many times, projects do not consider their possible impact on the environment or safety of the population. Once these factors are considered, they bring an increasing level of complexity to the project.

Example: Building a factory at a specific location might endanger local fauna or increase the levels of pollution, thus adding new variables to the project's feasibility and complexity levels (PMI, 2014).

L1. The project has no environmental or safety impact.
L2. The project has minimal environmental and safety impact.
L3. The project has significant environmental and safety impact, and key stakeholders are considering this information.
L4. The project has significant environmental and safety impact, and key stakeholders are not taking this information into account.

4.4.5. Communication Quality

This dimension is related to the quality of the project communication. Communication barriers can bring disruption to the project and are considered one of the key reasons for failure in projects (PMI, 2012). Challenges in communication can be related to language, cultural aspects, organizational structure, geographical location, and communication methods. It involves both direct and indirect elements (Cooke-Davies et al., 2011). Direct (or explicit) communication, such as written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or when the true intention is not directly revealed.

Example: In direct communication, more value is placed on honesty than on being polite; in indirect communication, the opposite may be true. This dimension can be greatly impacted by the cultural background of the people involved (Kerzner & Belack, 2010).

L1. Clear communication. The communication flows without issues and no clear barriers exist. No use of indirect communication or in case it is used, the cultural background allows it without impacting the performing team.
L2. Some issues with communications. There are some communication noises but without impacting the project. There is a limited use of indirect communication but it does not affect the performing team in such a way that will impact the management of the project.
L3. Significant issues with communications. There are significant communication issues with disruptions on the project. There is also frequent use of indirect communication,

which is not well received by the performing team. This can impact the management of the project.

L4. Constant issues with communications within the entire organization and stakeholders. There is severe impact on performance and indirect communication is constant and disruptive to the performing team. The management of the project is seriously compromised, as is the delivery of the product.

4.4.6. Knowledge and Experience

This dimension is related to how much knowledge and/or experience the project manager or a key team member has regarding all elements (parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product.

Example: Software development would be much more complex for a project manager with construction experience than for a project manager previously involved in the software industry (Hass, 2009).

L1. The decision-makers, project manager, and team have extensive experience with this type of project and knowledge of all elements of the project.

L2. The decision-makers, project manager, and team have good experience and knowledge of most elements of the project. There are just a few unknowns.

L3. The decision-makers, project manager, and team have significantly limited experience and knowledge of the elements of the project. There are a lot of unknowns.

L4. The decision-makers, project manager, and team have no experience and knowledge about any element of the project. Almost everything is unknown.

4.4.7. Impact on Society

This dimension is related to the impact of the project on society and how it will affect social interactions, stakeholders, and communities. A typical measure of impact is the social impact assessment (SIA), a methodology to review the social effects of infrastructure projects and other development interventions.

Example: The Affordable Care Act (Obamacare) in the United States had a huge impact on society due to the project’s complexity and how it would be made available to the users. This complexity aspects could have been considered upfront (Keil, Smith, Iacovou, & Thompson, 2014).

L1. There are no social impact(s).

L2. The social impact is minimal or very localized to a specific group without lasting consequences or ramifications to others. The possible impact is predictable.

L3. The social impact is significant and will bring unknown consequences to society on a local or even global level.

L4. The social impact is on a large scale and the consequences to society are unknown.

4.5. Improvements on the Model

The document analysis of real cases describing complex projects and which dimensions acted during these projects showed that seven additional dimensions were found. There is also a possibility that dimensions could be consolidated in case they are covering the same topic.

Considering the new dimensions, the total number of dimensions at this stage is 23: 16 initial dimensions discovered in Chapter 2 plus the seven additional dimensions gathered through the document analysis of the 27 case studies. The revised view of the model is presented in Figure 4.2 below.

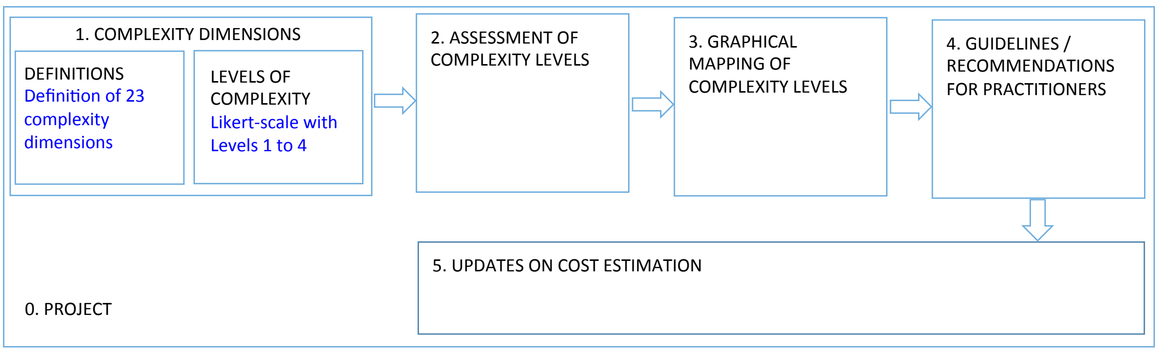


Figure 4.2 – Model update with additional complexity dimensions

4.6. Chapter Summary

The analysis of 27 case studies related to complex projects served to support the literature review findings but also to conclude that more dimensions of project complexity exist and should be considered.

Besides the four dimensions detailed by each project manager in their descriptions (Uncertainty, Technology, Product and Project Size, and Pace/Speed to Market), another seven dimensions were found as shown in Table 4.31:

Table 4.31 – Complex project database: other dimensions of complexity

Dimension	New from Case Studies
Budgetary Constraints	X
Knowledge and Experience	X
Cultural Resistance and Differences	X
Economic Uncertainty	X
Environment and Safety Impact	X
Communication Quality	X
Impact on Society	X

The next chapter will cover the survey and interviews that helped to validate the information gathered so far in the research.

CHAPTER 5 – SURVEY AND INTERVIEWS

Chapter 4 presented an analysis of 27 complex projects to validate and enhance the findings about complexity dimensions. These complex projects covered a range of industries such as aerospace, avionics, defence, engineering, information technology, and construction. The analysis uncovered seven complexity dimensions (in addition to the 16 found in the literature).

The methodology used to identify the 23 complexity dimensions that impact the cost estimation started with the collection of documentation via literature review of complexity dimensions and the cost-estimation process. The seminal authors on each field (project management, complexity, and cost estimation) were identified by checking the articles with more citations and listing the authors that appeared most frequently as bibliographic references. This was done by using the qualitative data analysis tool NVivo, which allowed the researcher to keep record of the main topics of each source. The research of articles, journals, textbooks, and other references was done using search engines like Google Scholar, Scopus, and the University of Huddersfield library. An initial list of 16 complexity dimensions resulted of this effort as described on section 2.5.

Following the process above, a further document review of existing case studies provided a list of 7 additional complexity dimensions as described on section 4.3. Even thought the document review technique is simpler than other techniques, this research will consider this technique as a primary because all documents were available to the researcher and the case studies contained clear information about complexity dimensions.

This chapter will cover the results of the following three empirical investigations:

1. The survey done with 54 participants to further validate and rank the complexity dimensions identified;

2. An intermediate validation conducted to validate the ranked complexity dimensions with participants from a global project management congress; and

3. In-depth interviews with 10 professionals to further confirm the details of the top complexity dimensions identified along with their impact on the cost-estimation process and the estimation practices that can be used to overcome the issues posed by the identified project complexities.

5.1. THE SURVEY

Following the initial analysis described in previous chapters, a survey was conducted to gather input from practitioners, academic researchers, and experts in the field of project management and complexity. The initial invitation was sent to 248 professionals; 54 of them answered the survey (21.8% response rate).

The survey covered several different industries as presented Figure 5.1. Construction was responsible for 41% of the respondents, followed by 24% from information technology, 7% from energy, 6% from manufacturing, 5% from defence, and the remaining 17% from other industries.

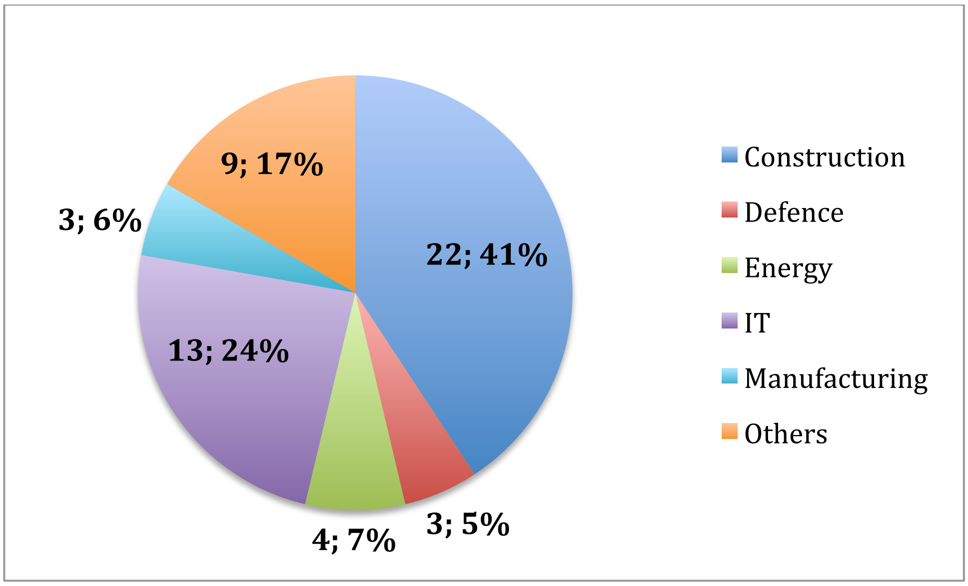


Figure 5.1 - Survey answers by industry

The geographical dispersion is represented in Figure 5.2 below. Most of the respondents were from Europe, the Middle East, and Africa (EMEA). These countries combined with Latin America (LATAM) to account for an 82% representation. This is due to the existing professional networks of the researcher (Latin America) and the supervisor (Europe and Middle East). Both USA and Canada (NAM) and Asia-Pacific (APAC) had a 9% representation.

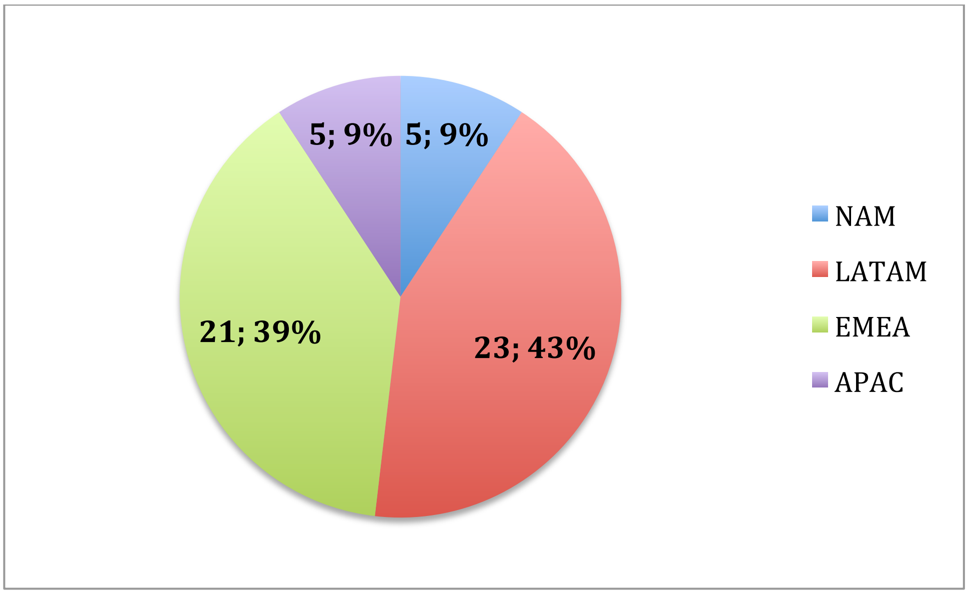


Figure 5.2 - Survey answers by region

Due to the low number of participants (3 to 4) from the Defence, Energy, and Manufacturing industries, their answer might not be representative of their industry. The same limitation is present for the Asia-Pacific (APAC) and North America (NAM) regions. Further research involving these industries and regions could be a subject of future research.

The respondents had five possible answers (levels) for how impactful a complexity dimension is on a project:

Level 5 – Extreme impact

Level 4 – Significant impact

Level 3 – Some impact

Level 2 – Minimal impact

Level 1 – No impact

The following steps were used to obtain a prioritized list of dimensions that would support the upcoming survey:

Step 1 – Calculate the percentage of respondents who selected each level (1-5) per dimension. For instance, the dimension Budgetary Constraint had 18.4% responses as level 5 (extreme impact), 39.5% as level 4 (significant impact), 28.9% as level 3 (some impact), 7.9% as level 2 (minimal impact), and 5.3% as level 1 (no impact). Step 2 – Create a weighted average using only extreme impact (5) and significant impact (4). Considering the case above, the average would be (5 x 18.4% + 4 x 39.5%) / 9 = 28.36%.

Step 3 – Obtain a priority list. The result of this approach is presented on Table 5.1 below.

Table 5.1 – Initial priority list of complexity dimensions

Weighted Average (5xExtreme + 4xSignificant)/9	Survey Rank	Dimension
34.50%	1	PM Maturity Level
33.92%	2	Risk
32.16%	3	Product and Project Size
31.58%	4	Knowledge and Experience
30.70%	5	Clarity of Goals
30.41%	6	Organizational Capability
30.12%	7	Communication Quality
29.82%	8	Uncertainty
28.36%	9	Degree of Trust
28.36%	10	Time Frame
28.07%	11	Technology
27.78%	12	Budgetary Constraints
27.49%	13	Dependency and Interdependency
26.90%	14	Political Influence (Politics)
26.02%	15	Stakeholder Interaction
23.68%	16	External Environmental Constraint
23.39%	17	Project Description
21.35%	18	Economic Uncertainty
19.59%	19	Innovation to Market
19.59%	20	Cultural Resistance and Differences
19.01%	21	Pace/Speed to Market
16.67%	22	Environmental and Safety Impact
10.23%	23	Impact on Society

For further improvement of this list, this research used the Relative Importance Index (RII) method. The RII formula is described below:

$RII = \frac{\Sigma W}{A \times N}$ (0≤RII≤1)

W = Weighting given to each factor

A = Highest weight

N = Number of respondents

The analysis covered both a consolidated and per industry view. Further consideration was given to the dimensions with RII equal to or greater than 0.70. This approach allowed the researcher to reduce the number of dimensions being analysed and separate the ones with lower importance (Faridi & El-Sayegh, 2006).

5.2. SURVEY RESULTS

The results were divided into industries. A consolidated list is also provided below. The results varied significantly by industry and were also different from the consolidated view.

5.2.1. Dimension Consolidated Rank - All industries

The consolidated view in Table 5.2 does not present a surprise with respect to the top three dimensions. According to the Project Management Institute (PMI, 2012), the scope of the product and project, the risks, and the time frame are fundamental parts of managing a project. Furthermore, the project management maturity level reflects how well the organization manages projects and covers several different aspects. It is interesting to see that budgetary constraints (one of the triple constraints) was placed at a lower level among the top ten dimensions impacting projects.

Table 5.2 – Rank by RII for all industries

Dimension	RII	Rank
Risk	0.804	1
Product and Project Size	0.800	2
Time Frame	0.770	3
Organizational Capability	0.763	4
Project Management Maturity Level	0.759	5
Uncertainty	0.756	6
Budgetary Constraints	0.741	7
Knowledge and Experience	0.741	7
Clarity of Goals	0.737	9
Technology	0.730	10
Degree of Trust	0.726	11
Communication Quality	0.719	12
Dependency and Interdependency	0.704	13
Economic Uncertainty	0.704	13
Stakeholder Interaction	0.704	13

Political Influence (Politics)	0.696	16
External Environmental Constraints	0.689	17
Project Description	0.682	18
Pace/Speed to Market	0.648	19
Innovation to Market	0.637	20
Cultural Resistance and Differences	0.630	21
Environmental and Safety Impact	0.626	22
Impact on Society	0.526	23

Both budget and schedule are considered dimensions for project success, but they are not the only ones (Shenhar, Levy, & Dvir, 1997). Other factors should also be considered as proposed by the authors. The first is project efficiency, which is related to the organizational capability to deliver projects and the knowledge and experience of the performing team, which again are a reflection of how mature an organization is with respect to managing projects. The next two are related to the impact on the customer and business success, which are not covered in this research since they are consequences of a successfully managed project and not dimensions that would impact it. The final factor is related to being prepared for the future, which is directly impacted by uncertainty levels, clarity of goals, and the technology available and being used.

5.2.2. Dimension Rank for Construction

Regarding construction projects, the survey results presented in Table 5.3 point to a significant impact on economic uncertainty and constraints on the available budget, with direct influence by the project size, and general level of uncertainty and risks (Bosch-Rekveldt et al., 2011). Economic uncertainty carries a strong influence worldwide and can erode business over time in all industries (Baker, Bloom, & Davis, 2012). The construction industry is no different, and one might suggest that due to the use of capital-intensive resources, it is impacted to a great extent. The authors propose that not only overall economic uncertainty should be considered but also economic policy uncertainty.

Table 5.3 – Rank by RII for construction

Complexity dimension	RII	Rank
Economic uncertainty	0.809	1
Budgetary constraints	0.800	2
Risk	0.800	2
Time frame	0.791	4

Product and project size	0.764	5
Degree of trust	0.745	6
Organizational capability	0.745	6
Uncertainty	0.745	6
Clarity of goals	0.718	9
External environmental constraints	0.700	10
Technology	0.700	10
Political influence (politics)	0.691	12
Project management maturity level	0.691	12
Communication quality	0.682	14
Environmental and safety impact	0.682	14
Knowledge and experience	0.682	14
Pace / Speed to Market	0.682	14
Project description	0.682	14
Stakeholder interaction	0.655	19
Dependency and interdependency	0.645	20
Innovation to market	0.618	21
Cultural resistance and differences	0.573	22
Impact on society	0.491	23

5.2.3. Dimension Rank for Information Technology

In the information technology industry, most notably software development, the size of the product to be developed is normally one of the key aspects to be considered. Furthermore, both the level of knowledge and experience of the team working on the project, and the existing process and methods used by the organization, which reflects that organizational capability to support such projects, also have an impact on the information technology industry (Gemino, Reich, & Sauer, 2007). Table 5.4 provides the details.

Table 5.4 – Rank by RII for information technology

Complexity dimension	RII	Rank
Product and project size	0.892	1
Risk	0.892	2
Knowledge and experience	0.846	3
Project management maturity level	0.846	4
Organizational capability	0.831	5
Communication quality	0.815	6
Clarity of goals	0.785	7

Technology	0.785	8
Stakeholder interaction	0.754	9
Time frame	0.754	10
Budgetary constraints	0.739	11
Degree of trust	0.723	12
Project description	0.723	13
Cultural resistance and differences	0.708	14
Uncertainty	0.708	15
Dependency and interdependency	0.692	16
Innovation to market	0.677	17
External environmental constraints	0.646	18
Political influence (politics)	0.646	19
Pace/speed to market	0.631	20
Economic uncertainty	0.585	21
Impact on society	0.523	22
Environmental and safety impact	0.492	23

5.2.4. Dimension Rank for Defence

Even though the number of respondents for the defence industry was limited to three individuals, the results showed in Table 5.5 seem to present a list of dimensions that are frequently considered impactful. The first is external environmental constraints, which is explained by the fact that defence projects have strong external influence from allies, enemies, partners, and other players. This brings a level of uncertainty that is maximized by the possible political influence of government officials, legislators, and defence entities (Held, McGrew, Goldblatt, & Perraton, 2000).

Table 5.5 – Rank by RII for defence

Complexity dimension	RII	Rank
External environmental constraints	1.000	1
Uncertainty	1.000	1
Environmental and safety impact	0.933	3
Political influence (politics)	0.933	3
Stakeholder interaction	0.933	3
Dependency and interdependency	0.867	6
Degree of trust	0.800	7
Knowledge and experience	0.800	7

Organizational capability	0.800	7
Risk	0.800	7
Technology	0.800	7
Cultural resistance and differences	0.733	12
Innovation to market	0.733	12
Pace/speed to market	0.733	12
Product and project size	0.733	12
Project management maturity level	0.733	12
Time frame	0.733	12
Economic uncertainty	0.667	18
Impact on society	0.600	19
Budgetary constraints	0.533	20
Clarity of goals	0.533	20
Communication quality	0.533	20
Project description	0.533	20

5.2.5. Dimension Rank for Manufacturing

Manufacturing projects normally involve the construction of new factories or the implementation of new equipment and processes to improve performance. Only three people represented this industry, which might impact the validity of the answers presented in Table 5.6. Nonetheless, clarity of goals may carry special importance since the project manager has to analyse all possible impacts of the existing structure, causing any unclear requirements to have a potential impact on operations (Hong, Nahm, & Doll, 2004). Technology is also a key aspect in manufacturing due to the constant need for more efficient and effective ways to manufacture (Lin & Berg, 2001).

Table 5.6 – Rank by RII for manufacturing

Complexity dimension	RII	Rank
Clarity of goals	0.867	1
Project management maturity level	0.867	1
Risk	0.867	1
Technology	0.867	1
Political influence (politics)	0.800	5
Communication quality	0.733	6
Cultural resistance and differences	0.733	6
Economic uncertainty	0.733	6
Impact on society	0.733	6
Knowledge and experience	0.733	6

Organizational capability	0.733	6
Product and project size	0.733	6
Project description	0.733	6
Uncertainty	0.733	6
External environmental constraints	0.667	15
Pace/speed to market	0.667	15
Stakeholder interaction	0.667	15
Time frame	0.667	15
Budgetary constraints	0.600	19
Dependency and interdependency	0.600	19
Environmental and safety impact	0.600	19
Degree of trust	0.533	22
Innovation to market	0.467	23

5.2.6. Dimension Rank for Energy

While working over a decade at one of the world's largest energy companies, the researcher was directly involved in several projects with different levels of complexity and size. During this time, the impact of different elements of a project and how they interact with each other, in other words the dependency and interdependency (Bosch-Rekveldt et al., 2011), became clear. Projects would normally need to involve aspects that were not necessarily part of the scope due to the nature of this business (i.e., safety, environment, health, and sustainability). The size of a project and level of effort required to implement it was were considered key factors (Asrilhant, Dyson, & Meadows, 2007). RII results provided in Table 5.7 below.

Table 5.7 – Rank by RII for energy

Complexity dimension	RII	Rank
Dependency and interdependency	0.850	1
Product and project size	0.800	2
Clarity of goals	0.750	3
Time frame	0.750	3
Uncertainty	0.750	3
Budgetary constraints	0.700	6
Project management maturity level	0.700	6
Risk	0.700	6
Communication quality	0.650	9
Organizational capability	0.650	9
Environmental and safety	0.600	11

impact		
Innovation to market	0.600	11
Project description	0.600	11
Stakeholder interaction	0.600	11
Degree of trust	0.550	15
Knowledge and experience	0.550	15
Economic uncertainty	0.500	17
External environmental constraints	0.500	17
Political influence (politics)	0.500	17
Technology	0.500	17
Pace/speed to market	0.450	21
Cultural resistance and differences	0.400	22
Impact on society	0.400	22

5.2.7. Dimension Rank for Other Industries

The relative importance index average for all other industries is provided on Table 5.8 below.

Table 5.8 – Rank by RII for other industries

Complexity dimension	RII	Rank
Degree of trust	0.800	1
Time frame	0.800	1
Project management maturity level	0.800	1
Product and project size	0.800	1
Knowledge and experience	0.800	1
Dependency and interdependency	0.778	6
Uncertainty	0.778	6
Communication quality	0.756	8
Technology	0.756	8
Political influence (politics)	0.756	8
Organizational capability	0.756	8
Budgetary constraints	0.733	12
Stakeholder interaction	0.733	12
Clarity of goals	0.733	12
External environmental constraints	0.711	15
Economic uncertainty	0.711	15
Risk	0.711	15
Cultural resistance and differences	0.689	18
Project description	0.689	18

Innovation to market	0.667	20
Pace / Speed to Market	0.644	21
Environmental and safety impact	0.600	22
Impact on society	0.578	23

5.3. DISCUSSIONS ABOUT THE SURVEY RESULTS

As per section 5.2, each industry had a different rank in the top dimensions considering the Relative Importance Index (RII). After separating the dimensions and analysing each one from the highest RII per industry to the lowest, the results were as follows:

5.3.1. Dimensions where all industries got RII ≥ 0.70

The dimensions Risk, Product and Project Size, and Uncertainty had RII greater or equal to 0.70 as presented on Table 5.9.

Table 5.9 - Dimensions where all industries got RII ≥ 0.70

Dimension	Industry	RII
Risk	I.T.	0.892
	Manufacturing	0.867
	Defence	0.800
	Construction	0.800
	Others	0.711
	Energy	0.700
Product and project size	I.T.	0.892
	Others	0.800
	Energy	0.800
	Construction	0.764
	Manufacturing	0.733
	Defence	0.733
Uncertainty	Defence	1.000
	Others	0.778
	Energy	0.750
	Construction	0.745
	Manufacturing	0.733
	I.T.	0.708

5.3.2. Dimensions where all but one industry had an RII ≥ 0.70

The dimensions Project Management Maturity Level, Organizational Capability, Time Frame, Technology, and Clarity of Goals had only one industry with RII lesser than 0.70 as presented on Table 5.10.

Table 5.10 - Dimensions where all but one industry had an RII ≥ 0.70

Dimension	Industry	RII
Project management maturity level	Manufacturing	0.867
	I.T.	0.846
	Others	0.800
	Defence	0.733
	Energy	0.700
	Construction	0.691
Organizational capability	I.T.	0.831
	Defence	0.800
	Others	0.756
	Construction	0.745
	Manufacturing	0.733
	Energy	0.650
Time frame	Others	0.800
	Construction	0.791
	I.T.	0.754
	Energy	0.750
	Defence	0.733
	Manufacturing	0.667
Technology	Manufacturing	0.867
	Defence	0.800
	I.T.	0.785
	Others	0.756
	Construction	0.700
	Energy	0.500
Clarity of goals	Manufacturing	0.867
	I.T.	0.785
	Energy	0.750
	Others	0.733
	Construction	0.718
	Defence	0.533

5.3.3. Dimensions where two industries had an RII < 0.70

The dimensions Knowledge and Experience, Budgetary Constraints, and Degree of Trust had two industries with RII lesser than 0.70 as presented on Table 5.11.

Table 5.11 - Dimensions where two industries had an RII < 0.70

Dimension	Industry	RII
Knowledge and experience	I.T.	0.846
	Others	0.800
	Defence	0.800

	Manufacturing	0.733
	Construction	0.682
	Energy	0.550
Budgetary constraints	Construction	0.800
	I.T.	0.739
	Others	0.733
	Energy	0.700
	Manufacturing	0.600
	Defence	0.533
Degree of trust	Others	0.800
	Defence	0.800
	Construction	0.745
	I.T.	0.723
	Energy	0.550
	Manufacturing	0.533

5.3.4. Dimensions where three or four industries had an RII < 0.70

The dimensions Dependency and Interdependency, Stakeholder Interaction, Political Influence (Politics), Communication Quality, Cultural Resistance and Differences, Economic Uncertainty, External Environmental Constraints, and Project Description had three or four industries with RII lesser than 0.70 as presented on Table 5.12.

Table 5.12 - Dimensions where three or four industries had an RII < 0.70

Dimension	Industry	RII
Dependency and interdependency	Defence	0.867
	Energy	0.850
	Others	0.778
	I.T.	0.692
	Construction	0.645
	Manufacturing	0.600
Stakeholder interaction	Defence	0.933
	I.T.	0.754
	Others	0.733
	Manufacturing	0.667
	Construction	0.655
	Energy	0.600
Political influence (politics)	Defence	0.933
	Manufacturing	0.800
	Others	0.756
	Construction	0.691
	I.T.	0.646
	Energy	0.500

Communication quality	I.T.	0.815
	Others	0.756
	Manufacturing	0.733
	Construction	0.682
	Energy	0.650
	Defence	0.533
Cultural resistance and differences	Manufacturing	0.733
	Defence	0.733
	I.T.	0.708
	Others	0.689
	Construction	0.573
	Energy	0.400
Economic uncertainty	Construction	0.809
	Manufacturing	0.733
	Others	0.711
	Defence	0.667
	I.T.	0.585
	Energy	0.500
External environmental constraint	Defence	1.000
	Others	0.711
	Construction	0.700
	Manufacturing	0.667
	I.T.	0.646
	Energy	0.500
Project description	Manufacturing	0.733
	I.T.	0.723
	Others	0.689
	Construction	0.682
	Energy	0.600
	Defence	0.533

5.3.5. Dimensions where all but one industry had an RII ＜ 0.70

The dimensions Environmental and Safety Impact, Impact on Society, Innovation to Market, and Pace/Speed to Market had all industries with RII lesser than 0.70 with the exception of one as presented on Table 5.13. A case could be made for not considering these dimensions any further, but further input from interviews will be recommended before making this decision.

Table 5.13 - Dimensions where all but one industry had an RII < 0.70

Dimension	Industry	RII
Environmental and safety impact	Defence	0.933
	Construction	0.682
	Others	0.600
	Manufacturing	0.600
	Energy	0.600
	I.T.	0.492
Impact on society	Manufacturing	0.733
	Defence	0.600
	Others	0.578
	I.T.	0.523
	Construction	0.491
	Energy	0.400
Innovation to market	Defence	0.733
	I.T.	0.677
	Others	0.667
	Construction	0.618
	Energy	0.600
	Manufacturing	0.467
Pace / Speed to Market	Defence	0.733
	Construction	0.682
	Manufacturing	0.667
	Others	0.644
	I.T.	0.631
	Energy	0.450

5.3.6. Comparison per RII

Using the Relative Importance Index (RII) as a factor, the following Table 5.14 provides a side-by-side comparison between the consolidated view for all industries (right side) and the dimensions with RII lower than 0.70 (left side).

Table 5.14 – Comparison between all industries x RII < 0.70

RII < 0.70	Dimension
None	Risk
	Product and project size
	Uncertainty
1 out of 6	Organization capability
	Project management maturity level
	Time frame
	Technology
	Clarity of goals
2 out of 6	Knowledge and experience
	Budgetary constraints
	Degree of trust
3-4 out of 6	Communication quality
	Dependency and interdependency
	Economic uncertainty
	Stakeholder interaction
	Political influence (politics)
	External environmental constraint
	Project description
	Cultural resistance and differences
5 out of 6	Pace / speed to market
	Innovation to market
	Environmental and safety impact
	Impact on society

Dimension
Risk
Product and project size
Time frame
Organization capability
Project management maturity level
Uncertainty
Budgetary constraints
Knowledge and experience
Clarity of goals
Technology
Degree of trust
Communication quality
Dependency and interdependency
Economic uncertainty
Stakeholder interaction
Political influence (politics)
External environmental constraint
Project description
Pace / speed to market
Innovation to market
Cultural resistance and differences
Environmental and safety impact
Impact on society

It can be observed that, with the exceptions marked above, the consolidated rank for all industries (right column) seems consistent. For that reason, it would be appropriate to analyse the interview results to corroborate the dimensions that should be considered relevant and the ones that should not be in the proposed model (Chapter 6). The next section will present the discussions about the interviews.

5.4. SURVEY VALIDATION WITH INPUT FROM PRACTITIONERS

A paper published during the Project Management Institute Global Congress Proceedings in Phoenix, Arizona (USA) on October 27, 2014, showed partial results of the research. The paper was entitled "Dimensions of Project Complexity: The impact on the Cost Estimation Process".

As part of the presentation of the paper, the researcher asked participants to provide their views on complexity dimensions before the 23 dimensions were discussed. The participants were divided into groups of three to four people asked to do the following:

- Discuss possible factors (dimensions) that can impact the level of complexity of your projects (i.e., risks).
- Identify what you consider the top two to three dimensions.

The results collected are presented in Table 5.15 below. In the left-hand columns a list of all the dimensions gathered by the participants who attended the presentation. In the right-hand column is a comparison with the existing 23 dimensions from this research.

Table 5.15 – Comparison between complexity dimensions provided by participants of congress with research

Complexity Factors (Dimensions) Listed by Participants of PMI Global Congress 2014	Complexity Dimensions from Research
Additional systems engineering processes needed	Organizational capability
Amount of regulatory oversight	External Environmental Constraints
Build sequencing for Critical Path items	PM Maturity Level
Bureaucracy	Organizational capability
Can it be validated?	PM Maturity Level
Changing politics	Political Influence (Politics)
Communications	Communication Quality
Conflicting methodologies	PM Maturity Level
Constraints – political, time, budget	External Environmental Constraints
Critical thinking – different styles and mind-sets	Organizational capability + Stakeholder Interaction
Cultural changes	Cultural Resistance and Differences
Degree to which business processes will need to change	Organizational capability
Field conditions	External Environmental Constraints
Has it been done before?	Knowledge and Experience
Impact and consequence of results	Impact on Society + Environmental and Safety Impact
Incomplete compliance regulations	External Environmental Constraints
Individual behaviour	Organizational capability + Stakeholder Interaction
Industry norms	External Environmental Constraints
Key resource availability	Organizational capability
Late decisions	Pace/Speed to Market
Number of approval levels	Organizational capability
Number of business areas	Product and Project Size
Number of interfaces	Dependency and Interdependency
Number of stakeholders and/or subcontractors	Stakeholder Interaction
Number of system interactions	Dependency and Interdependency
Organizational behaviour and change	Organizational capability
Outside influence	External Environmental Constraints
Poor leadership	Organizational capability

Project location	External Environmental Constraints
Relationship with the customer	Degree of Trust
Risks	Risk
Stability of requirements and regulations	External Environmental Constraints
Structural changes	Uncertainty
Team composition changes	Organizational capability
Team dynamics	Organizational capability
Technology dependencies and maturity	Technology
Territory, environment, language being unfamiliar	Cultural Resistance and Differences
The need to start earlier in the lifecycle	Time Frame
Time zones	External Environmental Constraints
Vendor supply being unpredictable	Uncertainty
Volume of data	Technology
Dimensions found on this research but not listed by participants	Budgetary Constraints
	Innovation to Market
	Project Description
	Economic Uncertainty

All 41 dimensions shared by participants were associated with the existing 23 dimensions, but participants did not mention four dimensions from the research:

- Budgetary Constraints
- Innovation to Market
- Project Description
- Economic Uncertainty

It should be pointed out that these dimensions, with the exception of budgetary constraints, are listed at the lowest level of importance/impact in the previous section, which supports the argument that they are not as relevant as the others.

5.5. IMPROVEMENTS ON THE MODEL BASED ON THE SURVEY RESULTS

The survey provided a better sense of priorities regarding which dimensions were considered more important than the others, but the list of 23 dimensions remained the same as presented on Figure 5.3. Therefore, the model will remain unchanged as per the last version in Chapter 4. Further interviews will be used to support the decision to eliminate or consolidate the list of dimensions.

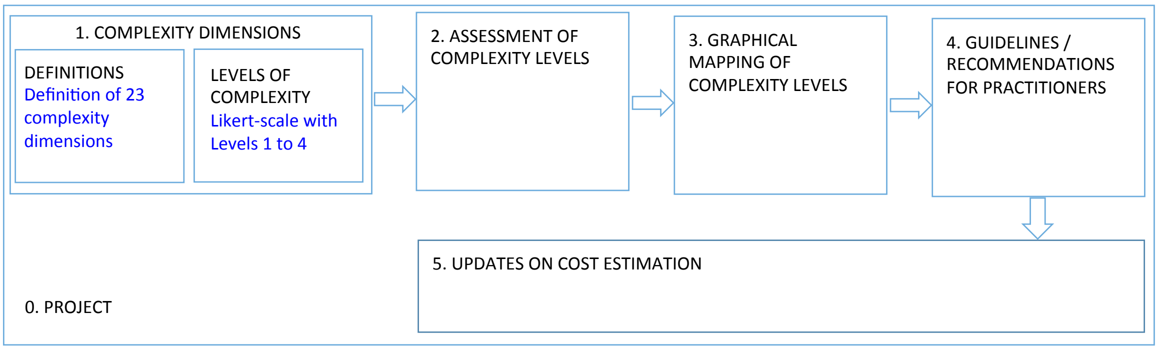


Figure 5.3 – Update on the model with 23 dimensions

The next section will describe the interviews with 10 practitioners and how the list of complexity dimensions could be updated.

5.6. THE INTERVIEWS

The interview process followed a semi-structured approach, as the questions were posed in a way that enabled interviewees to divert, adding comments and mentioning topics they found relevant. New ideas were brought into light and described in each interview transcript.

Out of the 248 people invited to take the survey, 54 (21.8%) responded . From those 54, 15 people (27.8%) were invited to be interviewed. The selection of interviewees was based on the following criteria:

- They had proven experience related to managing complex projects as either 1) experts or academics—people considered experts in their field of knowledge, with published work on project complexity, or professionals involved in teaching project management at the undergraduate and graduate levels; or 2) practitioners: people who manage complex projects as part of their work.
- They are from different industries, so to ensure broader representation of the interview results. The industries covered were construction, defence, energy, information technology, manufacturing, and others.
- They responded to all the survey questions.

Invitations were sent to these 15 people and a positive response was obtained from 10 professionals with the following demographics:

- Region where the work is being performed: Europe (30%), South/Central America (30%), North America (30%), Middle East (10%)

- Experience Type: Practitioner (60%), Expert/Academia (40%)
- Industry Background: Construction (30%), Defence (20%), Energy (10%), Information Technology (10%), Other (30%)

Each interview took between 60 to 90 minutes and all but one were recorded using LiveScribe with notes taken by the researcher. A professional transcriber was hired to type the recordings and the result was sent to each interviewee for approval. Once approval was obtained, a summary was produced as listed in section 5.7. Two sample transcripts of full interviews can be found in Appendix B.

To assure confidentiality, the interview participants will be identified as represented in Table 5.16 below:

Table 5.16 – List of participants that were interviewed

Participant ID	Experience	Region	Industry Background
Participant 1	Expert/Academia	North America	Other
Participant 2	Expert/Academia	North America	Defence
Participant 3	Practitioner	Europe	Energy
Participant 4	Practitioner	Europe	Other
Participant 5	Practitioner	South America	IT
Participant 6	Expert/Academia	South America	Other
Participant 7	Practitioner	Caribbean	Construction
Participant 8	Practitioner	Middle-East	Construction
Participant 9	Practitioner	Europe	Construction
Participant 10	Expert/Academia	North America	Defence

5.7. INTERVIEW RESULTS

The 10 people interviewed had distinct points of view related to some topics and were quite aligned on others. The following paragraphs will provide a summary of the conclusions obtained during the analysis of the feedback provided.

A rank of the top 10 dimensions based on the survey was created and interview participants (interviewees) were asked if they agree with the rank as presented below:

1 – Project Management Maturity Level

2 – Risk

3 – Product and Project Size

4 – Knowledge and Experience

5 – Clarity of Goals

6 – Organizational capability

7 – Communication Quality

8 – Uncertainty

9 – Degree of Trust

10 – Time Frame

Each interviewee was asked to select an additional five dimensions out of the remaining 18. Table 5.17 below represents the choices they made.

Table 5.17 – Top dimensions per interviewee

INTERVIEW QUESTIONNAIRE				Participant #									
Order	Complexity Dimension	Survey Rank	# Selections	1	2	3	4	5	6	7	8	9	10
1	Project Management Maturity Level	1		TOP 5 DIMENSIONS FROM SURVEY - MANDATORY QUESTION DURING INTERVEIWS									
2	Risk	2											
3	Product and Project Size	3											
4	Knowledge and Experience	4											
5	Clarity of Goals	5											
6	Organization Capability	6	7	X		X	X	X		X	X	X	
7	Political Influence (Politics)	14	5	X			X	X	X	X			
8	Communication Quality	7	4	X				X			X	X	
9	Time Frame	10	4			X			X	X	X		
10	Stakeholder Interaction	15	4	X			X	X	X				
11	Pace or Speed to Market	21	4		X		X				X		X
12	Degree of Trust	9	3	X			X		X				
13	Budgetary Constraints	12	3			X					X		X
14	Dependency and Interdependency	13	3		X	X						X	
15	Cultural Resistance and Difference	20	3					X	X	X			
16	External Environmental Constraints	16	2		X					X			
17	Innovation to Market	19	2		X	X							
18	Uncertainty	8	2		X								X
19	Impact on Society	23	1									X	
20	Project Description	17	1									X	
21	Technology	11	1										X
22	Economic Uncertainty	18	0										
23	Environmental and Safety Impact	22	0										

The following sections present the interview findings per dimension. For each of them, a description of the interviewees' points of view related to relevance of the dimension, how it impacts the cost-estimation process, and a list of guidelines for cost estimators are provided.

5.7.1. Project Management Maturity Level

The following analysis is represented by a tree node in Figure 5.4. It covers the aspects of relevance, impact on the cost-estimation process, and list of guidelines for cost estimators.

Name	References
Project Management Maturity Level	0
Impact Level on Cost Estimation	0
It has impact	4
It has Indirect Impact	1
It has no impact	2
Recommendations for Cost Estimators	0
Develop Methodology for Estimates and Contingencies	1
Gather More Information from Client	1
Hire Consultants	1
Increase PM Maturity Level	1
Use a Check-List with PM Knowledge Areas	1
Use Excel with Questionnaire for Contingency Calculation	1
Use the Right Tools	1
Use WBS	1
Relevance	0
Not Relevant	5
Not Sure	1
Relevant	11

Figure 5.4 – Tree node for the dimension Project Management Maturity Level

5.7.1.1. Relevance

The survey analysis using the Relative Importance Index placed the project management maturity level dimension in fifth place with RII = 0.759. These survey respondents agreed that the project management maturity level of an organization increases the complexity level of a project.

According to Interviewee 7, not only is project management maturity level a dimension of project complexity, but the other 22 dimensions actually reflect how mature or not an organization is. That begs the question whether the maturity level is a dimension by itself or actually a result of the other dimensions, which could be a topic for further research.

As stated by Interviewee 9, “Your first one is Project Management Maturity Level, and that’s important. I know that’s important and that it is a problem of most projects. Not to mention the need for excellence in project management and the need for PMO offices and PM excellence”. This statement associates project management maturity level with excellence in managing projects and the role of the project management office (PMO).

Interviewee 4 shared that this dimension is actually dependent on three factors: Is there trust in the people managing and performing the project?; Do they have the proper background?; and Are they able to follow the processes and procedures? The interviewee went on to say, “Basically, do you believe these people can do it, and are they really committed, or are they just kicking the tires type of thing?”

According to one of the interviewees, the project management maturity level does not replace skilled teams but it can serve as an important enabler. Another respondent considers the maturity level a competitive advantage.

Interviewees 1, 8, and 10 did not agree that this dimension is relevant and felt it should not be placed in the top ten most impactful dimensions. According to Interviewee 10, “Project Management Maturity Level doesn’t really resonate as a complexity dimension. It is essentially the same thing as Organizational Capability. In a way, it is also very similar to Knowledge and Experience…”, which supports the Interviewee 7’s view. Should this dimension be considered, or not listed at all?

According to Interviewee 1, instead of looking into project management maturity level, one has to focus on project management capability and not on defining levels.

Interviewees 3, 4, 5, 6, 7, and 9 propound the view that project management maturity level is a relevant complexity dimension, only contested by interviewees 1, 8, and 10. These findings suggest that the more mature an organization is with respect to project management, the more its employees share a common project-management language, and the more likely project-management processes are implemented, methodologies established, and benchmarking and continuous improvements in place. The view the project management maturity level is not to be considered a complexity dimension is disputed by three interviewees, which does not suggest it is irrelevant. On the other hand, the recommendation to consider its interaction with organization capability addresses the issue.

5.7.1.2. Impact on the Cost-Estimation Process

Interviewee 2 shares that there is a need for tools and standardization within the organization to manage a complex project. This means that it is not only about stating something is complex, but determining which degree of complexity exists and, based on that, defining a different estimating function.

In the words of Interviewee 4, “When you have an immature project, it’s quite difficult to know whether to put money into it or not. So in terms of obtaining funding, when you’re not certain about the cost-estimation process—Is it robust enough? Have I followed the right steps? —then that’s difficult to do”. The impact is related to the level of certainty that an estimate will cover the needs of the project, which would be achieved when the organization is more mature. More mature organizations generate more assurance that the estimate is properly done.

Interviewee 5 shares that faster deliveries are associated with a more mature project-management process, allowing the organization to use Rapid Development Solutions, which consequently help reduce costs even if the project is complex by result of other dimensions.

According to Interviewee 3, mature organizations should have developed a mature estimation process, to the point where “… the maturity of their projects and their project-management approach is, in fact, embedded into the way they build their estimations of time and cost”.

Interviewee 7 makes a cross-reference between the project management maturity level and the understanding of the broader environmental issues and how they influence the project outcome. In other words, it goes beyond the ‘mechanical’ aspects of cost estimating and must incorporate political, economic, and social influences.

Furthermore, Interviewee 6 provides a summary of previous comments, stating, “In lots of different ways, in each and every project, considering complex projects, you do have to have, for instance, a methodology. Considering complex projects you have to have a specific methodology to estimate costs, methodology that can spread all over the different products involved. [You must] have a tool because you are not dealing normally with lower budget projects, that could help you to plan and control your costs. So I believe maturity affects a lot, not only cost estimating, but time estimating and other project management elements”.

On the other hand, Interviewee 1 considers that the organizational capability should be considered instead of the project management maturity level. According to Interviewee 8, ‘real’ or very experienced estimators don’t care about this dimension because “… they work within tiers, they know the type of work that they are working on. They understand their industry and their market. Young estimators don’t know what they’re doing”.

Not much debate appeared when interviewees 2, 3, 4, 5, 6, and 7 provided more detailed answers as to whether and how the project management maturity level would impact the cost-estimation process. Only one interviewee disputed the impact of this dimension on the process of estimating costs, which leads to the conclusion that it should be considered impactful. Similarly to the relevance of the dimension, a possible consolidation of project management maturity level and organization capability should be considered.

5.7.1.3. Guidelines for Cost Estimators

Several interviewees provided recommendations for cost estimators when considering the project management maturity level of the organization. These recommendations are described in the following paragraphs and might be included as part of the proposed complexity model.

Would the use of the right tools be the answer? According to Interviewee 2, this might be the case. Organizations that are very mature in managing their projects would provide their project managers with the right tools to do their work. This includes cost estimation and any necessary information-gathering techniques.

Interviewee 3 recommends that cost estimators follow the process built into the existing methodology, considering that there is one. A proper methodology should allow an intelligent approach to contingency allocation and how to build these contingencies into the estimates. A given methodology will not necessarily allow for proper contingency allocation.

The approach used by Interviewee 6 is divided into a few steps. Initially the organization has to measure its project management maturity level, followed by implementing actions that would increase the maturity level, and if necessary get external help by hiring a consulting company.

Interviewee 5 recommends creating a checklist based on the project management knowledge areas (e.g., scope, time, cost, quality, human resources, and risks) to verify the experience level of the people involved in the project. Similarly, Interviewee 4 would use a simple technique employing an Excel spreadsheet with a questionnaire with answers ‘yes’ or ‘no’, or high, medium, and low. Based on the answers, the spreadsheet would provide a contingency margin, which could be used during the estimation process.

Contacting the client to better understand the strategic needs Interviewee 9’s recommendation. A more mature organization should have processes in place that enable it to find the overall cost and benefits of the project, and, once the information is available, use the work breakdown structure to identify tasks on the appropriate level for that project.

5.7.2. *Risk*

The following analysis is represented by the tree node in Figure 5.5. It covers the aspects of relevance, impact on the cost-estimation process, and list of guidelines for cost estimators.

Name	References
Risks	0
Impact Level on Cost Estimation	0
It Depends	3
It has impact	5
It has no impact	0
Recommendations for Cost Estimators	0
Add Contingency based on Difficulty Degree	1
Analyse Data Reliability	1
Create a Risk Management Team	1
Develop a Risk Assessment	2
Implement a Risk Management Process	2
Relevance	0
Not Relevant	3
Not Sure	1
Relevant	12

Figure 5.5 – Tree node for the dimension Risk

5.7.2.1. Relevance

The survey analysis using the Relative Importance Index placed the risk dimension in first place with RII = 0.804. Respondents believed that risks are impactful to a project, and the greater the probability or impact of risk, the greater the complexity of that project.

This becomes especially impactful when there are unknown or undefined risks that cannot be asserted via an action plan to reduce the impact or the probability of that risk becoming an issue. According to some survey participants, risks have to be managed continuously during the project life cycle. On the other hand, another respondent shares that risks are not necessarily associated with complex projects, since known risks are part of any project, and unforeseen risks (unknown unknowns) cannot be anticipated or acted upon.

Conceptually this dimension is related to the probability and impact of something negative happening in the course of a project – what risks exist in the project that can negatively impact it. The more a project is subject to unknown risks with high probability and high negative impact , the greater the project's complexity. This brings a question if the existence of high probability and impact risks result in complexity or the fact that these risks are unknown is what results in complexity.

The above statement is supported by Interviewee 2, who said, "I think risks could be number one in some services, because what a lot of people define complexity as is dealing with unknown situations. And when you talk about unknowns, you're dealing with potential risks. You know, there are risks that are known and there are risks that are unknown. Both of those can lead to complexity. It's the unknown risks that often lead to severe complexity".

According to Interviewee 5, risks are relevant since contingencies are normally defined based on them. Another view is provided by Interviewee 6, who stated that risks have a cultural aspect that might bias the way they are perceived or managed.

Interviewee 4 believes that risk might mean different things to different people, so the definition of risk is important. The influence of risk also depends on risk tolerance: Is the company more risk averse or more risk seeking? How tolerant is it to variability in the cost-estimation process?

Interviewee 1 did not agree that this dimension was relevant and felt it should not be placed among the top ten most impactful dimensions, since one can never identify all risks. Furthermore, the interviewee believes that "… risk management is overdone since there is always going to be something that comes up that you cannot plan for in advance".

Interviewee 10 emphasized the strong correlation between risk and uncertainty, between uncertainty and technology, and finally between risk, uncertainty, and innovation to market.

Based on the favourable arguments provided by Interviewees 2, 3, 5, 6, 7, and 9 related to the relevance of risk as a complexity dimension, and how high risk as a dimension ranked in the survey, the conclusion points to its relevance. The argument used by Interviewee 1 stated how impossible it is to know all risks, but this is not related to how relevant the dimension is. The correlation between risk and uncertainty can be found (PMI, 2012), but the argument does not suggest that risk should not be considered as relevant. The conclusion then is for the relevance of risk as a complexity dimension.

5.7.2.2. Impact on the Cost-Estimation Process

Interviewee 2 shares a view that risks are associated with all other complexity dimensions and one cannot separate out risks from them. "Any dimension you come up with that a project manager considers as important is going to have an associated risk with it. It could be a low risk or it could be a high risk". The same position is supported by Interviewee 5, who also believes that the project manager should convert all other dimensions into contingencies, and since risk influences all other dimensions, the impact of risks is clear.

According to Interviewee 3, a risk assessment should be done for every project and the contingencies should be built into the cost estimation, so there is a direct impact. This interviewee recommended making the contingency visible in the cost estimate and explained the logic behind this recommendation —planning a standard contingency regardless of the project type and risks is not productive.

Interviewee 6 also agrees that risk has a direct impact on the cost-estimation process and emphasizes that the absence of a risk assessment is not considered a project management best practice. "Directly because if you do not do it, or you forget to do it, if you do it wrong, or you forget to have a contingency plan, you do not have a management plan…. Or sometimes you do have space for that in your budget, sometimes you don't. If you don't have this culture, if you don't have the right answers for your risks process, you are in trouble. And, well, that's how it impacts the cost estimation. It's a direct impact".

The fact that Interviewees 2, 3, 5, 6, and 9 answered this question by explaining how risks would impact the cost-estimation process illustrates and supports the conclusion that risks have direct impact on the cost estimates. Additionally, it can be argued that risks are often associated with contingency during estimates, which, again, supports its impact on the cost-estimation process.

5.7.2.3. Guidelines for Cost Estimators

The interviewees provided a description of recommendations of how to consider risks during the cost-estimation process on complex projects, as follows.

The recommendation provided by Interviewee 2 states that the cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. In the Interviewee's own words, "Some projects that are a low risk, well, it doesn't have any impact on cost. If it's a high risk, then it could impact the size of the management reserve. If this project is considered to be 10% more complex than our previous project, you’ll increase your estimates by 10%. A budgetary estimate is when you take a traditional estimate for doing the job and you multiply it by a difficulty degree factor”.

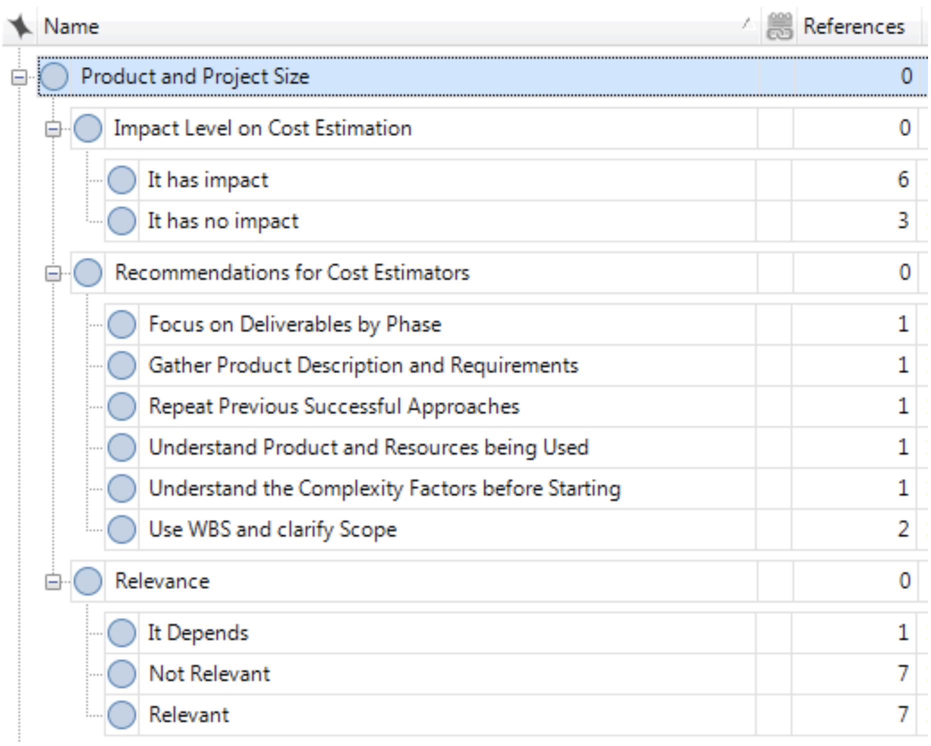
Interviewee 3 suggests starting by looking at the data sources to determine how reliable the data used for the cost estimation is, and to consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.

Creating a risk team with the participation of the project manager is the advice of Interviewee 6. This approach is based on having several people brainstorming to better understand all the parts of the project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase. The project manager has to consider that the other dimensions will somehow self-organize and impact the project in a positive or negative way, where the approach should focus on maximizing the chances of a positive impact.

Similarly, Interviewee 4 recommends that a risk assessment be done to analyse potential risks and create an action plan, supporting then the cost-estimation process. Furthermore, Interviewee 5 advises implementing a risk-management process, which is quite aligned with the other recommendations.

5.7.3. Product and Project Size

The following analysis is represented by a tree node in Figure 5.6. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.



Name	References
Product and Project Size	0
Impact Level on Cost Estimation	0
It has impact	6
It has no impact	3
Recommendations for Cost Estimators	0
Focus on Deliverables by Phase	1
Gather Product Description and Requirements	1
Repeat Previous Successful Approaches	1
Understand Product and Resources being Used	1
Understand the Complexity Factors before Starting	1
Use WBS and clarify Scope	2
Relevance	0
It Depends	1
Not Relevant	7
Relevant	7

Figure 5.6 – Tree node for the dimension Product and Project Size

5.7.3.1. Relevance

Regarding the dimension product and project size, Interviewees 3, 4, 6, and 7 agreed with its relevance, and Interviewees 1, 2, 5, 8, 9, and 10 disagreed that this complexity dimension is relevant. Interviewee 3 states, "Complexity is influenced by the scope and duration of the project. More items, more chances for interaction", which is aligned with the influence of interaction, and dependency and interdependency of the project elements. On the other hand, the number of elements does not necessarily translate into complexity. What is more significant is how much is known about the results of the interaction; if one does not know the outcome of an interaction, that's when the complexity emerges (Cicmil et al., 2007).

Even though interviewee 4 agrees that size is relevant, greater size does not necessarily mean more complex. What is more relevant is the team or organization's experience with managing such a project: the more information and knowledge one has, the less complex a project becomes even if it is a large product or project. On a separate note, Interviewee 7 thinks that there is not enough understanding between practitioners that the product or project size matters to complexity, and that applying the same approach used for small projects to large projects leads to failure.

On the other hand, several interviewees consider the product and project size to be irrelevant. As Interviewee 1 suggests, “All project work is complex regardless of its size, and project professionals have been dealing with complexity since ancient times. The difference today is it’s a much more common occurrence and has become a key area to navigate to make sure projects have added business value. So I do not believe there is any difference in product and project size in the complexity dimension”.

Supporting this position, Interviewee 2 believes that the size is not necessarily related to the risk of the project. A small project (e.g., three weeks) can still be high risk. Large projects probably have more risks, with more chances for cost overruns or schedule delays, but this does not mean it they are more complex. A similar argument is shared by Interviewee 5, who states that a larger budget due to the size of the project has a direct correlation with the size of the project.

A direct statement of the irrelevance of the size of the product or project was provided by Interviewee 8 and supported by Interviewee 9. They agreed that how well a project is managed is more impactful than the size of it.

Interviewee 10 had a few questions related to the definition of the dimension of product and project size. Would the size be related to the number of people, the physical size of the product, the duration of the project, and so on? As Interviewee 10 states, “I have concluded that instead of talking about size, I’m talking about the complexity of the system … . It’s a clear measure. This helps people understand how complex the system is in terms of the complexity of the product. And you can also talk about the complexity of the organization. Am I doing it in one function? Am I doing it in multiple functions in one organization? Am I doing it in multiple organizations? Am I doing it in multiple organizations in the same country, or am I doing it in multiple organizations globally? That’s another measure of complexity. And by the way, you can have the same product with different complexity of organizations”. The research suggests that this dimension should actually cover any or all of these aspects, as long as the project manager realizes that they can increase the complexity level of the project.

Even though survey analysis using the Relative Importance Index placed the dimension product and project size in second place with RII = 0.800, indicating that the project and product size is relevant and impactful to project complexity, a disconnect was found when the interviewees were asked if they agree with these results. Considering that the Relative

Importance Index rated this dimension high, the recommendation is to keep it as relevant in the final list. How relevant it would be for any specific project will depend on the project characteristics.

5.7.3.2. Impact on the Cost-Estimation Process

Interviewee 2 proposes a direct correlation between the size of the product or project and the cost estimation. The "larger the project, the greater chances for cost overruns" statement is supported by the argument that more contingencies have to be created for larger projects. Similarly, Interviewees 3 and 4 emphasize that larger projects will have greater interaction among different activities and elements. More elements create greater uncertainty, and an increased level of uncertainty directly impacts the cost-estimation process. Interviewee 6 mentions that more features, services, or modules normally increase the complexity level and require the use of specialists to reduce the impact of that complexity when estimating costs.

According to interviewee 5, one has also to consider the complexity of the product itself. A product becomes more complex not only based on its size but also on the knowledge and experience needed to manage a project that will deliver that product. That also means that if the project manager has already managed and delivered similar projects, the complexity level will decrease. In that case, it is not just about the size but the learning curve necessary to gather proper knowledge to be successful. How effective the planning is could be an important aspect in influencing the complexity of a project and the cost-estimation process, as proposed by Interviewee 9.

Interviewee 7 shares that a possible reason for failure when managing large projects or delivering large products is the assumption that what works on a smaller project can be replicated on a large one. Also, the larger the project, the longer the timeline to managed and a long timeline creates a more complex environment in which to estimate costs.

Disagreeing with the impact of product and project size, Interviewees 1, 8, and 10 emphasized that it is more about other variables such as how many times one has delivered similar products and managed projects, and how things are put together.

Since the arguments favouring the impact of product and project size on the cost-estimation process are based on practical experience, and no strong case was made to reject its impact, the conclusion points towards considering product and project size impactful.

5.7.3.3. Guidelines for Cost Estimators

Each interviewee provided recommendations for cost estimators when dealing with the impact of the product and project size. These recommendations are described in the following paragraphs and might be included as part of the proposed model.

When dealing with a new product or project, the use of the work breakdown structure (WBS) is paramount to a better understanding of the total scope of the project and each of the elements. Use all necessary resources like subject matter experts to ensure that the WBS is as complete as possible. The reason for that is the WBS will be used as the source for developing the schedule and the budget, so an incomplete WBS will reflect poor estimates for time and cost. In other words, if one knows well what to do or has delivered such a product before, the cost estimates will certainly be more accurate.

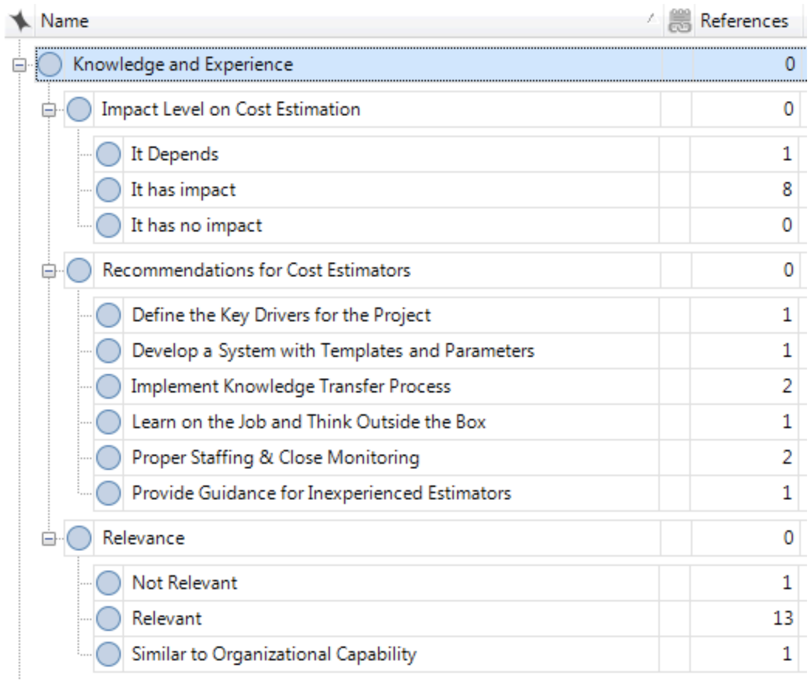
This recommendation is supported by Interviewees 1, 4, and 7, who emphasize the need to obtain a maximum granularity of the WBS elements. Another piece of advice is to frame the deliverables in such way that they can be delivered within the project phases, allowing several successes instead of a lengthy failure. The cost would also be easier to estimate and manage since one is delivering smaller components.

Interviewee 2 recommends that a project manager who starts a new project should hold back from working on other projects until acquiring a clear understanding of all product requirements. This could optimize the use of resources and improve the cost-estimation process. Also, the size of the products and projects should be considered when analysing the portfolio of that organization, which has a direct impact on the organizational capability as supported by Interviewee 3. Should the organization decide to deliver new or large products that were not being delivered before, the higher the risks and greater the impact on cost estimation.

Another recommendation shared by Interviewee 5 is to involve the customer in the clarification of the product requirements and consequently in the work to be performed during the project. Interviewee 6 concurs that the time invested in listening to the stakeholders, planning, and writing down the details of the product, how it will be used, and so on is important for the success of the project, as per the following statement: “I know this is not easy depending on the size of the project, but you do have to have all of them together in order to listen to them, in order to have a good product description, good product requirements. The requirements have to be very specific as well as assumptions, as well as restrictions, as well as, you know, everything that relates to the product description, in order to minimize problems with the size”. This is once again linked to the clarity of goals.

5.7.4. Knowledge and Experience

The following analysis is represented by a tree node in Figure 5.7. It covers the aspects of relevance, impact on the cost-estimation process, and list of guidelines for cost estimators.



Name	References
Knowledge and Experience	0
Impact Level on Cost Estimation	0
It Depends	1
It has impact	8
It has no impact	0
Recommendations for Cost Estimators	0
Define the Key Drivers for the Project	1
Develop a System with Templates and Parameters	1
Implement Knowledge Transfer Process	2
Learn on the Job and Think Outside the Box	1
Proper Staffing & Close Monitoring	2
Provide Guidance for Inexperienced Estimators	1
Relevance	0
Not Relevant	1
Relevant	13
Similar to Organizational Capability	1

Figure 5.7 – Tree node for the dimension Knowledge and Experience

5.7.4.1. Relevance

Interviewee 1 offers the perspective that the project has to benefit from the team members’ knowledge assets. Even people new to the organization or with less experience might have different knowledge assets to contribute. Experience has the caveat that it has to be kept up to date. Interviewee 3 complements this view by mentioning the link between knowledge and experience with the project management maturity level of the organization. The focus should be more towards the people and less on the organization because one might have a highly mature organization but a project manager who has limited knowledge and experience, which would result in a more complex environment.

One of the characteristics of a project is that it is unique (PMI, 2012), which means it was not done before with the same resources, time, constraints, etc., so Interviewee 2 believes that this uniqueness requires previous knowledge and experience about the particular type of project, reducing the complexity level. If you don't have information, knowledge, and experience, the project can be considered high-risk. Similarly, Interviewee 4 considers it important to know the organization's tolerance to contingency, and Interviewees 5 and 6 conclude that if one does not have the requisite knowledge and experience for a particular type of project, the cost will be higher and more contingency will be added.

A direct correlation between the lack of knowledge and experience and project failure is mentioned by Interviewees 7 and 9. If the cost estimation is done without knowledge or experience on similar projects, how could the project manager expect the estimate to be accurate?

The position of Interviewee 10 is more related to the possible interaction between knowledge and experience with the organizational capability, so it would be considered part of one dimension instead of two separate ones. In other words, Interviewee 10 considers this dimension subjective and quite similar to organizational capability. In some way, these two dimensions are related, but the knowledge and experience is related to the people involved in managing the project and estimating the necessary effort to deliver the product. The organizational capability is more related to the existence of processes to support the management of that specific project; for instance a software development company would have a very hard time estimating a project to build a bridge. It is not part of their business and so the organization has no processes or previous experience developing this project, and so on. As mentioned before, there is a correlation, but they are different dimensions. It can be argued that a new dimension might integrate these two existing dimensions covering both concepts. In any instance, the importance level would be high.

The survey analysis using the Relative Importance Index placed the knowledge and experience dimension in seventh place with RII = 0.741, which is within the top 10 but not aligned with the fact that all interviewees but one (Interviewee 10) recognize its importance and relevance. Based on the evidence provided by interviewees, it can be concluded that knowledge and experience is relevant as a complexity dimension.

5.7.4.2. Impact on the Cost-Estimation Process

Interviewee 1 believes that during the cost-estimation process a knowledgeable person (expert) would be valuable to provide input on analogous estimates based on their previous experience with similar projects. The same position is shared by Interviewee 7, who proposes that the cost estimator should have previous knowledge and experience. The cost estimator would then be able to discuss and consult on the subject matter. Interviewee 7 explains this view: “I would think that the estimator would discuss some of the issues with the subject matter experts. So let us take an engineer for instance. The engineer will do his designs, and he will pass his designs on to the estimator to develop his budget. But if the designer does not have the requisite knowledge or the requisite experience, his design will be inefficient. It could be that he has overdesigned elements, or he may have omitted particular design considerations. The estimator would be then pricing an incomplete or inefficient project”.

The other interviewees focused on the negative impact on the project of a lack of knowledge and experience on the part of the cost estimators, as summarized by Interviewee 6, who said, “You can’t afford to not have people prepared”. If the project team does not have the right resources to do the estimates, it might be necessary to outsource the estimates to avoid considerable estimation errors; on the other hand, this service would cost more. In case there is no budget to accommodate an external support, the cost estimate should consider contingencies to account for the lack of knowledge and more monitoring should be implemented.

One approach to mitigate a lack of or limited knowledge and experience is to create a database of estimates for more effective knowledge sharing. Interviewee 9 indicates that the most important aspects to be aware of are the intangibles. “It’s the intangibles which are really important. If you don’t acknowledge what the client is expecting then it’s not possible to get that out of the project,” Interviewee 9 stated.

Considering that all interviewees generally agreed with the impact that knowledge and experience has on the cost-estimation process, this dimension should be defined as impactful.

5.7.4.3. Guidelines for Cost Estimators

The following guidelines were based on recommendations by interviewees during the interview process. They are focused on what the cost estimator should do when dealing with a lack of or limited knowledge and experience on the part of the performing team.

The first advice comes from Interviewees 1 and 5, who believe that the organization should have or implement a knowledge transfer system—a database that will host previous estimates, lessons learned, and performance from various project types. Additionally, the project manager should look for people who have experience from similar projects and get their input, or in other words bring the necessary knowledge into the project.

Properly staffing the project with resources that have the knowledge and experience necessary to deliver the project is an important aspect, as shared by Interviewees 2, 3, and 8. If the internal people have the knowledge and experience, then the project is less complex and so is the cost-estimation process. If no internal resources are available, then there is a need to outsource part of the team, which increases costs, or to train the existing team. As stated by Interviewee 8, “If you don’t understand what you’re doing you can make a big mess”.

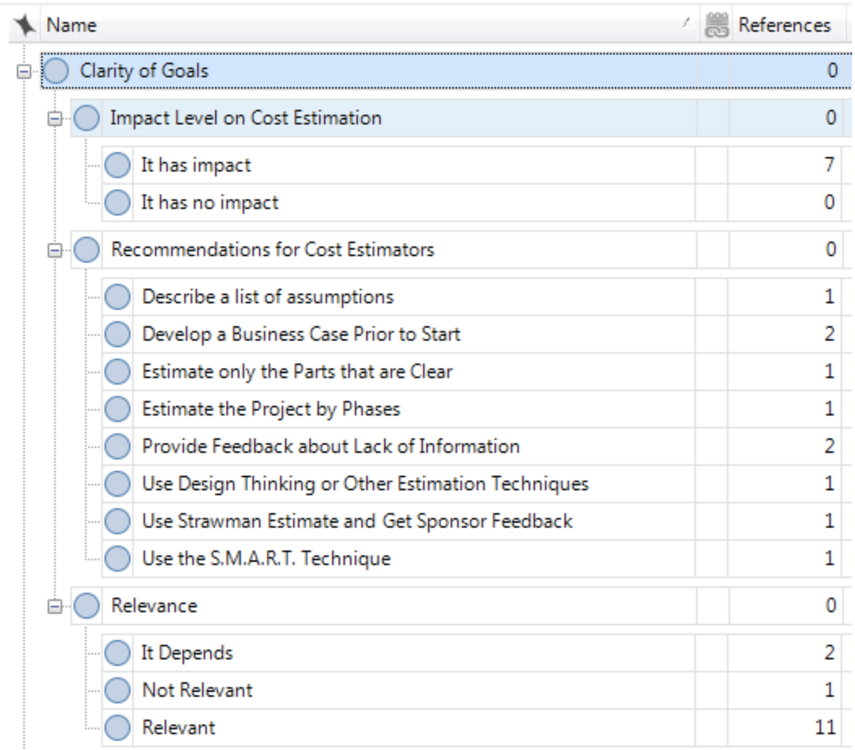
Another aspect to consider is the impact of a knowledgeable project team member leaving or being reassigned. Naturally, the complexity increases. Interviewee 6 considers that the organization should hire people with the proper experience and knowledge, well trained and ready to perform.

On the executive level, there is a responsibility to know whether the organization has the proper resources and to make the decision to move forward or not with a project. According to Interviewee 4, the sponsor has the responsibility to clarify what is the main driver of the project—scope, time, cost, or quality.

Another guideline is provided by Interviewee 7, who recommends that an inexperienced estimator should not be assigned to a complex project without some type of guidance. This strategy might be associated with the project management maturity level of the organization and the existence of systems or processes that ensure such an approach. This system should support the estimator and provide a recommendation to look for experts’ advice when the necessary knowledge is not present.

5.7.5. Clarity of Goals

The following analysis is represented by a tree node in Figure 5.8. It covers the aspects of relevance, impact on the cost-estimation process, and list of guidelines for cost estimators.



Name	References
Clarity of Goals	0
Impact Level on Cost Estimation	0
It has impact	7
It has no impact	0
Recommendations for Cost Estimators	0
Describe a list of assumptions	1
Develop a Business Case Prior to Start	2
Estimate only the Parts that are Clear	1
Estimate the Project by Phases	1
Provide Feedback about Lack of Information	2
Use Design Thinking or Other Estimation Techniques	1
Use Strawman Estimate and Get Sponsor Feedback	1
Use the S.M.A.R.T. Technique	1
Relevance	0
It Depends	2
Not Relevant	1
Relevant	11

Figure 5.8 – Tree node for the dimension Clarity of Goals

5.7.5.1. Relevance

As stated by Interviewee 1, "[Clarity of goals] is very important because you need to know how your project fits into the organization's strategic goals and objectives. If your project does not fit in, you should not be doing it". This statement points to the need that the project be aligned with the organization's strategy to assure no effort is invested in projects that will not contribute to the organization's overall goal.

According to Interviewee 3, "If you don't [know] what you're delivering inevitably you deal with that through major challenges during the execution or even at the point of launch", which emphasizes the importance of knowing what is being delivered to avoid creating major challenges during execution and launch.

Interviewee 6 also recommended using methodologies that allow better definition of project goals, without defining which ones to use. Further research might be recommended for that matter.

Interviewee 2 states that the relevance of clarity of goals depends on the definition of this dimension: "I need you to differentiate between goals and objectives. The reason is goals are high level. Objectives are generally low level. We don't ask project managers to define goals in a statement of work. We ask them to define objectives in a statement of work. And we expect the objectives to be tangible, and measurable, and verifiable. Goals, these are something that, in my mind, it's very high level". Following this logic, goals are high level and defined by top executives; for example, entering a new market. Objectives, on the other hand, are low level and stated in the statement of work by the project manager. Objectives could be defined by using the SMART (Specific, Measurable, Attainable, Realistic, and Time Bounded) approach. Even though the dimension was initially labelled "clarity of goals", calling it "clarity of goals and objectives" might provide a broader meaning.

Interviewee 10 shared the perception that clarity of goals and project description are very closely related. This is an interesting point, but the dimension project description is related to how clearly the project can be described, which involves not only goals and objectives but also the scope of the project, including details of what is going to be delivered (product, service, or result).

Interviewee 5 did not agree that this dimension was relevant and should be placed among the top ten most impactful dimensions. The interviewee's statement, "I'm sorry but I do not agree with the top ten. I believe that Political Influence, Stakeholder Interaction, [and] Cultural Resistance are much more impactful to the project", does not imply that clarity of goals is not important at all; rather it suggests that it should be given a lower level of importance.

The survey analysis using the Relative Importance Index placed the dimension clarity of goals in ninth place with RII = 0.737, putting this dimension in the top 10. The main argument for this placement is that a lack of clarity of goals or misalignment between the customer and the supplier creates additional complexity, considering that the project manager and team will not know what needs to be accomplished, which may cause restarts and reworks. Interviewees 1, 3, 4, 6, 7, 8, and 9 provided comments favourable to the relevance of clarity of goals, emphasizing that this dimension is necessary because the project manager needs to know how the project fits the organizational strategy. If it does not fit, it should not be done. It is suggested that a clear definition of these goals will increase the chances for project success.

5.7.5.2. Impact on the Cost-Estimation Process

Interviewee 1 shares that "If the project does not fit into the long-term strategy of the organization, its business case should not be approved because why are we going to invest resources into something that does not fit our own organization's goals and objectives?

Therefore, the cost estimate should not be done”. The statement is a direct recommendation to not approve a business case if the goals and strategy are not clear. The goals should be defined from the top of the organization reaching down to all levels.

The impact of not having clear goals is summarized by Interviewee 2: “If you don’t have the correct goals, then you don’t know what you’re doing”. One can also infer that a lack of clear goals will directly impact the planning and execution of a project since without knowing what has to be done, the final product, service, or result will probably be quite far from what the client requires.

Interviewee 3 points out that the impact is not limited to the initial launch of the project, but instead will cascade through the project’s duration, leaving cost estimators unsure what they are estimating for. If that happens, it will be quite difficult to put any ‘hard’ estimates on cost or time, and even define risky areas. Another impact is related to how well (or not) the project documentation will be developed.

As emphasized by Interviewee 4, “The estimate may be good, but you may be estimating the wrong things,” implying that it is possible to implement an effective cost estimation but still have an inefficient process if the estimation is for the wrong thing.

Interviewee 5 mentions, “If you don’t have clarity of goals you can do something wider to cover different targets. So it would cost much more”. This statement implies a direct impact on increasing the cost estimates since the estimator will end up needing to increase the scope of the project to be able to cover the unknowns. Similarly, Interviewee 7 presents a direct impact between lack of clarity and project documentation.

Finally, Interviewee 9 summarized by saying that if the project manager does not know how to define success (due to the lack of clarity of goals), then s/he will deliver average results, and average is close to failure.

Supported by 7 out of 10 interviewees (Interviewees 1, 2, 3, 4, 5, 7, and 9), clarity of goals should be considered as impactful to the cost-estimation process. Without clear goals, it is more difficult to understand the total scope of the project and produce an accurate cost estimate. No direct statements from the interviewees suggested otherwise.

5.7.5.3. Guidelines for Cost Estimators

Each interviewee provided recommendations for cost estimators when dealing with the need to have clear goals (or the lack of it). These recommendations are described in the following paragraphs and might be included as part of the proposed model.

Interviewee 8 recommends putting together a list of assumptions, recording the items being estimated and the ones that are not. Developing a business case prior to starting the project is recommended by Interviewees 1 and 5. According to Interviewee 1, many organizations decide to implement projects without a formally analysed and approved business case, but the most successful organizations are the ones that have defined a business case with proper cost estimates, have an executive board that reviews the business cases, and make decision on which cases should be part of the company's portfolio. Supporting this approach, Interviewee 5 suggested the development of even a small business case, allowing the asking of questions that could help clarify the project goals.

A statement by Interviewee 2—"Well, they're at the mercy of what they're given. If they don't feel that they have enough knowledge given to them, enough information to do the estimating properly, then they have to agree that they will only price out that portion of the project for which they have the information. They have to be willing to state 'I can't estimate this' —recommends estimating only the parts that are clear. Considering that the project manager is limited by what information he/she is given, there is a need to seek an agreement that the cost estimate is limited to the portion of the project that is known.

Interviewee 2 recommends estimating the project by phases. The use of progressive planning allows estimators to focus on determining detailed cost estimates for small portions of the project at a time. When one small portion or phase is completed, the estimator goes back and redefines the goals and budget for the next phase of the project.

Providing feedback about the lack of information is the advice of Interviewee 3. Similarly to the above, the estimators must be aware that a lack of information will impact the cost-estimation reliability and they should provide feedback about the areas that are imprecise. According to Interviewee 3, "This is advice to give advice". Supporting this recommendation, Interviewee 7 states that the estimator who understands that information is limited but proceeds to estimate the cost anyway will set up the project for failure. Then there is a need to go back to the stakeholders and ask for clear identification of the goals or any other missing information.

Interviewee 6's advice is to use Design Thinking or other estimation techniques. The recommendation is to wait, step back, and invest time in reviewing the goals and scope of the project.

Regarding techniques, Interviewee 4 recommends using the Straw Man estimate to get the sponsor's feedback. The Straw Man technique involves quickly putting together a first draft estimate with incomplete data in order to create a temporary cost estimate that should then be discussed with the sponsor. An important aspect of this technique is that it has to be done quickly without focusing on accuracy. According to the interviewee, "Slam it down, go and talk to the sponsor, and keep that communication channel open and clear".

Continuing the advice about techniques, Interviewee 4 proceeds to recommend the use of the SMART technique, a well-recognized technique used to describe objectives and requirements described in section 5.7.5.1. Should the definition of this dimension change to include clarity of objectives as well, the SMART technique should prove useful, keeping in mind that high-level goals will not necessarily use this technique for their definition. The recommendation is to start on a higher level and go down to the deliverable level. For the lower levels, this technique will allow a better cost estimate. On the other hand, it is crucial to understand the goals beforehand to avoid having a detailed and precise cost estimate of something that is not what the project is intended to be.

5.7.6. Organizational Capability

The following analysis is represented by a tree node in Figure 5.9. It covers the aspects of relevance, impact on the cost-estimation process, and list of guidelines for cost estimators.

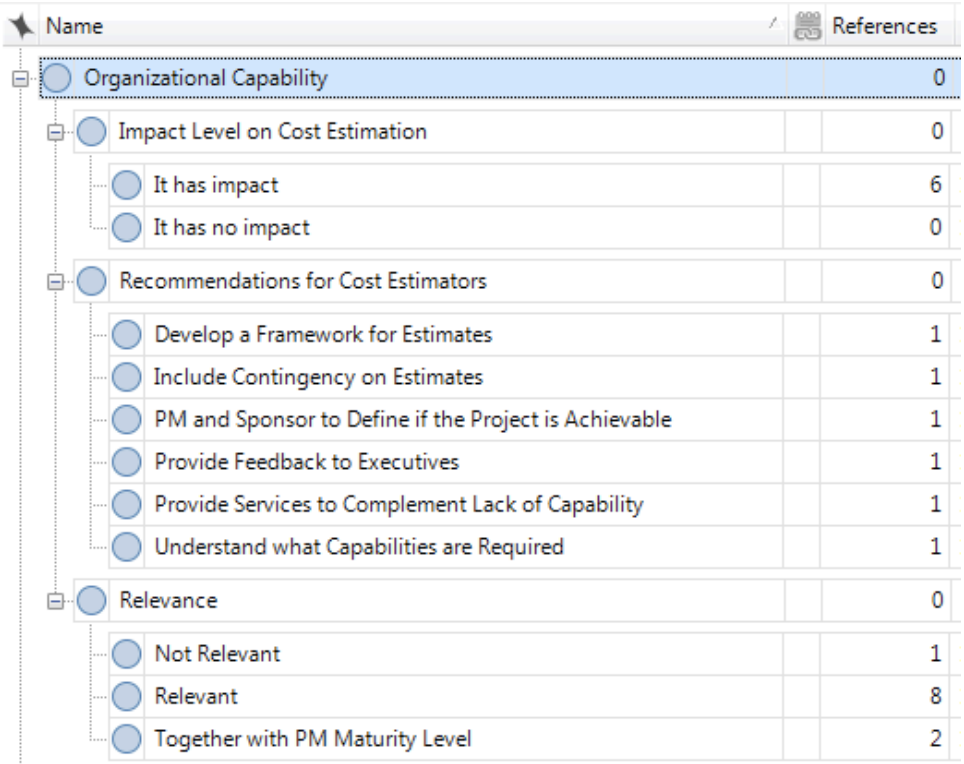


Figure 5.9 – Tree node for the dimension Organizational Capability

5.7.6.1. Relevance

Even though Interviewee 1 does not agree with the importance of project management maturity level, risks, nor product and project size, organizational capability is considered key for the performing organization to manage a complex project and should be ranked higher. Actually project management maturity level should be replaced by project management capability, or in other words the organizational capability to manage a project. Interviewee 8 also does not agree with the importance of this dimension, however all other eight interviewees do.

According to Interviewee 8, the organizational capability depends on what an organization does, which industry it is part of, and where it is located. Also brought into consideration is the number of complex projects the organization faces. As Interviewee 8 stated, “Maybe we don’t work on enough complex projects. For most projects you should know the intended outcome, maybe except for research projects like R&D projects where you don’t know what will happen. The most important is the Level of Information and the Time available to produce the estimate”. In summary, more importance should be given to how much information is available (and its accuracy) and the project’s time frame than to the capability of that organization.

According to Interviewees 4 and 7, organizational capability should be considered together with project management maturity level, as part of it or as one and the same. Interviewee 7 states, “I would have linked that with the Project Management Maturity Level. And the reason why I would have done that is because I think the two are connected. One of the reasons why I have Organizational Capability higher up is because it would have considered the issue of systems, the issue of intelligence, and Organizational Capability would also have addressed Knowledge and Experience”. This approach includes a link to the knowledge and experience dimension. It seems that these three dimensions are connected somehow and this view should be considered when developing the model.

Supporting the importance of the organizational capability, Interviewee 5 considers paramount a well-prepared organization with skilled people and proper resources not only to manage the project but also to control changes. Interviewee 9 emphasizes that many organizations focus on improving their project-management capabilities without investing in educating and preparing their leadership.

Considering that the Relative Importance Index placed organizational capability as the fourth most relevant dimension with an RII = 0.763, and that professionals agree that a more capable organization would better manage its projects, the evidence supports that this complexity dimension is impactful to a project and, therefore, the lack of it would make the project more complex.

5.7.6.2. Impact on the Cost-Estimation Process

Organizational capability seems to be associated with how mature an organization is in managing its projects, as proposed by Interviewee 1. One approach that could better support cost estimates would be the use of business cases and the availability of capable resources, the absence thereof causing significant impact on the accuracy of estimates.

The number of unknowns is directly associated with how capable of discovering requirements the organization and performing team are. More unknowns represent higher risks and also indicate an organizational capability that’s below the needs of the project. Interviewee 3 suggests that it all starts with clarity of goals—if the goals and objectives of the project are unclear, the requirements will be incorrect. When a project moves forward despite these limitations, the results are normally poor. A statement by Interviewee 7 supports this perception: “[Organizational capability] really is going to be allied to Risk and Knowledge and Experience. And the reason why I’m saying that is if I broke it down into inadequate systems, the poor intelligence, and inexperience or lack of qualified, competent people, it means that the basis for identifying the inputs to cost would be affected. And if the organization does not have a capability to properly identify all inputs, then it will in fact compromise its estimating process. And that is why I think it would impact cost".

The project team lacking the necessary skills is more probable as indicated by Interviewees 4 and 5, which is why looking for external help is recommended. If you don't, how would it be possible to rely on the cost estimates? Without an organization that is capable of providing proper estimates, the greater the chances of using large amounts of contingencies that can negatively impact project performance and of creating the need for rework. More rework, more costs.

A consensus of respondents indicated the impact of organizational capability on the cost-estimation process, but also affirmed the interaction between this dimension and others such as knowledge and experience, project management maturity level, and risks. For these reasons, it should be included in the final list of complexity dimensions.

5.7.6.3. Guidelines for Cost Estimators

Each interviewee provided recommendations for cost estimators when dealing with a limited organizational capability to deliver the project. These recommendations are described in the following paragraphs and might be included as part of the proposed model.

Executives have to provide proper organizational structure and resources to support the project management and team as recommended by Interviewees 1 and 9. Even with their busy schedule this is a crucial success factor and directly impacts the cost-estimation process. This is a necessary discussion. If this aspect is ignored, executives might put the organization at risk and fail to achieve their strategic goals.

Interviewee 3 shares a different perspective, that the organizational capability is somehow removed from the project itself. First there is a need to understand what it is being asked before determining whether the organization is capable or not. Also, Interviewee 4 considers it the sponsor and project manager's responsibility to define whether the project is achievable, so it is not about the estimation process but foremost a capability question. If the conclusion is that the organization cannot deliver, this capability has to be acquired somehow (internally or externally). Should no option be found, the recommendation is to not proceed with the project.

Interviewee 7 recommends the development of a system to help capture the relevant information for a proper cost estimate. Create a framework with templates and a process to support cost estimators.

Once the project team gathers the requirements, the customer should be able to validate them. If the customer cannot do that, there is a significant risk of poor cost estimation and the project manager should share this information with the customer as suggested by Interviewee 5.

Interviewee 8 emphasizes the importance of providing the most accurate estimates possible because, even though an estimate is not a commitment per se, the customer considers it to be. The interviewee stated, "Clients remember estimates. The first estimate that you give has to allow for all the problems that can come up, it has to be within a certain tolerance. It's all relative when it comes to these numbers. You need enough confidence in it; it has to be delivered because the client will remember it".

5.7.7. Political Influence (Politics)

The following analysis is represented by a tree node in Figure 5.10. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

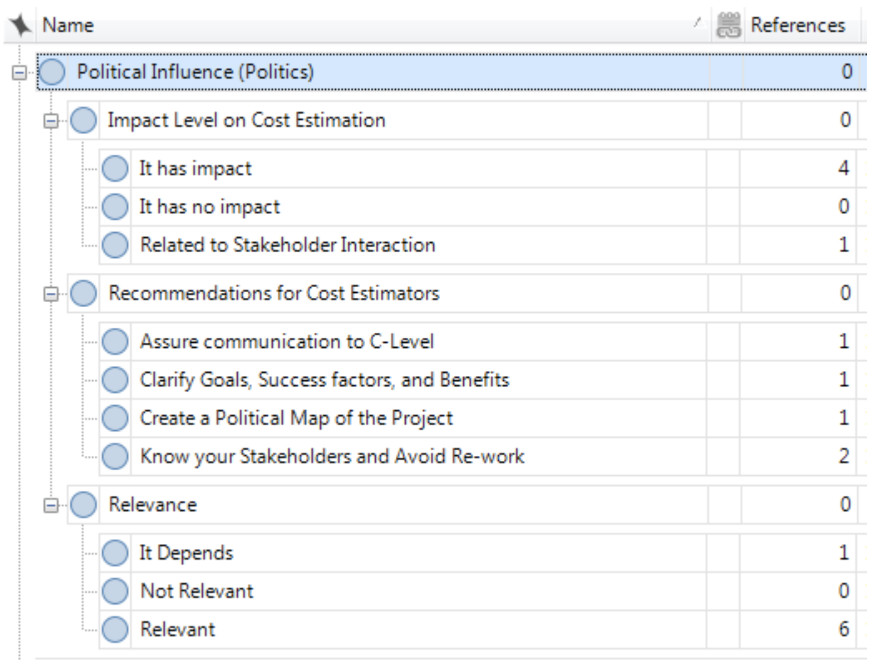


Figure 5.10 – Tree node for the dimension Politics

5.7.7.1. Relevance

Overall, Interviewees 1, 4, 5, 6, and 7 emphasized the importance of politics in projects to a greater or lesser degree depending on the project itself and culture.

Politics often has a negative connotation and for that matter impacts a project. Interviewee 1 supports the view that project managers should view politics in a positive way and understand how key stakeholders can impact their project. The recommendation is to identify the powerful stakeholders who are supporters and want the project to succeed, and maximize their political influence.

Interviewees 5, 6, and 7 see political influence as a relevant complexity factor and emphasize that the project manager should not underestimate how people's interactions, especially powerful stakeholders, can impact the project outcome. It should be noted that the dimension stakeholder interaction is closely related to political influence. Interviewee 7 worked for state-run organizations and also as a contractor for those same state-run organizations, which provides a good perspective on how political influence can dictate the development and implementation of projects.

Political influence can be both internal and external. Interviewee 4 states that organizations with strong silos will face stronger political influence due to functional departments fights, which by result increases complexity and impacts cost estimation. Considering external influences (i.e., government and regulatory organizations), there's a great deal of uncertainty due to a lack of control of these players.

The survey analysis using the Relative Importance Index placed political influence as 16th with an RII = 0.696, which is quite a low ranking. This result is interesting considering that interviewees indicated that this dimension was far more relevant than depicted in the survey. Supporting the relevance of political influence is the fact that five interviewees placed this dimension as part of their top five. For that reason, it should be considered in the final list of complexity dimensions.

5.7.7.2. Impact on the Cost-Estimation Process

Political influence might impact the cost-estimation process as per Interviewees 1, 4, 5, and 6. Viewpoints also differed according to whether the influence is internal or external to the organization.

Interviewee 4 focuses on large organizations, where there might be a greater chance of internal political 'fights' and the project manager might end up with an underperforming resource. This situation would impact an estimate directly. Besides that, Interviewees 5 and 6 propose that sometimes the project manager does not have any power to deal with political influences, has to escalate the issue, and sometimes even has to stop the project while waiting for a resolution.

Even though political influence normally increases costs, Interviewee 5 shares that it might have a positive impact if it forces the team to put more effort into the cost-estimation process.

Finally, Interviewee 7 proposes that political influence should not be taken into consideration. This interesting proposition is based on the assumption that "Most of the time the political influence is not a tangible, …. so it actually comes more as an influence rather than a requirement". The focus is more on the feasibility of the product to be delivered than politics. On the other hand, politics might be able to influence the definition of the project goals and consequently its objectives.

Evidence of the impact of political influence (politics) was provided by most interviewees and contested by only one interviewee. The available arguments provided by interviewees lead to the conclusion that this dimension should be considered relevant. It can be argued that in some cases politics would actually play an important role in how costs are estimated, as it may drive costs higher or lower.

5.7.7.2. Guidelines for Cost Estimators

What would you suggest the cost estimators do when dealing with a project where there is political influence? The guidelines listed below are based on responses provided by interviewees and might be included as part of the proposed model in Chapter 6.

One recommendation from Interviewees 1 and 4 is to create a good relationship with the key stakeholders, improve project-management networking skills, and keep communication active; include the project team and possible third parties; and count on executives to help with external political influence. Interviewee 6 extends this approach by suggesting the creation of a political map and associating it with the project risk plan. Contingencies might be added based on how great the risk is due to politics.

On the other hand, Interviewees 5 and 7 do not recommend that cost estimators deal with the impact of politics. What could be done instead is to have well-described goals, benefits, and success factors that support the success of the project, leaving political influence to be addressed as part of stakeholder management.

5.7.8. Communication Quality

The following analysis is represented by a tree node in Figure 5.11. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

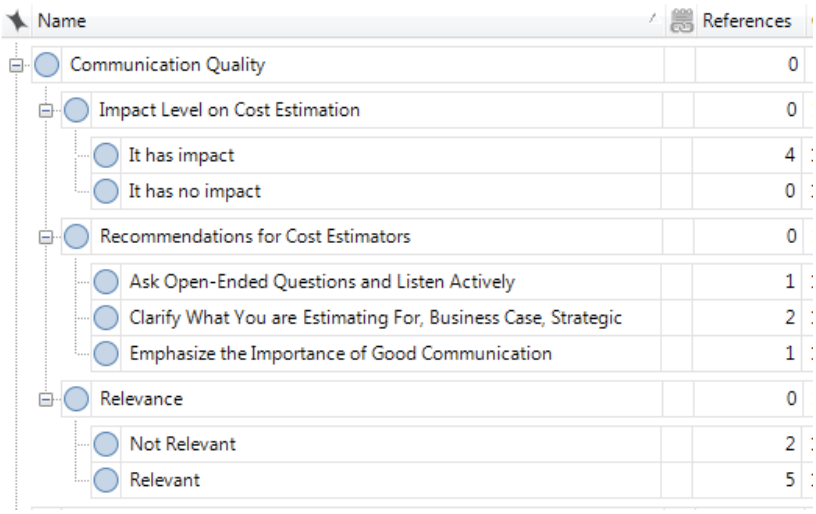


Figure 5.11 – Tree node for the dimension Communication Quality

5.7.8.1. Relevance

Interviewees 1, 5, and 9 provided detailed responses supporting the importance of communication quality. The ability to communicate with project stakeholders, recognizing their different information needs, frequency requirements, preferred delivery media, and level of importance is vital to the proper and accurate transfer of information. A lack of information results in unclear requirements which increase the complexity level of the project and by consequence the cost estimation. Interviewee 1 supports the need to not only listen to the stakeholders but also to understand their expectations.

According to Interviewee 5, communication quality "…is very impacting because due to communication problems, we don't get things done, we don't get the approvals, we create rework, we create resistance, we create extra work". On the same note, Interviewee 9 considers that the most important communication channel exists between the project owner and the supply organization, since there is a need to clearly understand what is expected and what the final project should be.

Even though communication quality did not rank within the top 10 complexity dimensions when using the Relative Importance Index (12^{th} place with RII = 0.719), the interviewees provided practical evidence of the relevance of this dimension. Supporting this position is the statement from the Project Management Institute that 90% of the project manager's work is directly or indirectly related to communication (PMI, 2012). For these reasons, communication quality will be placed among the complexity dimensions in the proposed model.

5.7.8.2. Impact on the Cost-Estimation Process

Interviewees 1, 5, 8, and 9 shared that communication quality has significant impact on the cost-estimation process as described in the following paragraphs.

One of the key communication channels is with the subject matter experts since they are the ones who will provide the estimates, according to Interviewees 1 and 9. The project manager and team might have a clear understanding of the product to be delivered and how the project will be performed, but if the experts do not accurately understand, the estimate will be faulty.

Not only is the information itself important, but also the way it's communicated. The communication preference should be defined by each stakeholder, which will improve results. According to Interviewee 8, communication is a two-way process, and the project manager should be cognizant of the possible barriers. Not only does the person communicating have to prepare a clear message, but the receiver has to understand it.

Interviewee 5 shares that external environmental constraints and cultural differences and resistance influence communication quality, so the project manager should consider these factors as well.

The practitioners interviewed did not provide an argument contrary to the possible impact of communication quality on the cost-estimation process. If the information necessary for estimates is not provided, it can be argued that estimators will not have what is needed to accurately estimate the costs.

5.7.8.3. Guidelines for Cost Estimators

Each interviewee provided recommendations for cost estimators when dealing with the impact of bad communication on a project. These recommendations are described in the following paragraphs and might be included as part of the proposed model.

"Talk to people, ask open-ended questions, actively listen, make sure you're reaching out to the right people as you develop your cost estimate, get people involved who are then later on going to help you support it". This recommendation by Interviewee 1 is comprehensive and focused on maintaining or improving communication quality. Interviewee 8 concurs, recommending talking to the customer about what you are estimating for, discussing any aspects that need more clarity so there is liability/commitment involved.

Communicating when, how, why, where, and so on is not the only aspect of a communication plan according to Interviewee 5. It is also about sharing the negative impacts of bad communication.

Align the value proposition clearly and develop a business case that supports the project feasibility. The project should be aligned with the organization's strategic objectives and expectations should be clarified. Once this is done, the remaining communication should be better and the estimates more precise, as shared by Interviewee 9.

5.7.9. Time Frame

The following analysis is represented by a tree node in Figure 5.12. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

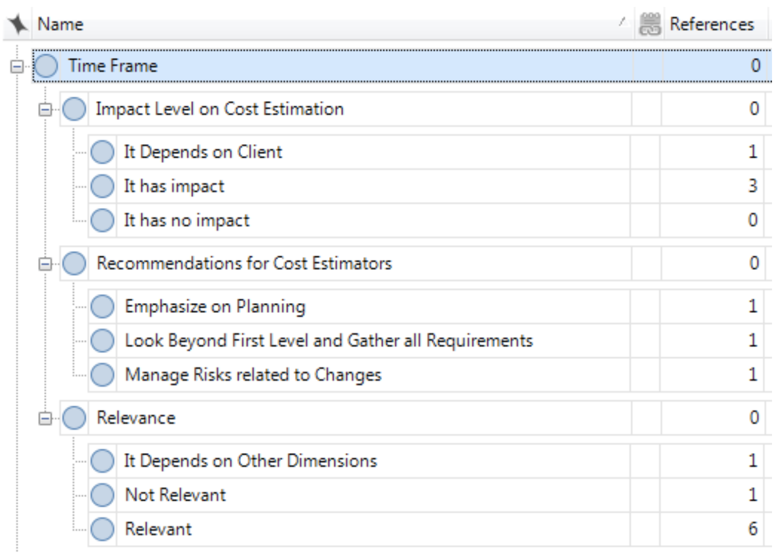


Figure 5.12 – Tree node for the dimension Time Frame

5.7.9.1. Relevance

Interviewee 3 proposes that a faster than necessary delivery would result in incomplete or missing information, which by result increases complexity. With this scenario there's a need for more organizational experience to deliver the project according to specifications. In other words time pressure increases risk which increases complexity. Interviewee 6 also supports this position.

A different view is provided by Interviewee 7, who poses the question whether the time frame should be considered an outcome of a lack of risk management, or if time frame prolongation is a result of a lack of knowledge and experience or understanding of the product and project size. These questions suggest that time frame is linked to the dimensions risk, knowledge and experience, and product and project size. For that matter, should this research consider time frame a by-product of other dimensions, or should it be considered a stand-alone dimension?

Interviewee 8 points out the difference between project time frame and estimate time frame. The dimension as presented in this research does not consider the time frame for the estimation process, but rather the time frame for the entire project. Estimates should certainly be revised during each project phase to make sure that new information or changing requests are considered.

When analysing the Relative Importance Index rank, it shows that time frame was placed as the third most relevant complexity dimension with an RII = 0.770. Interviewees 3, 6, 7, and 8 supported the relevance as well. Considering that time frame is related to how much time the project manager has available to deliver the project, a challenge appears when the project has to be delivered in less time than needed. The challenge in question provides the complexity factor that supports the decision to keep this dimension as relevant.

5.7.9.2. Impact on the Cost-Estimation Process

According to Interviewee 3, time frame becomes an issue when there are elements that should be delivered in less time than usual (e.g., one has to deliver something in three weeks that normally takes five). How does the project manager address such a constraint, and how does this impact the cost estimation? The moment one has to use schedule compression techniques like crashing or fast tracking (PMI, 2012), there is an immediate extra cost associated. Other questions are related to how skilled the resources are, do they have proper knowledge, and so on.

As mentioned previously, Interviewee 6 also considers time frame a constraint of the project. It can be related to a simple task, a group of deliverables, or the entire project. Another aspect that impacts the cost-estimation process is the unavoidable occurrence of changes. Since there will be changes to any project (long- or short-term), it is natural to assume that projects with a longer time frame will have more chances for changes. Additionally, Interviewee 8 considers that the client normally sets the time frame so the project manager and team have little to no control over it. This creates an additional level of complexity that could directly impact the cost estimates.

Interviewee 7 shares a perspective that underestimating the time frame might cause direct impact on costs. Considering that the only constant would be materials, all other resources (people, use of equipment, installations, etc.) might cost more if the time frame is extended, which could even make a project unfeasible.

As supported by three of the interviewees, the time frame impacts the cost-estimation process. Another interviewee considers something determined by the client that is still impactful to the cost estimate. That is, if the available time frame is not long enough to do proper planning, including estimating, the results of the planning process will be negatively impacted and the project results less accurate.

5.7.9.3. Guidelines for Cost Estimators

Interviewees 3, 6, and 8 provided the following guidelines based on their experience. These recommendations are for cost estimators when considering the impact that the project time frame has on the estimation process.

Do not underestimate the fact that the project will have changes and possibly new requirements. Interviewee 3 recommends looking beyond the first level of the work breakdown structure and that project managers should consider the risks due to changes.

Focus on planning and include the time frame in all project documents. Interviewee 6 suggests updating the planning documents with a constant analysis of the impacts on the time frame, which is the basis of the Rolling Wave Planning approach (PMI, 2012).

Interviewee 8 proposes that no recommendations can be provided to cost estimators since the time frame is defined by the client with no control on the part of the performing team. This view can be argued since the point is not to avoid an 'arbitrary' definition of the time frame by the client or another stakeholder, but rather how the cost estimator should deal with such a situation when it occurs.

5.7.10. Stakeholder Interaction

The following analysis is represented a by tree node in Figure 5.13. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

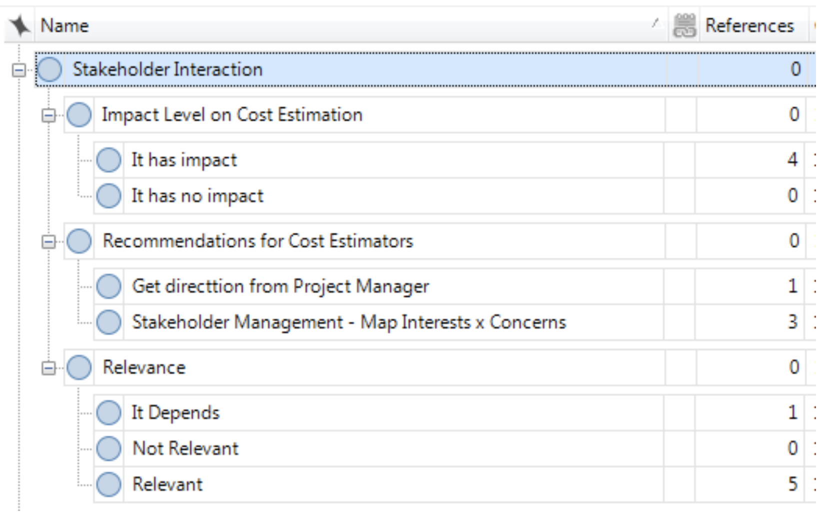


Figure 5.13 – Tree node for the dimension Stakeholder Interaction

5.7.10.1. Relevance

Interviewees 1, 4, 5, and 6 selected this dimension as one of the top 10 dimensions, and no interviewee was directly against its importance. Interviewee 4 suggests that the larger the project, the more important stakeholder management is. Additionally, Interviewee 5 points out a correlation between stakeholder interaction and political influence, especially when there are conflicts and different interests. All these interviewees emphasized how important the stakeholders' interactions are for project success, and how a lack of understanding could lead to increased complexity and failure.

Considering that four interviewees agreed with the relevance of stakeholder interaction with no conflicting argument from the other interviewees, the 13th place that this dimension achieved when using the Relative Importance Index (RII = 0.704) seems contradictory. Due to the importance of having direct feedback based on practical experience managing complex projects and estimating costs in such environments, this dimension shall remain part of the model.

5.7.10.2. Impact on the Cost-Estimation Process

Interviewees 1 and 5 support this view and point out that key stakeholders might bring their own interests and insights to the project, which could increase costs significantly if they are not understood until the end of the project.

Interviewee 4 emphasizes that it is all about how certain one is of what has to be done. A well-managed stakeholder interaction and open communication to understand stakeholder needs and expectations will create a more accurate cost estimate, making the final result less costly.

Why would underestimating the power of stakeholders be a concern? According to Interviewee 6, “Some people could be defensive, some people could just not understand why it’s being done, why he’s being moved, why the system will be changed, why the process will be different. So, when you ignore these stakeholders …, or their political influence, you do tend to have a problem... somehow in your project”.

Similarly to the relevance, Interviewees 1, 4, 5, and 6 believe that stakeholder interaction would impact the cost-estimation process. It can be argued that the cost-estimation process is based on estimating each deliverable, element, and activities needed for a project, so if the project manager does not consider a critical stakeholder and how that person can impact the project outcome, the cost estimates might be inaccurate.

5.7.10.3. Guidelines for Cost Estimators

Interviewees 1, 4, 5, and 6 shared their recommendations for cost estimators when facing a project environment where there are issues with stakeholders’ interactions. It remains to be determined whether this dimension should be included in the model to be proposed in Chapter 6.

A discovery effort is recommended by Interviewee 1 with a focus on understanding what interests and concerns the stakeholders have. During the project lifecycle it is expected that stakeholders would have different interests and new stakeholders might emerge, so the project manager should assure proper communication with them.

To support this approach, Interviewees 5 and 6 recommend implementing a stakeholder management process. According to Interviewee 5, it that can be broken down as follows: “The guideline would provide a way to identify the stakeholders, identify their interests, identify their motivations in order to provide them with the proper communications, evaluate their influence…. So we have techniques that we could apply and we should just put as a guideline to the cost estimator ‘Do this, do that.’ And, of course, you would cost more”. The process also comprises mapping all the stakeholders so to better understand them, maximize the positive ones (favourable to the project), influence the neutral ones to become positive, and neutralize the negative ones.

According to Interviewee 4, the project manager should be responsible for managing the interactions between stakeholders. The cost estimator should base the estimates on the information available, so it is recommend that close contact with the project manager be assured to incorporate any necessary input.

5.7.11. Pace or Speed to Market

The following analysis is represented by a tree node in Figure 5.14. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

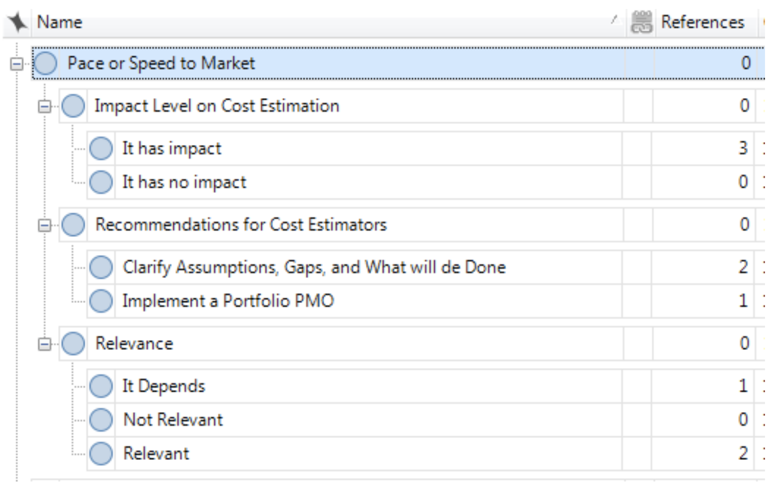


Figure 5.14 – Tree node for the dimension Pace or Speed to Market

5.7.11.1. Relevance

Interviewee 2 points out that a product new to the market or a time-sensitive research and development project would have a higher complexity level than another type of project. The main reason is the need to launch the product by a specific date to gain competitive advantage.

Additionally, Interviewee 4 suggests that the faster the project has to be delivered, the more resources will be needed. This is not necessarily the case since speed can be obtained by adding resources that are more skilled rather than just increasing quantity. A direct correlation between this dimension and complexity is provided by Interviewee 10 in the statement, “Speed to market is also important. If the speed to market is slower, than it’s not complexity. Only if it’s high-paced”.

There was a significant discrepancy between pace or speed to market’s low RII rank (19^{th} place with RII = 0.648) and the interviewees’ input. According to three practitioners, this dimension was part of their top 10 and should be considered relevant. Once again, practitioners’ examples based on real-life projects points to including this dimension as part of the potentially relevant complexity dimensions to be part of the model.

5.7.11.2. Impact on the Cost-Estimation Process

When the time to market is forced by top executives, without knowing its feasibility, the situation is difficult if not impossible, according to Interviewee 2. This can turn an easy project into a complex one. Interviewee 8 proposes that a tighter than normal pace might limit the level of information available for a proper estimate. This also impacts the quality of the solution design, which increases risks and, consequently, costs.

Interviewee 4 shares another impact on faster pace or speed to market—it does not allow the cost estimator enough time to do a detailed estimate, causing bigger assumptions and greater risks, which also mean larger contingencies.

According to three interviewees, the pace or speed to market has an impact on the estimation process for costs. This position is mostly due to an internal or external request that the project be delivered in a short period of time to increase competitive advantage.

One important note is that time frame should not be confused with pace or speed to market. As previously explained, the time frame is related to the time required to manage the project and deliver its results, and in most cases is based on the nature of the project. On the other hand, pace or speed to market is an external pressure to deliver the project to attend a specific market need. Both complexity dimensions impact the cost-estimation process.

5.7.11.3. Guidelines for Cost Estimators

Three interviewees provided recommendations for cost estimators when dealing with a high pace or faster speed to market projects. These recommendations are described in the following paragraphs and might be included as part of the proposed model.

According to Interviewee 2, there is no guideline for senior management on dealing with the impact of faster pace or speed to market. These are the people who normally bear most of the responsibility for issues related to this dimension. On the other hand, there is a technique developed for Project Management Offices (PMO) called Portfolio PMO. The role of the Portfolio PMO is to provide executives with feedback as to whether or not the speed to market is correct, allowing the organization to validate whether it can deliver the project at this time, in the future, or not at all. The cost estimator should receive the same input to support the estimation process.

Being clear of what assumptions are being made and which gaps of information exist allows the performing team and the cost estimator to better do their job. Interviewee 4 proposes that if there are a lot of assumptions due to a lack of information, the negotiation process to request more feasible delivery dates is compromised and the cost estimates will end up higher. The project manager and cost estimator should make the decision-maker (especially one with financial power) aware of the situation. Interviewee 8 recommends simply telling the client what you are delivering in order to open discussion on this topic.

5.7.12. Degree of Trust

The following analysis is represented by a tree node in Figure 5.15. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

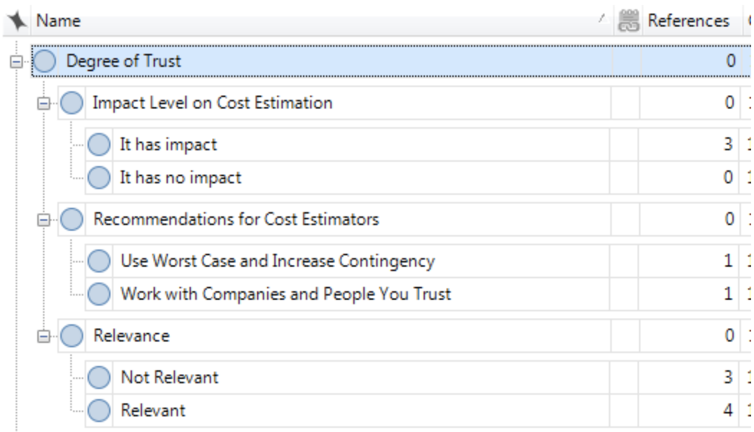


Figure 5.15 – Tree node for the dimension Degree of Trust

5.7.12.1. Relevance

Interviewees 1, 4, and 6 believed that degree of trust should be among the top 10 dimensions. According to Interviewee 4, the moment that we lose trust, the work to be done and the decision-making process consumes more time, increasing costs. When there is no trust, relationships and communications are less reliable, which leads to more complexity.

Degree of trust placed 11th in the survey with RII = 0.726, which was supported by three interviewees and considered relevant. The arguments supporting this assertion are based on the premise that if trust is lost, there is a breakdown of stakeholder relationships and communication. This possibility makes this dimension relevant; therefore, it should be included in the model.

5.7.12.2. Impact on the Cost-Estimation Process

According to Interviewee 1, it is especially important that the project manager trusts the client and vice versa. Interviewee 4 suggests that communications challenges and interdependencies between project elements already contribute to project complexity, but if there were a lack of trust, the entire project would be at risk from the top of the organization to the operational level.

A stronger opinion is shared by Interviewee 6, who states that trust is crucial for the project environment, which directly affects the cost-estimation process. In the interviewee's own words, "The degree of trust is, for me, the basis of everything: respect and everything else that we are supposed to have when working within a team, a group, a team of people that have a common objective to achieve. So if you do not have trust, you do not have anything".

As mentioned previously, Interviewees 1, 4, and 6 shared that the degree of trust impacts the cost-estimation process. If there is no trust between the performing team and stakeholders involved, the chances for project failure are greater. This failure is also associated with how the estimates are done. Since estimates depend on information provided by others, open communications is needed at all levels.

5.7.12.3. Guidelines for Cost Estimators

How should the cost estimator do his or her job when there is a lack of trust in the project environment? How can reliable estimates be created? The interviewees provided recommendations to deal with this situation.

Work with a best- and worst-case scenario in order to compensate for a lack of trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies and, depending on how bad the situation is, the complexity and risk would increase. Interviewee 4 recommends escalating when large contingencies are needed.

According to Interviewees 1 and 6, there is a need to assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted and the cost estimate would be based on it. On the other hand, if trust is broken, it is very hard to recover. There are ways to develop trust or improve bad situations; however, it cannot be ignored.

5.7.13. Budgetary Constraints

The following analysis is represented by a tree node in Figure 5.16. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

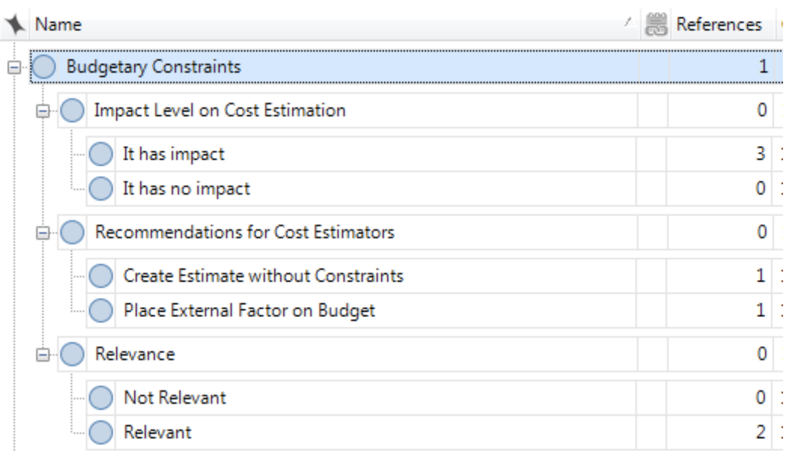


Figure 5.16 – Tree node for the dimension Budgetary Constraints

5.7.13.1. Relevance

According to Interviewee 10, the dimension related to budgetary constraints limits the amount of resources available for the project, which directly impacts the capability to deliver the project as requested. This constraint can be imposed by internal or external factors. Similarly, Interviewee 3 cautions that imposing budgetary constraints introduces challenges that might be hard to overcome.

There is direct support to the proposal that any budgetary constraints imposed on a project would be relevant and increase complexity. The survey analysis placed this dimension as 7th

when using the Relative Importance Index (RII = 0.741), and three practitioners recommended keeping budgetary constraints among the top 10 dimensions.

5.7.13.2. Impact on the Cost-Estimation Process

Only Interviewees 3 and 8 shared views on how budgetary constraints might impact the cost-estimation process. One question is whether budgetary constraint is a dimension by itself or should be considered a contributing element of the external organizational constraints. Interviewee 3 shares that placing an external factor on the budget is a normal cost management technique but can increase costs. Furthermore, Interviewee 8 believes that budget limitations might stop a project.

Cost estimation must take into account a limited budget to perform all necessary tasks and deliver the project, and some items might be underestimated to 'fit' within the constrained budget. This makes this dimension directly impactful to the process of estimating costs.

5.7.13.3. Guidelines for Cost Estimators

Similar to the impact analysis, not a lot is recommended for cost estimators when dealing with constraints related to budget. One recommendation is to estimate the costs without any constraints and review the impact that the constraint will cause once you apply it. This approach is based on Eli Goldratt's work on Critical Chain applied to project management (Goldratt, 2002). Interviewee 8 simply recommends the estimator document all information that is relayed to the client and performing team.

5.7.14. Dependency and Interdependency

The following analysis is represented by a tree node in Figure 5.17. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

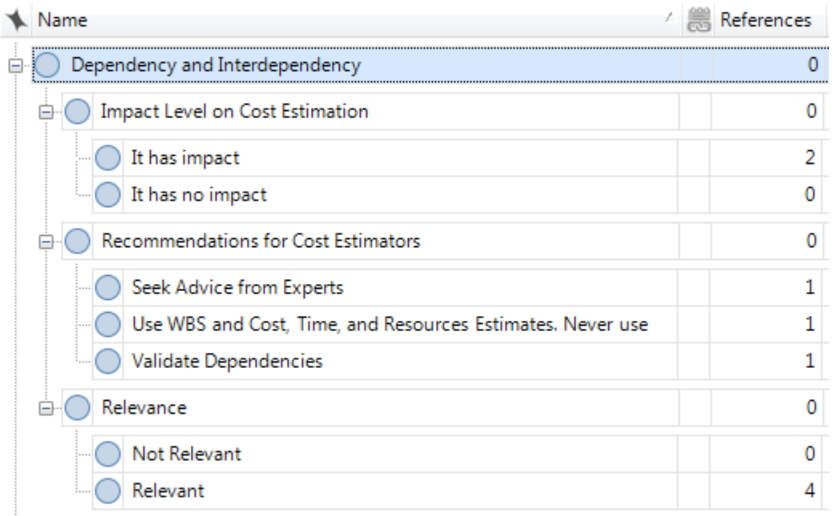


Figure 5.17 – Tree node for the dimension Dependency and Interdependency

5.7.14.1. Relevance

Interviewees 2, 3, and 9 considered the dependency and interdependency of the project elements as a relevant and impactful dimension. Since this dimension was not highly ranked in the survey analysis, Interviewee 2 proposes that most people answering the survey have never managed large or complex projects that had a great number of dependencies, stating, "When you have a great deal of dependencies, and a dependency on the front end of a project changes, it could have a real serious impact, financial impact, on all the dependencies downstream".

Supporting this view, Interviewee 3 mentions that the number of interactions between different elements of the project is an important factor in increasing complexity. It may impact schedule, risks, use of resources, and responsibility assignments that will influence the project assumptions. This entire combination results in a more complex environment. Adding to that, Interviewee 9 also points to the direct impact on the planning process.

Even though this dimension has been used as part of the definition of a complex project (refer to section 2.3 of this document), it was not selected as part of the top 10 complexity dimensions during the survey or by most interviewees. The survey analysis using the Relative Importance Index placed the dependency and interdependency dimension in 13th place with RII = 0.704, together with stakeholder interaction and economic uncertainty. It is not clear if this is due to a lack of understanding of the term by the survey participants and interviewees, to unclear definition of the term by the researcher, or to an unassertive conclusion from the literature review. Supported by many references (refer to section 2.5.1), the dependency and interdependency of the elements of the project will be considered as part of the list of relevant complexity dimensions.

5.7.14.2. Impact on the Cost-Estimation Process

Interviewees 2 and 3 provided input that dependency and interdependency of the project elements impacts the cost-estimation process. Dependency and interdependency might be considered a high-scoring complexity dimension by the survey and interviewees, but there are arguments supporting its impact on the cost-estimation process.

When the dependency or interdependency of the project parts is not known, a complete re-estimation of the project might be required once the missing information is provided. As affirmed by both interviewees, once the dependencies are understood, the estimates would be more accurate. Underestimating how one element can interact with other parts of the project is a mistake that should be avoided.

5.7.14.3. Guidelines for Cost Estimators

For guidelines to cost estimators when dependencies and interdependencies are not completely known, the interviewees shared recommendations as detailed below.

Interviewee 2 recommends going back and reviewing the dependencies to determine whether they impact other parts of the project, whether they are still valid, and whether changes were implemented. The reason is that estimators do their job based on available information. Once the information is known, there is a chance to re-assess the existing estimates and adjust if needed.

According to Interviewee 3, the focus should be understanding the dependencies and interdependencies. To do that, the estimator needs to consult the project manager and experts. There is a need to understand the schedule, the methodology used, and other plans. Furthermore, the estimator needs to make sure the organization understand that estimates will be as reliable as the information available.

Another recommendation is provided by Interviewee 9 who suggests not using “Lean” or “Agile” approaches in complex projects. Instead, focus on the work breakdown structure and other traditional planning approaches.

5.7.15. Cultural Resistance and Differences

The following analysis is represented by a tree node in Figure 5.18. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

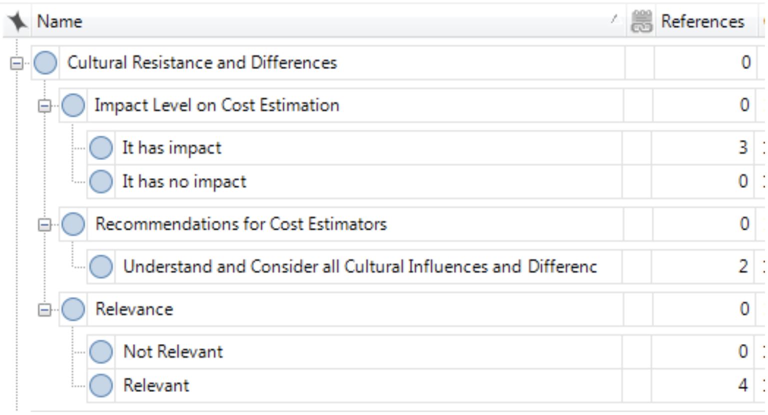


Figure 5.18 – Tree node for the dimension Cultural Resistance and Differences

5.7.15.1. Relevance

Interviewees 5, 6, and 7 selected cultural resistance and differences as part of their top 10. During the interviews, most interviewees supported somehow that projects become more complex when there are cultural differences and limited understanding of each group's cultural background. This might be especially true for projects involving different countries, cultures, belief systems, and work ethics. Interviewee 10 states that one cannot control cultural differences but can work on reducing resistance.

The fact that the survey analysis using the Relative Importance Index placed cultural resistance and difference at a low 21st place (RII = 0.630) creates a contradiction with the feedback from interviewed practitioners. Actually, three interviewees selected this dimension as relevant with respect to the level of impact it brings to projects. For that reason, a further analysis of the results should be performed in the upcoming section 5.8.

5.7.15.2. Impact on the Cost-Estimation Process

Is there impact on the cost-estimation process when the project is influenced by cultural differences? Interviewee 5 proposes that if the project manager wants to reduce cultural resistances, there might be a need for people to work in the same physical environment instead of virtually, which increases travel costs.

Cultural differences together with the development of projects in different countries can potentially increase complexity and risks. According to Interviewee 6, more than time zones or language barriers, cultural differences and resistance have a great impact.

From a pricing perspective, Interviewee 7 shares that when contractors have to compete for business with foreign companies that use low-cost resources or practices, the bidding process and estimates have to be on the lower end to ensure they have a chance to win the bid.

All the arguments point to considering this dimension as impactful for the cost-estimation process, but, as discussed with the relevance, a further analysis might be needed to confirm its consideration for the model.

5.7.15.3. Guidelines for Cost Estimators

Two interviewees provided objective recommendations for cost estimators when dealing with cultural resistance and differences in the project environment. These recommendations are described in the following paragraphs and might be included as part of the proposed model.

Interviewee 5 suggests bringing all the differences to an open discussion with the project stakeholders. Once the differences or reasons for resistance are understood, envision a plan to address them and incorporate this plan into a change-management process.

The world is becoming smaller and smaller due to technology, the Internet, and faster commutes. In line with this reality, Interviewee 6 recommends that the project manager learn more about the different cultures involved in the project, sharing any concerns with the cost estimators.

5.7.16. External Environmental Constraints

The following analysis is represented by a tree node in Figure 5.19. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

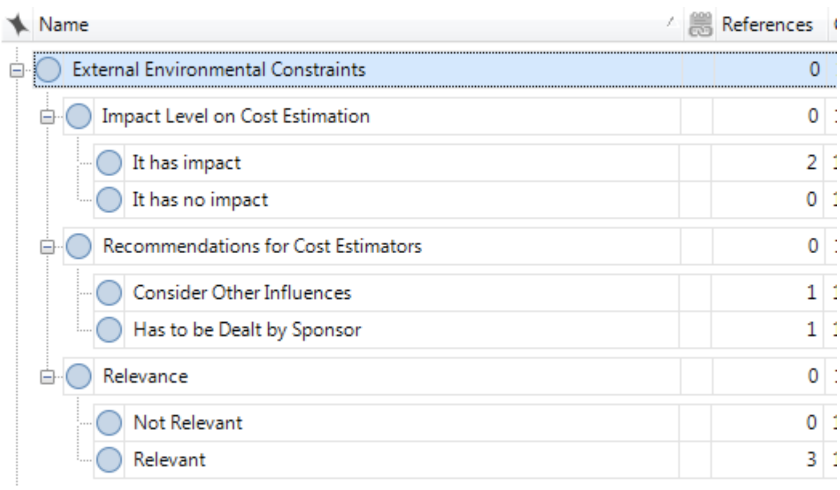


Figure 5.19 – Tree node for the dimension External Environmental Constraints

5.7.16.1. Relevance

Interviewees 2 and 7 considered this dimension as part of their top 10 but argued that other dimensions might also overlap with external environmental constraints, for instance political influence. Should this dimension be considered a separate element, or it is actually a summary of several others? This question should be considered when building the model in Chapter 6.

This dimension is similar to PMI's enterprise environmental factors (PMI, 2012, p.539), defined as "conditions, not under the immediate control of the team, that influence, constrain, or direct the project, program or portfolio".

A different perspective is shared by Interviewee 7, who described the following three environmental factors based on professional experience: social entitlement, criminal influence, and political influence. " Social entitlement. Wherever a project is being implemented, there is going to be a number of persons in the local environment that will suggest that they are to be engaged or employed in the project, or else the project does not proceed…. The second thing is what I call criminal influence (to have workmen on the site, you would have to pay a local criminal element to permit you to work on the site)….. Political appointments to contractor groups—they might not say appointments really; they might say political recommendations".

The survey analysis using the Relative Importance Index placed external environmental constraints dimension in 17th place with RII = 0.689, which is not a high score. As only two interviewees considered it relevant, further analysis will be done in section 5.8.

5.7.16.2. Impact on the Cost-Estimation Process

Interviewees 2 and 7 shared that external environmental constraints would impact the cost-estimation process.

As described in the previous section, some of the dimensions listed above could actually be placed under the category of external environmental constraints. Independently of how this will be addressed in this research, these constraints usually result in scope changes that might impact the duration of the project and, with that, increase the cost estimates. This also impacts project productivity.

5.7.16.3. Guidelines for Cost Estimators

Interviewee 2 does not think there is any recommendation that can be provided to cost estimators regarding external environmental constraints. It is something the project sponsor has to deal with and discuss with the project steering committee.

On the other hand, Interviewee 7 recommends that the project manager work on determining the external constraints and how they can impact the project. Once this is known, the manager should make provisions to address them.

5.7.17. Innovation to Market

The following analysis is represented by a tree node in Figure 5.20. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

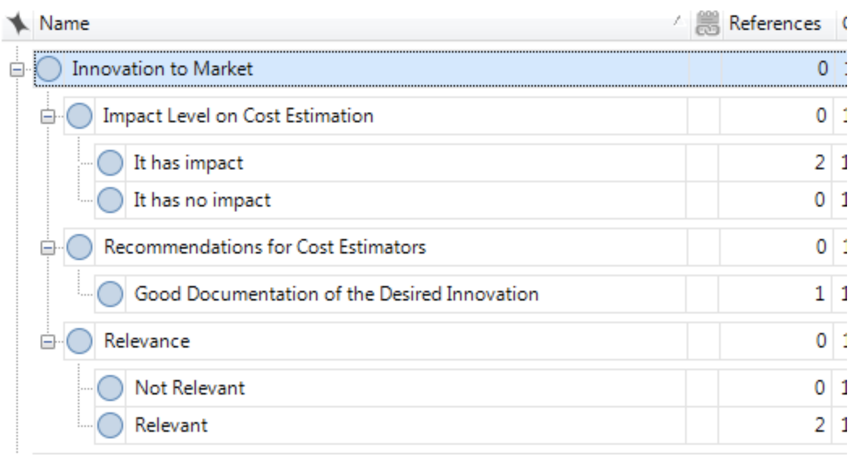


Figure 5.20 – Tree node for the dimension Innovation to Market

5.7.17.1. Relevance

Interviewees 2 and 3 considered innovation to market as part of their top 10 dimensions and were surprised by its low survey score. When an organization wants to launch a product that is new to the market and has not been done before, the project manager does not have a clear understanding of what needs to be done or all the elements involved. As described by Interviewee 2, in this situation one is at the infancy stages of the project and the cost of innovation to market is significant.

The need to manage a project with the objective to deliver a product, service, or result that is new to the market was not considered highly impactful in either the survey (20th place with RII = 0.637) or the interviews. However, the Diamond Model for projects (Shenhar & Dvir, 2007) considers innovation to market as one of the four pillars of the model, which is not aligned with the findings of this research.

This dimension may be eliminated from the list of relevant complexity dimensions and should be further analysed in the upcoming section.

5.7.17.2. Impact on the Cost-Estimation Process

Interviewees 2 and 3 considered that innovation to market might impact the cost-estimation process. Normally, high-level stakeholders do the initial estimate without a detailed work breakdown structure or another time-intensive process. This is especially common when innovation is involved, since there are no previous references for the estimates. It is a top-down approach, which takes less time, is less accurate, and requires fewer resources. Interviewee 3 concurs, stating that innovation is related to unknowns and so it carries more risks.

Like the relevance of innovation to market as a complexity dimension, the impact on the cost-estimation process was supported only by two interviewees.

5.7.17.2. Guidelines for Cost Estimators

Interviewee 2 believes that there are no guidelines that can be provided to cost estimators when working on a project that has a strong innovation factor. If any guideline would be provided, it should be addressed to the top level of the organization when defining the strategic plans for the company, possible benefits, and potential financial impact.

A more detailed documentation is recommended by Interviewee 3. The estimator and project manager should document what is expected from the product to be delivered, what type of innovation is required, how the innovation is different from what already exists, benefits, and consequences for the organization.

5.7.18. Uncertainty

The following analysis is represented by a tree node in Figure 5.21. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

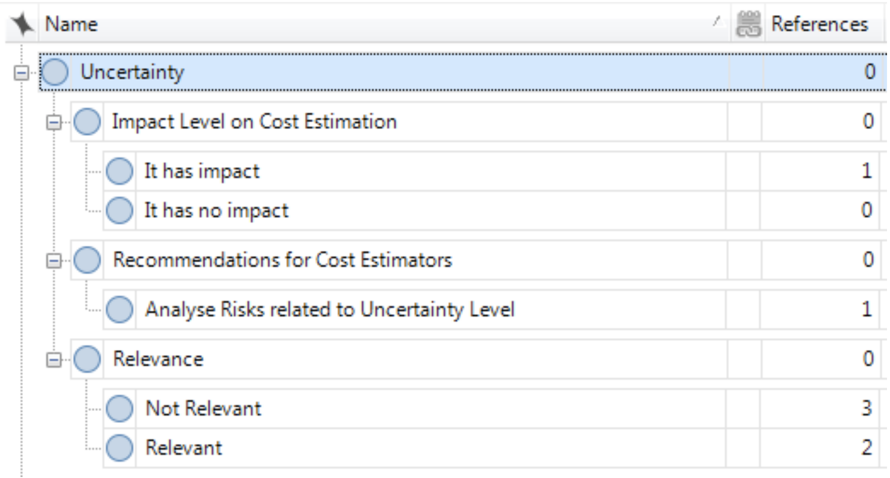


Figure 5.21 – Tree node for the dimension Uncertainty

5.7.18.1. Relevance

Interviewees 2 and 10 provide supporting comments as to why this dimension should be considered. Interviewee 10 recommends that uncertainty should be better defined as uncertainty of technology, market uncertainty, or innovation uncertainty. On the same topic Interviewee 2 suggests that uncertainty is related to risk and it can be derived from a lack of knowledge and experience or organizational capability. Uncertainty could lead to risks and risks lead to contingencies.

Uncertainty is another dimension that did not score high during the interviews, with only two people considering it relevant. On the other hand, the survey analysis using the Relative Importance Index placed uncertainty in sixth place with RII = 0.756.

Even though the reason for this discrepancy is not clear, uncertainty is one of the aspects of risks (PMI, 2012), which was considered highly relevant and impactful. The question to be addressed in section 5.8 is whether this dimension should be separate or incorporated with others.

5.7.18.2. Impact on the Cost-Estimation Process

According to Interviewee 2, there are two types of uncertainty to be considered: complete and partial uncertainty. Both would impact the cost-estimation process, but total uncertainty requires the organization to be more prone to take risks. If the organization is risk averse, it will be very difficult to implement such a project.

Partial uncertainty is a common situation in most projects, and estimators should be accustomed to this situation. Interviewee 2 explains, "Complete uncertainty means that you don't know what the probabilities are and you don't know what the impact is going to be. Partial uncertainty means you have some degree of knowledge of probabilities and impacts".

5.7.18.3. Guidelines for Cost Estimators

The only guideline provided is to analyse the risks involved with uncertainty and manage the situation through contingencies.

5.7.19. Impact on Society

The following analysis is represented by a tree node in Figure 5.22. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

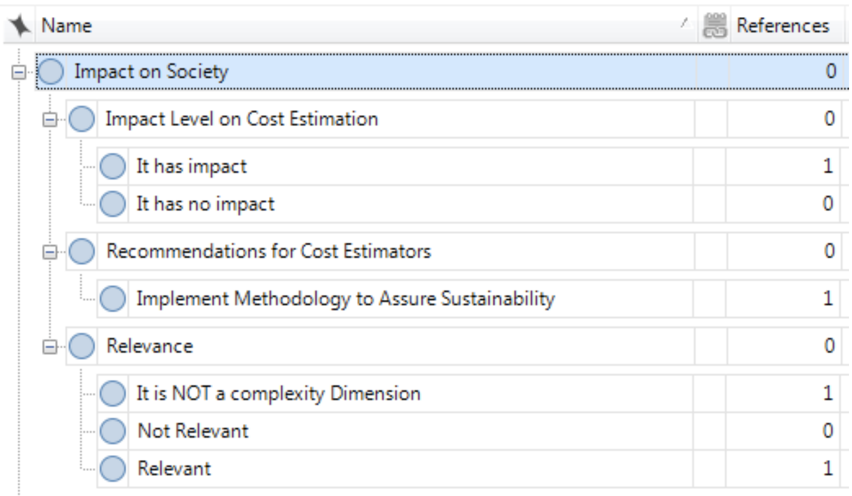


Figure 5.22 – Tree node for the dimension Impact on Society

5.7.19.1. Relevance

Impact on society had the lowest possible rank based on the survey. The survey analysis using the Relative Importance Index placed the risk dimension in last place (23rd) with RII = 0.526.

Similarly, only Interviewee 9 selected this dimension as somehow impactful, since not having control of the impact on society may lead to losing customers. Consideration should be made to eliminating this dimension from the model.

5.7.19.2. Impact on the Cost-Estimation Process

According to Interviewee 9, impact on society should be considered and its cost calculated. Once the costs are defined, analyse the negative effects they will have on the project.

5.7.19.3. Guidelines for Cost Estimators

Interviewee 9 proposes the use of tools that evaluate how sustainable the project is, define the impact on the environment and society, and decide whether the project should move forward or not.

5.7.20. Project Description

The following analysis is represented by a tree node in Figure 5.23. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

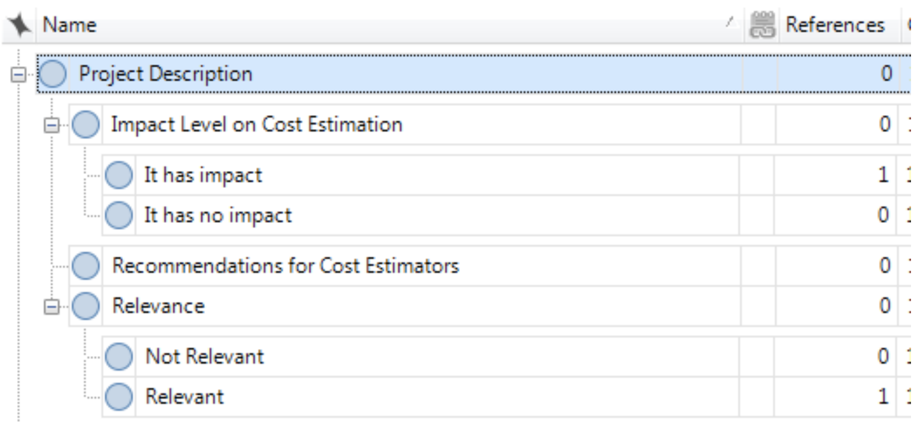


Figure 5.23 – Tree node for the dimension Project Description

5.7.20.1. Relevance

The project description complexity dimension is related to how easy or difficult it is to describe the project to the team and other stakeholders. This dimension received a low score by the interviewees, being placed 18th with a Relative Importance Index of RII = 0.682.

Only Interviewee 9 selected this dimension as part of the top 10, pointing out that a proper and early description of the project would save money and reduce complexity. It should be considered for elimination and will be discussed in section 5.8.

5.7.20.2. Impact on the Cost-Estimation Process

The best time to avoid cost overruns and project failure is during its conception phase or early in the planning process, as proposed by Interviewee 9. If the project cannot be properly described or defined, there is a great chance that the estimation process will be faulty. This dimension might be consolidated with the dimension clarity of goals.

5.7.20.3. Guidelines for Cost Estimators

No recommendations were provided.

5.7.21. Technology

The following analysis is represented by a tree node in Figure 5.24. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

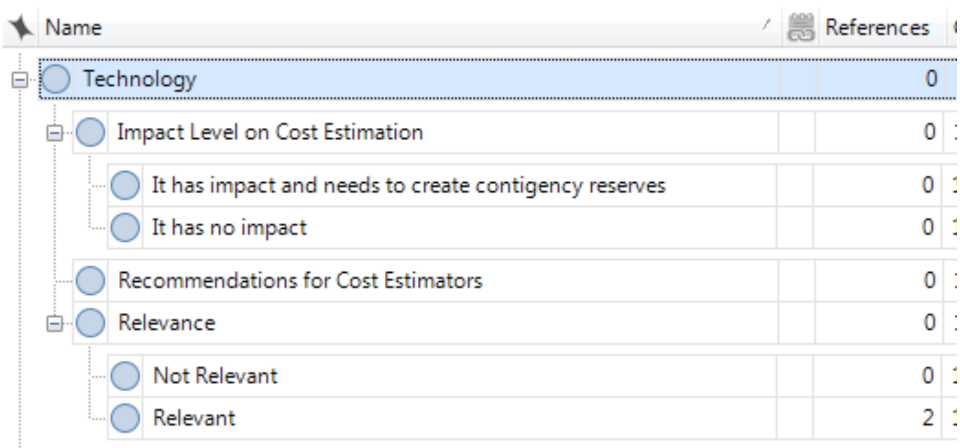


Figure 5.24 – Tree node for the dimension Technology

5.7.21.1. Relevance

Only Interviewee 10 selected the dimension technology as among the most important and emphasized that well-established technology leads to lower complexity and vice versa.

There was a significant discrepancy between the results for technology level obtained by the survey (10th place) with RII = 0.730 and those from the interviews. The difference might be due to the fact that technology is not part of many of the projects managed by the interviewees. The reason for this difference could be identified in an additional survey or interviews that can be done after this research. The decision whether to keep this dimension in the model or not should be addressed in section 5.8.

5.7.21.2. Impact on the Cost-Estimation Process

No additional details were provided by Interviewee 10 to support the impact of technology on the cost-estimation process. On the other hand, it could be questioned whether technology should be associated with innovation to market or even uncertainty.

5.7.21.3. Guidelines for Cost Estimators

No recommendations were provided.

5.7.22. Economic Uncertainty

The following analysis is represented by a tree node in Figure 5.25. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

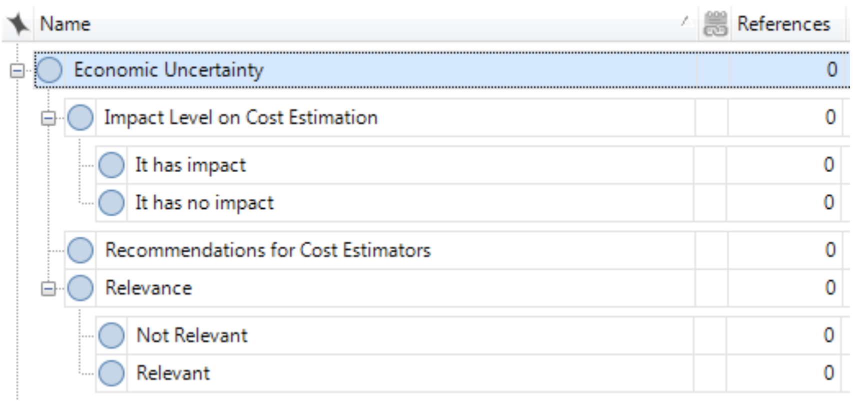


Figure 5.25 – Tree node for the dimension Economic Uncertainty

5.7.22.1. Relevance

Interestingly, economic uncertainty placed 13th in the survey with RII = 0.704, together with dependency and interdependency and stakeholder interaction, but no interviewee selected this dimension as relevant nor impactful on the cost-estimation process. Another argument to eliminate this specific dimension from the list of complexity dimensions included in the model is that it could be consolidated into the broader dimension uncertainty. More details will be given in the upcoming section.

5.7.22.2. Impact on the Cost-Estimation Process

No comments were provided.

5.7.22.3. Guidelines for Cost Estimators

No recommendations were provided.

5.7.23. Environmental and Safety Impact

The following analysis is represented by a tree node in Figure 5.26. It covers the aspects of relevance, impact on the cost-estimation process, and a list of guidelines for cost estimators.

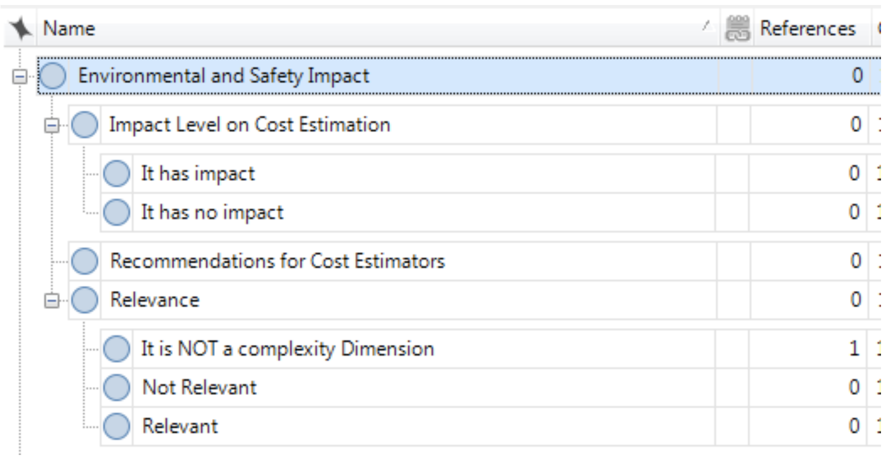


Figure 5.26 – Tree node for the dimension Environmental and Safety Impact

5.7.23.1. Relevance

This dimension was not mentioned by any interviewee and was ranked in 22nd place (second to last) with RII = 0.626, providing a clear argument to eliminate it as a complexity dimension.

5.7.23.2. Impact on the Cost-Estimation Process

No comments were provided.

5.7.23.3. Guidelines for Cost Estimators

No recommendations were provided.

5.8. DISCUSSION ABOUT THE INTERVIEW RESULTS

The 10 people interviewed had conflicting points of view related to some dimensions and were quite aligned on others. The following paragraphs will provide a summary of the conclusions obtained during the analysis of the feedback provided.

Table 5.18 shows the initial analysis and ranks the dimensions based on the number of people who considered the complexity dimension relevant.

Table 5.18 - Rank per the number of people considering the dimension relevant

Dimension	RII	Rank	Relevance			
			Relevant	Not Relevant	Other Considerations	No Comments
Knowledge and Experience	0.741	7	9	1	0	0
Organizational Capability	0.763	4	8	1	1	0
Clarity of Goals	0.737	9	7	1	2	0
Risk	0.804	1	6	1	2	1
PM Maturity Level	0.759	5	6	3	0	1
Political Influence (Politics)	0.696	16	5	0	0	5
Product and Project Size	0.800	2	4	6	0	0
Stakeholder Interaction	0.704	13	4	0	0	6
Pace/Speed to Market	0.648	19	4	0	0	6
Time Frame	0.770	3	3	0	1	6
Budgetary Constraints	0.741	7	3	0	0	7
Degree of Trust	0.726	11	3	0	0	7
Communication Quality	0.719	12	3	0	0	7
Dependency and Interdependency	0.704	13	3	0	0	7
Cultural Resistance and Differences	0.630	21	3	0	1	6
Innovation to Market	0.637	20	2	0	0	8

Dimension	RII	Rank	Relevance			
			Relevant	Not Relevant	Other Considerations	No Comments
Uncertainty	0.756	6	1	0	1	8
Technology	0.73	10	1	0	0	9
External Environmental Constraints	0.689	17	1	0	1	8
Project Description	0.682	18	1	0	0	9
Impact on Society	0.526	23	1	0	0	9
Economic Uncertainty	0.704	13	0	0	0	10
Environmental and Safety Impact	0.626	22	0	0	0	10

It can be observed that the dimensions uncertainty, technology, external environmental constraints, project description, impact on society, economic uncertainty, and environmental and safety impact were selected as relevant by either one interviewee or none.

Table 5.19 shows another breakdown ranking the dimensions per impact on the cost-estimation process.

Table 5.19 – Rank of dimensions per impact on the cost-estimation process

Dimension	RII	Rank	Impact on Cost Estimation			
			Has Impact	No Impact	Other Considerations	No Comments
Knowledge and Experience	0.741	7	9	0	0	1
Clarity of Goals	0.737	9	7	0	0	3
PM Maturity Level	0.759	5	6	1	0	3
Risk	0.804	1	5	0	0	5
Product and Project Size	0.800	2	4	3	3	0
Organizational Capability	0.763	4	4	0	1	5
Communication Quality	0.719	12	4	0	0	6
Stakeholder Interaction	0.704	13	4	0	0	6
Political Influence (Politics)	0.696	16	4	0	1	5

Dimension	RII	Rank	Impact on Cost Estimation			
			Has Impact	No Impact	Other Considerations	No Comments
Time Frame	0.770	3	3	0	1	6
Degree of Trust	0.726	11	3	0	0	7
Pace/Speed to Market	0.648	19	3	0	0	7
Cultural Resistance and Differences	0.630	21	3	0	0	7
Uncertainty	0.756	6	2	0	0	8
Budgetary Constraints	0.741	7	2	0	0	8
Dependency and Interdependency	0.704	13	2	0	0	8
External Environmental Constraints	0.689	17	2	0	0	8
Innovation to Market	0.637	20	2	0	0	8
Technology	0.730	10	1	0	0	9
Project Description	0.682	18	1	0	0	9
Impact on Society	0.526	23	1	0	0	9
Economic Uncertainty	0.704	13	0	0	0	10
Environmental and Safety Impact	0.626	22	0	0	0	10

The dimensions that were considered not impactful on the cost estimation because either only one interviewee selected them or none at all are technology, project description, impact on society, economic uncertainty, and environmental and safety impact.

Finally, another aspect to be considered was the number of recommendations provided for cost estimators, as presented in Table 5.20. This is especially important since the model will use these recommendations as guidelines for cost estimators, with the objective of creating awareness and supporting a better cost-estimation process.

Table 5.20 – Rank per number of recommendations provided for cost estimators

Dimension	RII	Rank	# Recommendations for Cost Estimation
PM Maturity Level	0.759	5	8
Clarity of Goals	0.737	9	8
Product and Project Size	0.800	2	6

Organizational Capability	0.763	4	6
Knowledge and Experience	0.741	7	6
Risk	0.804	1	5
Political Influence (Politics)	0.696	16	4
Time Frame	0.770	3	3
Communication Quality	0.719	12	3
Dependency and Interdependency	0.704	13	3
Budgetary Constraints	0.741	7	2
Degree of Trust	0.726	11	2
Stakeholder Interaction	0.704	13	2
External Environmental Constraints	0.689	17	2
Pace/Speed to Market	0.648	19	2
Uncertainty	0.756	6	1
Innovation to Market	0.637	20	1
Cultural Resistance and Differences	0.630	21	1
Impact on Society	0.526	23	1
Technology	0.730	10	0
Economic Uncertainty	0.704	13	0
Project Description	0.682	18	0
Environmental and Safety Impact	0.626	22	0

The dimensions that got no recommendations for cost estimators or only one were uncertainty, innovation to market, cultural resistance and differences, impact on society, technology, economic uncertainty, project description, and environmental and safety impact.

Analysing all the results together, a list of dimensions consistently appears at the bottom: impact on society, project description, technology, economic uncertainty, and environmental and safety impact. Out of these five, three had RII under 0.70: impact on society, project description, and environmental and safety impact. These three dimensions will be eliminated from the list of dimensions.

Furthermore, a group of dimensions also got lower scores on relevance, impact on cost estimation, and/or number of recommendations for cost estimators. These dimensions are uncertainty, cultural resistance and differences, innovation to market, and external environmental constraints. Except for the dimension uncertainty, all have RII lower than 0.70; therefore, they will also be eliminated.

With that, there are 17 dimensions remaining that will be considered for the proposed model as per Table 5.21 below:

Table 5.21 – Revised list of dimensions

Dimension	RII	RII Rank	Relevant	Has Impact	Number of Recommendations
Risk	0.804	1	6	5	5
Product and Project Size	0.800	2	4	4	6
Time Frame	0.770	3	3	3	3
Organizational Capability	0.763	4	8	4	6
PM Maturity Level	0.759	5	6	6	8
Knowledge and Experience	0.741	7	9	9	6
Budgetary Constraints	0.741	7	3	2	2
Clarity of Goals	0.737	9	7	7	8
Degree of Trust	0.726	11	3	3	2
Communication Quality	0.719	12	3	4	3
Stakeholder Interaction	0.704	13	4	4	2
Dependency and Interdependency	0.704	13	3	2	3
Political Influence (Politics)	0.696	16	5	4	4
Pace/Speed to Market	0.648	19	4	3	2
Uncertainty	0.756	6	1	2	1
Technology	0.730	10	1	1	0
Economic Uncertainty	0.704	13	0	0	0

Considering that several interviewees identified similarities between the dimensions below, they will be consolidated as follows:

- Project management maturity level and organizational capability will be consolidated and named organizational capability and maturity.
- Uncertainty and economic uncertainty will be consolidated and named uncertainty.

5.9. IMPROVEMENTS TO THE MODEL BASED ON THE INTERVIEW RESULTS

According to the conclusions from the progressive analysis of this research, this research proposes a final list of dimensions reduced from 23 to 15. The proposed list appears in Table 5.22 below in alphabetical order.

Valid arguments can be provided by other researchers indicating that some of the 15 complexity dimensions are intrinsically more important than others, or that a specific industry might consider certain complexity dimensions more relevant. For this research, these 15 complexity dimensions will be considered equally important, and the level of importance will be assessed by the practitioner when analysing a specific project.

Table 5.22 – Final list of complexity dimensions

#	Dimension
1	Budgetary Constraints
2	Clarity of Goals
3	Communication Quality
4	Degree of Trust
5	Dependency and Interdependency
6	Knowledge and Experience
7	Organizational Capability and Maturity
8	Pace/Speed to Market
9	Political Influence (Politics)
10	Product and Project Size
11	Risk
12	Stakeholder Interaction
13	Technology
14	Time Frame
15	Uncertainty

Now that the number of complexity dimensions that will be part of the model is established, it is necessary to define the following aspects to build the final model:

1 – How practitioners will assess the four levels of complexity for each dimension.

2 – Once the assessment is done, what is the best way to represent the results.

3 – After visualising the results, what will the practitioner have to do to gather relevant information to create awareness and obtain recommendations to include the complexity dimensions into account.

These will be addressed in the next chapter, which discusses the proposed model. For now, the only variation will be in the number of complexity dimensions as shown in Figure 5.27 below.

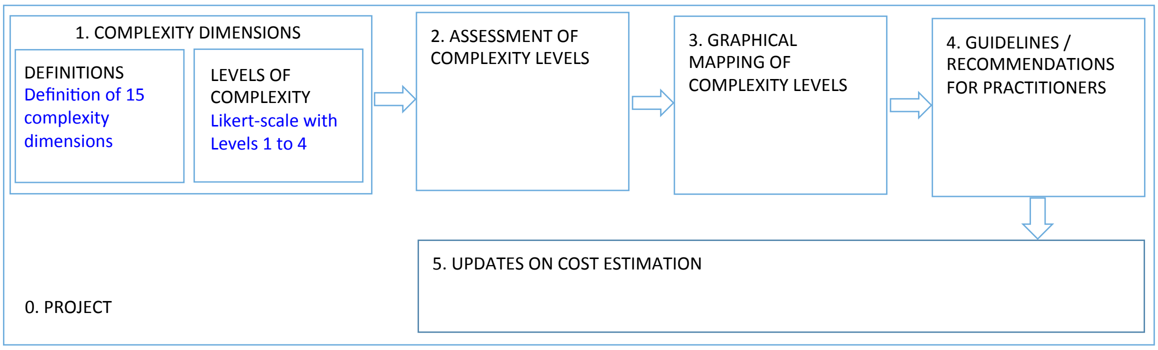


Figure 5.27 – Revised model

5.10. Chapter Summary

This chapter covered two important sources for this research—the survey with 54 practitioners, and the interview with 10 people from different industries and backgrounds. The survey results were analysed using the Relative Importance Index (RII), broken down by industries but also presented as a consolidated view. The findings were then shared during a global project management congress with validation of the existing dimensions found thus far.

The interviews allowed the researcher to go deeper into each dimension considered relevant by the interviewees and the impact these dimensions have on the cost- estimation process, as well as gather recommendations for cost estimators that will produce a set of guidelines used by the model to be proposed. Further improvements to the underlining aspects of the model were addressed through a set of answers obtained at that stage of the research.

The next chapter will cover the proposed model, background information and the process used to build it, together with a recommendation for its practical use.

CHAPTER 6 – MODEL PROPOSAL

This chapter presents the model that is being proposed to create awareness about the complexity dimensions when estimating costs for projects. The model will incorporate the complexity dimensions described in this research, recommend an assessment grid, and provide guidelines for practitioners.

6.1. Background

According to several authors, a model could be understood as a representation of a system or reality that can help people to know, understand, follow, or simulate the subject it represents (Williams, 2002; Badiou, 2007; Hass, 2009). For a model to be developed there is a need to define the necessary variables and a structure of how these variables interact with each other and within the model (Robinson, 2014).

In the case of this research, the variables of the proposed model are the complexity dimensions that would be assessed using a qualitative approach. The use of a qualitative approach is necessary considering that there is no definitive value or number that can be established to represent with absolute certainty the complexity level of a dimension for a specific project (Remington et al., 2009). The use of a subjective approach is supported by the fact that each project is unique (PMI, 2012) and that each cost estimator might have a different perspective and level of understanding, knowledge, or experience about the items to be estimated and consequently the complexity level of that project (Ken & Formoso, 2004).

A Likert scale assessment is proposed to allow practitioners to indicate the level of complexity of each dimension. The Likert scale has the advantage of allowing the practitioner to select from a range of options going from the lowest possible level of complexity that a dimension has on that project (i.e., level 1) to the highest level of complexity (i.e., level 4). It can be argued that the number of scale points on a Likert scale (three levels, four levels, five levels, and so on) does not impact reliability and validity of the results (Matell & Jacoby, 1971), so for that reason this research selected to not use the five-point Likert scale in order to avoid the mid-scale (Cummins & Gullone, 2000), and to implement a four-point scale instead (Si & Cullen, 1998).

The premise is that the same project might generate different results for its complexity dimensions when done by two different practitioners. For instance, practitioner ‘A’ might consider the level of complexity of ‘knowledge and experience’ to be 1 since s/he has a lot of knowledge and experience with this type of project, while practitioner 'B' would assess the level of complexity as 3 due to his/her lack of knowledge and experience. This variation is actually a representation of the reality for practitioners 'A' and 'B' and it should be considered. It can be argued that an optimistic or pessimistic view of the complexity level might skew the results from one side to another but that is part of the nature of a subjective assessment (Chang, D'Zurilla, & Olivares, 1994).

The model will work by providing the practitioner with a list of complexity dimensions, with a description of what each dimension means, and ask the practitioner to assess the level of complexity of each dimension on a scale of 1 (lowest level of complexity) to 4 (highest level of complexity). This assessment is based on the practitioner's view of how each dimension causes complexity in that specific project. More details are provided in section 6.2.

Once the values of complexity level (1 to 4) are defined per dimension, it would be time to represent the results. The results are represented by a table of numbers like Table 6.1. This table contains fictional values just to serve as example.

Table 6.1 – Table with levels of complexity dimensions (fictional values)

Complexity Dimension	Level (1-4)
Budgetary Constraints	2
Clarity of Goals	3
Communication Quality	2
Degree of Trust	1
Dependency and Interdependency	4
Knowledge and Experience	3
Organizational Capability and Maturity	3
Pace/Speed to Market	2
Political Influence (Politics)	4
Product and Project Size	2
Risk	1
Stakeholder Interaction	1
Technology	3
Time Frame	4
Uncertainty	3

Once the practitioner assesses the complexity level per dimension, the results could be plotted graphically for better visualisation. According to Hass (2009), a graphical representation is often better understood than a table with numbers and the message is captured faster;

Therefore, a graphical representation will be used to show the level of complexity of each dimension for a specific project.

There are a few ways to graphically represent numeric data: columns, lines, pie, bar, area, or scatter as presented in Figure 6.1; or stock, surface, doughnut, bubble, or radar as presented in Figure 6.2.

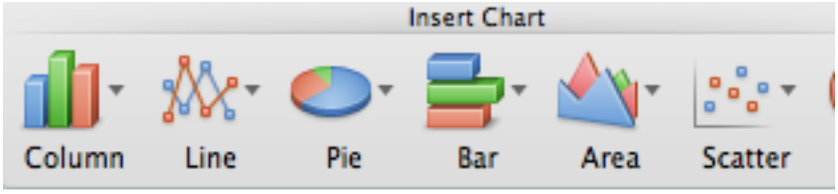


Figure 6.1 – Graphical representation types (source: Microsoft Excel for Mac 2011)

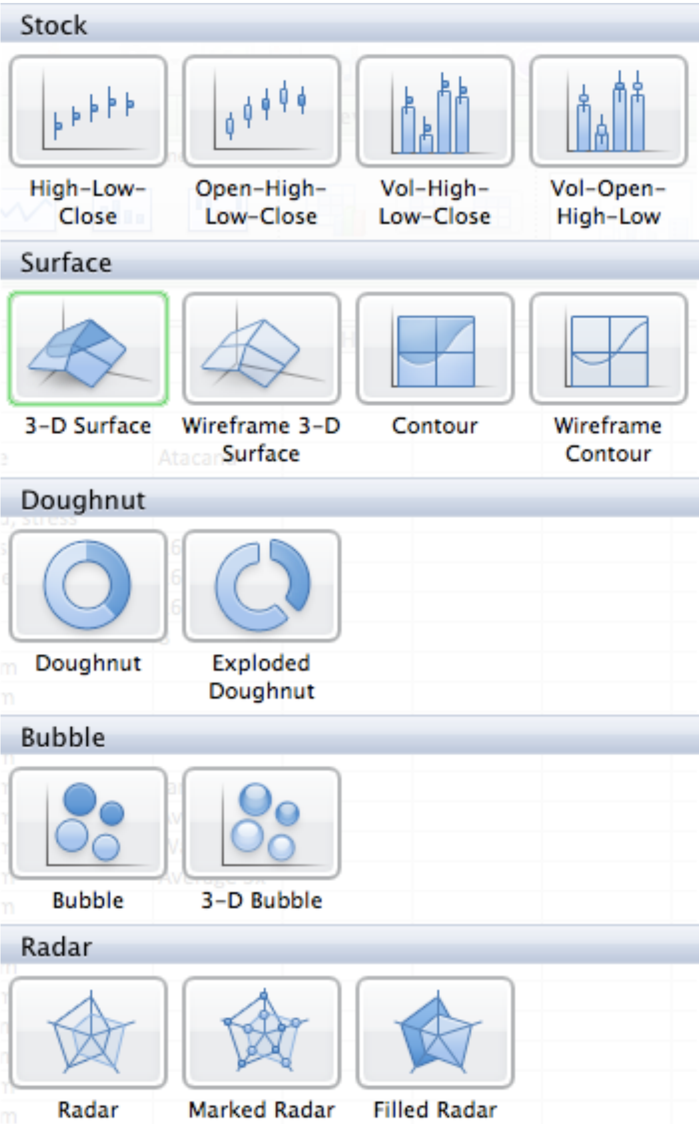


Figure 6.2 – Other graphical representation types (source: Microsoft Excel for Mac 2011)

The radar graph was chosen for the proposed model because it is a better representation of all the dimensions and their complexity levels in a single graph, in other words it shows how different dimensions affect the project. Diagrams like scatter diagram only show if the results are presented linearly or in a curve; and the bar or column diagram is limited by showing the scale of the dimensions. Based on the fictional numbers from Table 6.1, the radar graph will look like Figure 6.3.

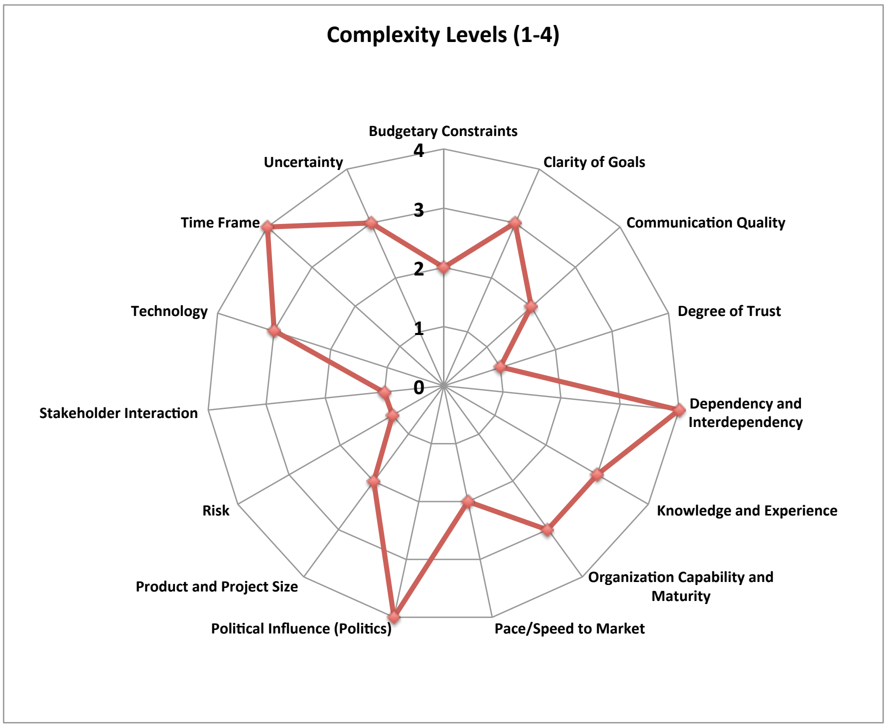


Figure 6.3 – Radar graph for complexity dimensions (fictional values)

Figure 6.4 shows an integrated view with the table and the graph together

Complexity Dimension	Level (1-4)
Budgetary Constraints	2
Clarity of Goals	3
Communication Quality	2
Degree of Trust	1
Dependency and Interdependency	4
Knowledge and Experience	3
Organizational Capability and Maturity	3
Pace/Speed to Market	2
Political Influence (Politics)	4
Product and Project Size	2
Risk	1
Stakeholder Interaction	1
Technology	3
Time Frame	4
Uncertainty	3

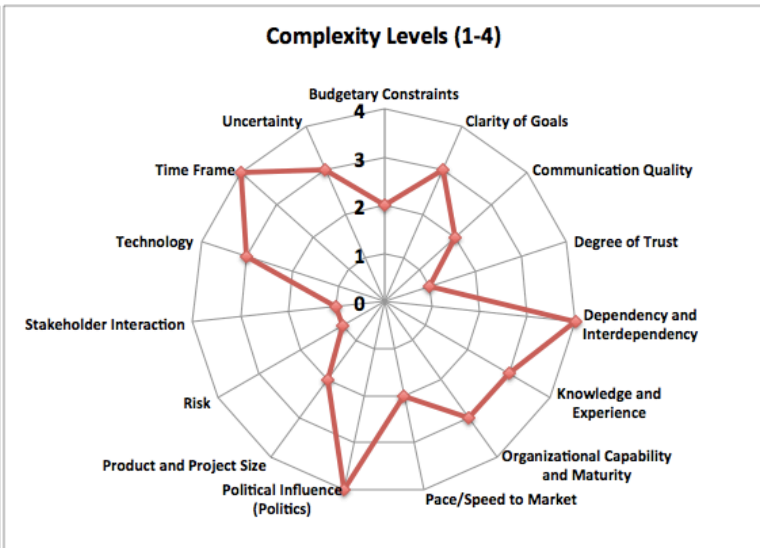


Figure 6.4 – Assessment of complexity dimensions with radar graph (fictional values)

The step of providing guidelines and the resulting updates is described in more details on the upcoming section. The next section will also provide a view of the elements of the model and describe each of them. A fictional case study will be provided for better understanding.

6.2. The Model

As explained in the previous chapter, the model is intended to create awareness about potential complexity dimensions that might impact the cost-estimation process. Once the assessment of complexity levels is done, the results are represented graphically; the practitioner will then select the dimensions with higher complexity level and obtain recommendations on how to adapt the project and the cost-estimation process to account for the identified complexities. The upcoming sections will provide more details about the model itself.

6.2.1. Structure of the Model

The model is divided into several elements that are represented in Figure 6.5, followed by a description of each element. The progressive development of the model is described on section 2.9, section 4.5, section 5.5, and section 5.9.

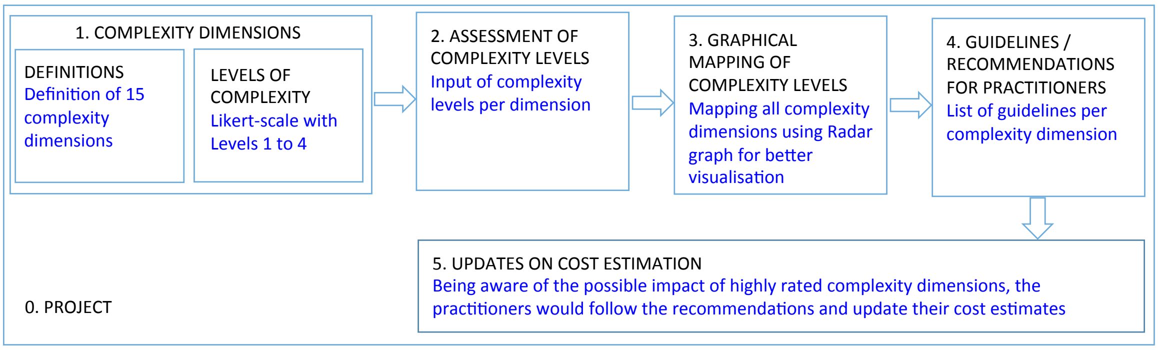


Figure 6.5 – Structure of the model

Element 0 – Project: This element describes the project itself, objectives, scope, other constraints (time, budget, and quality), stakeholders, external environment, acceptance criteria, technological level required, and so on. This is the description of the project where the cost estimation is needed.

Element 1 – Complexity dimensions: This element is divided into two parts:

1.1. Definitions: A detailed definition of each complexity dimension is provided to the user, ensuring proper understanding.
1.2. Levels of complexity: Defines how the complexity level will be assessed (type of scale used and the number of levels), and the description of each level per complexity dimension. More details on section 2.5.

Element 2 – Assessment of complexity levels: The practitioner will perform an assessment of the complexity level for each complexity dimension according to the parameters defined in element 1 above. The assessment defines the impact that a specific dimension would have on the project and consequentially on the cost-estimation process for that project. It ranges from 1 (lowest impact) to 4 (highest impact). See more details in section 6.2.3.2.

Element 3 – Graphical mapping of complexity levels: The assessment resulting from element 2 above will then be mapped in a radar graph allowing better visualisation of the results. More details on the previous section 6.1

Element 4 – Guidelines/recommendations for practitioners: A set of recommendations and guidelines will be provided to project managers and cost estimators for all dimensions with higher level of complexity (levels 3 and 4). These recommendations have the objective of providing steps that can be followed to reduce the impact of that dimension or considerations to be taken into account when estimating costs. It is important to note that if the practitioner would like to read the guidelines for levels 1 and 2, the model allows but the model proposes focus on the higher complexity dimensions. See more details in section 6.2.3.5.

Element 5 – Updates on cost estimation: Once the recommendations are followed and more relevant complexity dimensions taken into consideration, it is expected that the cost estimate will be more accurate.

The next section provides a fictional case study that would serve as basis for the explanation of each element of the model.

6.2.2. Supporting Case Study

To provide better understanding, the following subsections will be based on a fictional case study to exemplify how the model works. A full print of the model is provided at Appendix C.1.

Case study:

The project objective is to implement enterprise resource planning (ERP) software within the organization XYZ, also known as Phase 1. The strategy defined by the Chief Executive Officer (CEO) is to start the implementation within the financial department. The Chief Financial Officer (CFO), who heads the entire financial area, supports it. The other phases were not shared within the organization. XYZ has well-established project management processes and recently implemented their own methodology, granting them a level 3 in project maturity according to a recent assessment.

The main benefits for implementing the ERP system during phase 1 are to have more effective operations, serve the clients faster, and reduce payroll expenses. XYZ has experience managing projects within the range of USD 25–100 million, so the size of this project is not considered a problem. The main savings will come from reducing the 100 employees located in the accounting, accounts receivable, accounts payable, and administrative departments to only 20. The initial estimate for this phase of the project is to cost USD 1 million, and the alleged benefits were USD 5 million over a 2.5-year period. XYZ has the necessary budget to implement this project but it will affect other initiatives. Phase 1 should be implemented in six months, and after it is implemented, the organization will define the other phases and roll out to the remaining areas.

The following additional challenges for this project are listed below:

a) Organization XYZ has no experience implementing such projects, nor does it have knowledge about the technology used in an ERP system. On the other hand, XYZ is hiring the services of the renowned consulting company ABC, which specializes in implementing ERP systems.
b) The employees from the target departments (accounting, accounts payable and receivable, and administration) are part of a strong union and they are in direct opposition to the project. There is also strong political influence from other senior executives within the organization who are against the project.
c) The project manager from XYZ is not convinced that the project will produce all expected benefits in phase 1, but the Steering Committee who approved the project does not want to listen. “Just implement the project”, the project manager was told.
d) There are a lot of internal discussion and communication issues, with middle management feeling insecure about the possible next steps. This environment created barriers among

employees, department heads, consulting company ABC, and executives, causing a loss of trust.

e) The details of phase 1 were not provided to the project manager, nor was a look at the other phases. Clear goals were not shared, and neither was the feasibility study that supported the decision to implement phase 1.

f) The implementation time frame of six months was arbitrarily defined by the XYZ executives contrary to the 12 months recommended by the consulting company ABC, which is responsible for implementing the ERP system.

The next section provides a detailed explanation of each element of the model, using the case study as a reference.

6.2.3. Elements of the Model – A Detailed Explanation

6.2.3.1. Definition of Complexity Dimensions (Element 1.1 of the model)

As described in the conclusions and recommendations of Chapter 5, section 5.8, the number of complexity dimensions was reduced from 23 to 15. The list of dimensions is provided in alphabetical order in Table 6.2, followed by a brief description of each.

Table 6.2 – Final list of complexity dimensions

#	Dimension
1	Budgetary Constraints
2	Clarity of Goals
3	Communication Quality
4	Degree of Trust
5	Dependency and Interdependency
6	Knowledge and Experience
7	Organizational Capability and Maturity
8	Pace/Speed to Market
9	Political Influence (Politics)
10	Product and Project Size
11	Risk
12	Stakeholder Interaction
13	Technology
14	Time Frame
15	Uncertainty

1. Budgetary constraints: Normally all projects have a limited budget. This dimension is related to how the budget constrains the ability to manage the project, which might add to the project's complexity level If the organization is accustomed to managing a budget of a specific size (e.g., up to USD100 million), a larger cost (e.g., USD 1 billion) would add a level of complexity to the project (Flyvbjerg et al., 2010). Similarly, if the available budget is limited, the performing team might need to implement approaches that were not used before, which again creates an increased complexity level.
2. Clarity of goals: This dimension defines how well-defined the goals of the project are and the impact this has on how the project is managed and decisions are made. A lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance (Turner & Cochrane, 1993; Remington et al., 2009).
3. Communication quality: This dimension is related to the quality of communication during the project. Communication barriers can bring disruption to the project and are considered one of the key reasons for project failure (PMI, 2012). Challenges in communication can be related to language, cultural aspects, organizational structure, geographical location, and communication methods. Communication involves both direct and indirect elements (Cooke-Davies et al., 2011). Direct (or explicit) communication refers to written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or the true intention is not directly revealed.
4. Degree of trust: This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (e.g., supplier and project team; senior management and project manager). The more trust there is, the less complex the project will be (Muler & Geraldi, 2007).
5. Dependency and interdependency: This dimension deals with the relationship between the elements that make up the project (Baccarini, 1996). This relationship can be one of dependency (in which some elements are dependent on one another, and some are not) and/or interdependency (in which each element is mutually dependent on others). In a complex project, stakeholders might not know what the result of an interaction among the elements of that project will be.
6. Knowledge and experience: This dimension is related to how much knowledge and/or experience the project manager or a key team member has regarding all elements

(parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product (Cilliers, 2010).

7. Organizational capability and maturity: This dimension is related to how capable—structurally and technically—an organization is in managing the project and delivering the required product (Remington et al., 2009). It also addresses the degree of relative maturity that the organization has achieved in project management. The assumption is that more mature organizations will be better able to manage complex projects and deliver products (Levin & Ward, 2011).
8. Pace or speed to market: This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the product be aligned with market demands (Shenhar, 2001).
9. Political influence (politics): This dimension is related to the level of internal or external political influence involved in the project. According to several authors, if political influence and interests lead to the approval of a project that might not be feasible, the chances of an overestimation of benefits and underestimation of costs increase (Jaafari, 2001; Dill & Pearson, 2013).
10. Product and project size: Product or project size is another proposed dimension for project complexity (Vidal & Marle, 2008). Actually, Corbett and Campbell-Hunt (2002) claim that a project should be over a minimal size to be considered a complex project. The premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple project would deliver a standard component, followed by a subsystem, moving to delivering an entire system, and finally to producing an array or system of systems (Shenhar & Dvir, 2007).
11. Risks: Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project (Levin & Ward, 2011). This dimension defines specifically how much unknown (known-unknowns and unknown-unknowns) risks exist in a project and possible impacts on the management process and delivery of the final product.
12. Stakeholders' interaction: This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success

can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening in the project (Cooke-Davies et al., 2011).

13. Technology: The term *technology* is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used in a specific project. Normally technology complexity is found in projects that use a new or untried technology (Remington & Polack, 2007). The complexity in this case would be associated with the number and variation of inputs and possible outputs. The less the team or performing organization knows or has used that technology, the more complex the project will become.
14. Time frame: Time is often referred to as having a direct effect on how complexity is perceived by project team members and stakeholders (Remington et al., 2009). Time frame is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the time frame of the project, notably with ones that have long durations. The longer the time frame, the more chances that changes will impact the project, which increases the level of complexity.
15. Uncertainty: The Cambridge Dictionary (2016) defines *uncertainty* as "a situation in which something is not known, or something that is not known or certain". This dimension is related to the level of uncertainty existing not just in a project, but also in the product or the development process. Even though complexity is different from uncertainty (Baccarini, 1996), uncertainty can be considered a dimension that can increase or decrease the level of complexity of a project.

The next section will provide more details about the scaling process used to assess the complexity level for each dimension.

6.2.3.2. Level of Complexity (Element 1.2 of the model)

Once the practitioner understands what each dimension means, a selection of the complexity level is required. A four-point scale was selected to avoid cultural bias due to middle-point scale (Si & Cullen, 1998), with level 1 being the lowest possible level and level 4 being the highest. It is important to note that this assessment is subjective since it is based on the project manager's or cost estimator's understanding about how each complexity dimension might impact the cost-estimation process.

The following list provides an explanation of each level per complexity dimension, according to section 2.5. The complexity dimensions are presented in alphabetical order.

Dimension 1: Budgetary Constraints

Level 1 - There is no budget limitation, and the cost of the project is within the range the organization is accustomed to managing.

Level 2 - There is some budget limitation but it does not affect the capability to deliver the product. The cost of the project is no more than 50% above the range of what the organization is accustomed to managing.

Level 3 - There is a budget limitation that affects the capability to deliver the product. The cost of the project is no more than two times above the range of what the organization is accustomed to managing.

Level 4 - There is an extreme budget limitation for the size of the project, which will not allow the project to deliver the product. The cost of the project is at least five times above the range of what the organization is accustomed to managing.

Dimension 2: Clarity of Goals

Level 1 - The goals are well defined, with a clear understanding of the deliverables and objectives by all stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study are still valid when the project progresses.

Level 2 - The goals are for the most part properly defined, with good understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study may be adjusted when the project progresses.

Level 3 - The goals are not well defined, and the understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision makers, customers, suppliers, and partners) is unclear. The early decisions made during the feasibility study are mostly invalid.

Level 4 - The goals are not defined at all and there is no understanding of the deliverables or objectives by any stakeholders (project manager, team members, decision makers, customers, suppliers, or partners). The early decisions made during the feasibility study are not being considered any longer.

Dimension 3: Communication Quality

Level 1 - Clear communication. The communication flows without issues and no clear barriers exist. All communication is direct, and when indirect communication is used, the cultural background prevents it from impacting the performing team.

Level 2 - Some issues with communications. There are some communication noises but they do not impact the project. There is limited use of indirect communication but it does not affect the performing team in such a way that will impact the management of the project.

Level 3 - Significant issues with communications. There are significant communication issues with disruptions to the project. There is also frequent use of indirect communication, which is not well received by the performing team. This can impact the management of the project.

Level 4 - Constant issues with communications within the entire organization and among stakeholders. There is severe impact on performance, and indirect communication is constant and disruptive to the performing team. The management of the project is seriously compromised, as is the delivery of the product.

Dimension 4: Degree of Trust

Level 1 - There is trust among all the project stakeholders and they have been working together for a long time.

Level 2 - There might be some trust issues between some stakeholders but nothing that should impact the results of the project.

Level 3 - There is a lack of trust between key stakeholders, which can jeopardize the process of managing the project and delivering the product.

Level 4 - The lack of trust among all stakeholders is evident and the results will probably not be achieved. There is a need for intervention.

Dimension 5: Dependency and Interdependency

Level 1 - There is complete understanding by the decision-maker, project manager, and team of the dependency and interdependency of all elements of the project.

Level 2 - There is partial understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.

Level 3 - There is very limited understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.

Level 4 - The decision-maker, project manager, and team are not capable of understanding the interdependence or independence of the elements of the project.

Dimension 6: Knowledge and Experience

Level 1 - The decision-makers, project manager, and team have extensive experience with this type of project and knowledge of all project elements.

Level 2 - The decision-makers, project manager, and team have good experience and knowledge of most elements of the project. There are just a few unknowns.

Level 3 - The decision-makers, project manager, and team have significantly limited experience and knowledge of the elements of the project. There are a lot of unknowns.

Level 4 - The decision-makers, project manager, and team have no experience or knowledge about any element of the project. Almost everything is unknown.

Dimension 7: Organizational Capability and Maturity

Level 1 – The project-management maturity level is high (between 4 and 5 out of 5). The organization has a lot of experience with the type of project in question, with the proper structure in place and technical knowledge to support the management of the project and development of the product.

Level 2 – The project-management maturity level is medium-high (between 3 and 4 out of 5). The organization has some experience with the type of project in question will need to make some adjustment to the organizational structure, and has proper technical knowledge to support the management of the project and development of the product.

Level 3 – The project-management maturity level is low-medium (between 2 and 3 out of 5). The organization has very limited experience with the type of project in question, the organizational structure is inadequate, and the organization has limited technical knowledge to support the management of the project and development of the product.

Level 4 – The project-management maturity level is low (between 1 and 2 out of 5). The organization has no experience with the type of project in question, the organizational structure is inadequate, and the organization has no technical knowledge to support the management of the project or development of the product.

Dimension 8: Pace/Speed to Market

Level 1 – Regular: The time to deliver (pace) the product is not critical to the success of the organization.

Level 2 - Fast: The time to complete the project is important for competitive advantage, and not delivering on time might have a negative impact on the organization.

Level 3 - Time-critical: The time to deliver the product is critical for project success and delays can be reflected as failure of the project.

Level 4 - Blitz: Not only is the time to deliver critical, but is considered a crisis; therefore delivery cannot be delayed for any reason.

Dimension 9: Political Influence (Politics)

Level 1 - No political influence or interest with no impact on the project.

Level 2 - Limited or very punctual political influence or interest, with minimal impact on the project.

Level 3 - Considerable or spread political influence or interest, with considerable impact on the project.

Level 4 - Strong and multi-level political influence or interest, with major impact on the project.

Dimension 10: Product and Project Size

Level 1 - Standard: The project objective is to deliver a single component, with a minimal amount of work; for example, delivering a standard memory chip.

Level 2 - Subsystem: The project objective is to deliver a set of components that interact to produce a subsystem, where the amount of work is still within the range of capabilities of the performing organization; for example, assembling a motherboard.

Level 3 - System: The project objective is to deliver a series of subsystems that together produce a system, which requires a greater amount of work and interaction among several parts; for example, a new computer.

Level 4 - Array: The project objective is to deliver an array or series of systems, and the work to be performed is beyond the capabilities of the performing organization; for example, a computer network that had never been installed before.

Dimension 11: Risk

Level 1- The project risks are well known, and the team has experience managing them.

Level 2 - The project does not have a significant amount of unknown risks, and people with previous experience with them can manage the existing ones.

Level 3 - The project has a large amount of unknown risks, and the team has very limited experience managing them.

Level 4 - Almost all risks are unknown, mostly unknown-unknown risks. The team has no experience managing them.

Dimension 12: Stakeholder Interaction

Level 1 - The key stakeholders are aligned with the project objectives and requirements. Their interaction is effective and the high-level executives provide the necessary support for project success.

Level 2 - Most key stakeholders are aligned with the project objectives and requirements. Their interaction is good but sometimes there is some “noise”. Mostly the high-level executives provide the necessary support for project success.

Level 3 - Most of the key stakeholders are not aligned with the project objectives or requirements. Their interaction is not effective and many issues arise due to poor stakeholder interaction. There is very limited support from high-level executives.

Level 4 - The key stakeholders are not aligned with the project objectives or requirements, with conflicts and re-work common. Their interaction is ineffective and there is no support from high-level executives to ensure project success.

Dimension 13: Technology

Level 1 - Low-tech: No new technology is used. The project uses only low-tech technology that is already existent and well established. These technologies normally do not have a significant level of uncertainty or difficulty (e.g., a house).

Level 2 - Medium-tech: Some new technology. The project uses mostly medium-tech technology, which can be characterized as based on existing technologies or a limited use of new technologies (e.g., a new automobile).

Level 3 - High-tech: All or mostly new but existing technology. The project uses many new technologies that have been recently developed. It might use technology for the first time, but that technology was already created (e.g., a satellite).

Level 4 - Super high-tech: Critical technologies do not exist. The project uses or has to develop a technology that never existed before. The level of uncertainty is very high and the outcome cannot be established (e.g., the Apollo program/moon landing).

Dimension 14: Time Frame

Level 1 - There is no change in decision-makers, the requirements are stable, and the key relations and project plans remain the same over time.

Level 2 - The change of decision-makers over time is not significant, the key requirements are stable over time, and the key relations and project plans remain almost the same over time.

Level 3 - There are significant changes in decision-makers and requirements over time, and key relations and project plans are also changing over time.

Level 4 - The decision-makers changed over time and had conflicting interests, the requirements changed, producing a different product, and the key relations and project plans were completely changed.

Dimension 15: Uncertainty

Level 1 - Low level of uncertainty: While there is confidence in the outcome, there are some key variables for which one does not have precise values. It is possible to make some estimates, or to establish some "most likely lows" and "most likely highs" and then plan for the range.

Level 2 - Medium level of uncertainty: There are a variety of future scenarios, but it is possible to list them, and they are mutually exclusive and exhaustive.

Level 3 - High level of uncertainty: There are scenarios that can be constructed, but they are more illustrative of possibilities rather than exhaustive.

Level 4 - Complete uncertainty: In some cases, it is impossible to even frame scenarios. The understanding is so unstable that any scenario is merely a wish list. It may be years before the possibilities sort themselves out.

In summary, each level of the four-point scale can also be understood more generically as follows:

Level 1 – The complexity dimension has no impact on the cost-estimation process or project.

Level 2 - The complexity dimension has limited impact on the cost-estimation process and project.

Level 3 – The complexity dimension has significant impact on the cost-estimation process and project.

Level 4 – The complexity dimension has catastrophic impact on the cost-estimation process and project.

6.2.3.3. Assessment of complexity levels (Element 2 of the model)

This assessment defines a level of complexity for each dimension on a scale of 1 to 4, where level 1 would be the lowest level of complexity and level 4 the highest, for the case study in section 6.2.2. Once again it is important to note that this is a subjective assessment based on the understanding of the assessor. To provide better visual identification, the model highlights the complexity dimensions that require more attention with a red background (level 4), followed by level 3 with yellow background, and finally highlighting levels 1 and 2 in green. The assessment results are presented in Table 6.3.

Dimension 1: Budgetary Constraints = Level 2

XYZ has enough financial resources to support a USD 1 million project but considering that this project might affect other initiatives, this dimension is considered as level 2—limited budgetary constraints. There are some budget limitations, but they do not affect the capability to deliver the product.

Dimension 2: Clarity of Goals = Level 3

According to challenges 'd' and 'e' from the case study, the goals were not well defined, with unclear understanding of the deliverables and objectives by most of the stakeholders. The chosen level would be 3.

Dimension 3: Communication Quality = Level 3

The case study presents a scenario where there are significant issues with communication. Significant communication issues with constant internal discussions might cause disruptions to the project as described in the case study's challenge 'd'.

Dimension 4: Degree of Trust = Level 4

The case study presents an environment with significant barriers between employees and executives, where trust has been lost. Considering that there's a lack of confidence on the part of the people who have to do the financial work during the implementation, there might be a need for intervention.

Dimension 5: Dependency and Interdependency = Level 4

Considering that this is the fist time XYZ will implement an ERP system, the decision-maker, project manager, and team are not capable of understanding the interdependence or independence of the elements of the project, including the interaction between this project and other projects within the organization. That points to the highest level of complexity.

Dimension 6: Knowledge and Experience = Level 2

XYZ decision-makers, the project manager, and the performing team have very limited experience and knowledge about the project. No previous implementation of an ERP system has been performed. Were XYZ to implement phase 1 itself, Level 3 would be most appropriate for this dimension. However, since the consulting company ABC will implement phase 1, the more accurate level is 2.

Dimension 7: Organizational Capability and Maturity = Level 2

Even though XYZ was recently assessed as medium maturity in project management, it does not have the necessary structure to support this type of project. On the other hand, the consulting company ABC will compensate for the limited technical knowledge of XYZ. For that reason, level 2 is selected for this dimension.

Dimension 8: Pace/Speed to Market = Level 2

According to the executive team at XYZ, the project must be finished within six months instead of the recommended 12. This is necessary to allow XYZ to collect the benefits faster and create competitive advantage. Not delivering on time might have a negative impact on the organization. Level 2 is selected for this dimension.

Dimension 9: Political Influence (Politics) = Level 3

Level 3 of complexity is most appropriate since there is considerable political influence in play within XYZ where several high-powered stakeholders have conflicting interests.

Dimension 10: Product and Project Size = Level 1

The project objective is to implement a well-known ERP system for the financial department. Level 1 of complexity would be most appropriate considering that the size of this project is not considered large for XYZ and that the implementation is within the range of capabilities of the consulting company ABC.

Dimension 11: Risk = Level 3

There is a significant amount of unknown risks due to the issues described in the case study. Level 3 is most appropriate, especially considering that the project manager and team have limited understanding of the possible risks.

Dimension 12: Stakeholder Interaction = Level 4

The highest level of complexity for this dimension is granted since the key stakeholders are not aligned with the project objectives or requirements, their interaction is ineffective, and there is no support from high-level executives to ensure project success.

Dimension 13: Technology = Level 2

The complexity due to technology can be considered level 2 since the technology is well established in the integrated software arena. The project uses mostly medium-tech technology, which can be characterized as based on existing technologies or a limited use of new technologies.

Dimension 14: Time Frame = Level 3

The faster than recommended pace also affects the time frame. Changes to requirements are expected to happen over time, and key relations and project plans would consequently be changing over time.

Dimension 15: Uncertainty = Level 2

The level of uncertainty could be considered 3 since for XYZ it is impossible to list all future scenarios and outcomes, but considering that ABC will be implementing the software, level 2 is chosen as the complexity level of uncertainty.

Table 6.3 – Complexity-level assessment based on fictional case study

Complexity Dimension	Level (1-4)
Budgetary Constraints	2
Clarity of Goals	3
Communication Quality	3
Degree of Trust	4
Dependency and Interdependency	4
Knowledge and Experience	2

Organizational Capability and Maturity	2
Pace/Speed to Market	2
Political Influence (Politics)	3
Product and Project Size	1
Risk	3
Stakeholder Interaction	4
Technology	2
Time Frame	3
Uncertainty	2

6.2.3.4. Graphical mapping of complexity levels (Element 3 of the model)

Once the complexity level is assessed, the model will present the results in a radar graph allowing the user to visualise the levels per dimension. Figure 6.6 shows the radar graph for the fictional case study.

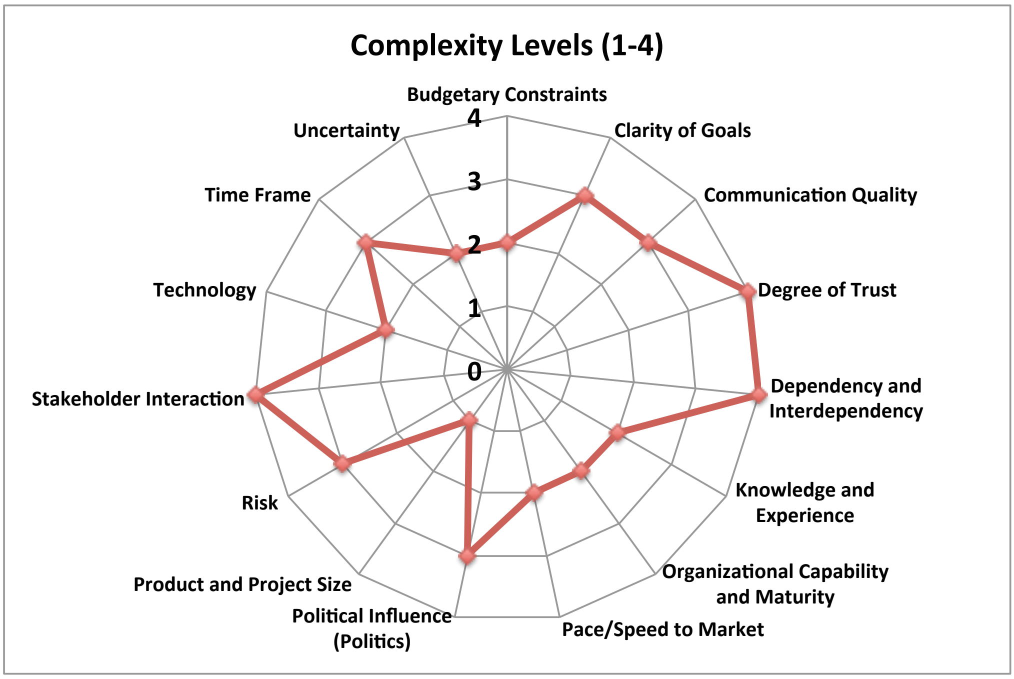


Figure 6.6 – Radar graph with results from fictional case study

6.2.3.5. Guidelines and recommendations for practitioners (Element 4 of the model)

Considering the 15 dimensions that are going to be part of the model, the following guidelines will be provided to project managers and cost estimators. Note that this is an initial list that should increase with contributions from practitioners as the model receives more input over time.

The priority is determined by the complexity level of each dimension. The highest priorities scored at level 4 (highlighted in red), followed by the ones with level 3 (highlighted in yellow), and finally the lowest priorities scored at levels 2 and 1 (highlighted in green).

6.2.3.5.1. High-priority guidelines (level 4)

6.2.3.5.1.1. Guidelines for dimension Degree of Trust

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.12.3 for more details.

1. Work with a best- and worst-case scenario to cover the situation in cases where there is no trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies. Depending on how bad the situation is, the complexity and risk could increase.
2. Assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted, and the cost estimate should reflect that assumption. On the other hand, if trust is broken it is very hard to recover. There are ways to develop trust or improve bad situations, but the reality cannot be ignored.

6.2.3.5.1.2. Guidelines for dimension Dependency and Interdependency

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.14.3 for more details.

1. Go back and review the dependencies, understand whether they impact other parts of the project, whether they are still valid, and whether changes were implemented. The reason for that is because estimators do their job based on the available information. Once the information is known, there is a chance to re-assess the existing estimates and adjust if needed.
2. Understand the dependencies and interdependencies. To do that, the estimator needs to consult the project manager and experts. There is a need to understand the schedule, the methodology used, and other plans. Furthermore, the estimator needs to

make sure the organization understand that estimates would be as reliable as the information available.

3. Do not use “lean” or “agile” approaches in complex projects. Instead, focus on the work breakdown structure and other traditional planning approaches.

6.2.3.5.1.3. Guidelines for dimension Stakeholder Interaction

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.10.3 for more details.

1. Implement a discovery effort to understand what interests and concerns the stakeholders have. During the project life cycle it is expected that stakeholders will have different interests and that new stakeholders might emerge, so the project manager should assure proper communication with them.
2. Implement a stakeholder management process to identify the stakeholders and their interests and motivations in order to provide them with the proper communications, and evaluate their influence.
3. Map all the stakeholders to better understand them, maximize the positive ones (favourable to the project), influence the neutral ones to become positive, and neutralize the negative ones.
4. Manage the interactions among stakeholders. The cost estimator should base the estimates on the information available, so it is recommended that close contact with the project manager be maintained to incorporate any necessary input.

6.2.3.5.2. Medium priority guidelines (level 3)

6.2.3.5.2.1. Guidelines for dimension Clarity of Goals

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.5.3 for more details.

1. Create a list of assumptions, recording the items that are being estimated and the ones that are not.
2. Develop a business case prior to starting the project. Many organizations decide to implement a project without a formally analysed and approved business case, but the most successful organizations are the ones that define a business case with proper cost

estimates and have an executive board that reviews business cases and makes decision on which ones should be part of the company's portfolio.

3. Develop even a small business case, allowing questions to be asked that could help clarify the project goals.
4. If cost estimators don't have enough information given to them, they should only estimate the part they know. Provide feedback about the lack of information. Seek an agreement that the cost estimate is limited to the portion of the project that is known.
5. Estimate the project by phases. The use of progressive planning allows estimators to focus on determining detailed cost estimates for small portions of the project at a time. When one small portion or phase is completed, the estimator has to go back to redefine the goals and budget for the next phase of the project.
6. Note that the estimator who understands that there are limitations of information but proceeds to estimate the cost will set up the project for failure. There is then a need to go back to the stakeholders and ask for clear identification of the goals or any other missing information.
7. Use Design Thinking or other estimation techniques. It is recommended to wait, step back, and invest time in going through the goals and scope of the project.
8. Use the Straw Man estimate and get the sponsor's feedback. The Straw Man technique consists of quickly putting together a first draft estimate with incomplete data so to create a temporary cost estimate that should then be discussed with the sponsor.
9. Use the SMART technique, starting on a higher level and going down to the deliverable level. For the lower levels, this technique will allow a better cost estimate. On the other hand it is crucial to understand the goals beforehand to avoid having a detailed and precise cost estimate of something that it not what the project is intended to be.

6.2.3.5.2.2. Guidelines for dimension Communication Quality

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.8.3 for more details.

1. Use communication techniques such as asking open-ended questions, active listening, making sure you are reaching out to the right people as you develop your cost estimate, and getting stakeholders involved in the cost estimation.

2. Discuss what you are estimating for with the customer. Discuss any aspects that need more clarity and involve the client so there is liability/commitment involved.
3. Create a communication plan with information including what to communicate, when, how, why, where, and so on.
4. Align the value proposition clearly and develop a business case that supports the project feasibility. The project should be aligned with the organization's strategic objectives and expectations should be clarified.

6.2.3.5.2.3. Guidelines for dimension Political Influence (Politics)

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.7.3 for more details.

1. Create a good relationship with the key stakeholders, improve the project manager's networking skills, and keep communication active. Include the project team and possible third parties.
2. Count on the executives to help with external political influence. Create a political map and associate it with the project risk plan. Contingencies might be added based on how big the risk is due to politics.
3. Ensure the existence of well-described goals, benefits, and success factors. These will actually support the success of the project. Political influence should actually be addressed as part of stakeholder management.

6.2.3.5.2.4. Guidelines for dimension Risk

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.2.3 for more details.

1. The cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. When there are high risks, increase the size of the management reserve.
2. Start by looking at the data sources and how reliable the data used for the cost estimation is, and consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.
3. Create a risk team with the participation of the project manager. This approach is based on having several people brainstorm to better understand all the parts of the

project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase.

4. The project manager or cost estimator has to consider that other dimensions will probably self-organize and impact the project in a positive or negative way, with focus on maximizing the chances of a positive impact.
5. Do a risk assessment to analyse the potential risks and create an action plan, supporting the cost-estimation process. Implement a risk-management process.

6.2.3.5.2.5. Guidelines for dimension Time Frame

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.9.3 for more details.

1. Do not underestimate the fact that the project will have changes and possibly new requirements.
2. Look beyond the first level of the work breakdown structure and understand that project managers should consider risks due to changes.
3. Focus on planning and include the time frame in all project documents.
4. Update the planning documents with constant analysis of the impacts on the time frame, which is the basis of the Rolling Wave Planning approach.

6.2.3.5.3. Low priority guidelines (levels 1 and 2)

6.2.3.5.3.1. Guidelines for dimension Budgetary Constraints

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.13.3 for more details.

1. Estimate the costs without any constraints and review the impact that each constraint will cause once you apply it. This approach is based on Eli Goldratt's work on Critical Chain applied to project management (Goldratt, 2002).
2. Document everything that is informed to the client and project team, so to support decisions based on a limited budget.

6.2.3.5.3.2. Guidelines for dimension Knowledge and Experience

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.4.3 for more details.

1. The organization should have or implement a knowledge-transfer system, a database that will host previous estimates, lessons learned, and performance results of various types of projects.
2. The project manager should look for people who have experience on similar projects and get their input, or in other words bring the necessary knowledge into the project.
3. Ensure proper staffing of the project by procuring resources that have the knowledge and experience necessary to deliver the project. If the internal people have this knowledge and experience then the project is less complex, and so is the cost-estimation process. If no internal resources are available, then there is a need to outsource part of the team, which increases costs, or to train the existing team.
4. Consider that complexity increases when a knowledgeable project team member leaves the organization or is allocated to another project. The organization should hire people with the proper experience and knowledge, who are well trained and ready to perform.
5. The executive level should know whether the organization has the proper resources to carry out the project and make the decision to move forward or not. The sponsor has the responsibility to clarify what is the main driver of the project—scope, time, cost, or quality.
6. Do not assign an inexperienced estimator to a complex project without some type of guidance. This might be associated with the project management maturity level of the organization and the existence of systems or processes that ensure such an approach. This system should support the estimator and provide a recommendation to look for experts' advice when the necessary knowledge is not present.

6.2.3.5.3.3. Guidelines for dimension Organizational Capability and Maturity

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to sections 5.7.1.3 and 5.7.6.3 for more details.

1. Ensure that the organization has and uses the right tools. Organizations that are very mature in managing their projects would provide their project managers with the right tools to do their work and manage complex projects. This includes the cost estimation and any necessary information-gathering techniques necessary for it.
2. Follow the process built into the existing methodology, considering that there is one. A proper methodology should allow an intelligent approach to contingency allocation and an understanding of how to build contingencies into the estimates.

3. Initially the organization has to measure its project management maturity level, followed by implementing actions that would increase the maturity level, and, if necessary, getting external help by hiring a consulting company.
4. Create a checklist based on the project management knowledge areas (i.e., scope, time, cost, quality, human resources, and risks) to verify how much experienced the people involved in the project have. One can use a simple Excel spreadsheet with a questionnaire with answers ‘yes’ or ‘no’, or high, medium, and low. Based on the answers, the spreadsheet would provide a contingency margin, which could be used during the estimation process.
5. Contact the client to better understand the strategic needs. A more mature organization should have processes in place that enable it to identify the overall cost and benefits of the project, and once the information is available use the work breakdown structure to identify tasks on the appropriate level for that project.
6. Executives have to provide proper organizational structure and resources to support the project management and team. Even with their busy schedules, this is a crucial success factor and directly impacts the cost-estimation process. If this aspect is ignored, executives might put the organization at risk and fail to achieve its strategic goals.
7. Understand what is being asked before addressing whether the organization is capable or not. It is the sponsor’s and the project manager’s responsibility to define whether the project is achievable, so it is not about the estimation process but foremost a capability question. If the conclusion is that the organization cannot deliver, this capability has to be acquired somehow (internally or externally). Should no option be found, the recommendation is to not proceed with the project.
8. Develop a system to help capture the relevant information for a proper cost estimate. Create a framework with templates and a process to support cost estimators. Once the project team gathers the requirements, the customer should be able to validate them. If the customer cannot do that, there is a significant risk of poor cost estimation, and the project manager should share this information with the customer.
9. Provide the most accurate estimates possible because even though an estimate is not a commitment *per se,* it is considered as such by the customer.

6.2.3.5.3.4. Guidelines for dimension Pace/Speed to Market

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.11.3 for more details.

1. Even though there is no guideline for senior management for dealing with the impact of a faster pace or speed to market, there is a technique developed for Project Management Offices (PMO) called Portfolio PMO. The role of Portfolio PMO is to provide executives with feedback as to whether or not the speed to market is correct, allowing the organization to validate whether it can deliver the project at this time, in the future, or not at all. The cost estimator should receive the same input to support the estimation process.
2. Be clear of what assumptions are being made and which gaps of information exist, allowing the performing team and the cost estimator to better do their jobs.
3. Consider that if there are a lot of assumptions due to the lack of information, the negotiation process requesting more feasible delivery dates is compromised and the cost estimates will end up higher.
4. The project manager and cost estimator should make the decision-maker (especially the one with financial power) aware of the situation. Simply tell the client what you are delivering, and this will open discussion on this topic.

6.2.3.5.3.5. Guidelines for dimension Product and Project Size

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.3.3 for more details.

1. When dealing with a new product or project, the use of the work breakdown structure (WBS) is paramount to better understanding the total scope of the project and each of the elements. Use all necessary resources, such as subject matter experts, to ensure that the WBS is as complete as possible. The reason is that the WBS will be used as the source for developing the schedule and the budget, so an incomplete WBS will reflect poor estimates of time and cost.
2. Obtain a maximum granularity of the WBS elements. Another piece of advice is to frame the deliverables in such a way that they can be delivered within the project phases, allowing several successes instead of a lengthy failure. The cost would also be easier to estimate and manage since one is delivering smaller components.
3. A project manager who starts a new project should hold back on working on other projects until a clear understanding of all product requirements is achieved. This

could optimize the use of resources and improve the cost-estimation process. Also, the size of the products and projects should be considered when analysing the organization's portfolio, as these factors have a direct impact on the organization's capability.

4. Should the organization decide to deliver new or large products that they were not delivering before, higher risks and greater impact on the cost estimation should be considered.
5. Involve the customer in the clarification of the product requirements and consequently in the work to be performed during the project. Listen to the stakeholders and plan and write down the details of the product and how it will be used in order to have a good product description and requirements.

6.2.3.5.3.6. Guidelines for dimension Technology

According to section 5.7.21, there are no recommendations at this time for project managers or cost estimators.

6.2.3.5.3.7. Guidelines for dimension Uncertainty

The project manager or cost estimator might consider the following recommendation(s) when estimating the costs of the project. Refer to section 5.7.18.3 for more details.

1. Analyse the risks involved with uncertainty and how to manage this situation through contingencies.

6.2.3.6. Updates on cost estimation (Element 5 of the model)

The updates on the cost estimation will be the result of implementing the recommendations and guidelines provided by the model. The updates can be beneficial at different stages as demonstrated in Figure 6.7.

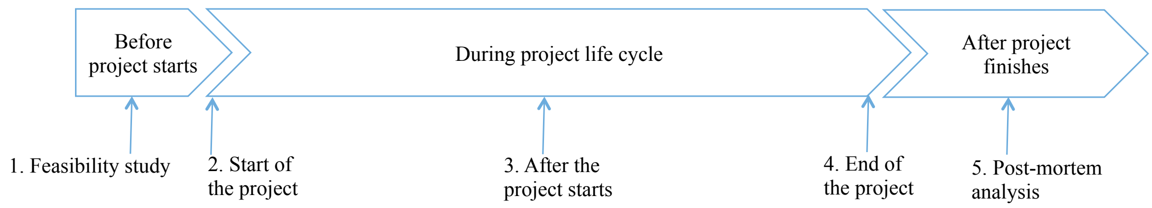


Figure 6.7 – Stages where the cost updates can be beneficial

1. Before the project starts: At this stage, the organization is going through a feasibility study, comparing the benefits and costs of the potential project. An initial analysis of the complexity dimensions and understanding of guidelines to reduce the impact of these complexities would prove useful in avoiding underestimating costs. On the other hand, there is the challenge of not having sufficient details about the project at this stage.
2. At the project start: Before the project is actually kicked off, an initial analysis of the complexity levels would prove useful in better guiding the project manager, cost estimator, and team on procedures to mitigate the impact of the identified complexities.
3. After the project starts: Even if the project already started, there is a benefit to analysing the complexity and implementing the guidelines so to adjust the initial cost estimate and update the upcoming phases of the project accordingly.
4. At the project end: When the project ends and before handing the final product to the client, an analysis of the complexity level of the project would allow the project team to make final adjustments to the project or product based on the guidelines, reducing any negative impact on the client.
5. After the project finishes: This post-mortem analysis serves as lessons learned with an updated cost estimate and list of recommendations for future projects with a similar scope.

The model would be an improvement to the existing cost-estimation process recommended by the Project Management Institute (PMI, 2012). The revised process would include additional steps related to Inputs, Tools & Techniques, and Outputs according to Figure 6.8 below.

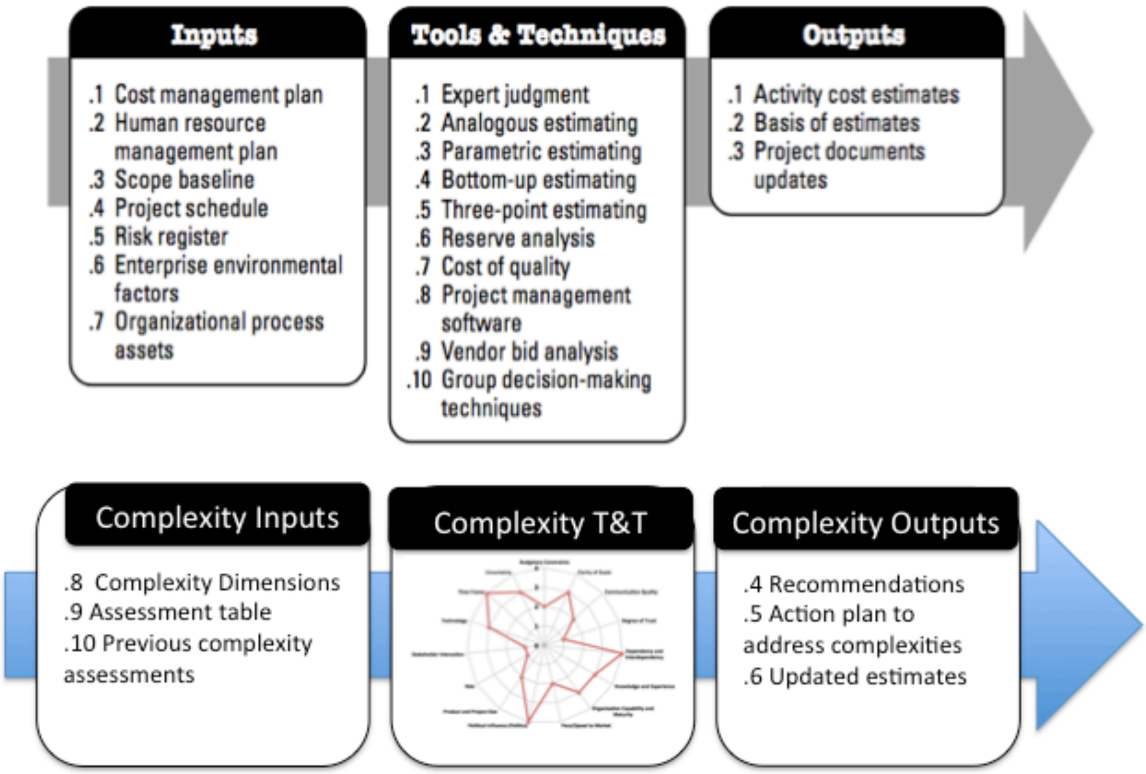


Figure 6.8 – Improved cost-estimation process

The model could also serve as a repository for new recommendations and guidelines as it evolves. New version of the model can be updated on an annual or semi-annual basis, and be shared with the project managers and cost estimators community of practice.

In summary, there are benefits to using the model at any stage of the project. Ideally a more preventive approach would be preferred but it might not be always possible.

The next section will provide a detailed step-by-step process to use the proposed model based on a real project.

6.3. Practical Step-by-Step Use of the Model

A step-by-step process for using the model is presented in the paragraphs below, using a real project managed by the researcher as a reference. Some details will be kept confidential. The example will show how a project manager or cost estimator practitioner would use the proposed model.

6.3.1. Project Shared Services

Project name: Shared Services

Project Objective:

Implement a pilot project for shared services within the organization, centralizing all activities that are not part of the core business to headquarters.

Company Background:

Company EX is part of the energy industry, well established, and with a long history of large projects. EX has a global presence, but each region operates independently from the others, which means that each region has its own back-office structure and personnel. *Back-office* refers to all services (or departments) that support EX's operations, such as human resources, accounting, information technology, office administration, procurement, accounts payable and receivable, and training. The main business of EX is to sell and distribute energy.

Project Background:

EX wanted to analyse the feasibility of implementing centralised service centres supporting all regions. For instance, the human resource service centre would provide payroll, career, training, and hiring, among other services. Considering that EX is a large organization, the project would be piloted in a regional affiliate named EXb, moving all back-office operations to the regional headquarters. Should this pilot be successful, a full rollout of the shared services approach would be done worldwide.

A feasibility study was done by the project manager and executive team. The initial cost estimate was USD 2 million (due to confidentiality, all numbers presented in this example are fictional) and the benefit was estimated at USD 5 million to be realized within three years. The costs included hiring a consulting company to help managing the project, cost of manpower to do the handover from EXb to EX's regional headquarters, training, and travel and lodging for personnel doing the handover. The benefits would be immediate reduction of manpower and, due to gain of scale, providing service centres with more negotiation power when dealing with suppliers.

The time frame for project delivery was 12 months. A decision was made to implement several project management best practices, such as investing more time in planning before executing the project. There was no issue with the time frame, nor any need to implement sooner due to market pressure, creating an environment where proper time for planning was allowed.

The key stakeholders, including executives, project manager, team members, functional managers, and headquarters personnel, were aligned with the objectives of the project. A decision was made to explain all the project details to the entire EXb organization to ensure good communication and build trust.

Main challenges of the project:

- Over 30 EXb employees would lose their jobs at the end of the project, so it could affect morale.
- The EXb people had to travel to EX headquarters, which is in a different part of the country, for handover, stay in a hotel for four-week periods, and return to their families only one weekend per month. There was a risk that many EXb employees would not want to be separated from their families for the duration of the project.
- Due to the employee-biased labour laws of the country, EXb employees could potentially bring lawsuits against the company that would significantly reduce the immediate benefits of the project. The probability of an employee winning such a suit was close to 100%. After the project, almost 40% of EXb employees did in fact bring such lawsuits and won, with additional costs on the order of USD 1.5 million.

Project management best practices used during the project:

- Frequent communication took place with all stakeholders.
- EXb implemented a three-month planning period prior to executing the project, which allowed the project team to do a detailed cost estimate and produce other project management deliverables (e.g., work breakdown structure, risk planning, etc.).
- EXb hired a job placement company to advise all employees who would potentially lose their jobs.
- The project was delivered one month prior to its deadline.

Overall the project was considered a success with the exception of the budget, since the cost estimate was underestimated by USD 1.5 million. The model, if used, would be able to identify the complexity aspects that caused the project to be over budget and recommend actions to mitigate or eliminate the impact. The next section will demonstrate how the model would be used.

6.3.2. Step-by-Step Use of the Model

The following step-by-step process will show how the model would be applied to a real project and which recommendations could have been used to reduce the impact on the cost-estimation process. Like section 6.2.2, a full print of the model is provided in Appendix C.2.

6.3.2.1. Step 1

The user will open the model and read the description of each of the 15 complexity dimensions as presented in Table 6.4.

Table 6.4 – Description of each level per complexity dimension

Complexity Dimension	Description of Complexity Dimension
Budgetary Constraints	Normally all projects have a limited budget. This dimension is related to how the budget constrains the ability to manage the project, which might add to the project's complexity level. If the organization is accustomed to managing a budget of a specific size (e.g., up to USD 100 million), a larger cost (e.g., USD 1 billion) would add a level of complexity to the project. Similarly, if the available budget is limited, the performing team might need to implement approaches that were not used before, which again creates an increased complexity level.
Clarity of Goals	This dimension defines how well defined the goals of the project are and the impact this has on how the project is managed and decisions are made. A lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance.
Communication Quality	This dimension is related to the quality of communication during the project. Communication barriers can bring disruption to the project and are considered one of the key reasons for project failure. Challenges in communication can be related to language, cultural aspects, organizational structure, geographical location, and communication methods. Communication involves both direct and indirect elements. Direct (or explicit) communication refers to written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or the true intention is not directly revealed.
Degree of Trust	This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (e.g., supplier and project team; senior management and project manager). The more trust there is, the less complex the project will be.
Dependency and Interdependency	This dimension deals with the relationships among the elements that make up the project. These relationships can be dependent (in which some elements are dependent on each other, and some are

	not) and/or interdependent (in which each element is mutually dependent on others). In a complex project, stakeholders might not know what the result of an interaction among the elements of that project will be.
Knowledge and Experience	This dimension is related to how much knowledge and/or experience the project manager or a key team member has regarding all elements (parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product.
Organizational Capability and Maturity	This dimension is related to how capable—structurally and technically—an organization is in managing the project and delivering the required product (Remington et al., 2009). It also addresses the degree of relative maturity that the organization has achieved in project management. The assumption is that more mature organizations will be better able to manage complex projects and deliver products.
Pace/Speed to Market	This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the product be aligned with market demands.
Political Influence (Politics)	This dimension is related to the level of internal or external political influence involved in the project. If political influence and interests lead to the approval of a project that might not be feasible, the chances of an overestimation of benefits and underestimation of costs increase.
Product and Project Size	It can be argued that a project should be over a minimal size to be considered a complex project. The premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple project would deliver a standard component, followed by a subsystem, moving to delivering an entire system, and finally to producing an array or system of systems.
Risk	Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project. This dimension defines specifically how much unknown (known-unknowns and unknown-unknowns) risks exist in a project and possible impacts on the management process and delivery of the final product.
Stakeholder Interaction	This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success can also be different. In many cases, powerful stakeholders have no direct participation in or awareness of what is happening in the project.
Technology	The term *technology* is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used in a specific project. Normally technology complexity is found in projects that use a new or untried

	technology. The complexity in this case would be associated with the number and variation of inputs and possible outputs. The less the team or performing organization knows or has used that technology, the more complex the project will become.
Time Frame	Time is often referred as having a direct effect on how complexity is perceived by project team members and stakeholders. Time frame is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the time frame of the project, notably with ones that have long durations. The longer the time frame, the more chances that changes will impact the project, which increases the level of complexity.
Uncertainty	The Cambridge Dictionary defines uncertainty as "a situation in which something is not known, or something that is not known or certain". This dimension is related to the level of uncertainty existing not just in a project, but also in the product or the development process. Even though complexity is different from uncertainty, uncertainty can be considered a dimension that can increase or decrease the level of complexity of a project.

6.3.2.2. Step 2

Once there is understanding about each complexity dimension, the user will evaluate each dimension on a scale of 1 to 4 (1 being the lowest level of complexity and 4 the highest). The analysis based on the real project described in section 6.3.1 is detailed below.

Dimension 1: Budgetary Constraints = Level 1

EXb has enough financial resources to implement the Shared Services pilot project without budget limitations, so this dimension does not affect its capability to deliver the project, pointing to a complexity level of 1.

Dimension 2: Clarity of Goals = Level 1

EXb did a great job clarifying the goals of the project and key deliverables to all stakeholders, so this dimension has no impact on the cost-estimation process, indicating a level 1 assessment.

Dimension 3: Communication Quality = Level 2

Even though EXb created and followed a comprehensive communication plan, making the project details available to the stakeholders, there was no way to eliminate the noise created by the people who would lose their jobs due to the project. There was some use of indirect communication, although it had no direct impact on the project. For these reasons, the level is assessed as 2.

Dimension 4: Degree of Trust = Level 3

As described in the above discussions of clarity of goals and communication quality, EXb followed the best practices of project management. This approach did not preclude the 30 people whose jobs would be eliminated from being suspicious of the executives. These employees questioned whether the communication was truthful and whether there were uncovered reasons for the project. The level of trust proved to be lower than expected, as more than 10 employees brought lawsuits against EXb. The level of complexity is considered to be 3.

Dimension 5: Dependency and Interdependency = Level 2

Even though this project is a pilot for shared services within the EX group, which would normally be assessed as level 3 or even 4, there is reasonable understanding by the decision-maker, project manager, and team of the dependency and interdependency of most elements. For that reason, the assessment of the complexity level falls on 2.

Dimension 6: Knowledge and Experience = Level 2

EXb had limited knowledge and experience about this type of project since it had never been implemented before, so it could be defined as level 3. On the other hand, the decision to hire an external consulting company to support this project reduces the complexity level to 2.

Dimension 7: Organizational Capability and Maturity = Level 1

EX (and consequently Exb) were assessed in the past as being highly mature in project management, considering its use of project management best practices, creation of its own methodology, and capabilities for benchmarking and continuous improvement. Allied to that, EX has vast resources and can put together the necessary organizational structure to support the project. Both situations point to a complexity level of 1.

Dimension 8: Pace/Speed to Market = Level 1

There was no pressure from the market to implement the project, besides the internal objective becoming a more effective energy company. EX and EXb were well positioned as leaders in the energy market. The assessment for this dimension is level 1.

Dimension 9: Political Influence (Politics) = Level 2

Level 2 of complexity would be most appropriate, considering that minimal political influence was affecting the project, other than the possible 'behind the scenes' conversations and discussions among the 30 people who would have their jobs eliminated. Some of them tried to influence executives to obtain advantages or assurances for the future.

Dimension 10: Product and Project Size = Level 1

The project size was quite small compared with other projects undertaken by EX and EXb. Projects over USD 100 million were not uncommon, which leads to a level 1 assessment of the complexity for this dimension.

Dimension 11: Risk = Level 3

The only aspect that would make this project move from level 2 to 3 is the fact that it was a pilot and never delivered before. There were simply unknown risks that even the most experienced companies would not have been able to discover.

Dimension 12: Stakeholder Interaction = Level 1

Due to the good alignment among the stakeholders involved in the project, their interaction was effective and high-level support was provided during the entire project. This scenario points to a complexity level of 1.

Dimension 13: Technology = Level 1

The project used previously used and well-established technology without any challenges for the project team, which directs the assessment of this dimension to level 1.

Dimension 14: Time Frame = Level 1

There were no changes in decision-makers, the requirements were stable, and the key relationships and project plans remained the same over time, which points to a level 1 in complexity related to time frame. The project was actually delivered one month prior to its deadline.

Dimension 15: Uncertainty = Level 2

The level of uncertainty could be considered 1 due to the relatively small size of the project for EXb. However, the fact that this was the first time a shared services project was implemented within the EX group, the complexity level will be assessed as 2.

The user will input the complexity levels as presented in Table 6.5. The complexity dimensions Degree of Trust and Risks scored a higher level of complexity. The other dimensions were assessed as level 1 or 2. It is important to remember that this process is subjective and depends on the user's perception of how impactful each dimension is for that project.

Table 6.5 – Shared services project: complexity-level assessment

Complexity Dimension	Level (1-4)
Budgetary Constraints	1
Clarity of Goals	1
Communication Quality	2
Degree of Trust	3
Dependency and Interdependency	2
Knowledge and Experience	2
Organizational Capability and Maturity	1
Pace/Speed to Market	1
Political Influence (Politics)	2
Product and Project Size	1
Risk	3
Stakeholder Interaction	1
Technology	1
Time Frame	1
Uncertainty	2

6.3.2.3. Step 3

Once the user assesses each dimension according to these four levels, the model will plot the dimensions into a graph as represented in Figure 6.9. Once plotted, the graph will give the user an overview of all the complexity dimensions and which ones are most relevant. Which dimensions had the higher complexity levels (degree of trust and risks) can be easily observed.

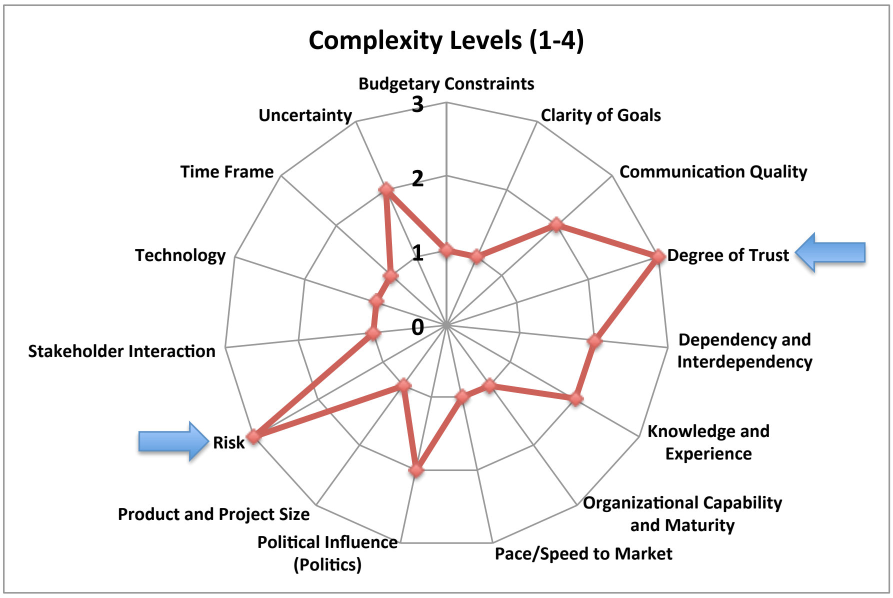


Figure 6.9 – Shared services project: graphical representation of the complexity dimensions

6.3.2.4. Step 4

A decision should be made regarding which complexity dimension guidelines the user will analyse and how to implement them. According to the assessment and as mentioned previously, two complexity dimensions were assessed at level 3 and should be addressed immediately action—degree of trust and risks.

Following these two dimensions, a possible next step would be to address the dimensions positioned at level 2, and finally those at level 1. The last two levels (levels 1 and 2) would get attention if enough resources and time are available to deal with them.

There is already a benefit to being aware of these complexity dimensions and how they might impact the cost-estimation process, but the model does not stop there. In the next step, the model provides a list of guidelines and recommendations that can be followed to reduce the impact of such complexity dimensions or to incorporate them into the cost estimate.

6.3.2.5. Step 5

The user decides which recommendations and guidelines to implement. A description of each guideline is provided below. Figure 6.10 shows how the model represents the guidelines for these two dimensions.

Guidelines for the complexity dimension degree of trust (refer to section 5.7.12.3 for more details):

1. Work with a best- and worst-case scenario to cover the situation in cases where there is no trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies. Depending on how bad the situation is, the complexity and risk could increase.
2. Assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted, and the cost estimate should reflect that assumption. On the other hand, if trust is broken it is very hard to recover. There are ways to develop trust or improve bad situations, but the reality cannot be ignored.

Guidelines for the complexity dimension risks (refer to section 5.7.2.3 for more details):

1. The cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. When there are high risks, increase the size of the management reserve.
2. Start by looking at the data sources and how reliable the data used for the cost estimation is, and consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.
3. Create a risk team with the participation of the project manager. This approach is based on having several people brainstorm to better understand all the parts of the project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase.
4. The project manager or cost estimator has to consider that other dimensions will probably self-organize and impact the project in a positive or negative way, with focus on maximizing the chances of a positive impact.
5. Do a risk assessment to analyse the potential risks and create an action plan, supporting the cost-estimation process. Implement a risk-management process.

Complexity Dimensions	Complexity Level	Guideline 1	Guideline 2	Guideline 3	Guideline 4	Guideline 5
Degree of Trust	3	1. Work with a best- and worst-case scenario to cover the situation in cases where there is no trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies. Depending on how bad the situation is, the complexity and risk could increase.	2. Assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted, and the cost estimate should reflect that assumption. On the other hand, if trust is broken it is very hard to recover. There are ways to develop trust or improve bad situations, but the reality cannot be ignored.			
Risk	3	1. The cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. When there are high risks, increase the size of the management reserve.	2. Start by looking at the data sources and how reliable the data used for the cost estimation is, and consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.	3. Create a risk team with the participation of the project manager. This approach is based on having several people brainstorm to better understand all the parts of the project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase.	4. The project manager or cost estimator has to consider that other dimensions will probably self-organize and impact the project in a positive or negative way, with focus on maximizing the chances of a positive impact.	5. Do a risk assessment to analyse the potential risks and create an action plan, supporting the cost-estimation process. Implement a risk-management process.

Figure 6.10 – Guidelines provided by the model for levels 3 and 4

6.3.2.6. Step 6

The final step covers how to implement the recommendations in a specific project. In the case of the Shared Services project presented in section 6.3.1, the following actions could mitigate the impact on cost estimation:

1. To address the trust issue related to the employees who would lose their jobs, the cost estimator should consider a worst-case scenario where employees might bring lawsuits against EXb and win. A contingency (or management reserve) should be considered that can cover anywhere from just a few employees bringing suits up to 50%. This would add between USD 100,000 and USD 2,000,000.
2. Another approach is to have an open conversation with these employees and ask if there is anything that can be done to assure them that EXb is looking out for their well-being after the project.
3. Establish a risk team to look for similar projects delivered in the past that led to employees losing jobs to better understand the likelihood of lawsuits. Revise the risk plan to include this possibility and calculate contingencies as described in item 1 above.

By following the action plan above, the following outcomes would be expected:

- Should the model be used during the feasibility study - prior to deciding if the project moves forward or not - the executives would know about the risks of lawsuits and trust issues. This information would help the executives to make a better decision on implementing or not the project
- Should the model be used after the project starts, the knowledge of the risks and trust issues could support the decision to allocate additional financial contingencies to the project budget.

- Another benefit of knowing about the risks and trust issues prior to the end of the project, is to have time to get closer to the employees, offering them more benefits during and after the project to mitigate the chance of lawsuits.

The upcoming section provides a summary of this chapter.

6.4. Chapter Summary

This chapter began by providing a theoretical background to support the construction of the model. The model itself was then proposed with details about its elements, description of each of the 15 dimensions, assessment of complexity level using a four-scale table with a description of each level, colour representation of the assessment results, graphical representation via radar graph, and a list of recommendations for practitioners.

Furthermore, a practical use of the model was introduced using a fictional case study and then providing a step-by-step process for implementing it using a real project.

The next chapter will cover the conclusions of this research, what was achieved compared with the original objectives, limitations, and future direction.

CHAPTER 7 – CONCLUSIONS

7.1. Introduction

The previous chapter described the proposed model to support the cost estimation for complex projects. This chapter reviews the research problem and objectives with a summary of the results obtained, reviews and proposes the contribution to practical and theoretical knowledge provided by this research, and, furthermore, lists the limitations of this research and proposes future research opportunities. Finally, a summary is provided at the end of the chapter.

7.2. Research Problem and Research Objectives

This research is part of a doctoral degree undertaken to address the problem of the lack of a model that takes into consideration the dimensions of complexity to support practitioners when estimating costs for complex projects. This research document provides the reader with a logical structure to navigate this discovery journey.

The aim of developing a model that incorporates complexity dimensions into the cost-estimation process for complex projects was broken down into five objectives. Each objective is described below with the respective results.

7.2.1. Objective One

The first objective was to explore the dimensions that determine the complexity of a project. This objective was achieved through a series of steps, starting with the literature review, which provided an initial list of 16 complexity dimensions (refer to section 2.5). These dimensions were confirmed and expanded by an additional seven through a document review of 27 complex project case studies (refer to section 4.4). The outcome was a list of 23 complexity dimensions that were later validated by over 50 practitioners during a global project management conference (refer to section 5.4). The initial list of 23 complexity dimensions in alphabetical order are: Budgetary Constraints, Clarity of Goals, Communication Quality, Cultural Resistance and Differences, Degree of Trust, Dependency and Interdependency, Economic Uncertainty, Environmental and Safety Impact, External Environmental Constraint, Impact on Society, Innovation to Market, Knowledge and Experience, Organizational Capability, Pace/Speed to Market, Political Influence (Politics), Product and Project Size, Project Description, Project Management Maturity Level, Risk, Stakeholder Interaction, Technology, Time Frame, and Uncertainty.

This series of steps allowed a more rigorous validation process, which provided more confidence about the results obtained up to that moment. Once objective one was achieved, it created the necessary knowledge and basis to analyse the complexity dimensions that are more important or impactful than others, which was a prerequisite to achieving objective three.

7.2.2. Objective Two

The second objective was to explore the characteristics of project cost estimations within the context of complex projects. This objective was achieved through a literature review, which provided the theoretical background to understanding the cost-estimation process used more often in projects and included additional input from two specific industries where cost-estimation processes were more abundant and with which the researcher had experience: construction and information technology. Details about the cost estimation process are described on section 2.6, information about the cost estimation on project-based industries is described on section 2.7, whereas the impact of complexity into the cost estimation is referred on section 2.8.

The findings revealed that the standard cost-estimation process used for project management (PMI, 2012) did not take into consideration a variety of complexity dimensions. A few exceptions were found, such as risk and time frame, but the majority of dimensions were not included in any cost-estimation process found during the literature review.

As important as the cost-estimation process itself, the impact that complexity has on estimating costs had to be considered as well. This review of the cost-estimation process and the impact of complexity are also foundational parts of this research. Both objectives one and two contribute directly to achieving objective four.

7.2.3. Objective Three

The third objective was to investigate which complexity dimensions are considered more important than others, eliminate the less relevant, and consolidate the similar ones. This objective was achieved by a further analysis of the initial results via a survey with 54 participants with the objective of ranking the level of importance of each complexity dimension. The survey was created to gather input from practitioners, academic researchers, and experts in the field on project management and complexity. The initial invitation was sent to 248 professionals, 54 of whom participated. The survey presented a brief explanation of each dimension and asked respondents to indicate the level of impact that the presented dimension would have on the cost-estimation process. A Likert scale varying from no impact to extreme impact was provided and the results were analysed using the relative importance index (RII). A rank of dimensions was provided per industry, covering construction, information technology, defence, manufacturing, energy, other industries, and a consolidated view (refer to sections 5.1, 5.2, and 5.3)

Based on the survey results, a further and deeper analysis was undertaken through detailed interviews. Of the 54 people who responded to the survey, a subgroup of 10 agreed to be interviewed. The interviewees were asked about the top five dimensions resulting from the survey, and were also able to select an additional five dimensions about which they described three main facets: the relevance of the complexity dimension, the impact of the dimension on the cost-estimation process, and guidelines for cost estimators. The results of the interviews served to generate a final list of 15 dimensions (refer to sections 5.6, 5.7, and 5.8). The final list has the following complexity dimensions in alphabetical order: Budgetary Constraints, Clarity of Goals, Communication Quality, Degree of Trust, Dependency and Interdependency, Knowledge and Experience, Organizational Capability and Maturity, Pace/Speed to Market, Political Influence (Politics), Product and Project Size, Risk, Stakeholder Interaction, Technology, Time Frame, and Uncertainty.

7.2.4. Objective Four

The fourth objective was to model the links between the complexity dimensions and their impact on the cost-estimation process. The objective was achieved by putting the following components into the model:

- Final proposed list of 15 complexity dimensions based on the literature review, case studies document review, validation during a global congress, survey, and interviews (refer to sections 5.5, 5.9 and 6.1).
- An assessment grid using a Likert scale with the following levels: level 1—no impact on the cost-estimation process and project; level 2—limited impact on the cost-estimation process and project; level 3—significant impact on the cost-estimation

process and project; and level 4—catastrophic impact on the cost-estimation process and project (refer to section 2.5).

- A graphical representation, via radar graph, of all 15 complexity dimensions and the result of the assessment (refer to section 6.1).

Using these components, a model would create awareness among cost estimators during different stages of the project. It can be used before the project starts to support the initial cost estimate and feasibility study by pointing to factors or dimensions that are normally not considered during traditional cost estimation. It can also be used to support the planning stages of the project, when a detailed cost estimation is performed to support the execution and delivery of the product, service, or result. It can also be applied as a review of the existing cost estimate at each new phase of the project (refer to section 6.2).

As stated previously, many authors state that a model represents a system or reality that can help people to know, understand, follow, or simulate the subject it represents (Williams, 2002; Badiou, 2007; Hass, 2009). A model that represents the complexity dimensions acting on a project brings to the user additional clarity on other aspects that might otherwise not be considered. It is proposed that a visual representation of this information through a radar graph would be most effective (Hass, 2009).

7.2.5. Objective Five

The fifth and final objective was to provide recommendations and guidelines for decision-making on a better upfront estimate of complex projects. This objective was achieved through the input received during the interviews, when each of the 10 practitioners provided recommended guidelines for each of the dimensions they considered most relevant. This information was then aggregated by complexity dimension and would serve as a list of recommended actions that a project manager or cost estimator can implement to reduce the impact of such dimensions on the project and consequently on the cost estimate.

As stated previously, each project is unique and as such each representation of complexity will also be a subjective and individual 'picture' of that project's complexity background. This aspect supports the initial thought that the proposed model should be dynamic, with the results of the assessment, mapping, and recommendations varying from project to project.

Furthermore, one cannot conclude that the list of over 60 recommended guidelines is complete or all-inclusive. The content was based on input from 10 practitioners and represents their collective viewpoint of what has to be done to deal with the complexity dimensions identified in a given project. It is recommended that this list be expanded with input from other practitioners as they use the model (refer to sections 5.7 and 6.2.3.5).

7.3. Contribution to Knowledge

This research contributes to existing knowledge by reviewing the concepts of complexity and summarizing them into a simplified view focused on one not knowing how each element of the project impacts the others and the project itself (section 2.3). Another important contribution to knowledge is to identify the complexity dimensions that impact projects and specifically impacting the cost estimation process. Following the identification of the complexity dimension, this research also provided a list of the more important dimensions and the less ones, which was not found on any previous research.

Finally, the research problem points to the lack of a model that takes into consideration the dimensions of complexity to support practitioners when estimating costs for complex projects. By developing such a model based on the literature review, case studies, survey, and interviews, this research would add to the 'pool' of existing knowledge. The other relevant aspect to be considered is that this model is not limited to a generic representation of the complexity level of a project, but is actually linked to the cost-estimation process and, furthermore, creates awareness about complexity factors during the cost estimation. It is expected that the results of this research will allow a better cost-estimation process for industries where project complexity occurs more often.

In summary, being able to represent the complexity dimensions that impact the cost-estimation process, assess their level of complexity, and provide guidance to practitioners represents a unique research proposal that has not been done before.

7.4. Limitations and Future Directions

As often occurs, the research efforts and consequently the results were subjected to constraints of time frame and available resources. The following list presents limitations of and future directions for this research:

a. The survey with 54 respondents was largely concentrated in the construction (41%) and information technology (24%) industries, which account for almost 70% of all results. This situation could influence the results towards these two industries and limit to represent other industries. Similarly, due to the network of both the researcher and the supervisor, 43% of respondents were based in Latin America and 39% in EMEA, accounting for 82% of all results.

b. The document review of 27 case studies was based on a group of 136 complex project reports from Aviation Week Network's Program Excellence initiative, covering the years 2008 to 2013. To ensure the broader representation of different industries, this research covered industries such as telecommunications, information technology, avionics, logistics, construction and engineering, defence, and education.
c. Further research could be done to improve the uptake of the model in a given industry and observe its effectiveness.
d. New publications in the literature after the publication of this research might provide additional insight.

7.5. Final words

There are two main areas where this research has contributed to existing knowledge. The first is the theoretical contribution of proposing a definition of complexity (section 2.3), a list of 15 complexity dimensions that would impact the cost-estimation process, and a model that would represent the complexity level of a project.

The second is the practical implementation of the proposed model by cost estimators. The model would help practitioners assess the status of a project related to the 15 complexity dimensions, map the results graphically, and provide guidelines that can be followed by cost estimators during their work. It is expected that the model will improve the accuracy of cost estimates.

APPENDICES

APPENDIX A – SURVEY TEMPLATE

EMAIL INVITATION FOR PARTICIPANTS

Dear Sir/ Madam

I am Leon Herszon, a PhD student, at School of Architecture and the Built Environment, the University of Huddersfield (UK). The main aim of my research is to develop a model that incorporates complexity dimensions into the cost estimation process for complex projects.

As part of achieving the research objectives, we are seeking the views of experienced project management practitioners in complex projects through a survey according to the following principles:

- Participation is completely voluntary.
- Participants are free to withdraw their consent at any time and all the information will be destroyed.
- The survey should take no longer than 20 minutes.
- Information and data obtained will be analysed by the researcher solely for the purpose of this research.

I would like to invite you to spend a few minutes of your busy time to think about the process of estimating costs in your last 3 (three) complex projects. If you have any concerns about the conduct of this research, please contact my supervisor, my local advisor, or me.

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Thank you,

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SURVEY: PROJECT COMPLEXITY DIMENSIONS THAT IMPACT THE COST ESTIMATION PROCESS

Letter to participants

Dear colleague,

As part of my PhD research, I would like to invite you to invest a few minutes to think about the process to estimate costs on your last 3 (three) complex projects. I am currently defining a complex project as a project where you cannot predict how one or more elements of the project might affect the others and, for that matter, you cannot completely predict the final outcome of the project.

When you estimated costs, which were the factors (hereafter called complexity dimensions) that you considered? For example, most practitioners consider risk as a factor when estimating costs. You will be provided with a list of 23 (twenty-three) complexity dimensions found during the initial stage of the research, with a brief definition and an example for clarification purposes.

Based on the list provided, you will be asked to assess how much impact each complexity dimension had on your projects. You may include any comments, and suggest others dimensions that might not have been listed.

The results of this survey will be helpful to identify the key dimensions that should be considered when building a model to support better cost estimates. You will have access to the final results as they become ready.

Your contribution is appreciated and your information will be kept **confidential**. Please feel free to contact me should you have any questions.

Thank you very much

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Survey – Part 1 of 3

Dear colleague:

Based on your experience and understanding, think about your last 3 (three) complex or challenging projects. What were the main factors of complexity (hereafter called complexity dimensions) that had a major impact when estimating cost? You are being asked to rank each of the listed 23 complexity dimensions on the Likert scale of 1 to 5. For each dimension, think of the project where this dimension had the most impact and rank it. Just mark with an "X" where it applies. The dimensions are listed in alphabetical order.

Please Answer the Following Question: How much impact did this dimension had when you estimated cost on your last 3 complex or challenging projects?

1. No impact
2. Minimal impact
3. Some Impact
4. Significant impact
5. Extreme impact

Dimension	Description	1	2	3	4	5
1. Budgetary Constraints	Normally all projects have a limited budget. This dimension is related to how it constrains the ability to manage the project, which might add to the complexity level of the project. Example: If there was a limit placed on the project's budget, the performing team might need to implement changes that had previously not been considered, such as reduced scope or performance.					

Dimension	Description	1	2	3	4	5
2. Clarity of Goals	This dimension defines how well defined the goals of the project are and the impact this had on how the project had been managed and its decisions made. The lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance. Example: A goal of "improving the work environment" is vague, not measurable, and not specific; different stakeholders may interpret it very differently.					
3. Communication Quality	This dimension is related to the quality of the project communication on the project. Communication barriers can bring disruption to the project and are considered one of the key reasons for failure in projects. Challenges in communication can be related to language, cultural aspects, organizational structure, geographical location, and communication methods. Communication has both direct and indirect elements. Direct (or explicit) communication, such as written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or when the true intention is not directly revealed. Example: In direct communication, more value is placed on honesty than on being polite; in indirect communication, the opposite may be true. This dimension can be greatly impacted by the cultural background of the people involved.					

Dimension	Description	1	2	3	4	5
4. Cultural Differences and Resistance	In today's world, team members and stakeholders might come from various parts of the world with different cultural backgrounds. Cultural differences can impact the project and create resistance around tasks that need to be performed. As cultural clashes increase, the more complexity is added to interactions between stakeholders. Example: The Airbus A380 project that was done by five different countries, faced confusion in work coordination due to country-specific cultural practices.					
5. Degree of Trust	This dimension examines the degree to which stakeholders have a trusting relationship with each other (i.e., supplier and project team; senior management and project team). The more trust there is, the less complex is the interaction. Example: If a project manager does not trust the team—and for that reason does not share sensitive but important information—there is additional level of complexity due to the lack of transparency and clear communication.					

Dimension	Description	1	2	3	4	5
6. Dependency and Interdependency	This dimension deals with the relationship between the elements that make up the project. This relationship can be one of dependency (in which some elements are dependent on one another, and some are not) and/or interdependency (in which each element is mutually dependent on others). In complex projects, you might not know what the result of an interaction between the elements of that project will be. Example: The weather forecast, where we don't know how, or if, a specific event occurring in another part of the world will impact the local weather—as in the "butterfly effect".					
7. Economic Uncertainty	This dimension is related to the existing economic environment for an organization (on a local, regional, country, or global level) and the challenges that this environment presents to the project. Economic uncertainty can result in a lack of stability with regard to many variables that might affect the project. Example: Times of economic crisis (i.e., the 2008 global financial crisis) have an impact on most organizations and consequently add complexity to existing projects.					
8. Environmental and Safety Impact	This dimension is associated with the degree to which a project may have an impact on the environment and/or safety of those within the organization and community. Example: Building a factory at a specific location might endanger local fauna or increase the levels of pollution, thus adding new variables to the project's feasibility and complexity levels.					

Dimension	Description	1	2	3	4	5
9. External Environment Constraints	This dimension is related to the existing external environment of an organization (on a local, regional, country, or global level) and how it adds to the complexity of a project. Factors such as changes to existing regulations, the fluctuation of the market, and a shift in the political or regulatory environment are included here. Example: A change in taxation can significantly impact the feasibility of a project.					
10. Impact on Society	This dimension is related to the impact of the project on society and how it will affect the social interactions, stakeholders, and communities. A typical measure of impact is the social impact assessment (SIA), a methodology to review the social effects of infrastructure projects and other development interventions. Example: The Affordable Care Act (Obamacare) in the United States had a huge impact on the project's complexity, and was perhaps not considered upfront.					
11. Innovation to Market	This dimension is related to the level of innovation or uniqueness of the product generated by the project. Innovation level impacts market-related activities, time, and effort to define and "freeze" requirements. The higher the innovation level, the more difficult it is to establish and keep the requirements as originally defined. Example: Releasing a similar product with a new colour involves a lower level of innovation than when the first Post-it® note was launched in the market, and no one has used it before.					

Dimension	Description	1	2	3	4	5
12. Knowledge and Experience	This dimension is related to how much knowledge and/or experience the project manager or a key team member have regarding all elements (parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product. Example: The development of a software would be much more complex for a project manager with construction experience than for a project manager previously involved in the software industry.					
13. Organizational Capability	This dimension is related to how capable (structurally, technically) an organization is in managing the project and delivering the required product. It is also directly associated with the appropriate selection of project personnel. Example: A company that does not have technical people with experience developing applications on the "cloud" would encounter an extra layer of complexity when they engage in such a project.					
14. Pace/Speed to Market	This dimension is related to how fast the project should be completed or the product should enter the market. The less time there is to manage and deliver a product, the more layers of complexity there are. Example: Responding to a catastrophe (i.e., 2005 Hurricane Katrina, 2010 Gulf of Mexico oil spill) with limited time to plan and execute is much more complex than implementing a frequently executed type of project.					

Dimension	Description	1	2	3	4	5
15. Political Influence (Politics)	This dimension is related to the level of political influence involved in the project. The political influence can be internal or external to the project and the organization. The stronger the political influences to assure approval of that project and to attend the interests of certain stakeholders, the higher the chances for an overestimation of benefits and underestimation of costs. Example: The Eurotunnel project suffered extensive political influence, which made the project more complex.					
16. Product and Project Size	This dimension is related to both the size of the product, service, or result produced by the project (measured by financial size, number of resources, number of elements, etc.), – or to the amount of work that needs to be done to deliver the product, service. This dimension is considered as a critical aspect of project complexity. Example: The London Olympics involved many different elements and sub-projects, several years to complete, and a budget in the order of Billion Pounds (£).					

Dimension	Description	1	2	3	4	5
17. Project Description	This dimension focuses on the level of difficulty encountered when describing the project, including all of its elements. Even though this might be influenced by how much knowledge or experience one has with a specific type of project, it is not the same as dimension # 9 (knowledge and experience). It is possible to have knowledge and experience about a project but be challenged when describing the project, its scope, interactions, and components. Example: Describing a project to create new software to control the stock market to an audience that has no financial literacy.					
18. Project Management Maturity Level	This dimension addresses the degree of relative maturity that the organization has achieved in project management. There are several models that measure this, all of which use a five-level approach. The assumption is that more mature organizations will be better able to manage complex projects and deliver the products. Example: A company like IBM, who has a more mature project management level, will be better equipped to manage the adaptive nature of complex IT projects than a company that is still working to get a common project management language implemented.					

Dimension	Description	1	2	3	4	5
19. Risk	A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project. Also it becomes clear that the more risks—specially the unknown ones—the more complex a project might be, since one does not know what can happen and the repercussion to the other elements of the project.					
20. Stakeholder Interaction	This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different (and some times conflicting) interests, motivations, and power levels. Their views of project success can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening on the project. Example: Financial managers in the company may look at the budget and meeting schedules, while technical managers may be concerned with the best solution to the customer, and may recommend increasing the budget to overcome unexpected problems, on take advantage of new opportunities.					

Dimension	Description	1	2	3	4	5
21. Technology	The term *technology* is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used on a specific project. Normally technology complexity is found on projects that use a new or untried technology. The less the team or performing organization knows or has used that technology, the more complex the project will become. Example: The Apollo program, which had the objective of landing Americans on the Moon and return them safely to Earth, had to create technologies that were never used before					
22. Time frame	Time, which is often being referred on the literature as having a direct effect on how complexity, was identified as a dimension by both project team members and stakeholders. Timeframe is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the timeframe of the project, notably with ones that have long durations. The longer the timeframe, the more chances that changes will impact the project, which increases the level of complexity. Example: Building the necessary transportation infrastructure for the 2014 Soccer World Cup was impacted by changes in priorities during the length of the project and ended up not being implemented.					

Dimension	Description	1	2	3	4	5
23. Uncertainty	Uncertainty presented itself as an important aspect of complexity, since one cannot forecast the outcome of the interactions between elements, which makes managing such project very challenging. This dimension is related to the level of uncertainty existing, not just in a project but also in the product, or in the development process. Other dimensions can also impact the level of uncertainty, like innovation to the market and technology. Example: Developing a new drug where the side effects are not known.					

Survey – Part 2 of 3

Considering the previous part, we would appreciate your input to the following questions. Note even though this part is OPTIONAL, we greatly appreciate your opinion.

1. Are there any other complexity dimensions that impacted your projects but were not listed before? Please describe below.
2. What do you think about the cost estimation process in general? Why is it so difficult to estimate cost for complex projects, and why there are so many projects ending over their planned time and budget?
3. Any additional comments you may have about this research?

Survey – Part 3 of 3

What was the variation in % between the original estimate and the final project cost?

For each one of the three projects, think of a **combined** level of complexity represented by the project (based of all dimensions you can imagine). Rank this complexity on the scale of *<Extremely High complexity, high complexity, medium complexity, low complexity>,* and assess the impact that this complexity had on the budget increase from the initial estimate to the final cost. Feel free to use your best approximation.

Project 1:

Complexity level: <Extremely High complexity, high complexity, medium complexity, low complexity>

Variation Percentage (**Δ%**): ________% or

Initial estimate (USD 000):______________ Final Cost (USD 000): ________________

Project 2:

Complexity level:

Variation Percentage (**Δ%**): ________% or

Initial estimate (USD 000):______________ Final Cost (USD 000): ________________

Project 3:

Complexity level:

Variation Percentage (**Δ%**): ________% or

Initial estimate (USD 000):______________ Final Cost (USD 000): ________________

Thank You Letter

Dear participant,

First of all, I would like to thank you for your time responding this survey. As mentioned before, your input is strictly confidential and the consolidated results will be shared with you as soon as ready.

Warm regards

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APPENDIX B – SUMMARY OF INTERVIEWS

A sample of the interviews with interviewee 1 and interviewee 2, presenting the key findings is presented on the next pages, divided by topics.

1. Feedback about Survey results:

<u>Question</u>: Based on your experience, would you agree with the top ten dimensions presented as a result of the survey? Why? In case you do not agree, which dimensions you would consider more impactful on the cost estimation process for complex projects? Why?

Participant 1: 'First of all, we really are not looking at Project Management Maturity Levels. What we want to look at instead is Project Management Capability, and this is an important distinction. And if we think we are only thinking in terms of levels, we are wrong. We need to be thinking in terms of capabilities. I also do not agree about the Risk part.'

Participant 2: 'The 2 most important skills that a project manager should have are the **ability to handle stress** and to **understand what's meant by burn out**. PMs that can handle stress and prevent burnout can handle any type of project. And any project you have can be considered to be complex based upon how you look at it.'

2. How Different is the Cost Estimation Process for Complex Projects

<u>Question</u>: How do you consider the cost estimation process to be different when dealing with complex projects? Why? Please elaborate based on your experience.

Participant 1: 'I do not really think it is different in dealing with complex projects. It is more a common concept today and key areas to ensure projects add business value. So I really do not think that there is any difference in it.'

Participant 2: 'If the project is perceived as being a complex project, and the project manager, you notice that I said "and," and the project manager believes that there are risks associated with it, and that's one of the five items you identified. It's the risks that identify the size of the management reserve to compensate for the complexity. The way **most project manager's deal with complexity is by management reserves**. And that could be a management reserve on time, or a management reserve on cost. But it's simply based upon the risk. I can manage a complex project that I think is a very, very low risk, and I won't consider any management reserve to help me. But if I think it's a complex project and I think there's a risk associated with it, I'll put in a management reserve, or I'll put in some padding in the schedule.'

3. Which Cost Estimation Process was Used on Last Complex Projects

Question: Which cost estimation process did you use on your last 2-3 complex projects? Was this approach successful? Why?

Participant 1: 'I always used analogous estimating. My business partner in my consulting firm used bottom-up estimating. I used analogous and we used my analogous estimate on everything we did. We had probably a 90 to 95% win rate. The win rate is far more than just your cost estimate because you have got to take into determination everything else that you are putting into your proposal, your understanding of the client situation, the problem, your ability to help the client, or to better than that, help the client, anticipate the client's future needs.'

Participant 2: 'See, this is a very hard question to answer. I'll tell you why. Because it's based upon whether it's an internal project, or whether it's being done for an external client as part of competitive bidding. If it's an **internal project**, I used to have certain criteria that I would use to manage complexity. I would consider a **management reserve of maybe 5 to 8%.** But if it's part of **competitive bidding**, and my marketing people tell me that **adjusting the cost to compensate for the complexity would make us non-competitive**, what am I going to do? So you have to clarify who the client is, whether it's an internal or an external client, because the way you look at it is different. But we had factors that we used to use for complexity.'

4. How Complexity Dimensions Interact with Each Other

Question: How do you think complexity dimensions interact with each other (dependency or interdependency between complexity dimensions)? How would this interaction impact the success/failure of the cost estimation process? Why?

Participant 1: 'I am not really sure how much they do interact with each other. I am looking at a paper I wrote for PMI in this area right now, and I am unsure how much they do interact. I would say there would be an interaction as to an overall view of the value of a project or a program to an organization; and, for example, if I were working in portfolio management, I would want to make sure that what I was doing really supported the organization's goals and objectives. Therefore, a lot of these dimensions would affect the overall goals and dimensions.'

Participant 2: 'It's very, very high. If you don't understand the interdependencies, then you could virtually get severely punished in a project. I mean, there's no question that the interdependencies are absolutely critical, provided you can define them up front and understand what they are. You've got 23 variables. If you take the 23 variables, you know, and you put forth a factorial expression and you look at 2 of these at a time, you know, you've got 24 times 25. I could come up with more than 600 different situations. So **some of these factors can come and go over the life of a project.**'

5. About the Complexity Dimension: Project Management Maturity Level

5.1. Question: From the survey results, it is observed that dimension Project Management Maturity Level is ranked #1 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'Absolutely. And so my suggestion, therefore, is to look at the Terry Cooke-Davies work, to look at the PMI, OPM3 knowledge book from 2013 and perhaps change it over to Capabilities. Therefore if you change it over to Capabilities, you want to be capable in cost estimating, right? You want to be capable in schedule management; you want to be capable in scope management. So really it is all about capability.'

Participant 2: 'I'd say the answer you would expect most people to say is yes, because in order to handle complex projects, project managers need the right tools. And organizations that are really reasonably mature in project management provide project managers with the right tools to handle project complexity. **based upon an individual's experience and the type of projects they manage, whether, for example, it's for an internal client or an external client, they can prioritize these differently**. It doesn't mean what you have is wrong. It means **it's their perspective of complexity**.'

5.2. Question: How do you think that the dimension Project Management Maturity Level will impact the estimation process of complex projects?

Participant 1: Answered previously.

Participant 2: 'Project managers need tools. There has to be some sort of standardization within the organization based upon, you know, the degree of complexity. It's not simply saying something is complex. There has to be degrees of complexity, and each degree of complexity has to be associated with perhaps a different estimating function. For example, the more complex something is, the greater the likelihood is that you'll go into the deeper levels of the work breakdown structure for estimating.'

5.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: Answered previously.

Participant 2: 'Well, it's not the maturity level you're advising them, it's whether or not the organization is mature enough to have templates, guidelines, templates, and checklists for assisting the project manager in evaluating complexity. The maturity level is irrelevant. It's **whether or not the methodology which is in level 3 of the maturity level provides you with the sufficient tools for analysing complexity.**'

6. About the Complexity Dimension: Risk

6.1. Question: From the survey results, it is observed that dimension Risk is ranked #2 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: We can never identify all risks, I believe risk management is overdone since There is always going to be something that comes up that you cannot plan for in advance. So I would change this dimension. I would change it over to Opportunities. There is too much attention to risk management, there are too many sophisticated tools and techniques. It has to be a full-time job, and it's important on very large projects, on projects that even are small. But you can overdo it, and that is what's going on to me in today's world.'

Participant 2: 'I think risks could be number one in some service, because what a lot of people define complexity is dealing with unknown situations. And when you talk about unknowns, you're dealing with potential risks. You know, there are risks that are known and there are risks that are unknowns. Both of those can lead to complexity. It's the **unknown risks that often leads to severe complexity**.'

6.2. Question: How do you think that the dimension Risk will impact the estimation process of complex projects?

Participant 1: Answered previously.

Participant 2: 'Whenever functional managers or workers would give me an estimate, I would ask them, "What's the risks associated with your estimate?" And they would then tell me, you know, 10%, no risk at all, we're sure we can do it for that cost. The Problem you have is that all of the other 22 items that you've identified, all are impacted by the risk they create. **Risk is attached to every one of the other 22 elements, every one.** Try to separate out risk—doesn't work. Any dimension you come up with that a project manager considers as important is going to have an associated risk with it. It could be a low risk, it could be a high risk.'

6.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: Answered previously.

Participant 2: 'Many times the cost estimation is based upon the risk estimation, the risk management plan you have for a project. Some projects that are a low risk, well, it doesn't have any impact on cost. If it's a high risk, then it could impact the size of the management reserve. **If this project is considered to be 10% more complex than our previous project, you'll increase your estimates by 10%.** A **budgetary estimate is when you take a traditional estimate for doing the job and you multiply it by a difficulty degree factor**.'

7. About the Complexity Dimension: Product and Project Size

7.1. Question: From the survey results, it is observed that dimension Product and Project Size is ranked #3 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'All project work is complex regardless of its size, and project professionals have been dealing with complexity since ancient times. The difference today is it's a much more common occurrence and has become a key area to navigate to make sure projects have add business value". So I do not believe there is any difference in product and project size in the complexity dimension.'

Participant 2: 'No I don't. The size of the project has nothing to do with the risk. I can have a very small project that lasts for 3 weeks, and I can deal with as a high risk project. Now it is true that the larger the project, the greater the risks. The larger the project the greater the cost overruns and the schedule slippages. In that regard, yes. But you could also have small projects and small products that have a great deal of risk and complexity as well.'

7.2. Question: How do you think that the dimension Product and Project Size will impact the estimation process of complex projects?

Participant 1: 'It's actually not about the size of the product or project, but it's about how many times you have done, or many other different variables, but it's not about the size.'

Participant 2: 'The larger the project, the greater the chance for cost overrun and schedule slippage. So the tendency is if it's a very large project to develop contingency plans for schedule slippages and cost overruns. Generally on a small project you might not put in a management reserve, but large projects, with regard to cost or time, you usually have some type of management reserve.'

7.2. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'If they have never done it before, I would give this individual advice that the most important thing to do is to do a work breakdown structure and make sure you understand the total scope of the project, and to make sure the WBS is as complete as it possibly could be because, to me, it is the most important tool in project and program management, and then it is what you use to do your schedule, and your cost estimate, and your resource estimate. If the person has done it before, and if the person has been successful, that is obviously a major help, and so I would hope that the person has documented what he or she did previously, and has it easily and readily available, and can retrieve it, and use it, and build upon it.'

Participant 2: 'If you're going to start on that project, you should hold back on one of the other projects until you understand that you're managing complexity. Or else you could have a significant financial problem in the middle of the year. So the size of the project and the products are normally considered as part of portfolio management. That's where the risks have to be considered.'

8. About the Complexity Dimension: Knowledge and Experience

8.1. Question: From the survey results, it is observed that dimension Knowledge and Experience is ranked #4 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'I believe Knowledge and Experience is exceedingly important, but what do we mean by knowledge? Often we think about knowledge, and we think of it as something that somebody acquires over the years. And it should say "Knowledge Assets" because that is what the person has. The person really does not have knowledge per-se; he or she has knowledge assets that one could bring to the project. Therefore, someone who is new to the organization, and is a young person, they have some different knowledge assets to share than someone who has been working for years and years. Experience is also great, but experience has to be kept up to date.'

Participant 2: 'I would have that as one of the 5. You know, the definition of a project, the traditional definition of a project is something you've never done before, and something you might never do again. It's unique. If it weren't unique, you wouldn't be managing it. A line manager would be managing it. And anything that's unique, you need information to know what you're doing. You don't have information, then all of a sudden it could become a high-risk complex project.'

8.2. Question: How do you think that the dimension Knowledge and Experience will impact the estimation process of complex projects?

Participant 1: 'A knowledgeable person can help to do the analogous estimate, and especially if the person's worked on comparable projects in the past, and also can probably speed it up.'

Participant 2: 'The question is whether or not you have the right resources capable of managing that project. If you don't have the right resources to have the knowledge and the experience, and you may have to outsource the work, it could be significantly more expensive than doing it internally. And you would really have to know that at the onset of the project, not downstream.'

8.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'My advice is hopefully that organization has some type of knowledge transfer system in place. Hopefully the person is able to then draw upon it and use it for the new project. So a knowledge database, like lessons learned, or database with results, and estimates.'

Participant 2: 'Again, that goes to the portfolio PMO. When they select a project, they have to make sure there's proper staffing in the organization for that project. The people selecting that project have to know whether or not the internal resources have the capability of managing it, or whether or not it has to be outsourced. If the internal resources can manage it, then normally the complexity is less than having to rely upon on contractors that may have questionable knowledge and experience, regardless of what they tell you in a proposal.'

9. About the Complexity Dimension: Clarity of Goals

9.1. <u>Question</u>: From the survey results, it is observed that dimension Clarity of Goals is ranked #5 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'It is very important because you need to know how your project fits in to the organization's strategic goals and objectives. If your project does not fit in, you should not be doing it.'

Participant 2: 'I need you to **differentiate between goals and objectives**. The reason is **goals are high-level**. Objectives are generally low-level. We don't ask project managers to define goals in a statement of work. We ask them to define objectives in a statement of work. And we expect the objectives to be tangible, and measurable, and verifiable. Goals, these are something that, in my mind, it's very high-level. For example, a goal could be to break into a new marketplace. The objective could be to develop a product that has certain characteristics. Those characteristics form a statement of work, but the goal doesn't form the statement of work.'

9.2. <u>Question</u>: How do you think that the dimension Clarity of Goals will impact the estimation process of complex projects?

Participant 1: 'If the project does not fit into the long-term strategy of the organization, its business case should not be approved because why are we going to invest resources into something that does not fit our own organization's goals and objectives? Therefore, the cost estimate should not be done.'

Participant 2: 'If you don't have the correct goals, then you don't know what you're doing, then what you have to do is to use progressive planning. You have to determine the cost for only a very small portion of the project. And then, when that small portion is completed, you try to redefine the goals and budget for the next phase of the project.'

9.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'People are often going to move forward without defined business cases that have been formally approved. This is how many organizations have worked for years. Successful organizations have defined business cases with cost estimates, have a Board or something that is reviewing them, and making decisions as to whether or not they should be part of the organization's portfolio.'

Participant 2: 'Well, they're at the mercy of what they're given. If they don't feel that they have enough knowledge given to them, enough information to do the estimating properly, then they have to agree that they will only price out that portion of the project to which they have the information. They have to be willing to state "I can't estimate this".

10. About the Complexity Dimension: Organizational capability

This dimension was selected by 7 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

10.1. Question: From the survey results, it is observed that dimension Organizational capability is ranked #06 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'I would change it higher, because as I said to you, one, I am not for this Maturity Level, I am not for Risk, I am not for Product and Project Size. So I would rank it higher. I think that Organizational Capability is more what I was getting at when we were talking about the Project Management Maturity level.'

Participant 2: No answer.

10.2. Question: How do you think that the dimension Organizational capability will impact the estimation process of complex projects?

Participant 1: 'Related to Organizational Capability, and if its a mature organization, it just goes back to my previous comment. They need to have defined business cases. It should be undertaken in the first place, but check if we do have the resources available to do it, resources being more than funding and people. I would look carefully at the cost estimate.'

Participant 2: No answer.

10.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'They should point out the importance… I think, as project professionals, we cannot really think that the executives are always going to do so. The executives have a lot of other things to do. But if we are not thinking about the organizational capability, what are we doing? We have to go back and we have to then say to them, that if we ignore it, we really are ignoring the whole strategy, and strategic change is going to happen through programs and projects. This shows then, that we have to use it to recognize the importance and value of project and program management, and if we are not doing it at the organizational level, executives then put the organization at risk, they may not achieve their strategic goals.'

Participant 2: No answer.

11. About the Complexity Dimension: Political Influence (Politics)

This dimension was selected by 5 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

11.1. Question: From the survey results, it is observed that dimension Political Influence (Politics) is ranked #14 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'Would I move it into the top 5? Probably not, but we cannot ignore it. We tend to view politics in a very negative way. However, we have to look at politics in a positive way, and we have to understand how the relationships work within the organization, who are the key players? Well, as a project manager, you have to have a network, and you have to be able to reach out throughout this network of people, and a successful project manager can do that. So we cannot ignore politics, we cannot ignore the influence of politics.'

Participant 2: No answer.

11.2. Question: How do you think that the dimension Political Influence (Politics) will impact the estimation process of complex projects?

Participant 1: Answered previously.

Participant 2: No answer.

11.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'Ensure you are communicating and interacting with the Chief Financial Officer and his or her staff at all times. To get to know them well, have a network, and enhance the network as much as possible.'

Participant 2: No answer.

12. About the Complexity Dimension: Communication Quality

This dimension was selected by 4 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

12.1. Question: From the survey results, it is observed that dimension Communication Quality is ranked #07 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'Project managers spend at least 90% of their time communicating, program managers spend more time communicating, portfolio managers spend more time communicating, so we need to be able to communicate to our stakeholders in different dimensions, recognizing that different people want to have different information available, different people want to be involved at different times. We cannot overlook influential stakeholders. We want to be able to communicate what is going on in a transparent way so we are not passing along rumours, and we want to be able to do this so that we show how important what we are doing is to the organization. We want to reach out to people, talk to them, understand their expectations as best as we can, see which ones we can beat, ask for their advice, be able to actively listen.'

Participant 2: No answer.

12.2. Question: How do you think that the dimension Communication Quality will impact the estimation process of complex projects?

Participant 1: ‘You want to be able to communicate with subject manager experts who may know something about what the new project's going to be, and you want to be able to communicate effectively so you can get information that will help you with your work breakdown structure and then will help you with your cost estimate. And you can use, of course a variety of ways to communicate with people and a variety of ways to talk to them so it becomes exceedingly important for anything anyone in program and project management.’

Participant 2: No answer.

12.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: ‘Talk to people, ask open-ended questions, actively listen, make sure you're reaching out to the right people as you develop your cost estimate, get people involved who are then later on going to help you support it.’

Participant 2: No answer.

13. About the Complexity Dimension: Time Frame

This dimension was selected by 4 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

13.1. Question: From the survey results, it is observed that dimension Time Frame is ranked #10 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: No answer.

13.2. Question: How do you think that the dimension Time Frame will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: No answer.

13.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: No answer.

14. About the Complexity Dimension: Stakeholder Interaction

This dimension was selected by 4 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

14.1. Question: From the survey results, it is observed that dimension Stakeholder Interaction is ranked #15 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'No, I think it should be higher up. I would have number 1 or number 2 be Organizational Capability and the other one, Communication, you decide. Then I would have Degree of Trust. Then I would have Knowledge and Experience, Clarity and Goals. I would probably then have Stakeholder Interaction or Politics, one of those 2.'

Participant 2: No answer.

14.2. Question: How do you think that the dimension Stakeholder Interaction will impact the estimation process of complex projects?

Participant 1: 'So it affects the cost estimating process because we could forget a critical stakeholder such as the Chief Financial Officer and his or her staff member and we therefore may be in deep trouble later on and cannot recover.'

Participant 2: No answer.

14.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'Find out what the person's concerns are. We also have to realize over the life of a project, stakeholders are going to have interests at different times, and new stakeholders are going to emerge. So it is a continual process. We have to talk to all our stakeholders, and we cannot assume they are going to talk to each other about our project.'

Participant 2: No answer.

15. About the Complexity Dimension: Pace / Speed to Market

This dimension was selected by 4 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

15.1. Question: From the survey results, it is observed that dimension Pace / Speed to Market is ranked #21 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: 'I have mixed emotion about this one. For those companies who are involved in new market development, they would probably rank this higher than a lot of the other ones on that page. If you get somebody that's involved in new product development, they could care less about politics, stakeholders, and external environment. Their concern is getting to the marketplace on a given day. Suddenly the speed to market made this a very, very complex project. The technology wasn't that complex, but the pace, it's the pace at which the technology had to be achieved that made it complex.'

15.2. Question: How do you think that the dimension Pace / Speed to Market will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: 'The problem that you have with time to market is that **there may not exist estimates for time to market**. They pick the time to market and then they try to force people beneath them to do the impossible. Sometimes you have to take that risk. But sometimes you can rework a very easy project into a very complex project.'

15.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: 'A guideline for senior management, there are none. Any time you have a complexity factor that is controlled by the people in the top floor of the building, there's no standard that can be used for protocol. It's more of a whim at the senior levels of management on what they want. I would love to have a set of standards that senior management can go by. Now, there is hope. There's a new technique in the marketplace called portfolio PMOs, and the goal of the portfolio PMO is to provide feedback to the executives as to whether or not the time to market is correct, the organization has the capacity to work on this project. If you were to come back to me in 2 or 3 years, I could probably tell you that there are guidelines we could use here. But right now I don't see any guidelines.'

16. About the Complexity Dimension: Degree of Trust

This dimension was selected by 3 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

16.1. Question: From the survey results, it is observed that dimension Degree of Trust is ranked #09 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: 'I would put it much higher because, first, I really do not like your first 3.'

Participant 2: No answer.

16.2. Question: How do you think that the dimension Degree of Trust will impact the estimation process of complex projects?

Participant 1: 'I think if we do not trust the people we are working with the project is going to fail. There has to be trust between the team. We have to be able to openly communicate with people; we have to communicate with people at all levels. If we do not trust the client and if the client does not trust us, the project is not going to succeed, or the client is not going want to use it at the end of the day, or it is not going to be sustained in the future. So trust is exceedingly important.'

Participant 2: No answer.

16.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: 'We assume trust from the beginning. We go into something and assume we can trust the people we are going to work with. So we are trying to convey what in the literature is termed *swift trust*. But once the trust is broken, it is very hard to get it back.'

Participant 2: No answer.

17. About the Complexity Dimension: Budgetary Constraints

This dimension was selected by 3 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

17.1. Question: From the survey results, it is observed that dimension Budgetary Constraints is ranked #12 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: No answer.

17.2. Question: How do you think that the dimension Budgetary Constraints will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: No answer.

17.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: No answer.

18. About the Complexity Dimension: Dependency and Interdependency

This dimension was selected by 3 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

18.1. Question: From the survey results, it is observed that dimension Dependency and Interdependency is ranked #13 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: 'It's much higher up. The reason could be that a lot of the people that did the survey never managed projects that were large and complex, that had a great deal of dependencies. When you have a great deal of dependencies, and a dependency on the front end of a project changes, it could have a real serious impact, financial impact, on all the dependencies downstream. A lot of people don't get involved in situations like that.'

18.2. Question: How do you think that the dimension Dependency and Interdependency will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: 'It can force re-estimation of the project. That's how serious it is. It forces re-estimation of the project. There's a point where the dependencies can change so significantly that re-estimation must be done.'

18.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: 'Go back and take a look at what the dependencies are and see whether the dependencies are still valid, I mean, the cost is still valid. Estimators estimate based upon the knowledge they are given. If that knowledge changes and you go back to the estimators, they have to be willing to re-assess whether or not their original estimates were correct and possibly come up with new estimates.'

19. About the Complexity Dimension: Cultural Resistance and Differences

This dimension was selected by 3 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

19.1. Question: From the survey results, it is observed that dimension Cultural Resistance and Differences is ranked #20 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

19.2. Question: How do you think that the dimension Cultural Resistance and Differences will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: No answer.

19.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: No answer.

20. About the Complexity Dimension: External Environment Constraints

This dimension was selected by 2 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

20.1. Question: From the survey results, it is observed that dimension External Environment Constraints is ranked #16 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: 'No, again it's too low. See my problem is that 16, 15, and 14 are all related. 14, 15, and 16 (Political influence, Stakeholder Interaction, External Environment Constraint) are called enterprise environmental factors. I can't separate them out. All 3 of these are enterprise environmental factors. And any time you have enterprise environmental factors; these are factors which could very well be beyond the control of the project manager. And, once again, these can require scope changes and re-planning of a project.'

20.2. Question: How do you think that the dimension External Environment Constraints will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: 'They require scope changes; you change the stakeholders, and all of a sudden, one stakeholder comes up with a great idea. In some cases it worked well. In other cases, it elongated the project because some of these people were afraid that if the project ended they would be out of work. Suddenly you have new stakeholders that want scope changes. The project was stopped and it was re-planned and re-directed.'

20.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: 'There's none. There are no guidelines for that. That's something that the sponsor has to deal with, the people in the government's committee.'

21. About the Complexity Dimension: Innovation to Market

This dimension was selected by 2 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

21.1. Question: From the survey results, it is observed that dimension Innovation to Market is ranked #19 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: 'I think that one is probably at the right level because this is a decision that is normally made to penetrate a new market. And when somebody makes a decision, I have to innovate because I want to be in this business. At this point you don't have a very clear understanding of what you're doing. You're in the infancy stages of the project. The cost of innovation to market is huge.'

21.2. Question: How do you think that the dimension Innovation to Market will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: 'The cost estimation process is a guess established by people that have long titles after their name, specifically, vice presidents and above. These are the people that sit at the top floor of the building behind mahogany desks. Their decisions are not based upon work breakdown structures. **Any time you see the word innovation, it's not being done at the bottom, it's being done at the top**.'

21.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: 'We can't. These are situations that affect the strategic plan of a company. And we have no guidelines for strategic plans. It's a recalculation of what they believe the financial benefits and value will be to the company in the long run. It's completely different when you do estimating at the bottom than when you do estimating at the top.'

22. About the Complexity Dimension: Uncertainty

This dimension was selected by 2 of the 10 people interviewed as part of the additional top five complexity dimensions that can impact the cost estimation process.

22.1. Question: From the survey results, it is observed that dimension Uncertainty is ranked #8 when estimating complex projects. Do you agree with this? And if so why?

Participant 1: No answer.

Participant 2: 'I see uncertainty the same way I look at goals. If you're not sure what you're doing, and that uncertainty is because of knowledge or capability, then you basically increase the risk. Anything that generates, in my mind, a high risk, is something that can convert a project into, you know, into a real serious situation. Uncertainty is one of them. **Uncertainty leads to risks, and risks lead to management reserves.** I would put it in 6 or 7. I'm not interested in organizational capability or communication quality.'

22.2. Question: How do you think that the dimension Uncertainty will impact the estimation process of complex projects?

Participant 1: No answer.

Participant 2: 'There are 2 types of uncertainty. There's complete uncertainty. And when you have **complete uncertainty**, you have to decide whether you're a risk-lover or a risk-avoider. Most project managers work with partial uncertainty. That's where you have risks, where you have partial uncertainty. Complete uncertainty means that you don't know what the probabilities are and you don't know what the impact is going to be. **Partial uncertainty** means you have some degree of knowledge of probabilities and impacts.'

22.3. Question: If we are preparing guidelines for estimators who are estimating complex projects, how do you think that we should advice them to consider this dimension in their estimates?

Participant 1: No answer.

Participant 2: 'I'd tell them again they have to look at what the risk is and what the management reserve is based upon the risk. Everything is going to come back to risk because risk is married to all of them.'

23. Other Complexity Dimensions

The dimensions below were selected just by one person so no details will be provided.

Participant 1: No answer.

Participant 2: No answer.

24. Complexity Dimensions not Selected during Interviews

The dimensions below were not selected by any person:

- Economic Uncertainty
- Environmental and Safety Impact

APPENDIX C – PRINTOUT OF THE MODEL

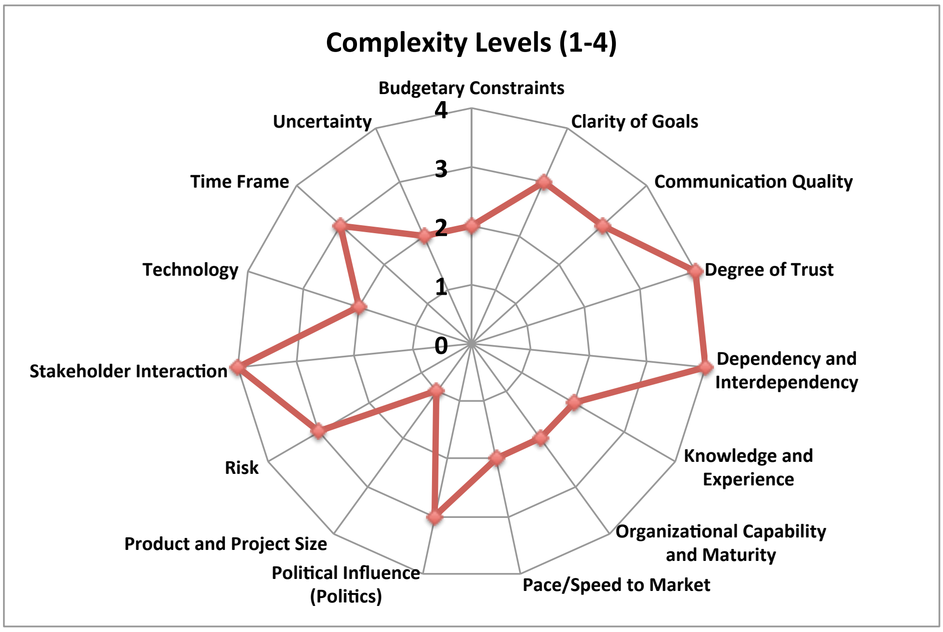
C.1 – Printout of the model using a fictional case study (section 6.2.2)

Project Information

Project name	Fictional XYZ
Objective	Implement ERP system for financial department
Project manager	Mr. X
Cost estimator	Mrs. Y
Time frame	6 months
Budget	USD 1 million
Background	The project objective is to implement an enterprise resource planning (ERP) software within the organization XYZ. The strategy defined by the Chief Executive Officer (CEO) is to start the implementation within the financial department. The Chief Financial Officer (CFO), who heads the entire financial area, supports it. This would be Phase 1 of the project. The other phases were not shared within the organization. The main benefits for implementing the ERP system during phase 1 are to have more effective operations, serve the clients faster, and reduce payroll expenses. The main savings will come from reducing the 100 employees located in the accounting, accounts receivable, accounts payable, and administrative departments to only 20. The initial estimate for this phase of the project is to cost USD 1 million and the alleged benefits were USD 5 million over a 2.5-year period. XYZ has the necessary budget to implement this project but it will affect other initiatives. Phase 1 should be implemented in 6 months and after phase 1 is implemented, the organization will define the other phases and rollout to the remaining areas.
Challenges	a) Organization XYZ has no experience implementing such projects in the past; neither have knowledge about the technology used on an ERP system. b) The employees from the target departments (accounting, accounts payable and receivable, and administration) are part of a strong union and they are in direct opposition of the project. There is also strong politic influence from other senior executives within the organization, who are against the project. c) The project manager from XYZ is not convinced that the project will bring all these benefits on phase 1 but the Steering Committee who approved the project does not want to hear the project manager – "just implement the project", the project manager was told. d) There are a lot of internal discussion and communication issues, with middle management feeling insecure about the possible next steps. This environment created a barrier between employees and executives where trust was lost. e) The details of phase 1 and the entire project, goals, or why it was considered feasible were not provided to the project manager. f) The implementation time frame of 6 months was arbitrarily defined by the XYZ executives and against the recommendation of 12 months provided by the consulting company responsible for implementing the ERP system.

COMPLEXITY DIMENSIONS - Score and mapping

			Description			
Complexity Dimension	**Description of Complexity Dimension**	**Level (1-4)**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Budgetary Constraints	Normally all projects have a limited budget. This dimension is related to how the budget constrains the ability to manage the project, which might add to the project's complexity level If the organization is accustomed to managing a budget of a specific size (e.g., up to $100 million), a larger cost (e.g., $1 billion) would add a level of complexity to the project. Similarly, if the available budget is limited, the performing team might need to implement approaches that were not used before, which again creates an increased complexity level.	2	There is no budget limitation, and the cost of the project is within the range the organization is accustomed to managing.	There is some budget limitation but it does not affect the capability to deliver the product. The cost of the project is no more than 50% above the range of what the organization is accustomed to managing.	There is a budget limitation that affects the capability to deliver the product. The cost of the project is no more than two times above the range of what the organization is accustomed to managing.	There is an extreme budget limitation for the size of the project, which will not allow the project to deliver the product. The cost of the project is at least five times above the range of what the organization is accustomed to managing.
Clarity of Goals	This dimension defines how well-defined the goals of the project are and the impact this has on how the project is managed and decisions are made. A lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance	3	The goals are well defined, with a clear understanding of the deliverables and objectives by all stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study are still valid when the project progresses.	The goals are for the most part properly defined, with good understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study may be adjusted when the project progresses.	The goals are not well defined, and the understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision makers, customers, suppliers, and partners) is unclear. The early decisions made during the feasibility study are mostly invalid.	The goals are not defined at all and there is no understanding of the deliverables or objectives by any stakeholders (project manager, team members, decision makers, customers, suppliers, or partners). The early decisions made during the feasibility study are not being considered any longer.
Communication Quality	This dimension is related to the quality of communication during the project. Communication barriers can bring disruption to the project and are considered one of the key reasons for project failure. Challenges in communication can be related to language, cultural aspects, organisational structure, geographical location, and communication methods. Communication involves both direct and indirect elements. Direct (or explicit) communication refers to written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or the true intention is not directly revealed.	3	Clear communication. The communication flows without issues and no clear barriers exist. All communication is direct, and when indirect communication is used, the cultural background prevents it from impacting the performing team.	Some issues with communications. There are some communication noises but they do not impact the project. There is limited use of indirect communication but it does not affect the performing team in such a way that will impact the management of the project.	Significant issues with communications. There are significant communication issues with disruptions to the project. There is also frequent use of indirect communication, which is not well received by the performing team. This can impact the management of the project.	Constant issues with communications within the entire organization and among stakeholders. There is severe impact on performance, and indirect communication is constant and disruptive to the performing team. The management of the project is seriously compromised, as is the delivery of the product.
Degree of Trust	This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (e.g., supplier and project team; senior management and project manager). The more trust there is, the less complex the project will be .	4	There is trust among all the project stakeholders and they have been working together for a long time.	There might be some trust issues between some stakeholders but nothing that should impact the results of the project.	There is a lack of trust between key stakeholders, which can jeopardize the process of managing the project and delivering the product.	The lack of trust among all stakeholders is evident and the results will probably not be achieved. There is a need for intervention.
Dependency and Interdependency	This dimension deals with the relationship between the elements that make up the project. This relationship can be one of dependency (in which some elements are dependent on one another, and some are not) and/or interdependency (in which each element is mutually dependent on others). In a complex project, stakeholders might not know what the result of an interaction among the elements of that project will be.	4	There is complete understanding by the decision-maker, project manager, and team of the dependency and interdependency of all elements of the project.	There is partial understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.	There is very limited understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.	The decision-maker, project manager, and team are not capable of understanding the interdependence or independence of the elements of the project.
Knowledge and Experience	This dimension is related to how much knowledge and/or experience the project manager or a key team member has regarding all elements (parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product.	2	The decision-makers, project manager, and team have extensive experience with this type of project and knowledge of all project elements.	The decision-makers, project manager, and team have good experience and knowledge of most elements of the project. There are just a few unknowns.	The decision-makers, project manager, and team have significantly limited experience and knowledge of the elements of the project. There are a lot of unknowns.	The decision-makers, project manager, and team have no experience or knowledge about any element of the project. Almost everything is unknown.
Organizational Capability and Maturity	This dimension is related to how capable—structurally and technically—an organization is in managing the project and delivering the required product (Remington et al., 2009). It also addresses the degree of relative maturity that the organization has achieved in project management. The assumption is that more mature organizations will be better able to manage complex projects and deliver products.	2	The project-management maturity level is high (between 4 and 5 out of 5). The organization has a lot of experience with the type of project in question, with the proper structure in place and technical knowledge to support the management of the project and development of the product.	The project-management maturity level is medium-high (between 3 and 4 out of 5). The organization has some experience with the type of project in question will need to make some adjustment to the organizational structure, and has proper technical knowledge to support the management of the project and development of the product.	The project-management maturity level is low-medium (between 2 and 3 out of 5). The organization has very limited experience with the type of project in question, the organizational structure is inadequate, and the organization has limited technical knowledge to support the management of the project and development of the product.	The project-management maturity level is low (between 1 and 2 out of 5). The organization has no experience with the type of project in question, the organizational structure is inadequate, and the organization has no technical knowledge to support the management of the project or development of the product.
Pace/Speed to Market	This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the product be aligned with market demands.	2	Regular: The time to deliver (pace) the product is not critical to the success of the organization.	Fast: The time to complete the project is important for competitive advantage, and not delivering on time might have a negative impact on the organization.	Time-critical: The time to deliver the product is critical for project success and delays can be reflected as failure of the project.	Blitz: Not only is the time to deliver critical, but is considered a crisis; therefore delivery cannot be delayed for any reason.
Political Influence (Politics)	This dimension is related to the level of internal or external political influence involved in the project. If political influence and interests lead to the approval of a project that might not be feasible, the chances of an overestimation of benefits and underestimation of costs increase.	3	No political influence or interest with no impact on the project.	Limited or very punctual political influence or interest, with minimal impact on the project.	Considerable or spread political influence or interest, with considerable impact on the project.	Strong and multi-level political influence or interest, with major impact on the project.
Product and Project Size	It can be argued that a project should be over a minimal size to be considered a complex project. The premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple project would deliver a standard component, followed by a subsystem, moving to delivering an entire system, and finally to producing an array or system of systems.	1	Standard: The project objective is to deliver a single component, with a minimal amount of work; for example, delivering a standard memory chip.	Subsystem: The project objective is to deliver a set of components that interact to produce a subsystem, where the amount of work is still within the range of capabilities of the performing organization; for example, assembling a motherboard.	System: The project objective is to deliver a series of subsystems that together produce a system, which requires a greater amount of work and interaction among several parts; for example, a new computer.	Array: The project objective is to deliver an array or series of systems, and the work to be performed is beyond the capabilities of the performing organization; for example, a computer network that had never been installed before.
Risk	Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project. This dimension defines specifically how much unknown (known-unknowns and	3	The project risks are well known, and the team has experience managing them.	The project does not have a significant amount of unknown risks, and people with previous experience with them can manage the existing ones.	The project has a large amount of unknown risks, and the team has very limited experience managing them.	Almost all risks are unknown, mostly unknown-unknown risks. The team has no experience managing them.
Stakeholder Interaction	This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening in the project.	4	The key stakeholders are aligned with the project objectives and requirements. Their interaction is effective and the high-level executives provide the necessary support for project success.	Most key stakeholders are aligned with the project objectives and requirements. Their interaction is good but sometimes there is some "noise". Mostly the high-level executives provide the necessary support for project success.	Most of the key stakeholders are not aligned with the project objectives or requirements. Their interaction is not effective and many issues arise due to poor stakeholder interaction. There is very limited support from high-level executives.	The key stakeholders are not aligned with the project objectives or requirements, with conflicts and re-work common. Their interaction is ineffective and there is no support from high-level executives to ensure project success.
Technology	The term technology is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used in a specific project. Normally technology complexity is found in projects that use a new or untried technology. The complexity in this case would be associated with the number and variation of inputs and possible outputs. The less the team or performing organization knows or has used that technology, the more complex the project will become.	2	Low-tech: No new technology is used. The project uses only low-tech technology that is already existent and well established. These technologies normally do not have a significant level of uncertainty or difficulty (e.g., a house).	Medium-tech: Some new technology. The project uses mostly medium-tech technology, which can be characterized as based on existing technologies or a limited use of new technologies (e.g., a new automobile).	High-tech: All or mostly new but existing technology. The project uses many new technologies that have been recently developed. It might use technology for the first time, but that technology was already created (e.g., a satellite).	Super high-tech: Critical technologies do not exist. The project uses or has to develop a technology that never existed before. The level of uncertainty is very high and the outcome cannot be established (e.g., the Apollo program/moon landing).
Time Frame	Time is often referred to in the literature as having a direct effect on how complexity is perceived by project team members and stakeholders. Time frame is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the time frame of the project, notably with ones that have long durations. The longer the time frame, the more chances that changes will impact the project, which	3	There is no change in decision-makers, the requirements are stable, and the key relations and project plans remain the same over time.	The change of decision-makers over time is not significant, the key requirements are stable over time, and the key relations and project plans remain almost the same over time.	There are significant changes in decision-makers and requirements over time, and key relations and project plans are also changing over time.	The decision-makers changed over time and had conflicting interests, the requirements changed, producing a different product, and the key relations and project plans were completely changed.
Uncertainty	The Cambridge Dictionary defines uncertainty as "a situation in which something is not known, or something that is not known or certain". This dimension is related to the level of uncertainty existing not just in a project, but also in the product or the development process. Even though complexity is different from uncertainty, uncertainty can be considered a dimension that can increase or decrease the level of complexity of a project.	2	Low level of uncertainty: While there is confidence in the outcome, there are some key variables for which one does not have precise values. It is possible to make some estimates, or to establish some "most likely lows" and "most likely highs" and then plan for the range.	Medium level of uncertainty: There is a variety of future scenarios, but it is possible to list them, and they are mutually exclusive and exhaustive.	High level of uncertainty: There are scenarios that can be constructed, but they are more illustrative of possibilities rather than exhaustive.	Complete uncertainty: In some cases, it is impossible to even frame scenarios. The understanding is so unstable that any scenario is merely a wish list. It may be years before the possibilities sort themselves out.



Complexity Dimension	Level (1-4)
Budgetary Constraints	2
Clarity of Goals	3
Communication Quality	3
Degree of Trust	4
Dependency and Interdependency	4
Knowledge and Experience	2
Organizational Capability and Maturity	2
Pace/Speed to Market	2
Political Influence (Politics)	3
Product and Project Size	1
Risk	3
Stakeholder Interaction	4
Technology	2
Time Frame	3
Uncertainty	2

Guidelines and Recommendations for Practitioners
Levels 3 and 4

#	Complexity Dimensions	Complexity Level	Guideline 1	Guideline 2	Guideline 3	Guideline 4	Guideline 5	Guideline 6	Guideline 7	Guideline 8	Guideline 9
2	Clarity of Goals	3	1. Create a list of assumptions, recording the items that are being estimated and the ones that are not.	2. Develop a business case prior to starting the project. Many organizations decide to implement a project without a formally analysed and approved business case, but the most successful organizations are the ones that define a business case with proper cost estimates and have an executive board that reviews business cases and makes decision on which ones should be part of the company's portfolio.	3. Develop even a small business case, allowing questions to be asked that could help clarify the project goals.	4. If cost estimators don't have enough information given to them, they should only estimate the part they know. Provide feedback about the lack of information. Seek an agreement that the cost estimate is limited to the portion of the project that is known.	5. Estimate the project by phases. The use of progressive planning allows estimators to focus on determining detailed cost estimates for small portions of the project at a time. When one small portion or phase is completed, the estimator has to go back to redefine the goals and budget for the next phase of the project.	6. Note that the estimator who understands that there are limitations of information but proceeds to estimate the cost will set up the project for failure. There is then a need to go back to the stakeholders and ask for clear identification of the goals or any other missing information.	7. Use Design Thinking or other estimation techniques. It is recommended to wait, step back, and invest time in going through the goals and scope of the project.	8. Use the Straw Man estimate and get the sponsor's feedback. The Straw Man technique consists of quickly putting together a first draft estimate with incomplete data so to create a temporary cost estimate that should then be discussed with the sponsor.	9. Use the S.M.A.R.T. technique, starting on a higher level and going down to the deliverable level. For the lower levels, this technique will allow a better cost estimate. On the other hand it is crucial to understand the goals beforehand to avoid having a detailed and precise cost estimate of something that it not what the project is intended to be.
3	Communication Quality	3	1. Use communication techniques such as asking open-ended questions, active listening, making sure you are reaching out to the right people as you develop your cost estimate, and getting stakeholders involved in the cost estimation.	2. Discuss what you are estimating for with the customer. Discuss any aspects that need more clarity and involve the client so there is liability/commitment involved.	3. Create a communication plan with information including what to communicate, when, how, why, where, and so on.	4. Align the value proposition clearly and develop a business case that supports the project feasibility. The project should be aligned with the organization's strategic objectives and expectations should be clarified.					
4	Degree of Trust	4	1. Work with a best- and worst-case scenario to cover the situation in cases where there is no trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies. Depending on how bad the situation is, the complexity and risk could increase.	2. Assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted, and the cost estimate should reflect that assumption. On the other hand, if trust is broken it is very hard to recover. There are ways to develop trust or improve bad situations, but the reality cannot be ignored.							
5	Dependency and Interdependency	4	1. Go back and review the dependencies, understand whether they impact other parts of the project, whether they are still valid, and whether changes were implemented. The reason for that is because estimators do their job based on the available information. Once the information is known, there is a chance to re-assess the existing estimates and adjust if needed.	2. Understand the dependencies and interdependencies. To do that, the estimator needs to consult the project manager and experts. There is a need to understand the schedule, the methodology used, and other plans. Furthermore, the estimator needs to make sure the organization understand that estimates would be as reliable as the information available.	3. Do not use "lean" or "agile" approaches in complex projects. Instead, focus on the work breakdown structure and other traditional planning approaches.						
9	Political Influence (Politics)	3	1. Create a good relationship with the key stakeholders, improve the project manager's networking skills, and keep communication active. Include the project team and possible third parties.	2. Count on the executives to help with external political influence. Create a political map and associate it with the project risk plan. Contingencies might be added based on how big the risk is due to politics.	3. Ensure the existence of well-described goals, benefits, and success factors. These will actually support the success of the project. Political influence should actually be addressed as part of stakeholder management.						
11	Risk	3	1. The cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. When there are high risks, increase the size of the management reserve.	2. Start by looking at the data sources and how reliable the data used for the cost estimation is, and consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.	3. Create a risk team with the participation of the project manager. This approach is based on having several people brainstorm to better understand all the parts of the project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase.	4. The project manager or cost estimator has to consider that other dimensions will probably self-organize and impact the project in a positive or negative way, with focus on maximizing the chances of a positive impact.	5. Do a risk assessment to analyse the potential risks and create an action plan, supporting the cost-estimation process. Implement a risk-management process.				
12	Stakeholder Interaction	4	1. Implement a discovery effort to understand what interests and concerns the stakeholders have. During the project life cycle it is expected that stakeholders will have different interests and that new stakeholders might emerge, so the project manager should assure proper communication with them.	2. Implement a stakeholder management process to identify the stakeholders and their interests and motivations in order to provide them with the proper communications, and evaluate their influence.	3. Map all the stakeholders to better understand them, maximize the positive ones (favourable to the project), influence the neutral ones to become positive, and neutralize the negative ones.	4. Manage the interactions among stakeholders. The cost estimator should base the estimates on the information available, so it is recommended that close contact with the project manager be maintained to incorporate any necessary input.					
14	Time Frame	3	1. Do not underestimate the fact that the project will have changes and possibly new requirements.	2. Look beyond the first level of the work breakdown structure and understand that project managers should consider risks due to changes.	3. Focus on planning and include the time frame in all project documents.	4. Update the planning documents with constant analysis of the impacts on the time frame, which is the basis of the Rolling Wave Planning approach.					

The next page presents a full printout of the model for better reading.

C.2 – Printout of the model using a real project (section 6.3.2)

Project Information

Project name	Shared Services
Objective	Implement a pilot project for shared services within the organization, centralizing all activities that are not part of the core business to headquarters.
Project manager	Mr. X
Cost estimator	Mrs. Y
Time frame	12 months
Budget	USD 2 millions
Final cost	USD 3.5 millions
Background	Company Background: Company EX is part of the energy industry, well established, and with a long history of large projects. EX has global presence and each region operates independently from the others, which means that each region has their own back-office structure and personnel. Back-office means all services (or departments) that support EX's operations like human resources, accounting, information technology, office administration, procurement, accounts payable and receivable, and training.. The main business of EX is to sell and distribute energy. Project Background: EX wanted to analyse the feasibility of implementing centralised service centres supporting all regions. For instance, the human resource service centre would provide payroll, career, training, hiring, between other services. Considering that EX is a large organisation, the project is going to be piloted on a small company named EXb, moving all back-office operations to the regional headquarters. Should this pilot be successful, a full rollout of the shared services approach would be done worldwide. The project had a feasibility study done by the project manager and executive team. The initial cost estimate was USD 2 million (due to confidentiality, all number presented hereafter are fictitious) and the benefit was estimated in USD 5 million to be realized within 3 years. The costs included a consulting company to help managing the project, cost of manpower to do the handover from EXb to EX's regional headquarter, training, and travel & lodging of personnel doing the handover. The benefits would be achieved by immediate reduction of manpower and due to gain of scale, providing service centres with more negotiation power when dealing with suppliers. The timeframe for the project delivery was set in 12 months. A decision was made to implement several project management best practices like investing more time on planning before starting to execute the project. There was no issue with the timeframe, neither there was a need to implement sooner due to market pressure. That created an environment where proper time for planning was allowed. The key stakeholders like executives, project manager, team members, functional managers, and headquarter personnel were aligned with the objectives of the project. A decision was made to explain all the project details to the entire EXb organization to assure good communication and build trust.
Challenges	- Over 30 EXb employees would lose their jobs at the end of the project, so it could affect morale. - The EXb people had to travel to EX headquarters for handover, which is in a different part of the country, stay in a hotel for 4-week periods, and return to their families only one weekend per month. There was a risk that many EXb people would not want to be separated from their families for duration of the project. - Due to the employee-biased labour laws of that country, EXb people would potentially enter lawsuits that could reduce significantly the immediate benefits of the project. The probability for an employee to win against the employer was close to 100%. After the project, almost 40% of EXb employees entered with lawsuits and won, with significant impact to estimated costs. The additional cost was in the order of USD 1.5 million.

COMPLEXITY DIMENSIONS - Score and mapping

			Description			
Complexity Dimension	**Description of Complexity Dimension**	**Level (1-4)**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
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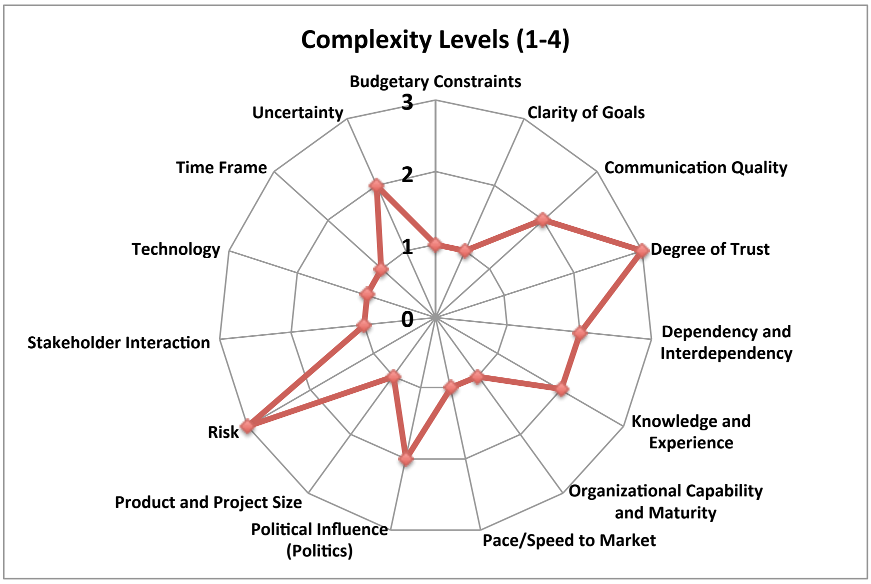
Clarity of Goals	This dimension defines how well-defined the goals of the project are and the impact this has on how the project is managed and decisions are made. A lack of clear goals often results in a diverse set of assumptions by various stakeholders, which might impact the implementation strategy and project performance	1	The goals are well defined, with a clear understanding of the deliverables and objectives by all stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study are still valid when the project progresses.	The goals are for the most part properly defined, with good understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision-makers, customers, suppliers, and partners). The early decisions made during the feasibility study may be adjusted when the project progresses.	The goals are not well defined, and the understanding of the deliverables and objectives by most of the stakeholders (project manager, team members, decision makers, customers, suppliers, and partners) is unclear. The early decisions made during the feasibility study are mostly invalid.	The goals are not defined at all and there is no understanding of the deliverables or objectives by any stakeholders (project manager, team members, decision makers, customers, suppliers, or partners). The early decisions made during the feasibility study are not being considered any longer.
Communication Quality	This dimension is related to the quality of communication during the project. Communication barriers can bring disruption to the project and are considered one of the key reasons for project failure. Challenges in communication can be related to language, cultural aspects, organisational structure, geographical location, and communication methods. Communication involves both direct and indirect elements. Direct (or explicit) communication refers to written or spoken words, signs, images, or any other method that explicitly reveals the true intention. Indirect (or implicit) communication refers to communication in which meaning is inferred or the true intention is not directly revealed.	2	Clear communication. The communication flows without issues and no clear barriers exist. All communication is direct, and when indirect communication is used, the cultural background prevents it from impacting the performing team.	Some issues with communications. There are some communication noises but they do not impact the project. There is limited use of indirect communication but it does not affect the performing team in such a way that will impact the management of the project.	Significant issues with communications. There are significant communication issues with disruptions to the project. There is also frequent use of indirect communication, which is not well received by the performing team. This can impact the management of the project.	Constant issues with communications within the entire organization and among stakeholders. There is severe impact on performance, and indirect communication is constant and disruptive to the performing team. The management of the project is seriously compromised, as is the delivery of the product.
Degree of Trust	This dimension examines the degree to which the people involved in the project have a trusting relationship with each other (e.g., supplier and project team; senior management and project manager). The more trust there is, the less complex the project will be .	3	There is trust among all the project stakeholders and they have been working together for a long time.	There might be some trust issues between some stakeholders but nothing that should impact the results of the project.	There is a lack of trust between key stakeholders, which can jeopardize the process of managing the project and delivering the product.	The lack of trust among all stakeholders is evident and the results will probably not be achieved. There is a need for intervention.
Dependency and Interdependency	This dimension deals with the relationship between the elements that make up the project. This relationship can be one of dependency (in which some elements are dependent on one another, and some are not) and/or interdependency (in which each element is mutually dependent on others). In a complex project, stakeholders might not know what the result of an interaction among the elements of that project will be.	2	There is complete understanding by the decision-maker, project manager, and team of the dependency and interdependency of all elements of the project.	There is partial understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.	There is very limited understanding by the decision-maker, project manager and team of the dependency and interdependency of all elements of the project.	The decision-maker, project manager, and team are not capable of understanding the interdependence or independence of the elements of the project.
Knowledge and Experience	This dimension is related to how much knowledge and/or experience the project manager or a key team member has regarding all elements (parts/components) of the product and the work that needs to be done on that project. This correlates to previous experience in developing a similar product.	2	The decision-makers, project manager, and team have extensive experience with this type of project and knowledge of all project elements.	The decision-makers, project manager, and team have good experience and knowledge of most elements of the project. There are just a few unknowns.	The decision-makers, project manager, and team have significantly limited experience and knowledge of the elements of the project. There are a lot of unknowns.	The decision-makers, project manager, and team have no experience or knowledge about any element of the project. Almost everything is unknown.
Organizational Capability and Maturity	This dimension is related to how capable—structurally and technically—an organization is in managing the project and delivering the required product (Remington et al., 2009). It also addresses the degree of relative maturity that the organization has achieved in project management. The assumption is that more mature organizations will be better able to manage complex projects and deliver products.	1	The project-management maturity level is high (between 4 and 5 out of 5). The organization has a lot of experience with the type of project in question, with the proper structure in place and technical knowledge to support the management of the project and development of the product.	The project-management maturity level is medium-high (between 3 and 4 out of 5). The organization has some experience with the type of project in question will need to make some adjustment to the organizational structure, and has proper technical knowledge to support the management of the project and development of the product.	The project-management maturity level is low-medium (between 2 and 3 out of 5). The organization has very limited experience with the type of project in question, the organizational structure is inadequate, and the organization has limited technical knowledge to support the management of the project and development of the product.	The project-management maturity level is low (between 1 and 2 out of 5). The organization has no experience with the type of project in question, the organizational structure is inadequate, and the organization has no technical knowledge to support the management of the project or development of the product.
Pace/Speed to Market	This dimension is related to how fast the project should be completed or the product should enter the market. The challenge is not just to have the necessary project pace so the product can be delivered on time according to the organization's strategy, but also that the product be aligned with market demands.	1	Regular: The time to deliver (pace) the product is not critical to the success of the organization.	Fast: The time to complete the project is important for competitive advantage, and not delivering on time might have a negative impact on the organization.	Time-critical: The time to deliver the product is critical for project success and delays can be reflected as failure of the project.	Blitz: Not only is the time to deliver critical, but is considered a crisis; therefore delivery cannot be delayed for any reason.
Political Influence (Politics)	This dimension is related to the level of internal or external political influence involved in the project. If political influence and interests lead to the approval of a project that might not be feasible, the chances of an overestimation of benefits and underestimation of costs increase.	2	No political influence or interest with no impact on the project.	Limited or very punctual political influence or interest, with minimal impact on the project.	Considerable or spread political influence or interest, with considerable impact on the project.	Strong and multi-level political influence or interest, with major impact on the project.
Product and Project Size	It can be argued that a project should be over a minimal size to be considered a complex project. The premise for this research is that size is related to the amount of work that needs to be done to deliver the product. The most simple project would deliver a standard component, followed by a subsystem, moving to delivering an entire system, and finally to producing an array or system of systems.	1	Standard: The project objective is to deliver a single component, with a minimal amount of work; for example, delivering a standard memory chip.	Subsystem: The project objective is to deliver a set of components that interact to produce a subsystem, where the amount of work is still within the range of capabilities of the performing organization; for example, assembling a motherboard.	System: The project objective is to deliver a series of subsystems that together produce a system, which requires a greater amount of work and interaction among several parts; for example, a new computer.	Array: The project objective is to deliver an array or series of systems, and the work to be performed is beyond the capabilities of the performing organization; for example, a computer network that had never been installed before.
Risk	Even though risk and uncertainty are related, they are definitively not the same. A risk has a probability of happening and a degree of impact should it happen. A proper risk assessment can allow an organization to set up the proper structure to manage a complex project. This dimension defines specifically how much unknown (known-unknowns and unknown-unknowns) risks exist in a project and possible impacts on the management process and delivery of the final product.	3	The project risks are well known, and the team has experience managing them.	The project does not have a significant amount of unknown risks, and people with previous experience with them can manage the existing ones.	The project has a large amount of unknown risks, and the team has very limited experience managing them.	Almost all risks are unknown, mostly unknown-unknown risks. The team has no experience managing them.
Stakeholder Interaction	This dimension deals with the different viewpoints of a project's stakeholders. Different stakeholders might have different and sometimes conflicting interests, motivations, and power levels. Their views of project success can also be different. In many cases powerful stakeholders have no direct participation or awareness of what is happening in the project.	1	The key stakeholders are aligned with the project objectives and requirements. Their interaction is effective and the high-level executives provide the necessary support for project success.	Most key stakeholders are aligned with the project objectives and requirements. Their interaction is good but sometimes there is some "noise". Mostly the high-level executives provide the necessary support for project success.	Most of the key stakeholders are not aligned with the project objectives or requirements. Their interaction is not effective and many issues arise due to poor stakeholder interaction. There is very limited support from high-level executives.	The key stakeholders are not aligned with the project objectives or requirements, with conflicts and re-work common. Their interaction is ineffective and there is no support from high-level executives to ensure project success.
Technology	The term technology is used here in its broader meaning. It is not limited to information technology but refers to any technology that needs to be used in a specific project. Normally technology complexity is found in projects that use a new or untried technology. The complexity in this case would be associated with the number and variation of inputs and possible outputs. The less the team or performing organization knows or has used that technology, the more complex the project will become.	1	Low-tech: No new technology is used. The project uses only low-tech technology that is already existent and well established. These technologies normally do not have a significant level of uncertainty or difficulty (e.g., a house).	Medium-tech: Some new technology. The project uses mostly medium-tech technology, which can be characterized as based on existing technologies or a limited use of new technologies (e.g., a new automobile).	High-tech: All or mostly new but existing technology. The project uses many new technologies that have been recently developed. It might use technology for the first time, but that technology was already created (e.g., a satellite).	Super high-tech: Critical technologies do not exist. The project uses or has to develop a technology that never existed before. The level of uncertainty is very high and the outcome cannot be established (e.g., the Apollo program/moon landing).
Time Frame	Time is often referred to in the literature as having a direct effect on how complexity is perceived by project team members and stakeholders. Time frame is related to the duration of the project, specifically when durations are extended due to the complexity of the project itself. This dimension deals with the time frame of the project, notably with ones that have long durations. The longer the time frame, the more chances that changes will impact the project, which increases the level of complexity.	1	There is no change in decision-makers, the requirements are stable, and the key relations and project plans remain the same over time.	The change of decision-makers over time is not significant, the key requirements are stable over time, and the key relations and project plans remain almost the same over time.	There are significant changes in decision-makers and requirements over time, and key relations and project plans are also changing over time.	The decision-makers changed over time and had conflicting interests, the requirements changed, producing a different product, and the key relations and project plans were completely changed.
Uncertainty	The Cambridge Dictionary defines uncertainty as "a situation in which something is not known, or something that is not known or certain". This dimension is related to the level of uncertainty existing not just in a project, but also in the product or the development process. Even though complexity is different from uncertainty, uncertainty can be considered a dimension that can increase or decrease the level of complexity of a project.	2	Low level of uncertainty: While there is confidence in the outcome, there are some key variables for which one does not have precise values. It is possible to make some estimates, or to establish some "most likely lows" and "most likely highs" and then plan for the range.	Medium level of uncertainty: There is a variety of future scenarios, but it is possible to list them, and they are mutually exclusive and exhaustive.	High level of uncertainty: There are scenarios that can be constructed, but they are more illustrative of possibilities rather than exhaustive.	Complete uncertainty: In some cases, it is impossible to even frame scenarios. The understanding is so unstable that any scenario is merely a wish list. It may be years before the possibilities sort themselves out.



Complexity Dimension	Level (1-4)
Budgetary Constraints	1
Clarity of Goals	1
Communication Quality	2
Degree of Trust	3
Dependency and Interdependency	2
Knowledge and Experience	2
Organizational Capability and Maturity	1
Pace/Speed to Market	1
Political Influence (Politics)	2
Product and Project Size	1
Risk	3
Stakeholder Interaction	1
Technology	1
Time Frame	1
Uncertainty	2

Guidelines and Recommendations for Practitioners
Levels 3 and 4

#	Complexity Dimensions	Complexity Level	Guideline 1	Guideline 2	Guideline 3	Guideline 4	Guideline 5
4	Degree of Trust	3	1. Work with a best- and worst-case scenario to cover the situation in cases where there is no trust that the information is accurate. For the worst-case scenario, the estimator would include contingencies. Depending on how bad the situation is, the complexity and risk could increase.	2. Assume trust from the beginning of the project. Either there is trust or there is not. The initial assumption should be that people can be trusted, and the cost estimate should reflect that assumption. On the other hand, if trust is broken it is very hard to recover. There are ways to develop trust or improve bad situations, but the reality cannot be ignored.			
11	Risk	3	1. The cost estimation is based on existing risks, how they are being assessed, and which responses to the risks are implemented. When there are high risks, increase the size of the management reserve.	2. Start by looking at the data sources and how reliable the data used for the cost estimation is, and consider not only a constant environment but also a variable one. The estimator has to consider various scenarios and factors that can impact the cost estimation.	3. Create a risk team with the participation of the project manager. This approach is based on having several people brainstorm to better understand all the parts of the project, how they interact, which tools to use, and so on. This should be done not only during the planning phase but also the execution phase.	4. The project manager or cost estimator has to consider that other dimensions will probably self-organize and impact the project in a positive or negative way, with focus on maximizing the chances of a positive impact.	5. Do a risk assessment to analyse the potential risks and create an action plan, supporting the cost-estimation process. Implement a risk-management process.

The next page presents a full printout of the model for better reading.

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