EXPLORING AND MEASURING PROJECT COMPLEXITY

A Dissertation

by

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ABSTRACT

Project complexity is a term that is not well understood in the construction industry in relation to academia and practice. Project complexity often refers to a measurement of the number of project elements and interactions between project elements or a relative comparison of difficulty to what was previously accomplished. Project complexity is a very critical factor that presents additional challenges to achieving project objectives. Impacts of project complexity can be negative if it is not assessed and managed appropriately. Developing a methodology to assess and measure project complexity can help project teams increase the likelihood of success and predictable project outcomes. This research proposed a constructive approach to assess and measure project complexity as a separate factor influencing projects including a model that helps identify the levels of project complexity. In this research, first, the concepts of complexity and its attributes were explored, and the literature relevant to defining and assessing project complexity was studied. A working definition of project complexity was then developed as a basis for describing project complexity. Project complexity was intentionally described in terms of managing projects rather than project physical features such as facility technology, types of materials, or project physical components to ensure that the research results could be generalized across a wide range of industry sectors. The possible project complexity attributes were then identified using complexity theory variables, the literature review results, and industry experience. The identified complexity attributes were used to develop the complexity indicators deemed to measure the associated attributes. The developed complexity indicators were then converted to survey questions for data collection purpose. The collected data was analyzed using statistical methods to test the significance of complexity indicators in differentiating low complexity projects from high complexity projects. The research result showed that thirty-seven complexity indicators associated with twenty-three complexity attributes were significant. These significant complexity indicators were considered to be truly representative of project complexity. The thirty-

seven significant indicators were then used as the input for the model development process.

The model developed in this research is a binary logistic regression that predicts the probability of high complexity or low complexity given the values of complexity indicators. In the research, the multivariable analysis was used as the method to develop the model, and the univariate method was used as an approach to selecting a subset of explanatory variables. The univariate method resulted in a set of 27 complexity indicators out of 37 initial significant indicators that functioned as the measures of project complexity. To generate the required input for the proposed model, the variable reduction process called Principle Component Analysis (PCA) was applied during the model development process to reduce the number of explanatory variables. PCA process resulted in a significantly smaller number of principal components functioning as the moderating variables in the model (10 PCs). However, this number of moderating variables was still not small enough to create a stable model. Therefore, the univariate method was applied the second time to the set of principle components. The second application of univariate method resulted in the final set of 8 principle components. Those principle components functioned as the final set of moderating variables in the developed model as it was sufficient to generate a stable model. This process helped in generating a numerically stable model while the subject observations were limited. The developed model helps scholars and practitioners in the field of project management assess complexity level of a project based on the applicably identified complexity measures. Given the identified complexity levels, project practitioners can facilitate the management process and formulate a management plan by applying an appropriate complexity management strategy.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION

1.1 Background

In the field of project management, both scholars and practitioners have referred to problems caused by complexity or problems of particular significance to complex projects. During the past few years, there has been an increasing tendency to draw attention to the particular challenges posed by complex projects. The discussion, however, has been somewhat hindered because the issue of theoretical foundations in project management research has been a central point of debate among both practitioner and scholarly communities for quite some time (Cicmil et al. 2009). The discussion about complexity in projects is simply one strand to the growing concern about the theoretical basis of the project management knowledge system, but it is an important one. What is at stake is a comprehensive understanding of what it takes to deliver complex projects successfully in all fields of human endeavor, and not simply in the field comprising the traditional arena from which the disciplines of project management emerged.

Complexity often refers to a measurement of the number of elements and interfaces or a relative comparison of difficulty to what an organization had previously accomplished. Complexity presents additional management challenges to achieving project objectives. References to low project complexity or high project complexity are commonplace across all industry sectors. However, most references to low or high complexity are often made by intuition and may often represent a relative assessment of complexity by comparison to other types of projects or to similar projects within an industry sector. There is no single nor standard definition for complexity that can be applied to all project cases; furthermore, there is no single depiction or understanding of complexity, what it means, and how to measure it.

Construction research often studies complexity as one of many variables. Some professional organizations have studied complexity as a singular subject (e.g., Project Management Institute with "Exploring the complexity of projects: Implications of complexity theory for project management practice" by Cicmil, 2009). Cicmil et al. (2009) identifies complexity as a factor that helps determine planning and control practices, hinders the identification of goals and objectives, or a factor that influences time, cost, and quality of a project. Most of these studies focus on the theoretical background of the topic and describe a broad definition of project complexity.

1.2 Problem

There is a need to study complexity as a separate factor influencing projects. This includes a need to define project complexity, study the individual and most important facets of complexity, and identify the influence of project complexity on different aspects of projects such as cost, schedule, quality, and project performance. Most facets of complexity are known to be constantly changing variables such as project type, project size, project location, project team experience, interfaces within a project, logistics/market conditions, geo-political and social issues, and permitting and approvals. Better understanding of project complexity and creating a complexity management strategy will influence how efficiently and economically projects are planned, executed, and managed.

1.3 Research Questions

Based on the literature review and project management perspective, the research questions have been developed to direct the research to the focused purpose. "1-*What is project complexity? 2-How will project complexity be characterized? 3- How will the level of project complexity be measured?"* are the central questions that need to be answered in this research. The answers for other additional questions including "4- *Which factors have more important contribution to project complexity?"* or "5- *How does the level of complexity drive project outcomes?"* are also important for investigating further aspects of project complexity. Addressing these research questions would make a considerable contribution to the body of knowledge in terms of project complexity.

1.4 Research Goals and Objectives

The overall goal of this research to address the research questions is to develop a model to describe project complexity, and then measure it. The purpose of this process is to define project complexity, identify project complexity attributes, and then develop certain methods/models to measure it. This goal will be achieved by attaining the following specific objectives:

- Define complexity and its attributes;
- Identify attributes that contribute to project complexity;
- Develop a complexity measurement approach;
- Develop a complexity predictive model

These research objectives provide the framework for this research.

1.5 Research Contribution

The successful completion of this research helps scholars and practitioners in the field of project management increase their understanding of project complexity and improve project management practices. The aim behind this research is twofold including a theoretical and practical component. Theoretically, the research will explore the root contributors to the complexity of projects; propose the description of those contributors from the perspective of complexity theory and complexity management; then provide a model that can predict the level of project complexity. In this manner, the research has its ambition to contribute to enriching the theoretical basis in the field of project management. In practical terms, the research aims to propose a critical and constructive way of explaining and measuring project complexity that can lead to a wider awareness and development of competencies for practitioners in managing complex projects.

CHAPTER II

LITERATURE REVIEW

To better understand the state of the art in terms of complexity, the publications relevant to project complexity have been reviewed. Other studies related to complexity management have also been reviewed to determine how project complexity was covered in various past research efforts. Additionally, relevant models and tools already developed were investigated for insights into different approaches to tool structure and format from other areas of research. A significant number of practical and academic studies have been collected, reviewed, and summarized. In particular, topics relevant to the following categories were reviewed to identify the current state of research in these areas:

1. Complexity theory
2. Project complexity definition
3. Attributes of complexity
4. Project complexity, risk, and difficulty
5. Assessing and measuring project complexity
6. Impacts of project complexity

Findings from the literature review are discussed in the followed sections of this chapter.

2.1 Complexity Theory and Management Practice

2.1.1 Complexity Theory

Many writers have introduced complexity theory into a specific field to define a complex system and describe the characteristics that create complexity for that system. Complexity theory generally defines what a complex system is within a specific area of interest (e.g., natural, biology, eco-system, computer science, human society, or financial market, etc.) and studies the interaction between the elements in that system. The existing theoretical issue of complexity theory is that there is still no commonly accepted definition of complexity, despite there being a large number proposed (Chu and Jelland, 2003). As defined by Valle (2000) and Lucas (1999), *complex system is a whole that consists of several elements interacting with each other in many different ways.* Numerous interdependent elements in a complex system continuously interact and spontaneously organize and reorganize themselves into increasingly elaborate structures over time. Unlike conventional systems (e.g. an aircraft or a computer), a complex system includes elements that do not necessarily have fixed relationships, fixed behaviors, or fixed quantities.

Complexity theorists indicate that critically interacting components might self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties. The systems should be best regarded and studied as wholes instead of separately considering and studying each component. Lucas (1999) categorized systems into four levels of complexity:

1) *Static complexity*: the simplest form of complexity is that related to fixed systems and does not change with time (e.g., a computer chip – complex but not changed over time);

2) *Dynamic complexity*: The systems are considered to be changed spatially and temporally; however, the alternation is in cyclic processes (e.g., seasons or a heartbeat);

3) *Evolving complexity*: the systems are non-cyclically changed in their spatial and temporal dimensions, and they evolve or alter through time into different complex systems (e.g., an aquatic form becomes land dwelling); and

4) *Self-Organizing complexity:* The systems are the combination of the internal constraints of closed systems (like machines) with the creative evolution of open systems (like people). Systems are regarded as co-evolving with its environment called co-evolutionary systems (e.g., human society, complexity of living organisms- Darwinian natural selection). With this form, complexity is usually characterized by a progression in complexity so that over time the system becomes larger and more sophisticated.

In Theories of Complexity (2003), Chu has considered two fundamental properties generating complexity for a system: *radical openness* and *contextuality*. Radical openness and contextuality are probably present in most natural systems. With radical openness, multi sub-systems are embedded in a non-boundary system. Other systems could partly or totally be embedded in a complex system (e.g. the economic system is partially embedded in an ecological system and impacts it; cause and effect chains propagate from economic system into the ecological system). With contextuality, a system includes one or more elements that also occur in a different system or if it is itself a shared element between more than one system. In these other systems, the shared elements take part in causal processes different from those included in the original system. Radical openness and contextuality are properties that make the control and prediction of complex systems very difficult. In the presence of contextuality, the risk of unforeseen side effects increases. In addition, if the system is radically open, these side effects might propagate uncontrollably over system boundaries (Edmonds, 1999).

With endeavors of quantifying or modeling complexity theory, scientists have attempted to apply quantitative techniques to existing systems or organizations. However, most attempts to quantify deal with either the parts (traditional reduction) or look to simplify the system to a single or few parameters. Complexity could be simplified by making its features and properties reducible, and the modelers can ignore some features without substantially compromising the validity of the models. However, readers and/or users have to be aware of inherent limitations of these models and acknowledge that they cannot represent the full complexity of the system.

2.1.2 Complexity Theory and Management Practice

In the management area, under certain condition, the systems of interest to complexity theory perform in steady, predictable ways; under other conditions they exhibit behavior in which regularity and predictability is lost. Almost undetectable differences in initial conditions lead to gradually diverging system reactions until eventually the evolution of behavior is quite dissimilar. The systems of interest are dynamic systems with capability of changing over time. Some systems constantly change, but do so in a relatively regular manner; while other systems lack this stability. Unstable systems move further and further away from their starting conditions until or unless these systems are brought up short by some over-riding constraint (Rosenhead, 1998). Stable and unstable behaviors are part of the traditional range of physical science. In the management field, Stacey (1992) indicates that a system behavior may also be divided into two zones: 1) stable zone where if the system is disturbed, it returns to its initial state; and 2) unstable zone where a small disturbance leads to movement away from starting point, which in turn generates further divergence. Which type of these behaviors is exhibited depends on the conditions, which are included in the organization. Under some appropriate conditions, systems may operate at the boundary between these zones, sometimes called a phase transition, or the 'edge of chaos', in which they exhibit a sort of bounded instability, that is, the unpredictability of specific behavior within a predictable general structure of behavior.

The general lesson from complexity theory for management practice is that successful strategies, especially in the longer term, do not result from fixing an organizational intention and mobilizing around it; they emerge from complex and continuing interactions between people. Management complexity theorists tend to emphasize the importance of openness to accident, coincidence, and chance. Strategy is the emerging resultant (Rosenhead, 1998). Rather than trying to consolidate stable equilibrium, the organization should welcome disorder as a partner, use instability positively. In this way, new possible futures for the organization will emerge, arising out of the ferment of ideas which it should try to provoke. Instead of a perfectly planned corporate death, the released creativity leads to an organization which continuously re-invents itself. Members of an organization in equilibrium with its environment are locked into stable work patterns and attitudes; far from equilibrium, behavior can be changed more easily.

In *Strategic Management and Organizational Dynamics*, Stacey (1993) creates a key distinction between ordinary management and extraordinary management that could be applied for managing project complexity. Ordinary management is required in order to conduct day-to-day problem solving to achieve the organization's established objectives. It employs a logical analytic process involving data analysis, goal setting, evaluating options against goals, rational choice, implementation through the hierarchy, and monitoring. Competent ordinary management is necessary if the organization is to deliver cost-effective performance. In contrast, extraordinary management is what is required if the organization is to be able to transform itself in situations of open-ended change. The problems and practices of ordinary management have been repeatedly addressed in management texts. What is innovative is the concept of extraordinary management. Extraordinary management requires the activation of the implicit knowledge and creativity within the organization. Ordinary management should not necessarily drive out extraordinary management. It is rather that both are needed in viable organizations, and they must be able to coexist.

2.2 Definition of Project Complexity

Through the literature review, more than thirty definitions of complexity were found. In this section ten definitions of complexity in general and project complexity in particular are introduced. These definitions are originated from a wide variety of disciplines, and some of them are radically different from the others. All definitions have gone through a three phase screening process. This process eliminated the definitions based on:

1. Definitions designed to explain complexity of disciplines that are not related to project management.
2. Similar definitions in different studies (the most cited definition has been selected).
3. Definitions that consist of uncertainty elements. The literature often uses uncertainty to describe complexity. The use of uncertainty has purposely been avoided in the definition, as uncertainty is more often associated with risks rather than complexity.

The result of this screening process is shown in Table 2.1.

Table 2.1 Project complexity definitions

	Authors	Year	Complexity or Project Complexity
1	Dictionary		(1) Consisting of many varied interrelated parts; (2) Complicated, involved, intricate
2	Perrow	1965	The complexity of a task is the degree of difficulty and the amount of thinking time and knowledge required to perform the task.
3	Gidado	1996	Project Complexity is the measure of the difficulty of implementing a planned workflow in relation to the project objectives.
4	Baccarini	1996	Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependency.
5	Edmonds	1999	Complexity is that property of a model, which makes it difficult to formulate its overall behavior.
6	Sbragia	2000	The number of elements in the project, intensity of interactions between elements, and difficulty of cooperation between the functional areas.
7	Brockmann and Girmscheid	2007	The complexity is the degree of manifoldness, interrelatedness, and consequential impact of a decision field.
8	Hass	2008	Complexity is characterized by a complicated or involved arrangement of many inter-connected elements that it is hard to understand or deal with.
9	Vidal and Marle	2008	Project complexity is the property of a project, which makes it difficult to understand, foresee and keep under control its overall behavior.
10	Remington, Zolin, and Turner	2009	A complex project demonstrates a number of characteristics to a degree, or level of severity, that makes it difficult to predict project outcomes or manage project.

2.3 Complexity Attribute

The next step in better understanding complexity is to identify the attributes of complexity. Scholars have focused on the identification of complexity attributes more than any other topic in the field of project complexity. Studies in this area have evolved significantly over the past twenty years. Baccarini (1996) identified two major attributes of complexity including organizational complexity and technical complexity. Organizational complexity reflects the view that a project is a task containing many interdependent elements. Since this dimension of complexity is related to the structure of the project, Williams (1999) refers to this factor as “structural complexity.” Technical complexity deals with complexity related to the transformation processes, which convert inputs into outputs.

Remington and Pollack (2007) added two attributes of complexity to the body of literature those are directional complexity and temporal complexity. Directional complexity is found in situations where the goal is not completely agreed upon among all project stakeholders. Temporal complexity reflects the complexities related to volatility over the duration of the project that is caused by the environment.

Brockmann and Girmscheid (2007) argue that while these factors are contributing to the project complexity, they do not cover all possible layers of complexity. They believe that structural complexity, technical complexity, directional complexity, and temporal complexity are some of the elements of task complexities. Then, they introduced four other attributes of the complexity: social complexity, cultural complexity, operative complexity, and cognitive complexity. Social complexity depends on the number and level of communication between the workforces of the project. Cultural complexity is related to the history, experience and sense making processes of the stakeholders of the project. Operative complexity deals with the degree of independency of organizations that are involved in the project during the decision making process.

While these categories might have a major impact on the project, they are not considered as major complexity attributes for the purpose of this study. Scholars in different disciplines have studied the influence of culture, norms, and cognitive issues on the project and it is unnecessary to include these attributes in the project complexity literature. Also, studying the influence of these factors on the project especially in a way Brockmann and Girmscheid (2007) developed the framework, might not be a topic of interest for this practical research.

Several other attributes of complexity can be found in the literature that can be categorized as one of the components of the major factors that have already been introduced. For example, project size (GAPPS, 2007) is an element of structural complexity and context dependency (Lee and Xia, 2002) is one of the temporal complexity components.

Uncertainty factors introduced by some of the scholars are categorized into uncertainty in goals and uncertainty in methods. Lebcir (2006) introduced uncertainty as one of the factors influencing the complexity of the project. It has two important dimensions. Uncertainty in goals that means the project is ill defined at the beginning of its execution and uncertainty in methods that reflect the lack of knowledge on how to achieve project goals. Thus, uncertainty factors can be eliminated from the list of major complexity attributes.

In summary, four major attributes of complexity have been selected based on previous practical and academic studies: structural complexity, technical complexity, directional complexity, and temporal complexity. These major complexity factors are not exclusively independent from each other. For example, team expertise could have an impact on all four categories. As the expertise of the team increases, the project will benefit from the more optimized organization, better technical process, clearer goals and better handling of the environment. In the remaining parts of this section, each one of these major factors has been defined and explained. Also, components of these categories are introduced.

2.3.1 Structural Complexity

Structural complexity depends on number of elements involved in the project and interdependence of these elements relative to each other. For example, project organization elements such as number of stakeholders or number of engineering disciplines involved in the project. Technical elements such as the number of project components, and the interdependence could be the number of interfaces both management and technical between elements. Number of distinct disciplines, methods, or approaches involved in performing the project influences the complexity of the project, more elements means a project that is relatively more difficult to manage. Project size is one of the elements of structural complexity. As the project size increases, the number of elements such as activities, number of employees, and required resources increases. Thus, as the project size increases, the level of complexity of the project increases. Also, large projects are probably more important for stakeholders than the small projects. Because the financial impact (positive or negative) of this project on the project's stakeholders is higher (GAPPS, 2007).

In most projects the elements are interdependent of each other with mutual tie that means each element's output becomes other elements' input (Williams, 1999). In such projects, both elements and their snowball effects should be managed properly.

2.3.2 Technical Complexity

Technical complexity can be defined as the transformation processes, which convert inputs into outputs. It is divided into facility operational requirements, project characteristics, and the level of knowledge required for the project. Examples of technical complexity are sophistication of control system, number of operators; location of project, type of work force skills needed, and right type of technical expertise. Innovation means that the new project is radically different from the previous ones meaning that developers are not fully confident regarding the best methods to be used in the project, and the outcomes of these methods. So, the higher the level of innovation, the higher is the technical complexity.

Technology is rapidly changing in some of the project management disciplines such as software and IT business more than others. Executing a project in the fields with constant changing technology could increase the project complexity in two ways. First, the selected method to executing the project might change during the life cycle of the project and second, delays in the execution of the project could result in an outcome that is outdated by other competitors.

2.3.3 *Directional Complexity*

Directional complexity is found in projects where the goals or goal-paths for the project are not understood or agreed upon at all levels of the project hierarchy. An example of directional complexity is the alignment between organizations and/or within each organization such as stakeholders having different objectives for a project as compared to the project team members. Stakeholder cohesion is achieved when all or most of the stakeholders are in agreement about the characteristics of a project, the methods, and the expected outcomes, the level of directional complexity decreases. Urgency and flexibility of cost, time, and scope (Hass, 2008) impacts the level of complexity. Cost, time, and scope of the project are three of the most important characteristics of the project. A tight-budgeted fast track projects with an uncertain scope is more complex to manage than a project that has a defined scope with more flexible cost and time.

2.3.4 *Temporal Complexity*

Temporal complexity refers to volatility over the duration of the project, where project durations are extended and where the fluctuation in the environment (market, technical, political, or regulatory) could affect project direction. For example, market changes potentially impacts product sales, political issues, or new technologies. One of the most important characteristics of temporal complexity is its dynamic nature. It is caused by changes in business and technological environment. Controlling this type of complexity requires constant monitoring of the environment through the life cycle of the project. Changes may come from either the nature of the environment or a lack of knowledge about the environment (Lee and Xia, 2002). Two sources of change are:

- Context dependency: It is referred to the different elements of market such as competition, cultural configuration and local laws and regulations (Vidal and Marle, 2008).
- Time scale of the project: Negative or positive changes in the environment could affect the projects with a longer time frame compared to a project with a short duration.

Dynamism of the market, political or regulatory environment influences the level of complexity. Dynamic is a factor that addresses the potential external impacts such as magnitude of legal, social, or environmental implications. For example, a construction project executed in Washington D.C. likely has more political complexity than a similar project in another urban area.

2.4 The Difference between Project Complexity, Risk, and Difficulty

Three aspects of projects are risks (uncertainties), difficulty (how hard something is to achieve) and complexity (complexity previously defined). While the researcher has attempted to separate and isolate these three concepts, it must be acknowledged that project teams are often faced with tradeoffs between these three concepts. Three key understandings to effectively manage complex projects are: (1) how well a project team differentiates the attributes of project complexity from risk associated with those attributes; (2) how well a project team plans and manages the attributes of complexity; (3) and how effectively the project team manages areas where outside forces influence the attributes. The more complex a project, the greater the number of project elements that must be addressed to ensure project success. Hence, greater and more comprehensive attention to project complexity attributes can be expected to lower a project's initial risk profile.

Additionally, project complexity typically begets project difficulty, which in turn makes the project harder to complete and requires special effort to keep project risks in check. However, it is acknowledged that difficult project objectives, such as compressed schedules or critical resource shortages, may actually cause a project team to choose *more* complex methods to achieve aggressive project goals. At this point complexity and risk are observed to diverge; that is, the team can intentionally increase the complexity of a project in the form of re-sequenced work, alternate partnerships, challenging procurement strategies, multi-sourcing of materials, and increased manpower with little to no impact to the overall project risk profile. Increased complexity is managed by maintaining positive control over any new project interfaces. In fact, some risks may be mitigated as a result of a more complex approach. Since complexity and risk can track independent of each other, they can only be categorized as two different properties within a project.

A key difference between complexity and risk has to do with the "knowns" and "unknowns" of the project. Project risk management attempts to quantify and measure the unknown events, or the known events with uncertain outcomes or timing of occurrence that may impact project results. On the other hand, project complexity focuses on the known properties of a project and how the properties interrelate.

Both complexity and risk can evolve over the life cycle of a project, but how this evolution takes place is very different. Complexity evolves as more "knowns" develop throughout the various project phases. The "knowns" may include logistics requirements, legal considerations, governance structures, partnerships, and scope definition. Note that these complexity components are not risks to the project but are fundamental elements of a project that when identified, can and must be managed effectively for success. However, complex elements can, and often do, drive project risks based on the level of uncertainty that is also a part of some project elements. The degree of complexity within a project can increase the overall risk profile strategy (a need to address unknowns), but the impact of risk on complexity is based on implementation of a risk mitigation strategy (increasing the "knowns.")

2.5 Assessing and Measuring Project Complexity

Previous studies explained in this literature review show that for all practical purposes, the project risk framework is not sufficient to identify and measure all the possible positive and negative effects associated with risk, uncertainty, or complexities related to the project. Notably, there is a crucial need for efficient complexity modeling in order to identify and assess the project complexity factors.

In this section, different methods of assessing and measuring complexity will be introduced. One of the downsides of project complexity studies is that while significant number of studies exist in identifying attributes of complexity, assessing complexity, and defining the concept of complexity, the discipline lacks an integrated study that defines the project complexity, introduces its attributes, and proposes a methodology to measure the level of complexity of each project. For example, the studies related to measuring complexity tend to focus on a small range of attributes and try to measure the level of complexity based on those attributes.

The researcher is trying to develop a model that identifies the project complexity level and its impact on the project. In order to accomplish this goal, analysis of previous project complexity measurement methods and tools are required. Some of these methodologies could help develop an efficient and sophisticated model.

By conducting a literature search and structured interviewing of practitioners, Gidado (1996) has defined project complexity and identified the factors that influence its effect on project success. Also, the study proposes an approach that measures the complexity of the production process in construction (Gidado, 1996).

Lee and Xia (2002) introduced a two dimensional framework for assessing information system development (ISD) project complexity. The framework proposes four types of software project complexity: structural organizational complexity, structural Information Technology (IT) complexity, dynamic organizational complexity, and dynamic IT complexity. Based on field interviews, focus group discussions, and a large-scale survey of ISD project managers, a measure of ISD project complexity with 17 indicators was developed.

An initial pool of indicators of project complexity was generated from the literature review and a one-hour focus group discussion with 50 information system practitioners. Combining items from these two sources resulted in an initial pool of 33 items for measuring ISD project complexity. Sorting procedure, using four ISD researchers cut another five factors. The pilot study cut another six and the rest were evaluated in the survey. In order to enhance project success rate, project managers must first understand the relative weights of the four different types of ISD project complexity under their unique context, and take specific measures to manage them accordingly (Lee and Xia, 2002).

Another study by Kim and Wilemon (2003) introduces a template of complexity measures based on several sources of complexity for new product development. Authors suggest complexity assessment template steps as follow:

1. Preliminary assessment
2. Construct the complexity instrument
3. Incorporate perceived complexity challenges into the product development
4. Periodically assess complexity
5. Past launch learning

Applying this method could identify complexity of a project, identify perceptual gaps, and identify changing patterns of complexity along project life cycle.

Global Alliance for Project Performance Standards (GAPPS) developed a project manager standard in 2007. As a major section of the project performance standard, GAPPS developed a comprehensive project management complexity measurement tool called CIFTER. The Crawford-Ishikura Factor Table for Evaluating Roles (CIFTER) provided a seven factor model on which management complexity of projects is assessed. A total project complexity score is created by adding the scores from all seven factors outlined in the CIFTER. The total CIFTER score is used to categorize each project as either below Global Level 1 (scores less than 12), Global Level 1 (scores 12 to 18) or Global Level 2 (score 19 or more). Table 2.2 shows influencing factors as well as the method to evaluate them based on the CIFTER tool. Each of the seven factors in the CIFTER was rated on a point scale of one to four with the total number of points across the seven factors determining whether a project is Global 1, Global 2, or neither.

Table 2.2 Crawford-Ishikura Factor Table for Evaluating Roles (CIFTER)

No	Project Management Complexity Factor	Description and Points			
1	Stability of the overall project context	Very High (1)	High (2)	Moderate (3)	Low (4)
2	Number of distinct disciplines, methods, or approaches involved in performing the project	Low (1)	Moderate (2)	High (3)	Very High (4)
3	Magnitude of legal, social, or environmental implications from performing the project	Low (1)	Moderate (2)	High (3)	Very High (4)
4	Overall expected financial impact (positive or negative) on the project's stakeholders	Low (1)	Moderate (2)	High (3)	Very High (4)
5	Strategic importance of the project to the organization or the organizations involved	Very low (1)	Low (2)	Moderate (3)	High (4)
6	Stakeholder cohesion regarding the characteristics of the product of the project	High (1)	Moderate (2)	Low (3)	Very low (4)
7	Number and variety of interfaces between the project and other organizational entities	Very low (1)	Low (2)	Moderate (3)	High (4)

Aitken and Crawford (2007) tested the model applying a range of statistical analysis tools to the data sub-set including Pearson Correlations, Regression Analysis, and Psychometric Stability tests including Cronbach Alphas. The regression analysis shows that 71.3% of the variance in the GAPPS Complexity Level scores can be explained by the seven-factor CIFTER model. This is a significant portion of the variance and each of the factors except for Factor 2 (Number of Distinct Methods and Disciplines) make a significant unique contribution. These results provide support for the CIFTER as a valid self-assessment tool. Hass (2008) presented a framework to diagnose the elements of complexity that exist on a particular project so that the project team can make the appropriate complexity management decisions.

Based on Standish Group's recipe for project success and best practices in each knowledge areas of Project Management Body of Knowledge (PMBOK) this paper presents eleven categories of factors influencing projects. An expert rates each category as highly complex, moderately complex, or independent. Aggregating the result of the ratings for all categories could result in identifying the project as highly complex, moderately complex, or independent. A spider chart is used to aggregate the ratings (Figure 2.1). The project complexity approach can be used in preparing the business case for a new project proposal, initiating and planning a new project, and recovering a troubled project.

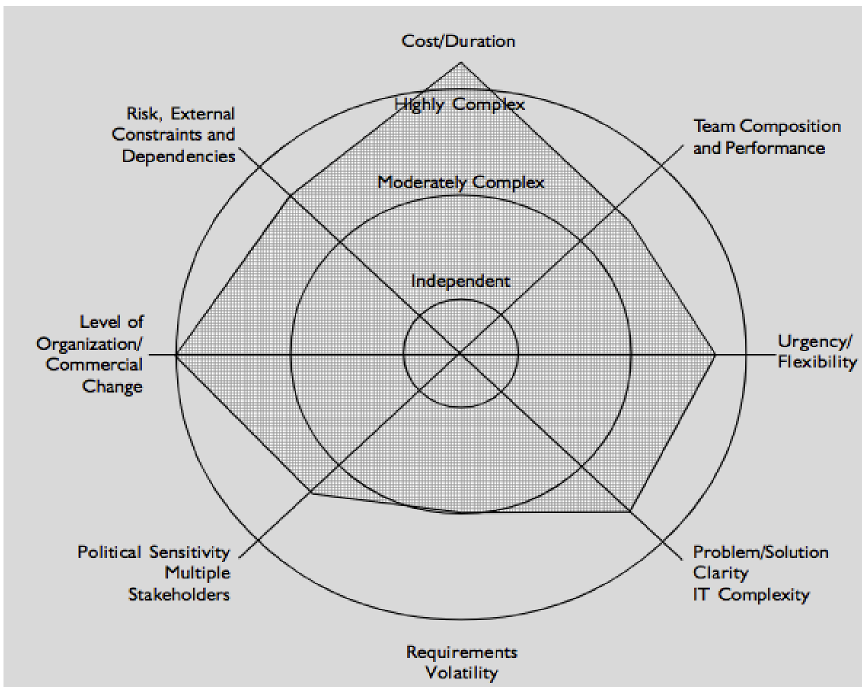


Figure 2.1 Overall Project Complexity

Maylor, Vidgen, and Carver (2008) developed a model of managerial complexity based on two rounds of workshops with project practitioners. The authors' empirical findings in contrast with the literature review, suggest that complexity has both structural and dynamic qualities. The management of such processes is characterized by managers having to cope with a potentially complex array of tasks and uncertainty as to their performance (e.g., duration).

The first round of the workshops were held within small groups to establish project complexity themes and to test the data collection method. A second round was conducted at a meeting with more than 100 project managers. The result is shown in the Figure 2.2. The authors have explained every category and subcategory in detail in order to transfer a good knowledge of how to use the model.

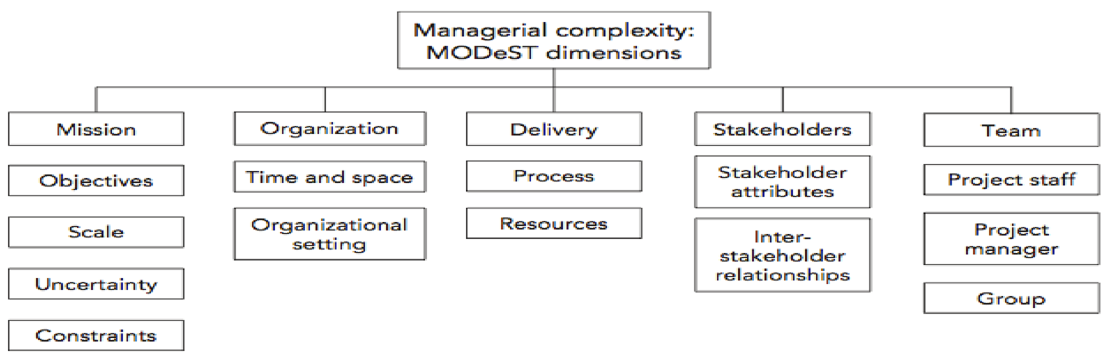


Figure 2.2 Project Complexity Dimensions developed by Maylor et al. (2008)

Many respondents described a further set of elements that were identical in nature to the structural set but that involved change. For instance "organizational structure" was a clear influence on complexity; however, many respondents noted that "organizational changes during project" also provided another element. Further analysis showed that for every structural element there is a corresponding dynamic element (Maylor et al., 2008).

It is noted that a concept often has a profile of its impact on the complexity and outcomes of the project. For example, "lack of senior management support" as one of the contributing factors has the same negative effect as "interference by senior management" does. Thus, this profile can be stated as "the right amount of a factor is beneficial but too much or too little increases the level of complexity that project managers experience" (Maylor et al., 2008).

Remington et al. (2009) argued that project management models tend to focus either on severity factors or dimensions of complexity. The study proposed an operational distinction between the terms dimension of complexity, which shows where the complexity comes from and the severity, which indicates to what extend it will be a problem. The model is based on twenty-five interviews with selected project managers. The results were selection of seven factors that contribute to the perception of complexity. The factors are goals, stakeholders, interfaces and dependencies, technology, management processes, work practices, and time.

The USDA (2009) has developed a method to evaluate project complexity. The users rank fifteen complexity factors in a matrix from one to five for each factor. A brief explanation of issues to consider while ranking the factors is provided. For example, the provided explanation for "project objective" is:

- Are the project objectives clearly defined?
- Were clear definitions of the deliverables received for accomplishing this project?

The considered factors are sponsor, project objectives, mandates, internal work processes, technical requirements, team location, end user impact, initial project estimates (cost and effort), deadline, team expertise, team size, team availability, stakeholder involvement, and external dependencies. The aggregated result of the matrix is determined as the complexity level of each project.

Lebcir and Choudrie (2011) introduced four driving factors of project complexity based on previous studies including: 1) infrastructure size, 2) infrastructure interconnectivity, 3) infrastructure newness, and 4) project uncertainty. The impact of these factors on the project life cycle was modeled using the system dynamic method. The structure of the model was validated through workshops involving several project teams in the organization.

Vidal, Marle, and Bocquet (2011) developed a method to measure the complexity level of a project using Delphi and Analytic Hierarchy Process (AHP) methods. Based on an extensive literature review, the authors identified seventy possible complexity factors. Then, using the Delphi method, 18 essential factors were selected as the most influential factors on project complexity. Some of the identified factors of project complexity are:

- Number of stakeholders
- Variety of information systems
- Location
- Variety of interests of stakeholders
- Dependencies with the environment and specifications
- Availability of resources, interdependencies of systems
- Objectives, processes, team communication, cultural variety
- Environmental complexity

Using the AHP method, the authors weighted each factor against each other and the weight of the factors adds to one. The result has been validated using previous projects as case studies.

Sinha, Kumar, and Thomson (2006) argued that the complexity level changes during the lifecycle of the project. They developed a framework that measures the complexity in the lifecycle of the project using Complexity Index (CI).

Brockmann and Girmscheid (2007) demonstrated that the complexity level of the project changes through the life cycle of the project. Based on six case studies and thirty-five interviews, the authors argue that the complexity level of the project is the highest at the start of the project and it decreases as the project is executed (Figure 2.3). Also, some issues such as change orders or legal disputes might change the complexity level of the project by a significant amount (Figure 2.4).

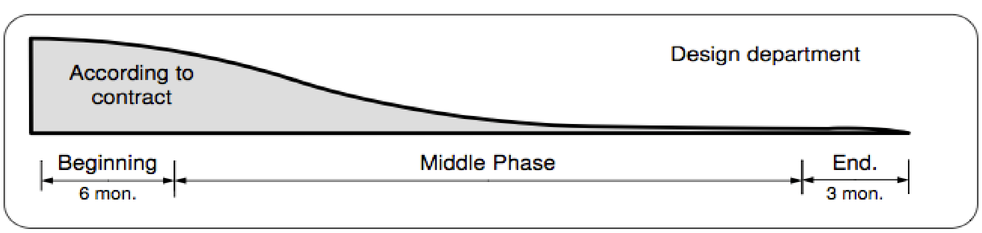


Figure 2.3 Complexity curve during the lifecycle of the project

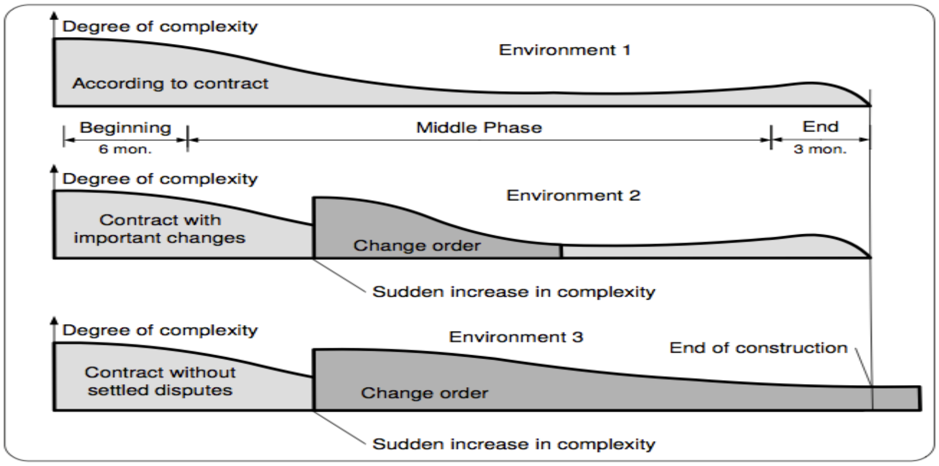


Figure 2.4 Overall complexity curves

2.6 Literature Findings

Several definitions of complexity were found from a wide range of disciplines as specifically discussed in each section of literature review. However, there still was no commonly accepted definition of project complexity, despite a large number proposed. Each author had a different perspective on defining project complexity. Thus, this research defined complexity specific for projects in the construction industry using the definitions from literature as a starting point. For the purposes of this research, the myriad definitions can be consolidated to the following central idea for further discussion: *Project complexity is the degree of differentiation of project elements, interrelatedness between project elements, and consequential impact on project decisions.* Also, all the attributes of complexity suggested by scholars were discussed. While a fair amount of papers and books can be found around different methods of measuring complexity, it seems that very few scholars have studied the influence of project complexity on project characteristics. A detailed study of the impacts of project complexity may help practitioners understand project complexity and manage it properly. In addition, the literature indicates that project complexity is basically measured by measuring complexity attributes. Therefore, an approach to measuring project complexity attributes would help to thoroughly understand the complexity of a project.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Approach

To fully explore, assess, and measure project complexity, a research framework is developed to support the interaction of the primary research objectives described in the introduction section. The research process is conducted through seven tasks. Task 1 starts with the in-depth exploration of the concept of complexity and its attributes. Contemporary literature on the subject of complexity is reviewed, and background experience is gathered. Research questions and research objectives are identified to direct the research around the focused point. Task 2 reviews the developed definitions of project complexity and describes project complexity by developing a working definition and identifying potential complexity attributes as a basis for this research. After developing a description of complexity and long-term objectives to address complexity, a research plan is developed. Task 3 proposes an approach to develop the complexity indicators deemed to measure the associated complexity attributes and the relevant hypothesis. The data related to testing hypothesis is collected through a data collection process and statistically analyzed to verify the developed complexity indicators. Data collection process is conducted in Task 4. In Task 5, the collected data is reviewed and descriptively analyzed to interpret its characterizations, and then statistical methods are applied to analyze the data and test relevant hypothesis to determine which identified attributes are truly representative of project complexity. Task 6 develops a predictive model based on the statistical analysis results to create a constructive way for measuring complexity level of a project. The developed model is validated and tested in Task 7 to examine that it is developed appropriately. The research approach is visually described in Figure 3.1.

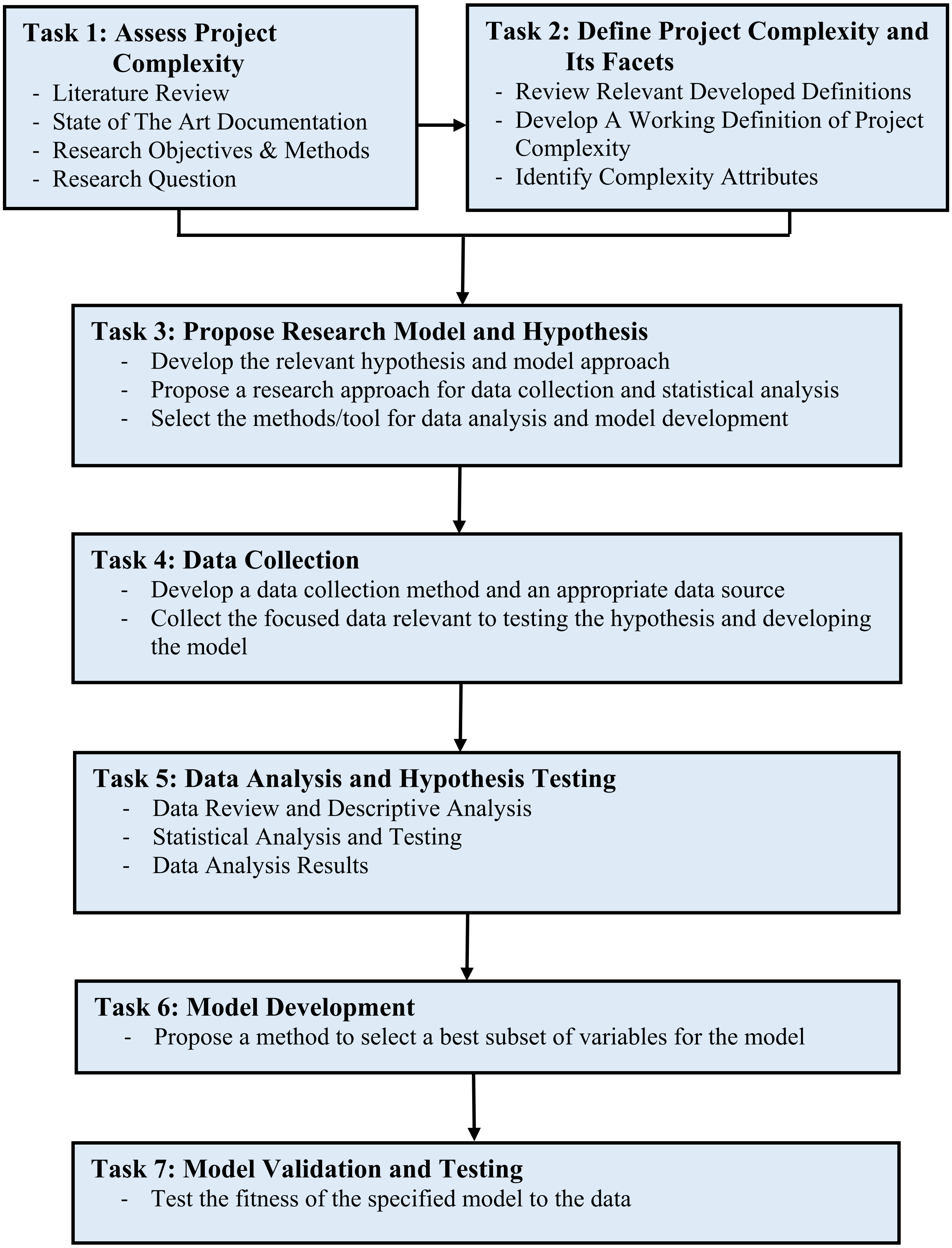


Figure 3.1 Research Approach

3.2 Project Complexity Definition Development

Throughout the literature review, several definitions of complexity were found from a wide range of disciplines. However, there is still no commonly accepted definition of project complexity, despite a large number of definitions proposed. One of the difficulties in addressing the topic of complexity is that the term is broadly and intuitively applied. Without a solid definition, complexity tends to be a catch-all category that can be used when project results are unpredictable, when a project has many interacting parts, when details of a project are poorly understood, or for a myriad of other project conditions outside of what is typically perceived as "normal." Project professionals and teams have an intuitive sense of when a project is complex, but the reasons for that complexity are widely varied and depend on that person's or project team's experiences, resource availability, stakeholder considerations, and many other factors, both objective and subjective. Additionally, the perception of complexity can be compounded by multiple project factors, which if not managed effectively may have a negative impact on the project outcome.

To ensure that the research results can be generalized across industry sectors or within an industry sector with different types of projects, project complexity is chosen to be described in terms of managing projects (e.g., internal project team interfaces, site logistics, permitting, etc.) rather than complexity related to project physical features (e.g., types of materials, quantities of materials, number of systems, and facility technology).

After the substantial consideration of project complexity definitions as shown in Table 2.1 in the literature review, the following definition of project complexity was developed as the basis of this research:

> ***"Project complexity is the degree of interrelatedness between project attributes and interfaces, and their consequential impacts on predictability and functionality."***

Project attributes indicated in this definition could be managerial features including project stakeholders/regulatory agencies, or could be the management of project physical features such as managing project components/locations/technologies. This definition attempts to capture the essence of how project attributes, such as project scope, team organizational dynamics, project location, policies and regulations, unfamiliar technologies, and workforce skill sets, interact both within a project and with entities outside of the project. Without targeted strategies to manage complexity the project outcomes may be negatively impacted. With proper management strategies in place to control a diverse set of project attributes and associated interfaces that lead to increased project complexity, the probability that projects can be both successful and predictable is increased.

3.3 Complexity Attribute and Indicator Development

With the developed definition of project complexity, a methodology is developed to identify the level of project complexity. The term "complexity attribute" is selected to represent the factors that describe project complexity. Initially, 40 complexity attributes were identified using complexity theory variables, the literature review results, and industry experience. The description for each attribute was then created that includes: 1) attribute definition, 2) examples, 3) measures, 4) and impacts. Table 3.1 shows an example of complexity attribute description, and the detailed descriptions for all complexity attributes are presented in Appendix A.

Table 3.1 Example of Attribute Description

Attribute	Attribute Definition	Example	Measure	Impact
Change Management (dynamics of market and environment)	Overall effort on a project to prepare for and mitigate or manage changes to project scope and/or project environment. Also considered a systematic approach or protocol to manage changes within a project.	Design changes, contracting strategy changes, market-driven changes, unknowns/risks that occur during project execution, regulatory changes, construction method changes, etc.	Effectiveness of change management and its mitigation, the number of changes in a specific duration, timing of changes, etc.	Impacts on project cost, project schedule, project objectives, resources demand, etc.

Creating these descriptions of complexity attributes aids in eliminating or combining the attributes in an attempt to reduce the number of attributes to a more meaningful and manageable number because of the similarity or duplicability. The 40 identified complexity attributes were reviewed and combined. This process ultimately results in a reduced list of 35 complexity attributes. Five complexity attributes that are excluded from the initial list or combined with other attributes are: 1) Project Visibility; 2) Project Size; 3) Type of Project; 4) Time Scale of the Project; and 5) Types of Risks that are being managed. The retained complexity attributes are then grouped into categories to aid in understanding the general nature of the attributes. Eleven categories are proposed including:

1) Stakeholder Management;
2) Project Governance;
3) Legal;
4) Fiscal Planning;
5) Interfaces;
6) Scope Definition;
7) Location;
8) Design and Technology;
9) Project Resources;
10) Quality; and
11) Execution Targets.

A category can have a number of different complexity attributes. Table 3.2 presents the list of thirty-five complexity attributes associated with eleven categories after being combined and grouped.

Table 3.2 Thirty-five Identified Complexity Attributes and Attribute Definitions

Category	No	Attribute	Attribute Definition
Stakeholder Management	1	Clarity of business objectives	Mutual understanding among stakeholders and team members of achievable, worthy project outcomes and tradeoffs that will make a project a success and create a comparative advantage from the viewpoint of all stakeholders.
	2	Level of stakeholder cohesion	The effort to meet and maintain the original business objective and scope intent identified by the original sponsorship through current project activities.
	3	Public profile	How the project/company is perceived by the public, how the project is impacting local community or geographical area
	4	Social and political influences surrounding project location	Project impact on local social and political groups (stakeholders)
Governance	5	Joint ventures	The cooperation of two or more individuals or businesses in which each agrees to share profit, loss and control in a specific enterprise.
	6	Level of authorizing approvals and duration of receiving proposals	Efficiency in making project decisions (organizational structure design for making project decisions, stakeholder management)
	7	Level of control	The degree of authorization to enact changes through a lifecycle of a project.
	8	Owner, partnerships	Governance structure sponsoring a given project
Legal	9	Legal	The amount of behavior that a body of law attempts to regulate.
	10	Permitting and regulatory requirements	Building, environmental, and code compliance required for initial site construction access, construction phase, and facility / location startup and operation.

Table 3.2 Continued

Category	No	Attribute	Attribute Definition
Fiscal Planning	11	Commercial burdens	Financial elements affecting the cost and execution requirement of a project.
	12	Fiscal planning, or financing (funding stream, uncertain political environment)	Project's funding plan can introduce project complexity through number of partners, fiscal/economic climate, political environment (stakeholders, government regulations)
Interfaces	13	Interfaces within the project	An interaction, in the form of a discussion or deliverable, between people, teams and/or organizations for the purpose of communicating (handoffs/ approvals/decisions), to influence and advance the project.
	14	Number of participants	The number of stakeholders associated with a project. It is important to note that these stakeholders can be internal and external to the owner company and internal and external to the project team.
	15	Number of suppliers, subcontractors, contractors	The quantity of supplier, subcontractors and contractors associated with a project. The total count is independent of who holds the contract; it may be the owner, general contractor or multiple general contractors.
Scope Definition	16	Change Management (dynamics of market and environment)	Overall effort on a project to prepare for and mitigate or manage changes to project scope and/or project environment. Also considered a systematic approach or protocol to manage changes within a project.
	17	Clarity of scope definition	Degree to which project services, deliverables and facilities have been defined at the beginning of a project.
Location	18	Climate	The impact of design, equipment, construction and operating considerations required to deal with long term weather.
	19	Local content requirements	The local labor or sourcing regulations, restrictions or requirements enforced on the project resulting from physical jobsite location and project type.

Table 3.2 Continued

Category	No	Attribute	Attribute Definition
Location	20	Logistics	The effort required to physically procure, transport, install and integrate materiel and personnel for the purpose of completing a project
	21	Number of locations	Distinct geographical locations of project team members
	22	Physical location	Geographic location of the final constructed asset, the physical location of project activities (e.g., engineering, fabrication, construction), and the physical location of key stakeholders including project team members (e.g., sponsors, partners, suppliers, contractors, etc.).
Design and Technology	23	Design (number of process steps, HSE hazards, # of recycles, exotic materials)	The depth of design and number of process steps, HSE hazards, exotic materials, type of project (LNG, power plant, offshore, onshore).
	24	Technology	The application of technical processes, methods, components, and/or knowledge to execute the project.
Project Resources	25	Direct field labor management	Skill set requirements for construction workforce and staff support assigned to a field project.
	26	Productivity	This seems like a subset of scoping effort with an affect to schedule and costs.
	27	Resource availability	The cost of resources compared to the project budget
	28	Team experience	Depth of expertise and knowledge in areas required for the project execution, in the locality (cultural and language consideration) and are familiar with the implicit and explicit customer expectations of performance.
	29	Turn over	Relates to the turnover of stakeholders associated with a project. It is important to note that these stakeholders can be internal and external to the owner company and internal and external to the project team.

Table 3.2 Continued

Category	No	Attribute	Attribute Definition
Quality Management	30	Quality of suppliers, subcontractors, contractors	The quality of suppliers, subcontractors and contractors who participate in the completion of a project.
	31	Unfamiliar procurement	Purchasing equipment or services in a new region or business sector
Execution Targets	32	Cost targets	The various budget, commercial, and contractual factors that impact the number of interfaces impact cost during the execution of a project.
	33	Schedule targets	Level of Schedule aggressiveness (duration, overlap of engineering and construction) in relation to industry benchmarks for project type
	34	Schedule	The steps/activities identified to meet time objectives
	35	Strategic importance of the project	Impact of the project on the organization's overall profitability, growth, future industry position, and internal strategic alignment

The identified complexity attributes presented in Table 3.2 are used to develop the complexity indicators deemed to measure the associated attributes. Each attribute-measuring indicator was then converted to one question for data collection purpose. For complexity measuring purposes, each attribute has one or more indicators relevant to measuring it. Figure 3.2 presents the complexity measurement hierarchy for a single category, and Table 3.3 presents an example of a complexity attribute, attribute definition and the relevant complexity indicators that are used to measure the attribute. This hierarchical framework is discussed in more detail in the data collection process section that follows.

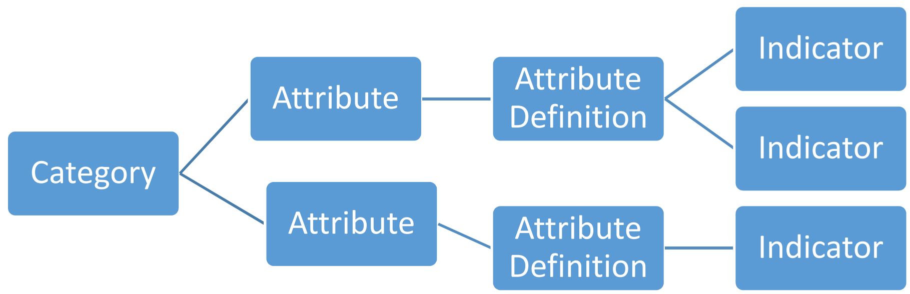


Figure 3.2 Complexity Measurement Hierarchy

Table 3.3 Example of Attribute Definition and Its Indicator

Category	Attribute	Attribute Definition	Complexity Indicator
Scope Definition	Change Management (dynamics of market and environment)	Overall effort on a project to prepare for and mitigate or manage changes to project scope and/or project environment. Also considered a systematic approach or protocol to manage changes within a project.	CI-30_Impact of the magnitude of change orders on project execution. CI-31_Impact of the timing of change orders on project execution.

3.4 Proposed Model and Research Hypothesis

As discussed previously, the central purpose of this research is to identify complexity attributes and develop a model to describe and measure project complexity. The proposed model is a predictive model used to predict the complexity level of a project (Low Complexity vs. High Complexity) based on identified complexity indicators proven significant in differentiating low complexity projects from high complexity projects. Basically, the proposed model is a function where project complexity is a response variable (dependent variable), and the significant complexity indicators are predictive variables (independent variables). The output of the model is binary with respect to the level of project complexity (Low Complexity vs. High Complexity) depending on the input, that is, complexity indicators. In order to determine the input for the model, complexity indicators must be identified, and the significance of these indicators in differentiating low complexity projects from high complexity projects must be tested. If an identified complexity indicator is not statistically significant for describing and measuring project complexity, it must be excluded from the model. The significance level (α) for testing the hypothesis is discussed in Chapter 4 – Data Analysis and Research Results. To provide the input for the proposed model, a research hypothesis is developed to test the significance of identified complexity indicators. This proposed hypothesis is:

Alternative Hypothesis (H1) – The identified project complexity indicators are significant in differentiating low complexity projects from high complexity projects.

Null Hypothesis (H0) – The identified project complexity indicators are not significant in differentiating low complexity projects from high complexity projects.

The assessment of these hypothesis drove the data collection and analysis techniques. This hypothesis is quantitatively tested for each indicator that is developed to measure the associated complexity attribute. There are 101 complexity indicators developed to measure thirty-five complexity attributes presented in Table 3.2; therefore, 101 corresponding individual hypotheses are tested. The hypothesis is tested using statistical methods based on a factual historical project data collected through a survey. The hypothesis testing process results in a list of significant complexity indicators that function as the measures of project complexity and as the input to the model. Apart from this main research hypothesis, other additional hypotheses related to testing the proposed model are also described and tested in Chapter 5 – Model Development.

3.5 Data Collection

3.5.1 Data Collection Process

The database used for statistical analysis in this research is collected based on a survey of a completed research project. Construction Industry Institute (CII) has conducted many research projects to identify and measure all possible impacts of project attributes on project outcomes, and then to develop appropriate management practices for project practitioners. One of these research projects entitled “CII RT 305-11 - Measuring Project Complexity and Its Impacts” conducted an intensive survey to collect factual data for the relevant statistical analyses. Completed past projects were identified and selected to collect the factual data necessary to test the proposed hypothesis. A part of the data collected from CII's survey is appropriate and closely related to the data required to test the proposed hypothesis in this research, so the related data from CII's research project is necessary and appropriate to be used as a database for conducting the statistical analysis and model development for this research.

The factual data captured from industry projects are analyzed to present the levels of project complexity and the levels of each contributor to project complexity. The data set are characterized and structured in two subsets including 1- General Project Information and 2- Project Complexity Metrics. Quantitative and historical project data on each nominated project is analyzed to build profiles of the types of projects involved in the research and to assess the level of complexity in each project. Project complexity is measured by measuring the identified attributes. Therefore, apart from general project information, the data was collected based on the degree of each contributor to project complexity and measures of each complexity contributor. Figure 3.3 shows an example of factual historical data from a completed project that had been collected for the CII research project and used for this research. Details about the survey data collection of the CII RT 305 research project are provided in the Section 3.5.2.

20- Project Management Team

Project Management Team (PMT) Size and Experience

Project Phase	Estimated PMT Size		Estimated Years of Industry Experience
	Peak	Average	Average
Detailed Engineering/Design	36 FTEs	25 FTEs	50 Years
Procurement	13 FTEs	10 FTEs	29 Years
Construction	97 FTEs	71 FTEs	73 Years

Note: FTE is Full Time Equivalent

Figure 3.3 Examples of Survey Questions

3.5.2 Survey Data Collection of CII RT 305 Research

In CII RT 305 research, the research team implemented a data collection process to collect the data that was usable to test the proposed hypothesis and to determine which indicators truly contribute to project complexity. When developing a data collection approach, the intent of the data collection, the type of data collected, possible analysis processes, sample sizes, interpretation, and advantages/disadvantages of the approach were considered to derive a set of survey questions. The questions used to collect the data were based on the developed complexity indicators central to the measurement of complexity attributes. The data was collected by conducting a survey through the CII's online survey software. Data analysis helped in confirming the definition of complexity including theoretical concepts and complexity attributes, determining different levels of complexity, and providing the basis for assessing the impact of project complexity on the use of best practices. The survey then captured industry data on the proposed definition of complexity, levels of project complexity, and measures of complexity attributes. Through the survey, data was collected in a manner that could facilitate statistical analysis of relationships between levels of complexity and impacts of project complexity on project characteristics and performance. This data collection process is described in detail in the following sections.

3.5.2.1 Questionnaire Development

a. Questionnaire Development Process

CII RT 305 research team developed a draft survey that was then reviewed by the industry members before sending out the survey. The full draft survey used to collect data for CII RT 305 research is presented in Appendix B. The questionnaire development process included looking at the information of each attribute (attribute description in Appendix A) prepared by each industry member and developing a set of questions to be incorporated into the survey. The survey requested the respondent to complete two surveys, one for a lower complexity project and one for a higher complexity project. To improve the ease of responding to the survey and to maximize the number of survey responses, a seven-point scale was dominantly used for the questions as a basis for assessing certain complexity attributes.

b. Types of Question and Response Format

The survey questionnaire was developed based upon the matrix of complexity attributes (Figure 3.4). Questions were developed for each attribute to encourage consistent responses for dataset comparisons. The survey was refined with an industry perspective by adjusting the question wording to match the intent of the attribute.

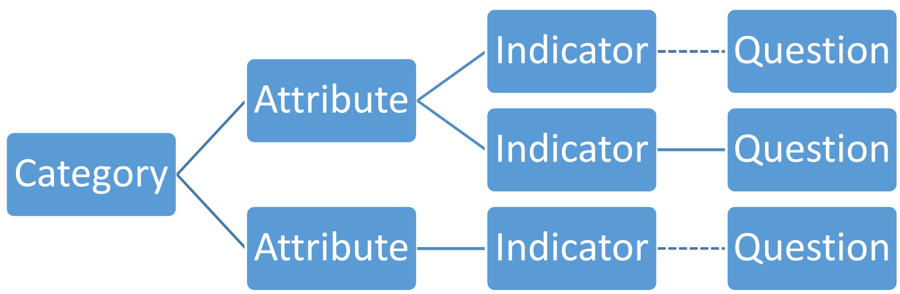


Figure 3.4 Complexity Description Hierarchy for Survey

The survey, containing 106 survey questions and requiring 152 responses, was structured into three sections as presented in Appendix B including: 1) General Project Description; 2) Project Complexity Metrics; and 3) Best Practice Implementation. Responses were either a number, yes/no, or an ordinal scale (e.g., one to seven with one being low and seven being high for a measure). Figure 3.5 shows some examples of survey questions with different types of measures in three sections of the survey.

Section 1 - General Project Information Section

20- Project Management Team

Project Management Team (PMT) Size and Experience

Project Phase	Estimated PMT Size		Estimated Years of Industry Experience
	Peak	Average	Average
Detailed Engineering/Design	________FTEs	________FTEs	________Years
Procurement	________FTEs	________FTEs	________Years
Construction	________FTEs	________FTEs	________Years

Section 2 - Project Complexity Metrics

26- What was the impact of required approvals from external stakeholders on the original project execution plan?

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

28- How many executive oversight entities above the project management team had decision-making authority on your project execution plan?

Number: ____________

41- Did the project experience any delays or difficulties in securing project funding?

☐ Yes ☐ No ☐ Don't Know

71- What percentage of project/construction management staff actually worked on the project compared to planned project/construction management staff?

☐	☐	☐	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

Section 3- Best Practice Implementation

93- Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

Based on the definition, to what extent was Constructability implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

Figure 3.5 Examples of Survey Questions

Section 1, General Project Description, consisted of sixteen questions that provided general information and project characteristics of the surveyed projects such as project type, project cost/schedule, design/procurement/construction contract type. This project information section was based on CII benchmarking data format. Section 2, Project Complexity Metrics, consisted of 72 questions with 92 responses used to collect data for 92 developed complexity indicators that were used to measure the thirty-five identified complexity attributes. There were some multiple-indicator questions. Each multiple-indicator question was used to collect data for two or more relevant indicators. Section 3, Best Practice Implementation, had thirteen questions asking the level of best practice implementation for each project. At the beginning of the survey, each respondent was asked to prepare a survey for one high complexity project and one low complexity project based on their understanding of complexity. The intent of the survey was to assess the different complexity indicators based on responses between low complexity and high complexity projects. Differences have to be statistically significant to argue that the indicator was a true reflection of project complexity. Appendix B shows the complete survey questionnaire and response format.

3.5.2.2 Pilot survey

After the questionnaire framework was developed for the survey, a pilot test was conducted both using hard copies of the survey and the CII online survey software to refine the survey questionnaire, test the appropriateness of each question, and ensure the survey was viable. The survey was pilot tested by several CII research team members on a total of ten projects. The responses for the pilot survey were gathered and analyzed to eliminate any questions or information that was not appropriate to the survey. These pilot surveys helped identify several issues with the survey and helped identify potential statistical analyses that would be conducted on the data collected from full deployment of the survey.

3.5.2.3 Survey Deployment

The next step of data collection process for CII RT 305 research was the implementation of the survey. The survey process was conducted online with a large sample size. The survey transmittal memorandum, survey instructions, and questionnaire were uploaded to the CII online survey system and sent to CII members. The questionnaire was sent to 140 CII company members to collect data.

3.6 Data Analysis

The data analysis focuses on testing the significance of complexity indicators in measuring project complexity to create a basis for the model development process. Statistical analysis was conducted that was consistent with the data characteristics. For example, since project complexity is measured by different complexity indicators that describe it, a statistical analysis is implemented to determine which indicators should be really considered to measure project complexity effectively. In other words, testing which complexity indicators that are statistically significant in differentiating between low complexity projects and high complexity projects helps the researcher determine which factors have an important contribution to project complexity. After that the measuring process is focused on these significant indicators.

The analysis result is then reviewed with respect to a construction industry perspective and publications on complexity. This is to ensure that the appropriate indicators that are even not statistically significant, but important in measuring complexity from a practical perspective, are not missed. Whereas, the indicators that are statistically significant but not necessary in measuring project complexity should be excluded. This effort may decrease or increase the number of complexity indicators, but it makes the research result more practically applicable. The results of the statistical testing are interpreted with the intent of identifying critical practices and decisions that are impacted by project complexity. Chapter 4 presents more details of the statistical analysis process. JMP is the statistical software used for the statistical analysis and for model development. Appendix C provides a brief description of the JMP software.

3.7 Model Development

The collected project data is analyzed to create a basis for model development. The univariate analysis results in a set of significant complexity indicators that are used as the predictive variables (independent variables) for the model. The model developed based on the collected data can be used by project teams to predict the categorical levels of project complexity (Low Complexity vs. High Complexity). The model as developed has a binary output showing the level of project complexity based on the inputs that are complexity indicators. Therefore, a binary logistic regression model is appropriate to be developed to assess project complexity levels.

Binary logistic regression is a form of regression that is used when the dependent variable is a contradiction, and the independent variables are of any type. Binary logistic regression can be used to predict a categorical dependent variable on the basis of continuous, ordinal, and/or categorical independents. Generally, binary logistic regression estimates the probability that a characteristic is present (e.g., estimate probability of "success") given the values of explanatory variables. In this case, the dependent categorical variable describes the probability of low complexity given the values of complexity indicators.

For the model development process, the proposed model is developed based on the results of statistical analysis. The multivariate method is used to develop a logistic model. This method helps select a subset of explanatory variables that account for maximum variability in the outcome of the model. The developed logistic model from this research helps scholars and practitioners in the field of project management measure complexity of projects based on the identified indicators. To create the required input for the proposed model, Principle Component Analysis (PCA) is implemented during the model development process to reduce the number of explanatory variables. The model, after being developed, is tested using appropriate tests to examine the fitness of model and to ensure the developed model is appropriate. Figure 3.6 presents the process of data analysis and model development. The model development process is shown in details in Chapter 5.

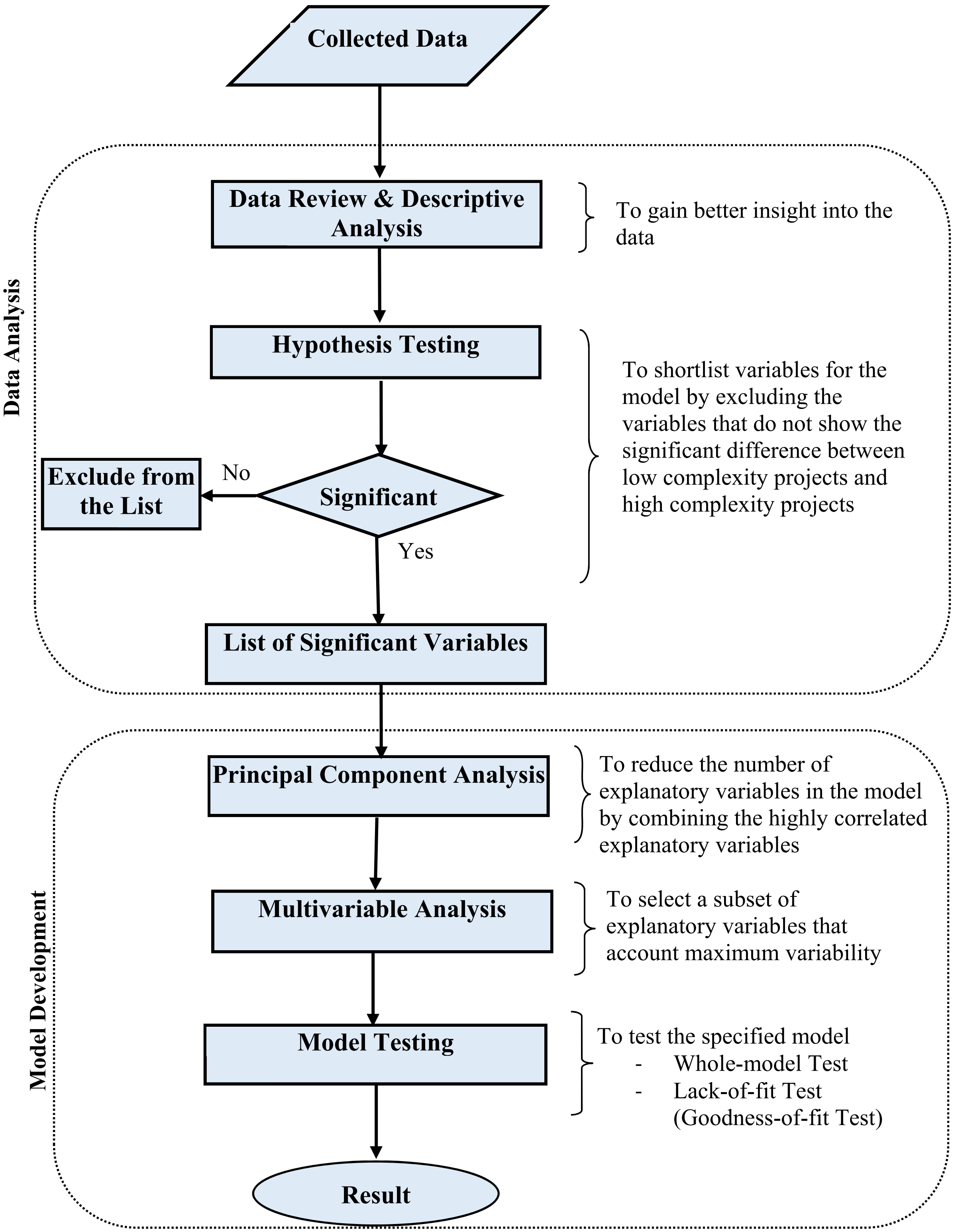


Figure 3.6 Data Analysis and Model Development Process

CHAPTER IV

DATA ANALYSIS AND RESEARCH RESULTS

4.1 Data Review

The data collected from CII research project as presented in Chapter 3 is the input for the statistical analysis and model development process. The data analysis focuses on testing the statistical significance of complexity indicators in differentiating low complexity projects from high complexity projects to create a basis for the model development process. The statistical analysis consistent with the data characteristics is conducted. Because project complexity is measured by different complexity indicators that describe the associated complexity attributes, the statistical analysis focused on determining which indicators should be considered to be significant and best reflect project complexity. In other words, testing which complexity indicators are statistically significant in differentiating between low complexity projects and high complexity projects helps the researcher determine which indicators have an important contribution to project complexity.

4.1.1 Data Characteristics

A total of 44 projects was collected, of which 30 projects were high complexity projects and 14 projects were low complexity projects, as subjectively rated by the respondent at the start of the questionnaire. In the final question in the "Project Complexity Metrics" section, the respondents were asked again about the complexity level of the project. This question asked the respondents to evaluate the project's complexity on an ordinal seven-point scale with one being low complexity and seven being high complexity. The average score for the 14 low complexity projects was 2.34, and the average score for the 30 high complexity projects was 5.25 average. This confirmed that the perception of low versus high complexity initially classified by the survey respondents was consistent with the survey data. Appendix D briefly shows the response results for each question of the survey regarding to low complexity verse high complexity.

The data set was structured into two sections as presented in Appendix B including: 1) General Project Description and 2) Project Complexity Metrics. Section 1-General Project Description provided general information and project characteristics of the collected projects such as project type, project cost/schedule, design/procurement/construction contract type. Section 2-Project Complexity Metrics consisted of 72 measurement questions related to 92 complexity indicators. These indicators were used to measure 35 identified attributes associated with the 11 categories.

The data of the "Project Complexity Metrics" section were collected based upon the matrix of complexity attributes (Figure 3.4). The data of this section in the CII's survey is used for the data analysis of this research. This section of complexity metrics originally included 72 survey questions with the data for 92 complexity indicators. One question that was originally not in the complexity metrics section of CII's survey (Question #20, this question was in the General Project Description section) asked about Project Management Team size (PMT) (Figure 4.1). After reviewing the collected data as well as the literature, it was decided that team size is relevant to describing project complexity. As a result, the data from this question, comprising of nine indicators, was considered as part of the complexity metrics and added to the database for analysis. As a result, the final database used for statistical analysis in this research includes 101 complexity indicators.

20- Project Management Team

Project Management Team (PMT) Size and Experience

Please indicate the peak and average number of participants on the Project Management Team (PMT) during the execution phases of the project.

Project Phase	Estimated PMT Size		Estimated Years of Industry Experience
	Peak	Average	Average
Detailed Engineering/Design	________FTEs	________FTEs	_______Years
Procurement	________FTEs	________FTEs	_______Years
Construction	________FTEs	________FTEs	_______Years

Figure 4.1 The survey question added to the data of complexity metrics

4.1.2 Coding Data and Generating Missing Data

4.1.2.1 Cleaning up and coding the collected data

The data of 44 historical projects (30 high complexity projects and 14 low complexity projects as subjectively rated by the survey respondents) collected from CII research includes 101 complexity indicators as described previously. These 101 indicators are believed to measure the 35 associated complexity attributes in 11 categories as described in the section of data collection in Chapter 3. This data are then cleaned up and coded to be applicable to the JMP computer software. The process includes the following tasks:

- ✓ The original description of each indicator is coded by using short abbreviation and ordered numbering system. Table 4.1 shows an example of how the description of each indicator is coded.

Table 4.1 Example of how the indicator description is abbreviated for JMP input

Original complexity indicator description	Abbreviated description for JMP input
20a-Peak number of Project Management Team (PMT) reflecting Full Time Equivalents (FTE's) during the Detailed Engineering/Design phase?	20a_PeakFTE_E/D
83-What percentage of craft labor was sourced locally? (within 100 mile radius of Job Site)	Q83_%LocalCraftLabor

- ✓ The first question answered with "High Complexity Project" or "Low Complexity Project" is coded by using number "1" or "0" respectively.
- ✓ All other questions with categorical data answered by "Yes" or "No" are coded by using number "1" or "0" respectively.

- ✓ The data with percentage ranges is normalized and then converted to the ordinal data. Figure 4.2 shows an example of how the percentage-range data is coded.

83- What percentage of craft labor was sourced locally? (within 100 mile radius of Job Site)

	☐	☐	☐	☐	☐	☐
Original Data	0-19%	20-39%	40-59%	60-79%	80-99%	100%
Coded Data	1	2	3	4	5	6

Figure 4.2 Example of converting percentage data to ordinal data

- ✓ All the answers with N/A are removed from the database.

4.1.2.2 Generating the Missing Data

The coded data is screened using JMP's data cleanup function to capture the level of data missing for each variable. Table 4.2 shows the level of data missing of 101 indicators.

Table 4.2 Level of data missing captured by using JMP's Data Screening Feature

Order	Complexity Indicators	Number of Missing Points (Out of 44)	Percent (%)
1	Q20a_EngPMTSizePeak	6	14%
2	Q20b_EngPMTSizeAverage	7	16%
3	Q20c_EngPMTYearsExp	15	34%
4	Q20d_ProcPMTSizePeak	7	16%
5	Q20e_ProcPMTSizeAverage	8	18%
6	Q20f_ProcPMTYearsExp	16	36%
7	Q20g_ConPMTSizePeak	7	16%

Table 4.2 Continued

Order	Complexity Indicators	Number of Missing Points (Out of 44)	Percent (%)
8	Q20h_ConPMTSizeAverage	7	16%
9	Q20i_ConPMTYearsExp	16	36%
10	Q21_InfluenceOnSuccess	1	2%
11	Q22a_InternalStakeActive	1	2%
12	Q22b_ExternalStakeActive	1	2%
13	Q23a_InternalStakeholders	1	2%
14	Q23b_ExternalStakeholders	11	25%
15	Q24_ClearGoals	1	2%
16	Q25_InternalApprovals	1	2%
17	Q26_ExternalApprovals	10	23%
18	Q27_Inspection	0	0%
19	Q28_OversightExecutives	2	5%
20	Q29_FinancialApproval	2	5%
21	Q30_AuthorityLevels	2	5%
22	Q31_ChangeOrdersAbove	3	7%
23	Q32_SponsoringEntities	9	20%
24	Q33_VenturePartners	18	41%
25	Q34_StatusReports	1	2%
26	Q35_TotalPermits	6	14%
27	Q36_PermitDiff	5	11%
28	Q37_ExternalAgencies	6	14%
29	Q38_DesignDiff	9	20%
30	Q39_ImpactExternalAgencies	5	11%
31	Q40_FundingPhases	8	18%
32	Q41_FundingDelays	6	14%

Table 4.2 Continued

Order	Complexity Indicators	Number of Missing Points (Out of 44)	Percent (%)
33	Q42_FundingUnderstood	2	5%
34	Q43_ProjectEconomics	5	11%
35	Q44a_NumOrg	6	14%
36	Q44b_NumPMLeads	12	27%
37	Q44c_NumEngOrg	5	11%
38	Q44d_NumPrimeDesign	11	25%
39	Q44e_NumPrimeOrg	6	14%
40	Q44f_NumPrimeContractor	14	32%
41	Q44g_NumSubPrimeContractor	13	30%
42	Q44h_NumSubPrimePM	32	73%
43	Q44i_NumVendors	16	36%
44	Q44j_NumVendorsPM	34	77%
45	Q44k_NumPermitAgencies	15	34%
46	Q44l_NumPermitAgenciesPM	27	61%
47	Q45a_EffectiveCommunicationOwner	3	7%
48	Q45b_EffectiveCommunicationDesigner	1	2%
49	Q45c_EffectiveCommunicationContractor	1	2%
50	Q45d_EffectiveCommunicationSubcontractor	9	20%
51	Q45e_EffectiveCommunicationVendors	12	27%
52	Q45f_EffectiveCommunicationAgencies	18	41%
53	Q46a_OwnerDesignerTogether	2	5%
54	Q47a_OwnerContractorTogether	3	7%
55	Q48a_DesignerEngineerTogether	2	5%
56	Q49_ScopeProcessUnderstood	1	2%
57	Q50_PercComp	7	16%

Table 4.2 Continued

Order	Complexity Indicators	Number of Missing Points (Out of 44)	Percent (%)
58	Q51_TimingImpact	0	0%
59	Q52_MagnitudeImpact	1	2%
60	Q53_ScopeChange	1	2%
61	Q54_ManagementChange	3	7%
62	Q55_ManagementChangeFollowed	0	0%
63	Q56_ManagementEffective	0	0%
64	Q57_RFI	0	0%
65	Q58_Remoteness	2	5%
66	Q59_PopulationDensity	1	2%
67	Q60_InfrastructureLevel	1	2%
68	Q61_Location	1	2%
69	Q62_PercComp	4	9%
70	Q63_Countries	3	7%
71	Q64_CountriesConstruction	2	5%
72	Q65_DocumentsTranslated	2	5%
73	Q66_SecurityRequirements	1	2%
74	Q67a_ExLocEng	4	9%
75	Q67b_ExLocFab	7	16%
76	Q67c_ExLocCon	5	11%
77	Q68a_TechnologyEngineering	1	2%
78	Q68b_TechnologyConstruction	2	5%
79	Q68c_TechnologyFacility	2	5%
80	Q69_DesignIntegration	0	0%
81	Q70_Systems	6	14%
82	Q71_PercStaff	1	2%

Table 4.2 Continued

Order	Complexity Indicators	Number of Missing Points (Out of 44)	Percent (%)
83	Q72_PercField	6	14%
84	Q73_PercPersonnel	4	9%
85	Q74_PercDelay	3	7%
86	Q75_WorkaroundsMaterials	2	5%
87	Q76_FieldLaborQuality	0	0%
88	Q77_BulkMaterials	1	2%
89	Q78_PermEquip	2	5%
90	Q79_PercLaborTurn	3	7%
91	Q80_PercConTurn	2	5%
92	Q81_PercBulk	3	7%
93	Q82_PercPerm	3	7%
94	Q83_%LocalLabor	1	2%
95	Q84_PercReuseEquip	2	5%
96	Q85_ConstructionTolerances	3	7%
97	Q86_MaterialsSpecifications	3	7%
98	Q87a_IndustryCostCompare	5	11%
99	Q87b_IndustryScheduleCompare	6	14%
100	Q88_PercCompStart	7	16%
101	Q89_PercActualStart	7	16%

The missing data is generated with different approaches depending on the types of data measurement unit including:

- For continuous measurement unit, counted number, and percentage: The mean value of high complexity projects is used for the missing data of high complexity projects, and the mean value of low complexity projects is used for the missing data of low complexity projects.
- For ordinal units, categorical (yes/no) units, percentage ranges: The median of high complexity projects is used for the missing data of high complexity projects, and the median value of low complexity projects is used for the missing data of low complexity projects.

4.2 Database Statistical Analysis

4.2.1 Theoretical Basis

The focus of the statistical analysis is to test the research hypothesis that assesses the significance of a complexity indicator in differentiating low complexity projects from high complexity projects. Several different statistical tests are used based on the type of question response. One of the primary objectives of this research is to determine how to measure complexity while focusing on a large array of measures. Survey respondents were asked two separate times to evaluate the complexity level of their project, once at the beginning of the survey and once toward the end. These answers were statistically evaluated compared to each of the indicators. The primary question of interest is "Is there a clear difference between low complexity projects and high complexity projects with regards to a specific indicator?" Both exploratory and inferential statistics were used to determine if this difference existed.

4.2.1.1 Exploratory Statistics

Figure 4.3 and Figure 4.4 present an example of exploratory data analysis. Exploratory statistics in this research are graphical displays including boxplots and bar-chart graphics to visualize the data. Side-by-side boxplots (Figure 4.3) are used whenever the data were counts, dollars, or other numerical values. The boxplots illustrates the distribution of the data, indicating minimum and maximum values, first quartile and third quartile, median, and outliers.

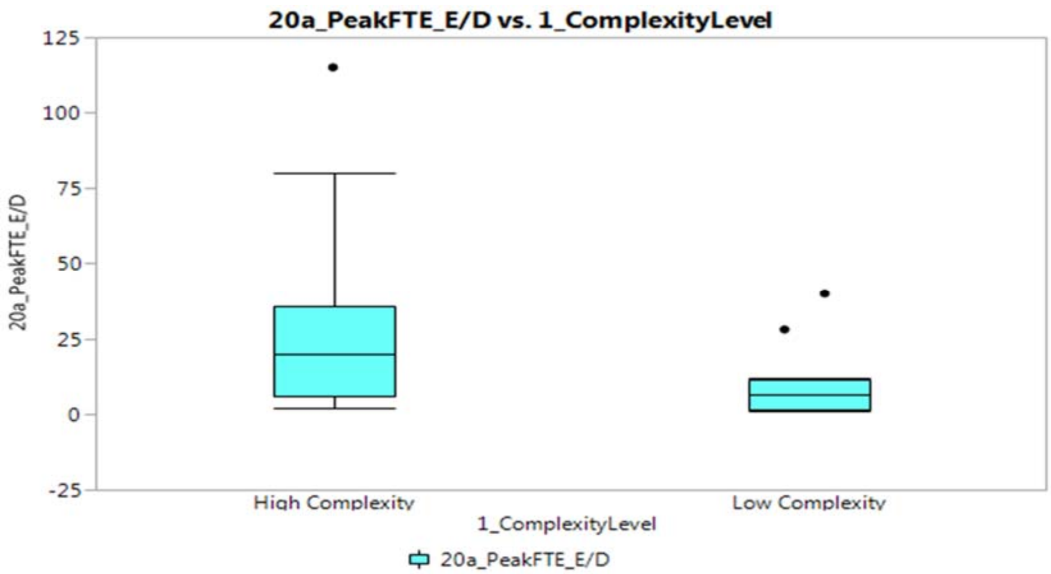


Figure 4.3 Example of Side-by-side boxplots

Bar charts (Figure 4.4) are used to describe the distribution of both Likert (ordinal scale) and binary (Yes/No) type data. The X-Axis of the bar chart consists of the Likert scale responses, and the Y-Axis consists of the observed frequencies of each of the different possible responses.

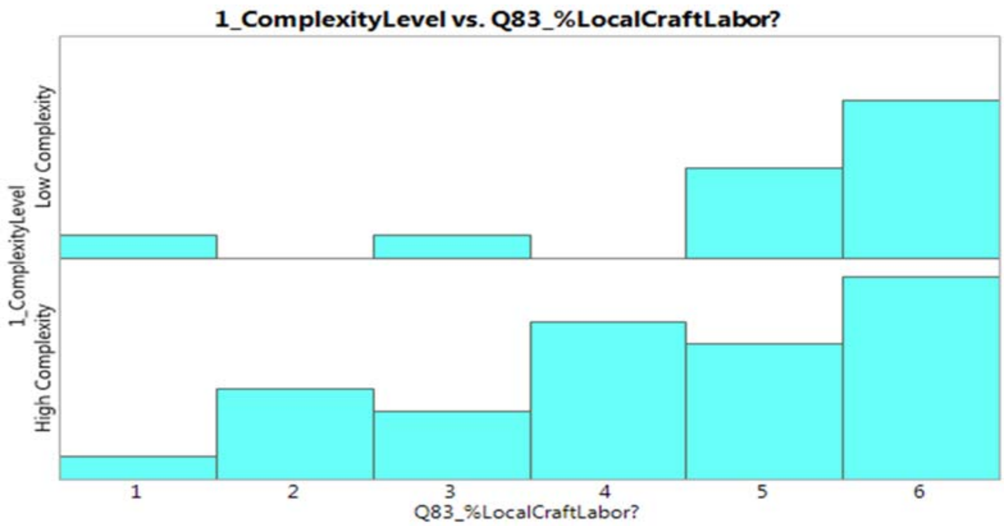


Figure 4.4 Example of bar-chart

4.2.1.2 Inferential Statistics

Depending on the type of data collected from CII's research, the methods of analysis vary. This is due to the fact that there are different assumptions and limitations to the statistical analysis tests. Table 4.3 summarizes the basic formal statistical methods that are used for data analysis in this research. This table includes information about each of the statistical tests, the null hypothesis and alternative hypothesis for each test, and the corresponding assumptions. P-values that indicate the statistical significance of differences between the two groups (low complexity projects vs. high complexity projects) are generated through the relevant tests.

Table 4.3 Statistical Analysis Methods

Statistical Test	Null/Alternative Hypothesis	Assumptions
Two-Sample T-Test (Adjusted R-Squared): This test was used where the response is a count or numerical value.	*Null Hypothesis:* The means for high complexity projects and low complexity projects are the same. *Alternative Hypothesis:* The means for high complexity projects and low complexity projects are different.	• The two groups (high complexity and low complexity projects) follow a normal distribution. • Each project was independent from other projects.
Kruskal-Wallis/Wilcoxon Test: This test was used for Likert data where it could not be assumed that the data follows a normal distribution.	*Null Hypothesis:* The probability that median of high-complexity projects is greater than median of low-complexity projects on this question is 0.5 (The distributions are the same). *Alternative Hypothesis:* The probability that median of high-complexity projects is greater than median of low-complexity projects on this question is not equal to 0.5 (The distributions are not the same).	• The two groups follow an identically scaled distribution. • Each project was independent of other projects.

Table 4.3 Continued

Statistical Test	Null/Alternative Hypothesis	Assumptions
Chi-Squared Test (Nagelkerke's R-Squared): This test was used for survey questions with binary responses ("Yes" or "No" response), testing whether the observed frequencies of "Yes" or "No" are equal for both high complexity projects and low complexity projects.	*Null Hypothesis:* The observed frequencies of "Yes" and "No" for high complexity projects are not different from those for low complexity projects. *Alternative Hypothesis:* The observed frequencies of "Yes" and "No" for high complexity projects are different from those for low complexity projects.	• Each project was independent of other projects

4.2.2 Data Analysis and Research Results

4.2.2.1 General Data Characterizations and Descriptive Analysis

To run the analysis, JMP software is used for the statistical approaches (both formal and descriptive as described in Table 4.3). Initially, the survey data set is descriptively analyzed to ensure data characteristics are understood. Among 44 projects, there are 30 heavy industrial projects, 3 light industrial projects, 3 building projects, 3 infrastructure projects, and 5 other-type projects. The project cost data ranges from $0.4 million to $5,600 million (average $140 million for low complexity projects and $417 million for high complexity projects). The total schedule durations for the projects are from 8 months to 70 months (average 25 months for low complexity projects and 30 months for high complexity projects). Appendix D provides more details for descriptive analysis result of survey data.

4.2.2.2 Testing for Differences between High Complexity Projects and Low Complexity Projects

The primary goal of this research is to fully explore and assess project complexity and then develop a model to measure project complexity level. In other words, the complexity indicators that are significant in differentiating low complexity projects from high complexity projects need to be identified and tested. The significance level of 0.05 (α=0.05) was initially chosen to test the significance of each complexity indicator in differentiating low complexity projects from high complexity projects. Twenty-four out of 101 complexity indicators were found significant with the significance level of 0.05 as a result of the analysis. This result was then reviewed from an industry perspective. The reviewing of initial analysis result revealed that all aspects of project complexity were not sufficiently described by these 24 complexity indicators. Based on practical perspective, several other complexity indicators that had p-values close to 0.05 were important in measuring project complexity and should be included in the list. The significance level was ultimately increased from 0.05 up to 0.1.

With the significance level of 0.1 (α=0.1), there are 36 complexity indicators (CIs) belonging to 23 complexity attributes statistically significant in differentiating low complexity projects from high complexity projects (the indicators that have p-value not greater than 0.1). This result is reviewed again. Among 101 tested complexity indicators, three CIs including: CI_16-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the construction phase of the project; CI_25-Project location is remote from highly-populated areas; and CI_26-Level of infrastructure existing at the site to support the project) are not statistically significant (p-values greater than 0.1). However, these three CIs are important in measuring complexity based on industry perspective and then added to the list of significant complexity indicators.

Among the 36 statistically significant indicators that have p-value not greater than 0.1, there are two indicators that had high correlations with two other indicators. The first indicator is "CI_14b-Average number of participants during the detailed engineering/design phase" that has very high correlation with the indicator "CI_14a-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project". The correlation coefficient between these two indicators is 0.99 (R=0.99). The second indicator is "CI_15b-Average number of participants during the procurement phase" that has very high correlation with the indicator "CI_15a-Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project". The correlation coefficient between these two indicators is 0.98 (R=0.98). Statistically, two or more highly correlated indicators may measure the same characteristic of project complexity. As a result, those two indicators (CI_14b and CI_15b) described above are excluded from the significant indicator list. Ultimately, a list of 37 complexity indicators that measure 23 complexity attributes was finalized. The significant indicators are then renumbered from 1 to 37 as presented in Table 4.4. These indicators are considered as the measures of project complexity and used as basis for the process of developing the project complexity predictive model.

Table 4.4 Significant complexity indicators in differentiating low complexity projects from high complexity projects

Category	Attribute	Complexity Indicator (CI)	P-value
1. Stakeholder Management	1. Strategic importance of the project	CI-1_Influence of this project on the organization's overall success (e.g., profitability, growth, future industry position, public visibility, and internal strategic alignment).	0.0821

Table 4.4 Continued

Category	Attribute	Complexity Indicator (CI)	P-value
	2. Project impact of local social and political groups (stakeholders)	CI-2_Impact of required approvals from external stakeholders on the original project execution plan.	0.0341
		CI-3_Impact of required inspection by external (regulatory) agencies/entities on original project execution plan.	0.0012
2. Governance	3. Joint ventures 4. Owner, partnerships	CI-4_Total number of joint-venture partners in this project.	0.0631
	5. Level of authorizing approvals and duration of receiving proposals	CI-5_Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan.	0.047
	6. Level of control	CI-6_Number of times on this project that a change order will go above the Project Manager for approval.	0.0542
3. Fiscal Planning	7. Fiscal planning, or financing (funding stream, uncertain political environment)	CI-7_Number of funding phases (gates) from concept to project completion.	0.0756
		CI-8_Specific delays or difficulties in securing project funding.	0.025
4. Quality	8. Quality of suppliers, subcontractors, contractors	CI-9_Quality of bulk materials during project execution.	0.0181
5. Legal		CI-10_Number of total permits to be required.	0.0761

Table 4.4 Continued

Category	Attribute	Complexity Indicator (CI)	P-value
	9. Permitting and regulatory requirements	CI-11_Level of difficulty in obtaining permits.	0.0497
		CI-12_Difficulty in obtaining design approvals.	0.0718
	10. Legal	CI-13_Impact of external agencies on the project execution plan.	0.039
6. Interfaces	11. Interfaces within the project	CI-14_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project.	0.0207
	12. Number of participants	CI-15_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project.	0.0313
		CI-16_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the construction phase of the project.	0.4612
7. Execution Target	13. Cost targets	CI-17_Compare target project funding against industry/internal benchmarks.	0.0118
	14. Schedule targets	CI-18_Compare target project schedule against industry/internal benchmarks.	0.0366
8. Design and Technology	15. Design (number of process steps, HSE hazards, # of recycles, exotic materials)	CI-19_Difficulty in system design and integration on this project compared to a typical project for your company.	0.0048

Table 4.4 Continued

Category	Attribute	Complexity Indicator (CI)	P-value
	16. Technology	CI-20_Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase.	0.0138
		CI-21_Company's degree of familiarity with technologies that will be involved in construction project phase.	0.0065
		CI-22_Company's degree of familiarity with technologies that will be involved in operating facility project phase.	0.0106
9. Location	17. Number of locations	CI-23_Number of execution locations which will be used on this project during detailed engineering/design phase.	0.0324
	18. Logistics	CI-24_Number of execution locations which will be used on the project during fabrication (bulk materials and equipment) phase.	0.0114
		CI-25_Project location is remote from highly-populated areas.	0.9773
	19. Physical location	CI-26_level of infrastructure existing at the site to support the project.	0.1698
		CI-27_Impact of project location on the project execution plan.	0.017
10. Scope Definition	20. Change Management (dynamics of market and environment)	CI-28_Identify the percentage of eng./design completed at the start of construction.	0.0524
		CI-29_Clarity of the change management process to key project team members.	0.0757
		CI-30_Impact of the magnitude of change orders on project execution.	0.003

Table 4.4 Continued

Category	Attribute	Complexity Indicator (CI)	P-value
		CI-31_Impact of the timing of change orders on project execution.	0.0129
		CI-32_ RFIs drive project design changes.	0.0268
11. Project Resources	21. Direct field labor management	CI-33_Percentage of project/construction management staff who will work on the project compared to planned project/construction management staff.	0.0994
		CI-34_Quality issues of skilled field craft labor during project construction.	0.0381
	22. Resource availability	CI-35_Frequency of workarounds (work activities out of sequence to continue) because materials are not available when needed to support construction.	0.0293
	23. Turn over	CI-36_Percentage of craft labor turnover.	0.0459
		CI-37_Percentage of craft labor sourced locally (within 100 mile radius of job site).	0.0866

4.3 Data Analysis Conclusion

The complexity indicators and associated complexity attributes listed in Table 4.4 are proven to be significant in differentiating low complexity projects from high complexity projects. These indicators are used to describe the complexity of a project and as the input for developing a project complexity predictive model. This finding assists project management researchers and practitioners in identifying blind spots embedded in the project development process, and then developing an appropriate management strategy to deal with project complexity. Implementing proper management strategies relevant to the identified complexity indicators helps organizations in reducing the likelihood that the associated attributes will cause poor project performance.

CHAPTER V

PROJECT COMPEXITY PREDICTIVE MODEL

5.1 Model Approach

One of the questions for the proposed model is, "What type of model is appropriate for describing project complexity level?" The collected project data, as presented in Chapter 4 is categorized into two groups including a group of low-complexity projects and a group of high-complexity projects. The Univariable Analysis in Chapter 4 resulted in thirty-seven complexity indicators that are statistically significant in differentiating low complexity projects from high complexity projects with the significance level of 0.1 ($\alpha = 0.1$). These significant complexity indicators (presented in Table 4.4) are used as the predictive variables (independent variables) for the model. The model developed based on the collected data will be used by project teams to predict the categorical levels of project complexity (Low Complexity vs. High Complexity). The model as developed has a binary output showing the level of project complexity based on the inputs that are complexity indicators. Therefore, a binary logistic regression model is appropriate to assess project complexity level.

Differentiating from a usual linear regression model where the outcome variable is assumed to be continuous, logistic regression model is a form of regression where the outcome variable is binary or dichotomous, and the predictor variables are of any type (Hosmer and Lemeshow, 1989). Binary logistic regression can be used to predict a categorical dependent variable on the basis of different measurement-scale independents; to determine the effect size of the independent variables on the dependent variable; to rank the relative importance of independent variables; and to assess interaction effects. The impact of predictor variables is usually explained in terms of odds ratios. Logistic regression applies maximum likelihood estimation after transforming the dependent variable into a logit variable. A logit variable is the natural log of the odds of the dependent variable equaling a certain value (usually "1" in binary logistic models) or not (usually "0" in binary logistic models). Logistic regression estimates the odds of a certain event (value) occurring. This means that logistic regression calculates changes in the log odds of the dependent, not changes in the dependent variable itself. Specifically, binary logistic regression estimates the probability that a characteristic is present (e.g. estimate probability of "success") given the values of explanatory variables. In this case, a single categorical variable; $P_{[0]} = P(Y = 0|Xi = x)$ describes the probability of low complexity given the values of complexity indicators. The probability of high complexity is $P_{[1]} = 1 - P_{[0]}$. The general equation of binary logistic regression model is summarized in Table 5.1.

Table 5.1 Binary Logistic Regression Equation

$P_{[0]} = P(Y=0\|Xi=xi) = \frac{\text{Exp}(Lin[0])}{1+Exp(Lin[0])}$	P[0] is probability of the outcome that the project is a low complexity project. P[1] is probability of the outcome that the project is a high complexity project.
P[1] = 1 - P[0]	P[1] < 0.5 => Low Complexity Project P[1] > 0.5 => High Complexity Project P[1] = 0.5 => Complexity Level is Not Identified

Lin[0] is the logit of the model or logit of the response that is described by the log of odd ratio ($\frac{P_{[0]}}{1-P_{[0]}}$). Equation 5-1 presents the formula of Lin[0]. In this case, Lin[0] is a linear regression that describes the relationship between the model logit and complexity indicators via the moderating variables called Principal Components. The Principal Components (PCs) are generated from the Principal Component Analysis (PCA) that is described in Section 5.4.

The equation of Lin[0] is presented as follows:

$$\text{Lin}[0] = \text{Logit}(P_{[0]}) = \ln\left(\frac{P_{[0]}}{P_{[1]}}\right) = \ln\left(\frac{P_{[0]}}{1-P_{[0]}}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad \text{(Eq. 5-1)}$$

Where:

β_0 is the intercept of the linear regression

β_n is the regression coefficient of the explanatory variable "n"

$X = (X_1, X_2, ..., X_k)$ is a set of explanatory variables. In this case, X_i are the Principal Components generated from the PCA process.

The equation of Lin[0] for the proposed model in this research was generated from the logistic regression model development process using JMP software that is presented in Section 5.5.

To develop a logistic regression model, several approaches to variable selection including univariate method, stepwise methods, or best subsets selection method have been historically used by researchers. However, stepwise, best subsets, and other mechanical selection procedures have been criticized because they can yield an implausible model (Greenland, 1989) and select irrelevant, or noise variables (Flack and Chang, 1987). Additionally, when there are too many explanatory variables, the model building process using stepwise or best subsets method requires a variety of modeling steps and takes time. For this reason, the univariate method is used as an approach to variable selection, and multivariable analysis is used as a method to develop the logistic model in this research. This method helps select a subset of explanatory variables that account for maximum variability in the outcome of the model. The developed logistic model from this research can help scholars and practitioners in the field of project management assess complexity level of a project based on applicably identified complexity attributes/indicators. The data analysis and model development process is presented in Figure 5.1.

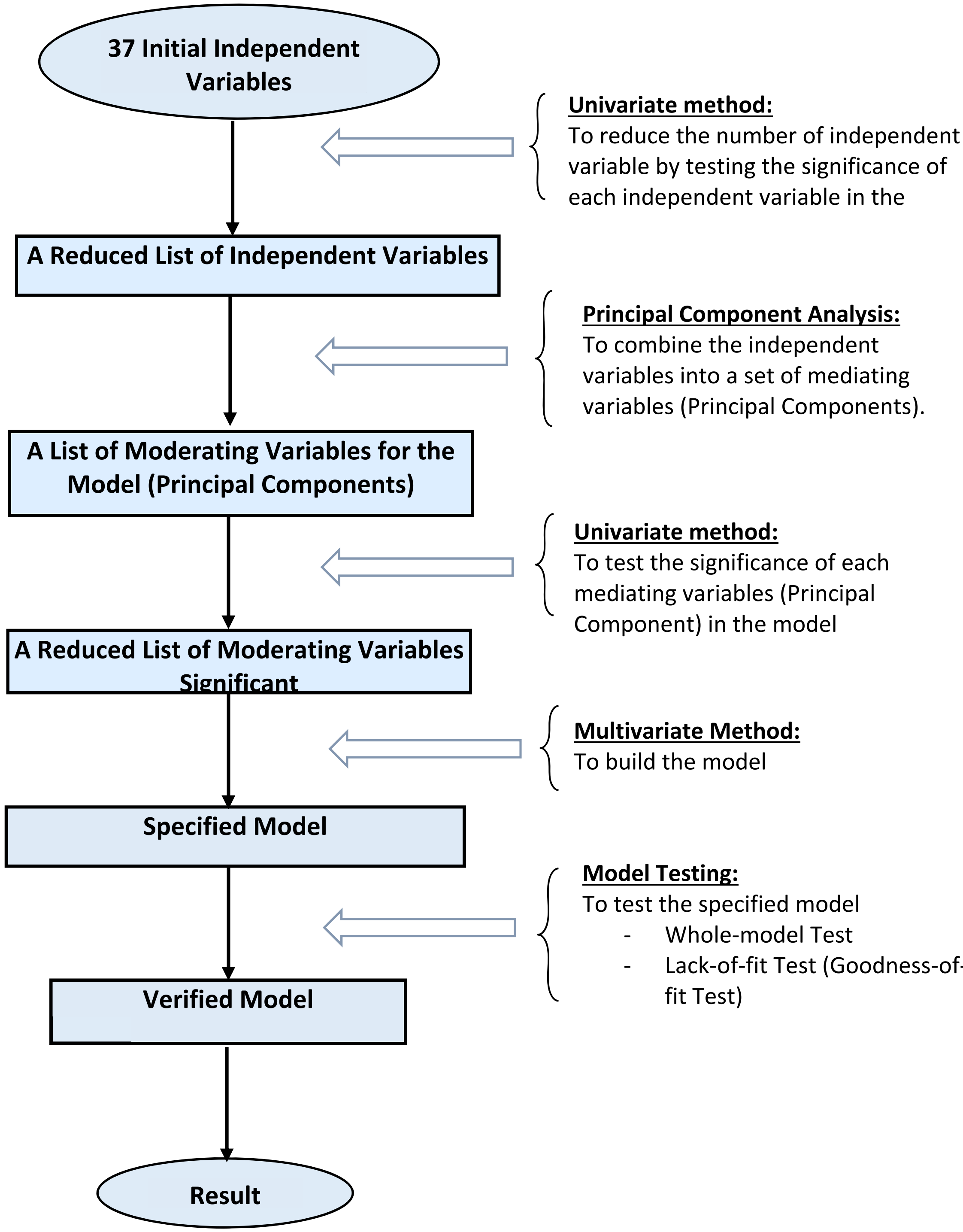


Figure 5.1 Data Analysis and Model Development Process

5.2 Univariate Analysis

To select a subset of variables for the model, one school of thought argues for the inclusion of all scientifically relevant variables into the multivariate model regardless of their contribution to the model (Hosmer and Lemeshow, 1989). Generally, the appropriateness of the decision to begin the multivariate model with all possibly relevant variables depends on the overall sample size and the number of each outcome group relative to the total number of candidate variables. When the data are adequate to support such an analysis, it is possibly useful to begin the multivariate modeling with all relevant variables. However, when the data are inadequate, this approach can produce a numerically unstable multivariate model. When this occurs, the Wald statistics should not be used to select variables because of the unstable nature of the results. In this case, univariate analysis is an appropriate method for selecting a subset of variables for the model. In this research, the sample size includes 44 subjects relative to 37 candidate variables. With this sample size, the data is not adequate to support the analysis. As a result, the univariate analysis needs to be applied to select a subset of explanatory variables for the proposed model.

The model development process is started with the univariate analysis to select a subset of variables for the model. With univariate analysis, a subset of variables for the model is selected by testing the significance of each indicator among thirty-seven initial complexity indicators to the model. These thirty-seven complexity indicators resulted from the data analysis in Chapter 4. The purpose of the univariate analysis is to minimize the number of explanatory variables to build a model that still explains the data. The rationale for minimizing the number of variables in the model is that the resultant model is more likely to be numerically stable, and is more easily generalized. The more variables included in a model, the greater the estimated standard errors become, and the more dependent the model becomes on the observed data (Hosmer and Lemeshow, 1989).

The univariate method involves testing of a statistical hypothesis to determine whether an independent variable in the model is significantly related to the outcome variable, or in other words, whether the independent variable is helpful in predicting the outcome. The approach to testing the significance of a variable in the model relates to the question *"Does the model that includes the variable in question tell us more about the outcome than does a model that does not include that variable?"* This question is answered by comparing the observed values of the response variable to those predicted by each of two models; the first with and the second without the variable in question. If the predicted values with the variable in the model are significantly better than the predicted values when the variable is not in the model, then the variable in question is proven significant. The comparison of observed to predicted values is based on the log likelihoods of the full model (the model that includes the variable in question) and the reduced model (the model without the variable). Table 5.2 summarizes the univariate analysis relevant to hypothesis testing.

Table 5.2 Summary of Univariate Analysis

Analysis	Purpose	Hypothesis	Significance Level (α)
Univariate Analysis	This test examines if the complexity indicator is significantly related to the outcome (Complexity level).	*Null Hypothesis:* The predicted value with the complexity indicator in the model is not better than the predicted value without the complexity indicator in the model. *Alternative Hypothesis*: The predicted value with the complexity indicator in the model is better than the predicted value without the complexity indicator in the model.	$\alpha = 0.1$

In order to conduct the univariate method, JMP statistical software is used as the tool to run the analysis. The Pearson chi-square test is used to generate p-values for the nominal and ordinal variables, while the Likelihood ratio test is used to obtain p-values for the continuous variables. The univariate analysis process using JMP software results in a list of p-values of complexity indicators as shown in Table 5.3. These p-values are used to test the hypotheses indicated in Table 5.2.

Table 5.3 P-value of 37 complexity indicators resulted from the univariate analysis

Category	Complexity Indicator	P-value for model
Stakeholder Management	CI-1_Influence of this project on the organization's overall success (e.g., profitability, growth, future industry position, public visibility, and internal strategic alignment).	0.3409
	CI-2_Impact of required approvals from external stakeholders on the original project execution plan.	<0.0001
	CI-3_Impact of required inspection by external (regulatory) agencies/entities on original project execution plan.	0.0078
Governance	CI-4_Total number of joint-venture partners in this project.	0.0047
	CI-5_Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan.	0.0418
	CI-6_Number of times on this project that a change order will go above the Project Manager for approval.	0.001
Fiscal Planning	CI-7_Number of funding phases (gates) from concept to project completion.	0.0172
	CI-8_Specific delays or difficulties in securing project funding.	0.0431
Quality	CI-9_Quality of bulk materials during project execution.	0.0224
Legal	CI-10_Number of total permits to be required.	0.0009
	CI-11_Level of difficulty in obtaining permits.	0.1141

Table 5.3 Continued

Category	Complexity Indicator	P-value for model
	CI-12_Difficulty in obtaining design approvals.	0.0667
	CI-13_Impact of external agencies on the project execution plan.	0.0914
Interfaces	CI-14_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project.	0.0036
	CI-15_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project.	0.0043
	CI-16_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the construction phase of the project.	0.3994
Execution Target	CI-17_Compare target project funding against industry/internal benchmarks.	0.0039
	CI-18_Compare target project schedule against industry/internal benchmarks.	0.0383
Design and Technology	CI-19_Difficulty in system design and integration on this project compared to a typical project for your company.	0.0041
	CI-20_Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase.	0.0421
	CI-21_Company's degree of familiarity with technologies that will be involved in construction project phase.	0.0313

Table 5.3 Continued

Category	Complexity Indicator	P-value for model
	CI-22_Company's degree of familiarity with technologies that will be involved in operating facility project phase.	0.1584
Location	CI-23_Number of execution locations which will be used on this project during detailed engineering/design phase.	0.0329
	CI-24_Number of execution locations which will be used on this project during fabrication (bulk materials and equipment) phase.	<0.0001
	CI-25_Project location is remote from highly-populated areas.	0.2534
	CI-26_Level of infrastructure existing at the site to support the project.	0.5037
	CI-27_Impact of project location on the project execution plan.	0.0561
Scope Definition	CI-28_Identify the percentage of engineering/design completed at the start of construction.	0.3518
	CI-29_Clarity of the change management process to key project team members.	0.2103
	CI-30_Impact of the magnitude of change orders on project execution.	0.0106
	CI-31_Impact of the timing of change orders on project execution.	0.0590
	CI-32_ RFIs drive project design changes.	0.3049

Table 5.3 Continued

Category	Complexity Indicator	P-value for model
Project Resources	CI-33_Percentage of project/construction management staff who will work on the project compared to planned project/construction management staff.	0.1379
	CI-34_Quality issues of skilled field craft labor during project construction.	0.0272
	CI-35_Frequency of workarounds (work activities out of sequence to continue) because materials are not available when needed to support construction.	0.0475
	CI-36_Percentage of craft labor turnover.	0.0200
	CI-37_Percentage of craft labor sourced locally (within 100 mile radius of job site).	0.0554

5.3 Selection of Complexity Indicators for the Model

To test a statistical hypothesis, the traditional significance level of 0.05 (α=0.05) is frequently used. With the traditional significance level of 0.05, there are 22 complexity indicators proven to be important to the model. However, Mickey and Greenland (1989) showed that the use of a more traditional significance level of 0.05 to select the significant variables for a logistic regression often fails to identify variables known to be potentially important. One problem with any univariate approach with a small significance level is that it ignores the variables, which may be weakly associated with the outcome individually, but an important predictor of outcome when taken together (Hosmer and Lemeshow, 1989).

Mickey and Greenland (1989) suggested the significance level of 0.25 as a screening criterion for selection of candidate variables. With the 0.25 level, 31 CIs were statistically significant to the model. These 31 CIs were initially used for further model development process. The model development process with this number of variables using JMP resulted in an unstable model with unrealistically large standard errors. The result of this unstable model was because the number of explanatory variables, after being reduced, is still large relative to the number of observed subjects. As a result, the significance level of 0.1 (α=0.1) is chosen to allow the suspected complexity indicators to become candidates for inclusion in the multivariate model. This significance level also allows the univariate analysis to reduce the variables to a reasonable number to obtain a stable model.

With the significance level of 0.1, there are 27 complexity indicators found significant to the model (the indicators have p-values smaller than 0.1). The complexity indicators with p-values greater than 0.1 are indicated not to be significant to the model then excluded from the course of multivariate analysis. The final list of these significant indicators is presented in Table 5.4. This set of variables is used as the input for multivariate approach to develop the model.

Table 5.4 27 complexity indicators significant to the model with corresponding p-values

Category	Complexity Indicator	P-value for model
Stakeholder Management	CI-2_Impact of required approvals from external stakeholders on the original project execution plan.	<0.0001
	CI-3_Impact of required inspection by external (regulatory) agencies/entities on original project execution plan.	0.0078
Governance	CI-4_Total number of joint-venture partners in this project.	0.0047

Table 5.4 Continued

Category	Complexity Indicator	P-value for model
	CI-5_Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan.	0.0418
	CI-6_Number of times on this project that a change order will go above the Project Manager for approval.	0.001
Fiscal Planning	CI-7_Number of funding phases (gates) from concept to project completion.	0.0172
	CI-8_Specific delays or difficulties in securing project funding.	0.0431
Quality	CI-9_Quality of bulk materials during project execution.	0.0224
Legal	CI-10_Number of total permits to be required.	0.0009
	CI-12_Difficulty in obtaining design approvals.	0.0667
	CI-13_Impact of external agencies on the project execution plan.	0.0914
Interfaces	CI-14_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project.	0.0036
	CI-15_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project.	0.0043
Execution Target	CI-17_Compare target project funding against industry/internal benchmarks.	0.0039
	CI-18_Compare target project schedule against industry/internal benchmarks.	0.0383

Table 5.4 Continued

Category	Complexity Indicator	P-value for model
Design and Technology	CI-19_Difficulty in system design and integration on this project compared to a typical project for your company.	0.0041
	CI-20_Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase.	0.0421
	CI-21_Company's degree of familiarity with technologies that will be involved in construction project phase.	0.0313
Location	CI-23_Number of execution locations which will be used on this project during detailed engineering/design phase.	0.0329
	CI-24_Number of execution locations which will be used on this project during fabrication (bulk materials and equipment) phase.	<0.0001
	CI-27_Impact of project location on the project execution plan.	0.0561
Scope Definition	CI-30_Impact of the magnitude of change orders on project execution.	0.0106
	CI-31_Impact of the timing of change orders on project execution.	0.0590
Project Resources	CI-34_Quality issues of skilled field craft labor during project construction.	0.0272
	CI-35_Frequency of workarounds (work activities out of sequence to continue) because materials are not available when needed to support construction.	0.0475

Table 5.4 Continued

Category	Complexity Indicator	P-value for model
	CI-36_Percentage of craft labor turnover.	0.0200
	CI-37_Percentage of craft labor sourced locally (within 100 mile radius of job site).	0.0554

While a subset of variables that explain maximum variability in the outcome is selected, the research also aims to develop a model with a minimum number of predictive variables because too many predictive variables in a regression model may cause a problem that the number of parameters to be estimated is larger than the number of observations. This model is considered to be over-fitting and lack of degree of freedom. As a result, the projected model is unstable. The Principal Component Analysis (PCA) process presented in Section 5.4 helps fulfill these two contrasting objectives in the model building process. The principle component analysis is implemented during the model development process to reduce the number of variables in the model by combining the highly correlated predictive variables. The model, after being developed, is tested using model utility tests including whole-model test and lack-of-fit test (goodness-of-fit test) to examine the fitness of model and to guarantee that the developed model is appropriate. Details of the model test process are provided in Section 5.5 (Model Test).

5.4 Principal Component Analysis

5.4.1 Theoretical Basis

Principal component analysis (PCA) is a linear combination process that analyzes variance in the variables and reorganizes them into a new set of components called artificial variables or composite variables. Specifically, PCA is the process used to identify highly correlated variables and group them together as new uncorrelated variables, thus making the interpretation of the relationship between explanatory variables and response variable more efficient. This process is sometimes called a variable reduction procedure (Jolliffe, 2002). One advantage of PCA is that, while dramatically reducing the dimensionality of the original data set, it retains most of the initial information (Massey, 1965). PCA is useful when the obtained data has a large number of variables, and there is possibly some redundancy in those variables. The redundancy mentioned here means that some of the variables are highly correlated with one another, possibly because they are measuring the same construct. Because of the redundancy, PCA helps reduce the observed variables into a smaller number of principal components that will account for most of the variance in the observed variables.

The components generated from this process are the linear combinations of original variables. The PCA process calculates a score for each observed subject on a given principal component. The subject's actual scores is optimally weighted and then summed to compute their scores on a given component. The general form for the formula to compute scores on each component extracted in the PCA is presented in Equation 5-2.

$$C_i = \beta_{i0} + \beta_{i1}(X_1) + \beta_{i2}(X_2) + \ldots + \beta_{in}(X_n) \qquad \text{(Eq. 5-2)}$$

Where:

C_i is the extracted component "i"

β_{i0} is the intercept of the linear regression describing component "i"

β_{in} is the regression coefficient (or weight) for observed variable "n", as used in creating component "i"

X_n is the observed variable "n"

The number of new components extracted in a PCA process is equal to the number of observed variables being analyzed. However, only the first few components account for meaningful amounts of variance, so only these first few components are retained, interpreted, and used in subsequent analyses. These first few components are called Principal Components (PCs). All components extracted in PCA are uncorrelated with one another. The PCA process helps reduce the number of variables for the logistic regression model by retaining only those principal components that account for maximum variance of the variables. The retained PCs function as moderating variables in the logistic regression model.

5.4.1.1 Determine the Number of Meaningful Components to Retain

The major objective in the application of PCA is to replace the large number of variables by a relatively smaller number of principal components, which nevertheless discard very little information. Jolliffe (2002) discussed several types of criterion for determining how many meaningful components should be retained for interpretation. Among those, two criteria that are frequently used include: 1) the eigenvalue-one criterion (Kaiser's rule); and 2) the cumulative percentage of total variation.

Eigenvalue-one Criterion (Kaiser, 1960): The eigenvalue-one criterion is most simply and commonly used for solving the number-of-components problem. This is the most obvious criterion for choosing the number of principal components. The eigenvalue of a given component represents the amount of variance in the population that is accounted for by the component. Under the eigenvalue-one criterion, any component with eigenvalue equal or greater than 1.00 is retained and interpreted. The rationale for this criterion is that each observed variable typically contributes one unit of variance to the total variance of the population. Any component that displays an eigenvalue equal or greater than 1.00 is accounting for a greater amount of variance than the average variance contributed by one original variable. Such a component is therefore accounting for a meaningful amount of variance, and it is worthy of being retained. The components with eigenvalues less than 1.00 account for less than average variance contributed by each original variables and so are not worth retaining.

Cumulative Percentage of Total Variation: This criterion involves retaining components by successively choosing the principal components to have the largest possible variance. Jolliffe (2002) suggested the cut-off point for cumulative percentage of variance somewhere between 70 percent and 90 percent depending on the practical details of a particular data set. The smaller cut-off point is generally chosen as the number of original variables is large (Jolliffe, 2002). When the number of variables is very large, choosing high cut-off point of cumulative percentage of variance may give an impractically large number of principal components for further analysis. The PCA is therefore not useful in terms of variable reduction. In such cases the threshold should be set somewhat lower than 70 percent.

For this research, the eigenvalue-one criterion is chosen as the selective criterion for retaining the principal components. The cumulative percentage of total variation is used to verify and assess the appropriateness of the number of retained components.

5.4.1.2 Variance Rotation – Varimax Method

Variance rotation is a linear transformation that is performed on the factor solution for the purpose of making the solution easier to interpret. Variance rotation maximizes variance of variables on the retained components. As more than one component is retained in the analysis, the interpretation of an unrotated factor pattern is usually difficult, so performing a rotation will make the interpretation easier. For this research, variance rotation process with Varimax-method using JMP generates the rotated factor-loading matrix for the retained components.

5.4.1.3 Interpretation of Principal Component

Interpreting the retained components means determining which variable(s) is measured by each of the retained components (identifying the variables that demonstrate high loading for a given principal component and determining what these variables have in common). Specifically, the interpretation of PCs helps in describing what each PC means and what characteristics each PC has in terms of measuring project complexity. Section 5.4.2 presents details about the implementation of principal component analysis to combine the identified complexity indicators into the principal components for the logistic regression model.

5.4.2 Combining Complexity Indicators Using Principal Component Analysis

The univariate analysis results in a list of twenty-seven complexity indicators that are significantly important for predicting the outcome (Table 5.4). These indicators are split into three groups to conduct the principal component analysis based on the relationship of the complexity indicators to management levels (decision-making levels). The management levels from a project management viewpoint in this research include inter-organizational management level, organizational management level, and project management level. The rationale for this grouping is that the complexity indicators at the equivalent management level are possibly highly- correlated; therefore, the PCA process can maximize the variable reduction. PCA process is conducted within each group of complexity indicators. The retained principal components of each group are used for fitting the logistic model. The result of principal component analysis is described in detail for each group in this research.

5.4.2.1 Group 1 - Inter-organizational Management Level

Inter-organizational management level refers to the highest level of project management related to decision-making level. This management level requires the involvement of multiple organizations (owners, designers, and/or constructors) and/or authorizing agencies in the decision-making process to manage a project. The reference from an industry perspective of CII RT 305 research team indicates that CI_2 and CI_3 are related to project stakeholder management; CI-10, CI_12, CI_13 are the indicators related to legal or authorization of project; and CI-14 and CI_15 are the indicators related to project interfaces. These seven complexity indicators are used to describe project complexity at the inter-organizational management level because several parties/agencies are possibly involved in managing a project when these complexity indicators are applied. Table 5.5 presents the description of seven complexity indicators for Group 1.

Table 5.5 Seven Complexity Indicators for Group 1

Complexity Indicator	Category
CI-2_Impact of required approvals from external stakeholders on the original project execution plan.	**Stakeholder Management**
CI-3_Impact of required inspection by external (regulatory) agencies/entities on original project execution plan.	
CI-10_Number of total permits to be required.	**Legal**
CI-12_Difficulty in obtaining design approvals.	
CI-13_Impact of external agencies on the project execution plan.	

Table 5.5 Continued

Complexity Indicator	Category
CI-14_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project.	**Interfaces**
CI-15_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project.	

The principal component analysis process using JMP generated a loading matrix (Figure 5.2) that shows the weighting factors of complexity indicators on each component.

Loading Matrix

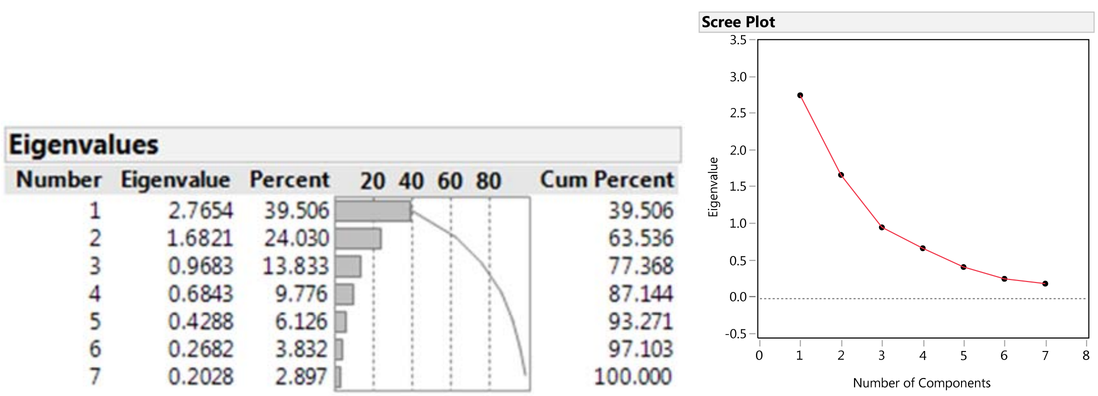
	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7
CI_14	0.25294	0.84719	-0.23284	0.14480	-0.27313	-0.20023	-0.16858
CI_15	-0.02981	0.91272	0.00778	0.09832	0.29658	0.20780	0.15867
CI_2	0.48929	-0.35632	-0.52741	0.56559	0.18817	-0.01322	0.00218
CI_3	0.85590	-0.05502	-0.14490	-0.07786	-0.37474	0.29205	0.10780
CI_10	0.43252	-0.01066	0.77963	0.44853	-0.05618	-0.00189	-0.02549
CI_12	0.88893	0.03253	0.05716	-0.21939	0.10180	-0.30099	0.23745
CI_13	0.86676	0.01160	0.06136	-0.28008	0.27735	0.09428	-0.28384

Figure 5.2 Factor Loading Matrix of Complexity Indicators on Each Component for Group 1

As described above, in principal component analysis, the number of components extracted is equal to the number of variables being analyzed. Because seven variables are analyzed in this group, seven components are extracted. The first component is expected to account for a fairly large amount of the total variance. Each succeeding component accounts for progressively smaller amount of variance. Although a large number of components are extracted here, only the first few components are important enough to be retained for interpretation.

Figure 5.3 is one of the outputs from principal component analysis for Group 1 using JMP that presents the eigenvalues of extracted components. In Figure 5.3, the column "Number" presents the name of components including seven components extracted from the PCA process (Number 1 to 7). These components are arranged in the order of eigenvalue magnitude from greatest to smallest as shown in column "Eigenvalue". The column "Percent" presents the amount of variance that each component accounts for, and the column "Cum Percent" presents the cumulative percent of variance that are accounted for by those components. The Scree Plot visually presents the eigenvalues of all extracted components.

It can be seen from this output that the eigenvalue for component 1 is 2.76, while the eigenvalue for components 2 is 1.68. This pattern is consistent with an earlier statement that the first components extracted tend to account for relatively large amounts of variance, while the later components account relatively smaller amounts.



Eigenvalues

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	2.7654	39.506		39.506
2	1.6821	24.030		63.536
3	0.9683	13.833		77.368
4	0.6843	9.776		87.144
5	0.4288	6.126		93.271
6	0.2682	3.832		97.103
7	0.2028	2.897		100.000

Figure 5.3 Variance Distribution of Components Generated from PCA for Group 1

The output in Figure 5.3 shows that only components 1, 2 demonstrate eigenvalues greater than 1.00, so these components are retained as principal components under the eigenvalue-one criterion. The cumulative percent of variance of these two components is 63.5% accounting for most of total variance of the population. With this justification, the first two components of Group 1 are retained as the principal components for rotation and interpretation. Variance rotation output and the equations of these two retained principal components from JMP for Group 1 are shown in Figure 5.4 and Table 5.6.

Rotated Factor Loading

	Factor 1	Factor 2
CI_14	0.189098	0.863683
CI_15	-0.097754	0.907964
CI_2	0.514486	-0.318862
CI_3	0.857624	0.008923
CI_10	0.432114	0.021604
CI_12	0.884036	0.098692
CI_13	0.863490	0.076166

Variance Explained by Each Factor

Factor	Variance	Percent	Cum Percent
Factor 1	2.7594	39.420	39.420
Factor 2	1.6881	24.116	63.536

Figure 5.4 Rotated Factor Loading of Principal Components for Group 1

Table 5.6 Principal Component Loading Equation for Group 1

PC 1.1 = - 1.849 + 0.091***CI_2** + 0.141***CI_3** + 0.011***CI_10** + 0.199***CI_12** + 0.175***CI_13** + 0.002***CI_14** - 0.003***CI_15**	**PC 1.2 =** - 0.504 - 0.094***CI_2** - 0.004***CI_3** + 0.0003***CI_10** + 0.027***CI_12** + 0.017***CI_13** + 0.021***CI_14** + 0.033***CI_15**

The rotated-factor-loading matrix for Group 1 shows that the first principal component (PC 1.1) is highly loaded with CI_2, CI_3, CI_10, CI_12, and CI_13. The second principal component (PC 1.2) is highly loaded with CI_14 and CI_15. The interpretation for each principal component in Table 5.7 describes the characteristics of each PC in terms of measuring project complexity.

Table 5.7 Interpretation of Principal Components for Group 1

Component	High Loading CI	Interpretation	PC Short Description
PC 1.1	CI-2_Impact of required approvals from external stakeholders on the original project execution plan. CI-3_Impact of required inspection by external (regulatory) agencies/entities on original project execution plan. CI-10_Number of total permits to be required. CI-12_Difficulty in obtaining design approvals. CI-13_Impact of external agencies on the project execution plan.	The common characteristic of these variables is related to the regulatory requirements and authorization of a project. Required inspection by external agencies, number of required permits, and difficulty in obtaining permits or design approvals will impact the authorization to proceed for the project. Therefore, PC 1.1 loaded with these variables is representative for measuring project complexity contributed by project compliance and authorization.	Project Compliance and Authorization

Table 5.7 Continued

Component	High Loading CI	Interpretation	PC Short Description
PC 1.2	CI-14_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the detailed engineering/design phase of the project. CI-15_Peak number of participants (Full Time Equivalents (FTE)) on the project management team during the procurement phase of the project.	These indicators are used to measure project complexity by measuring the size of project management team (PMT) and impacts of PMT size on project execution. The interaction between people, teams, or organizations to execute a project will largely influence project performance. The greater project team size, the more interaction and communication are required, as a result, the more complex the project is. PC 1.2 is thus used to measure project complexity created by project management team size.	Project Management Team Size

5.4.2.2 Group 2 - Organizational Management Level

Organizational management level refers to the project management level that the decision-making process is beyond the authorization of project team, but the decisions can be proceeded within the organization to manage and execute a project. The reference from an industry perspective of CII RT 305 research team indicates that CI_4, CI_5, and CI_6 are related to the governance of a project; CI_7 and CI_8 are related to fiscal planning of project; and CI_17 and CI_18 are the complexity indicators related to project execution target. These seven indicators are used to describe project complexity at the organizational management level. Table 5.8 presents the description of seven complexity indicators for Group 2.

Table 5.8 Seven Complexity Indicators for Group 2

Complexity Indicator	Category
CI-4_Total number of joint-venture partners in this project.	**Governance**
CI-5_Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan.	
CI-6_Number of times on this project that a change order will go above the Project Manager for approval.	
CI-7_Number of funding phases (gates) from concept to project completion.	**Fiscal Planning**
CI-8_Specific delays or difficulties in securing project funding.	
CI-17_Compare target project funding against industry/internal benchmarks.	**Execution Target**
CI-18_Compare target project schedule against industry/internal benchmarks.	

The loading matrix that shows the weighting factors of complexity indicators on each component for Group 2 as shown in Figure 5.5 was generated from the PCA process using JMP statistical software.

Loading Matrix	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7
CI_5	0.31481	-0.09139	0.91296	-0.05717	0.15716	-0.03214	0.17336
CI_6	0.74353	-0.40133	-0.05534	-0.12454	0.14870	-0.38613	-0.31034
CI_4	0.60717	-0.28354	0.09651	0.58680	-0.29803	0.29898	-0.13815
CI_7	0.72705	-0.34133	-0.38399	-0.06881	0.11087	0.03947	0.43459
CI_8	0.62137	0.22955	0.02382	-0.63341	-0.18751	0.32628	-0.13347
CI_17	0.47744	0.56485	-0.09350	0.25424	0.60010	0.11768	-0.07513
CI_18	0.53543	0.62600	0.00778	0.14294	-0.42898	-0.32113	0.11747

Figure 5.5 Factor Loading Matrix of Complexity Indicators on Each Component for Group 2

There are seven variables analyzed in this group, so seven components are extracted. Figure 5.6 is an output from principal component analysis for Group 2 that presents the eigenvalues of these seven extracted components. It can be seen from this output that the eigenvalue for component 1 is 2.45, while the eigenvalues for components 2 and 3 are 1.12, 1.00 respectively. This pattern consistent with an earlier statement that the first components extracted tend to account for relatively large amounts of variance, while the later components account relatively smaller amounts.

Eigenvalues

Number	Eigenvalue	Percent	Cum Percent
1	2.4499	34.999	34.999
2	1.1299	16.142	51.141
3	1.0027	14.324	65.465
4	0.8541	12.202	77.667
5	0.7272	10.389	88.056
6	0.4645	6.636	94.692
7	0.3716	5.308	100.000

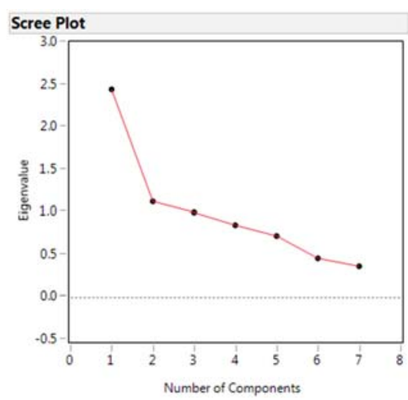


Figure 5.6 Variance Distribution of Components Generated from PCA for Group 2

From this output, components 1, 2, and 3 demonstrated eigenvalues greater than 1.00, so these three components are retained as principal components under the eigenvalue-one criterion. The cumulative percent of eigenvalue of these three components that is 65.4%, is also representative for most of the total population variance. With this justification, the first three components of Group 2 are finally retained for rotation and interpretation. Variance rotation output and the equations of extracted principal components from JMP for Group 2 are shown in Figure 5.7 and Table 5.9.

Rotated Factor Loading

	Factor 1	Factor 2	Factor 3
CI_5	0.100677	0.060174	0.962906
CI_6	0.829412	0.103324	0.135531
CI_4	0.620938	0.113225	0.244921
CI_7	0.854253	0.159535	-0.193264
CI_8	0.354912	0.543830	0.132856
CI_17	0.075257	0.740582	-0.040319
CI_18	0.063919	0.818711	0.065165

Variance Explained by Each Factor

Factor	Variance	Percent	Cum Percent
Factor 1	1.9491	27.844	27.844
Factor 2	1.5671	22.387	50.231
Factor 3	1.0664	15.235	65.465

Figure 5.7 Rotated Factor Loading of Principal Components for Group 2

Table 5.9 Principal Component Loading Equation for Group 2

PC 2.1 = - 0.799 -0.015***CI_5**	**PC 2.2 =** - 3.615 - 0.011***CI_5**	**PC 2.3 =** - 0.427 +0.266***CI_5**
+ 0.023***CI_6** + 0.503***CI_4**	- 0.005***CI_6** - 0.106***CI_4**	+ 0.002***CI_6** + 0.264***CI_4**
+ 0.425***CI_7** + 0.181***CI_8**	- 0.048***CI_7** + 0.709***CI_8**	- 0.246***CI_7** + 0.133***CI_8**
- 0.083***CI_17** - 0.105***CI_18**	+ 0.393***CI_17** +0.418***CI_18**	- 0.067***CI_17** + 0.004***CI_18**

The rotated-factor-loading matrix for Group 2 shows that the first principal component (PC 2.1) is highly loaded with CI_4, CI_6, and CI_7. The second principal component (PC 2.2) is highly loaded with CI_8, CI_17, and CI_18, and the final retained principal component in this group (PC 2.3) is highly loaded with CI_5. The interpretation for each principal component in Table 5.10 describes what characteristics each PC represents in terms of measuring project complexity.

Table 5.10 Interpretation of Principal Components for Group 2

Comp -onent	High Loading Complexity Indicator	Interpretation	Short Description
PC 2.1	CI-4_Total number of joint-venture partners in this project. CI-6_Number of times on this project that a change order will go above the Project Manager for approval. CI-7_Number of funding phases (gates) from concept to project completion.	The common characteristic of these indicators is related to management structure (project organization structure including number of partners, level of authorization to enact changes, and funding stream) that is organized to manage a project. The nature of PC 2.1 is related to a governance structure sponsoring the given project. Therefore, PC 2.1 measures organizational breakdown structure that contributes to complexity of a project.	Organizational Breakdown Structure
PC 2.2	CI-8_Specific delays or difficulties in securing project funding. CI-17_Compare target project funding against industry/internal benchmarks.	CI_17 and CI_18 are used to measure project complexity that can be created by project execution targets compared to industry benchmarks on project complexity. The more aggressive the execution target is, the more complex the project is likely to be. The	Aggressivenes s of Project Performance Targets

Table 5.10 Continued

Comp-onent	High Loading Complexity Indicator	Interpretation	Short Description
	CI-18_Compare target project schedule against industry/internal benchmarks.	commercial, contractual factors, and level of schedule aggressiveness impact cost and schedule during the execution of a project. CI_8 is related to organizational management level in securing project funding to execute the project. This factor can be influenced by the economic climate, political environment, or the target of the project to organizational goals. Therefore, PC 2.2 loaded with these indicators measures project complexity by measuring the aggressiveness of project performance targets.	
PC 2.3	CI-5_Number of executive oversight entities above the project management team who will have decision-making authority over the project execution plan.	The level of authorizing approvals may regulate the management approach to a project. A high complexity project requires more executive oversight entities above the PMT for making decision on the execution	Executive Oversight Level

Table 5.10 Continued

Comp -onent	High Loading Complexity Indicator	Interpretation	Short Description
		plan. Therefore, the number of executive entities above the PMT indicates the complexity level of a project. As a result, PC 2.4 measures project complexity created by the number of executive oversight levels structured to manage a project.	

5.4.2.3 Group 3 - Project Management Level

At project management level, the decisions can be made by the project team to manage and execute a project. The complexity factors included in this group are typically generated and managed at the project management level when executing a project. The reference from an industry perspective of CII RT 305 research team indicates that CI-9 is the complexity indicator related to project quality; CI_19, CI_20, and CI_21 are the complexity indicators related to the design and technology of project; CI-23, CI_24, and CI_27 are related to project location; CI_30 and CI_31 are related to scope definition of project; and CI_34, CI_35, CI_36, and CI_37 are related to project resources. These thirteen complexity indicators are used to describe project complexity at the project management level. Table 5.11 presents the descriptions of these thirteen complexity indicators for Group 3.

Table 5.11 Thirteen Complexity Indicators for Group 3

Complexity Indicator	Category
CI-9_Quality of bulk materials during project execution.	**Quality**
CI-19_Difficulty in system design and integration on this project compared to a typical project for your company.	**Design and Technology**
CI-20_Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase.	
CI-21_Company's degree of familiarity with technologies that will be involved in construction project phase.	
CI-23_Number of execution locations which will be used on this project during detailed engineering/design phase.	**Location**
CI-24_Number of execution locations which will be used on this project during fabrication (bulk materials and equipment) phase.	
CI-27_Impact of project location on the project execution plan.	
CI-30_Impact of the magnitude of change orders on project execution.	**Scope Definition**
CI-31_Impact of the timing of change orders on project execution.	
CI-34_Quality issues of skilled field craft labor during project construction.	**Project Resources**
CI-35_Frequency of workarounds (work activities out of sequence to continue) because materials are not available when needed to support construction.	
CI-36_Percentage of craft labor turnover.	
CI-37_Percentage of craft labor sourced locally (within 100 mile radius of job site).	

The loading matrix that shows the weighting factors of complexity indicators on each component for Group 3 as shown in Figure 5.8 was generated from the PCA process using JMP statistical software.

Loading Matrix

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10	Prin11	Prin12	Prin13
CI_31	0.49935	-0.11627	0.36507	-0.71978	-0.07157	-0.07811	-0.09645	0.19958	-0.05381	-0.04501	-0.00969	0.05691	0.13099
CI_30	0.65512	-0.06065	0.38139	-0.61279	-0.04528	-0.01492	0.04806	0.04201	0.05694	0.09155	0.01007	-0.07642	-0.14920
CI_27	0.27662	0.45554	-0.04124	0.14499	0.57550	-0.44967	-0.34901	0.15270	0.09008	-0.06476	-0.02557	-0.03863	-0.01580
CI_23	0.06670	-0.07656	0.69370	0.52325	0.21403	0.18076	0.02624	0.25777	-0.24974	0.16035	0.02691	-0.01583	-0.00244
CI_24	0.28443	-0.31676	0.68342	0.41319	-0.06987	-0.10851	0.15691	-0.05128	0.35175	-0.10919	-0.02261	-0.00896	0.02883
CI_20	0.39957	0.63030	0.04053	0.19206	-0.42636	-0.34904	0.18859	0.08171	-0.07799	-0.08076	0.18329	0.10939	-0.02279
CI_21	0.43559	0.74916	0.05365	0.12168	-0.35410	0.18051	0.01064	-0.01351	-0.02574	-0.00987	-0.21299	-0.16086	0.03264
CI_19	0.65441	0.28456	0.31270	-0.03285	0.36248	0.17447	-0.01411	-0.44535	-0.11082	-0.04371	-0.02252	0.12980	0.00152
CI_35	0.68389	0.06679	-0.23238	0.19876	-0.20705	0.42097	-0.35639	0.08014	0.19393	0.16252	0.09418	0.08889	0.00340
CI_34	0.81366	-0.27354	-0.28105	0.09314	0.15652	0.17673	0.05828	-0.02570	-0.07920	-0.19077	0.19238	-0.18774	0.02738
CI_9	0.71953	-0.37224	-0.38117	0.18134	0.03884	0.07426	0.13028	0.22400	-0.06320	-0.17304	-0.19652	0.12799	-0.04924
CI_36	0.70929	-0.12392	-0.38146	0.06997	0.15856	-0.32873	0.28934	-0.06471	0.03211	0.32398	-0.03071	-0.01868	0.05240
CI_37	-0.29364	0.56119	-0.09137	-0.23247	0.43235	0.38593	0.36294	0.19247	0.16798	-0.01614	0.04607	0.03242	0.01287

Figure 5.8 Factor Loading Matrix of Complexity Indicators on Each Component for Group 3

There are thirteen indicators analyzed in this group, so thirteen components are extracted. Figure 5.9 shows the outputs from principal component analysis for Group 3 using JMP that presents the eigenvalues of thirteen extracted components and the Scree Plot.

Eigenvalues

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	3.8548	29.653		29.653
2	1.9185	14.758		44.411
3	1.7631	13.563		57.973
4	1.5519	11.938		69.911
5	1.1086	8.527		78.439
6	0.9088	6.991		85.429
7	0.5574	4.288		89.717
8	0.4377	3.367		93.084
9	0.2965	2.281		95.365
10	0.2587	1.990		97.355
11	0.1691	1.301		98.656
12	0.1265	0.973		99.629
13	0.0482	0.371		100.000

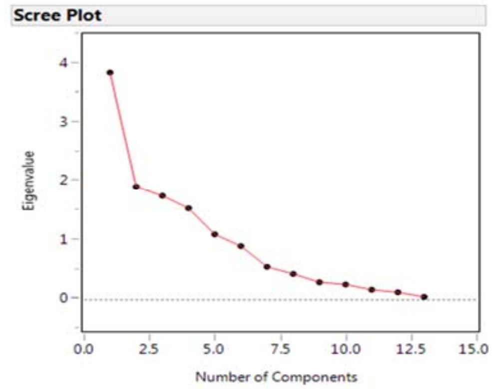


Figure 5.9 Variance Distribution of Components Generated from PCA for Group 3

From this output, components 1, 2, 3, 4, and 5 demonstrate eigenvalues greater than 1.00, so these five components are retained as the principal components for Group 3 under the eigenvalue-one criterion. The cumulative percent of variance of these five components is 73.71% accounting for most of the total population variance.

With this justification, the first five components of Group 3 are finally retained for rotation and interpretation. Variance rotation output and the equations of extracted principal components from JMP for Group 3 are shown in Figure 5.10 and Table 5.12.

Rotated Factor Loading	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
CI_31	0.082442	0.953649	0.005289	-0.017743	-0.052570
CI_30	0.204230	0.946704	0.109261	0.073924	0.022730
CI_27	0.172324	-0.051646	0.138883	0.055738	0.763681
CI_23	-0.105206	-0.066962	-0.009496	0.877697	0.158539
CI_24	0.095380	0.140600	0.028006	0.873277	-0.177875
CI_20	0.078747	0.026909	0.875391	0.028712	0.056443
CI_21	0.051548	0.092452	0.920857	-0.014092	0.186205
CI_19	0.294562	0.434643	0.248639	0.312359	0.551727
CI_35	0.641786	0.066886	0.435912	0.024375	-0.039539
CI_34	0.893183	0.198498	0.011453	0.063779	0.087505
CI_9	0.908729	0.054243	-0.015757	0.030431	-0.077882
CI_36	0.803573	0.112997	0.071805	-0.078744	0.155377
CI_37	-0.384064	-0.053090	0.011493	-0.338721	0.620714

Variance Explained by Each Factor

Factor	Variance	Percent	Cum Percent
Factor 1	3.0227	23.251	23.251
Factor 2	2.0932	16.102	39.353
Factor 3	1.9039	14.646	53.999
Factor 4	1.7670	13.592	67.591
Factor 5	1.4102	10.848	78.439

Figure 5.10 Rotated Factor Loading of Principal Components for Group 3

Table 5.12 Principal Component Loading Equation for Group 3

PC 3.1 = - 1.299- 0.05***CI_31** - 0.03***CI_30** + 0.027 ***CI_27** - 0.05***CI_23** - 0.001***CI_24** - 0.043***CI_20** - 0.068***CI_21** + 0.014***CI_19**+ 0.106***CI_35** + 0.202***CI_34** + 0.252***CI_9** + 0.248***CI_36** - 0.083***CI_37**	**PC 3.2 =** - 1.352 + 0.286***CI_31** +0.266***CI_30** - 0.037***CI_27** - 0.067*CI_23 + 0.001***CI_24** - 0.038*CI_20 - 0.01***CI_21** + 0.081*CI_19 - 0.037***CI_35** - 0.007*CI_34 - 0.062***CI_9** -0.037*CI_36 + 0.0148 ***CI_37**	**PC 3.3 =** - 1.066 - 0.026***CI_31** -0.005***CI_30** - 0.031***CI_27** -0.034***CI_23** + 0.001***CI_24** +0.430***CI_20** + 0.485***CI_21** - 0.004***CI_19** + 0.113***CI_35** - 0.065***CI_34** - 0.059***CI_9** - 0.052***CI_36** - 0.041***CI_37**
PC 3.4= - 0.671 - 0.041***CI_31** - 0.013***CI_30** + 0.02***CI_27** + 0.438***CI_23** + 0.059***CI_24** - 0.004***CI_20** - 0.029***CI_21** +0.082***CI_19** - 0.012***CI_35** -0.002***CI_34** - 0.013***CI_9** - 0.066***CI_36** - 0.108***CI_37**	**PC 3.5=** -2.785 - 0.038***CI_31** - 0.015***CI_30** + 0.255***CI_27** +0.124***CI_23** - 0.015***CI_24** - 0.099***CI_20** - 0.027***CI_21** + 0.203***CI_19** - 0.059***CI_35** + 0.041***CI_34** - 0.04***CI_9** + 0.088***CI_36** + 0.306***CI_37**	

The rotated-factor-loading matrix for Group 3 shows that the first principal component in this group (PC 3.1) is highly loaded with CI_9, CI_34, CI_35, and CI_36. The second principal component (PC 3.2) is highly loaded with CI_19, CI_30, and CI_31. The third principal component (PC 3.3) is highly loaded with CI_20, and CI_21. The fourth component (PC 3.4) is highly loaded with CI_23 and CI_24; and the fifth retained principal component in this group (PC 3.5) is highly loaded with CI-27 and CI_37. The interpretation for each principal component in this group in Table 5.13 describes what characteristics each PC represents in terms of measuring project complexity.

Table 5.13 Interpretation of Principal Components for Group 3

Comp -onent	Variables have high loadings	Interpretation	Short Description
PC 3.1	CI-9_Quality issues of bulk materials during project execution. CI-34_Quality issues of skilled field craft labor during project construction. CI-35_Frequency of workarounds (work activities out of sequence to continue) because	PC 3.1 is loaded with the indicators that are related to the management of project resources including the availability as well as quality of materials, equipment, and personnel used for the project. Quality and availability of project resources reflected by quality of suppliers, subcontractors, and contractors have substantial impacts on project performance. Any deviation of these factors largely contributes to project complexity. As a result, in the complexity predictive model, PC 3.1 measures project resource management.	Project Resource Management

Table 5.13 Continued

Comp-onent	Variables have high loadings	Interpretation	Short Description
	materials are not available when needed to support construction. CI-36_Percentage of craft labor turnover.		
PC 3.2	CI-19_Difficulty in system design and integration on the project compared to a typical project of the company. CI-30_Impact of the magnitude of change orders on project execution CI-31_Impact of the timing of change orders on project execution.	The common characteristic of these indicators is related to how well the project scope is defined resulting in change orders and the impacts that the change management process have on project execution. The difficulty of system design and integration results in an ambiguous project scope and increases the number of change orders regarding both magnitude and timing of change orders. This matter likely increases project complexity. Therefore, PC 3.2 typically measures project complexity by measuring project scope clarity and change orders generated while executing a project.	Project Scope Clarity and Change Orders

Table 5.13 Continued

Comp -onent	Variables have high loadings	Interpretation	Short Description
PC 3.3	CI-20_Company's degree of familiarity with technologies that will be involved in detailed engineering/ design project phase. CI-21_Company's degree of familiarity with technologies that will be involved in construction project phase.	These indicators are used to measure the impacts of technology familiarity on project execution. The familiarity of process technology to a project team significantly impacts the applicability of technical methods to execute the project, and the low level of technology familiarity likely creates more complexity for the project. PC 3.3 loaded with these variables is therefore representative for measuring project complexity created by the degree of technology familiarity of project teams.	Degree of Technology Familiarity
PC 3.4	CI-23_Number of execution locations, which will be used on this project during detailed engineering/design phase.	PC 3.4 has high loadings from the indicators that are used to measure impacts of the number of Design/Fabrication execution locations and logistics on project execution. The greater number of Design/Fabrication execution locations requires more communication and complicated	Number of Design/Fabri cation Execution Locations

Table 5.13 Continued

Comp -onent	Variables have high loadings	Interpretation	Short Description
	CI-24_Number of execution locations, which will be used on this project during fabrication (bulk materials and equipment) phase.	interaction between project team members. The distinct geographical locations of project team members, the effort required to physically procure, transport, install, and integrate material and personnel for the purpose of completing a project will decrease or increase the level of project complexity depending on how many Design/Fabrication execution locations the project has and the level of logistics support.	
PC 3.5	CI-27_Impact of project location on the project execution plan. CI-37_Percentage of craft labor sourced locally (within 100 mile radius of job site).	The construction location significantly impacts how a project is executed. The availability and quality of project resources are largely influenced by the location where the project is constructed. Without early considering the impacts of construction location on project execution plan likely increases the complexity of a project. The management process that the project team applies to execute a project is also significantly influenced by project construction location and the	Project Construction Location and Local Resources

Table 5.13 Continued

Comp -onent	Variables have high loadings	Interpretation	Short Description
		availability of local resources. Thus, PC 3.5 loaded with these indicators is a measurement of project complexity by measuring the impacts of project construction location on project execution plan.	

5.4.3 Summary of Principal Component Analysis

The process of principal component analysis using JMP software results in a set of ten principal components (10 PCs) that are retained for multivariate analysis. These principal components include two components retained from Group 1, three components retained from Group 2, and five components retained from Group 3. The equations and descriptions of the retained principal components are presented in Table 5.6, Table 5.7, Table 5.9, Table 5.10, Table 5.12, and Table 5.13. In the complexity predictive model, these principal components function as the moderating variables representative for twenty-seven complexity indicators. These variables are then fitted to the model using JMP in the following section of this chapter (model Fitting and Testing).

5.5 Model Fitting and Testing

The ten principal components retained from the principal component analysis function as the moderating variables in the logistic model. These components are loaded with 27 complexity indicators that were proven to be significant to the model with the univariate analysis. The model was initially fitted with these ten moderating variables using JMP software. However, the model development process resulted in a model with all numerically unstable parameters and unrealistically large standard errors as shown in Figure 5.11.

Parameter Estimates

Term		Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	Unstable	-116.67778	6126.1013	0.00	0.9848
PC 1.1	Unstable	-80.211924	17557.208	0.00	0.9964
PC 1.2	Unstable	5.05365304	3739.5352	0.00	0.9989
PC 2.1	Unstable	22.4771528	22144.792	0.00	0.9992
PC 2.2	Unstable	-101.65966	9094.271	0.00	0.9911
PC 2.3	Unstable	-1.4570114	6896.1253	0.00	0.9998
PC 3.1	Unstable	-2.8751828	17074.093	0.00	0.9999
PC 3.2	Unstable	13.680852	2853.3159	0.00	0.9962
PC 3.3	Unstable	-34.248311	13171.491	0.00	0.9979
PC 3.4	Unstable	-182.19009	17220.141	0.00	0.9916
PC 3.5	Unstable	61.3165618	12447.776	0.00	0.9961

For log odds of 0/1

Figure 5.11 Initial Model with All Unstable Parameters

The result of this unstable model is because the number of explanatory variables (10 PCs) in the model is still large relative to the number of subject observations (44 observed projects). As a result, the univariate method is applied again to reduce the number of explanatory variables in order to generate a stable model.

5.5.1 Verification of Variable Significance

The univariate method is applied once again to select an appropriate subset of explanatory variables for the model. This subset of variables for the model is selected by testing the significance of each principal component among the ten components retained from the PCA process. JMP statistical software is used as the tool to run the analysis. The univariate analysis process using JMP software results in a list of p-values of principal components from the Likelihood Ratio tests as shown in Table 5.14. These p-values are used to verify the significance of principal components.

Table 5.14 P-value of ten principal components resulted from the univariate analysis

Principal Components	P-value	Description
PC1.1	<0.0001	Project Compliance and Authorization
PC1.2	0.0272	Project Management Team Size
PC2.1	0.0094	Organizational Breakdown Structure
PC2.2	0.0007	Aggressiveness of Project Performance Targets
PC2.3	0.1594	Executive Oversight Level
PC3.1	0.0714	Project Resource Management
PC3.2	0.0205	Project Scope Clarity and Change Orders
PC3.3	0.0094	Degree of Technology Familiarity
PC3.4	0.0007	Number of Design/Fabrication Execution Locations
PC 3.5	0.3324	Project Construction Location and Local Resources

The significance level of 0.1 is chosen again to test the significance of each retained component to the model. The significant level of 0.1 is chosen instead of the traditional significance level of 0.05 to allow the potentially important variables to be included in the model. This significance level of 0.1 helps avoid losing the relevant information while create a stable model. With the significance level of 0.1, two components including PC2.3 and PC3.5 are not statistically significant to the model because their p-values are greater than 0.1. These two variables then are excluded from the model. Eight variables including PC1.1, PC1.2, PC2.1, PC2.2, PC3.1, PC3.2, PC3.3, and PC3.4 that have p-values smaller than 0.1 are statistically significant to the model. These eight components will be included in the multivariate process to fit the model. The final list of these significant components is presented in Table 5.15.

Table 5.15 Eight Significant Principal Components with Corresponding P-values

Principal Components	P-value	Description
PC1.1	<0.0001	Project Compliance and Authorization
PC1.2	0.0272	Project Management Team Size
PC2.1	0.0094	Organizational Breakdown Structure
PC2.2	0.0007	Aggressiveness of Project Performance Targets
PC3.1	0.0714	Project Resource Management
PC3.2	0.0205	Project Scope Clarity and Change Orders
PC3.3	0.0094	Degree of Technology Familiarity
PC3.4	0.0007	Number of Design/Fabrication Execution Locations

5.5.2 Fitting the Logistic Regression Model

The model development in this research is a logical process in which a set of explanatory variables is selected to explain a substantial amount of the variability in the response variable. After being developed, the binary logistic regression model estimates the probability that the project is a low complexity project or a high complexity project given the input that are the identified complexity indicators. The significance of these complexity indicators is statistically verified by applying the univariate method. The univariate process results in a list of 27 statistically significant indicators (Table 5.4). These significant indicators are then combined by using the principal component analysis to reduce the number of explanatory variables in the model. The variable reduction helps in developing a numerically stable model while not losing too much information. The PCA process generates a set of moderating variables composed by the significant complexity indicators. Each moderating variable is completely independent with the other variables. The significance of these moderating variables is also verified by the univariate method. The application of univariate methods for the retained principal components results in eight significant components that are functioned as the explanatory variables of the model. With the application of univariate method to select a subset of explanatory variables, the selected variables are considered to be important to the model when standing together in the model. Because the moderating variables are uncorrelated with one another, and these variables are proven to be significant to the model, the model effect tests testing the effect of each variable on the model is not necessary.

The principal components that are proven to be significant to the model function as the input for the multivariate process to fit the ultimate model. The multivariate method is conducted using JMP. The multivariate analysis process using JMP software results in the model equation as presented in Table 5.16 with the estimate coefficients of the explanatory variables. Figure 5.12 presents the original model output from JMP with corresponding model parameters. The multivariate process using JMP also generates the testing factors that are used for the model tests. These factors and corresponding model tests are presented in the section of model test that follows.

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-5.6121821	2.6795419	4.39	0.0362*
PC 1.1	-2.4593257	1.2595079	3.81	0.0509
PC 1.2	0.74882994	0.9575477	0.61	0.4342
PC 2.1	-1.8759966	2.3279386	0.65	0.4203
PC 2.2	-3.7588578	2.4394678	2.37	0.1234
PC 3.1	0.10437852	1.1675122	0.01	0.9288
PC 3.2	-0.8181208	1.0673106	0.59	0.4434
PC 3.3	-3.0932628	2.3299259	1.76	0.1843
PC 3.4	-4.8669469	2.7679017	3.09	0.0787

For log odds of 0/1

Figure 5.12 Original Model Output from JMP

Table 5.16 Binary Logistic Regression Equation

Probability that the project is a **Low Complexity Project:** $P_{[0]} = P(Y=0 \mid Xi=xi) = \dfrac{\text{Exp}(Lin[0])}{1+Exp(Lin[0])}$	**Lin(0)** = $\ln\left(\dfrac{P_{[0]}}{1-P_{[0]}}\right)$ = **-** 5.61 - 2.46***PC1.1** + 0.75***PC1.2** - 1.87***PC2.1** - 3.76***PC2.2** + 0.1***PC3.1** - 0.82***PC3.2** - 3.09***PC3.3** - 4.86***PC3.4**
Probability that the project is a **High Complexity Project:** $P_{[1]} = 1 - P_{[0]}$	

Lin[0] is the logit of the model or logit of the response that is described by the log of odd ratio ($\frac{P_{[0]}}{1-P_{[0]}}$). In this case, Lin[0] is a linear regression that describes the relationship between project complexity level and complexity indicators via the moderating variables that are Principal Components (PCs). PCs in the equation are the moderating variables generated from Principal Component Analysis (PCA) as presented in Section 5.4. Table 5.17 presents the equations of eight principal components that are generated from PCA process and functioned as moderating variables in the developed model.

Table 5.17 Equations of Principal Components Generated from JMP

PC 1.1 = - 1.849 + 0.091***CI_2** + 0.141***CI_3** + 0.011***CI_10** + 0.199***CI_12** +0.175***CI_13** + 0.002***CI_14** - 0.003***CI_15**	**PC 1.2 =** - 0.504 - 0.094***CI_2** - 0.004***CI_3** + 0.0003***CI_10** + 0.027***CI_12** + 0.017***CI_13** + 0.021***CI_14**+ 0.033***CI_15**
PC 2.1 = - 0.799 - 0.015***CI_5** +0.023***CI_6** + 0.503***CI_4** + 0.425***CI_7** + 0.181***CI_8** - 0.083***CI_17** - 0.105***CI_18**	**PC 2.2 =** - 3.615 - 0.011***CI_5** - 0.005***CI_6** - 0.106***CI_4** - 0.048***CI_7** + 0.709***CI_8** + 0.393***CI_17** + 0.418***CI_18**

Table 5.17 Continued

PC 3.1 = - 1.299 - 0.05***CI_31** - 0.03***CI_30** + 0.027 ***CI_27** - 0.05***CI_23** -0.001***CI_24** - 0.043***CI_20** - 0.068***CI_21** + 0.014***CI_19** + 0.106***CI_35** + 0.202***CI_34** + 0.252***CI_9** + 0.248***CI_36** - 0.083***CI_37**	**PC 3.2 =** -1.352 + 0.286***CI_31** + 0.266***CI_30** - 0.037***CI_27** - 0.067***CI_23** + 0.001***CI_24** - 0.038***CI_20** - 0.01***CI_21** + 0.081***CI_19** - 0.037***CI_35** - 0.007***CI_34** - 0.062***CI_9** - 0.037***CI_36** + 0.0148 ***CI_37**
PC 3.3 = - 1.066 - 0.026***CI_31** - 0.005***CI_30** - 0.031***CI_27** - 0.034***CI_23** + 0.001***CI_24** + 0.430***CI_20** + 0.485***CI_21** - 0.004***CI_19** + 0.113***CI_35** - 0.065***CI_34** - 0.059***CI_9** - 0.052***CI_36** - 0.041***CI_37**	**PC 3.4=** - 0.671 - 0.041***CI_31** - 0.013***CI_30** + 0.02***CI_27** + 0.438***CI_23** + 0.059***CI_24** - 0.004***CI_20** - 0.029***CI_21** + 0.082***CI_19** - 0.012***CI_35** - 0.002***CI_34** - 0.013***CI_9** - 0.066***CI_36** - 0.108***CI_37**

5.5.3 Model Test

Because the moderating variables are uncorrelated with one another, and these variables are proven to be significant when standing together in the model, the model effect test that tests the effect of each variable on the model is not necessary. Therefore, the model utility test process includes only two types of model test that are: **1) Whole model test** that compares the whole model fit (the specified model with all significant variables) to the flat model that omits all the effects except the intercept parameters; and **2) Lack-of-fit test** (sometimes called goodness-of-fit test) that verifies whether or not the model fits the data well. This test examines whether the specified model is good enough, or a saturated model is required. The saturated model mentioned here is the model that required possible interactions between the variables. Table 5.18 summarizes the model test process and the testing results based on the outputs from JMP Statistic Software.

Table 5.18 Model Test Summary

Model Test	Purpose	Hypothesis	Significance Level (α)	Testing Result
Whole Model Test	This test examines if the flat model (the model with only intercept) is enough, or the specified model (the model with the effects) is required.	_Null Hypothesis:_ The flat model is good enough. _Alternative Hypothesis_: The model with effects is required.	$\alpha = 0.05$	• P-value < 0.0001 => *The flat model is not enough, and the specified model is required.*
Lack-of-fit Test (Goodness-of-fit Test)	This test verifies whether or not the model has fitted the data well.	_Null Hypothesis_: The model has no lack-of-fit (the fitted model is correct). _Alternative Hypothesis:_ The model has some lack-of-fit.	$\alpha = 0.05$	• P-value = 0.998 =>*There is no evidence to reject the null hypothesis. The fitted model is correct, and the specified model passes the test.*

Whole Model Test: The whole model test table (Figure 5.13) shows the test that compares the whole model fit to the flat model that omits all the regressor effects except the intercept parameter. The detailed output from JMP for the whole model test is presented in Figure 5.13.

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	20.790601	8	41.5812	<.0001*
Full	6.731019			
Reduced	27.521620			

RSquare (U)	0.7554
AICc	36.7562
BIC	47.5197
Observations (or Sum Wgts)	44

Measure	Training	Definition
Entropy RSquare	0.7554	1-Loglike(model)/Loglike(0)
Generalized RSquare	0.8565	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.1530	∑ -Log(ρ[j])/n
RMSE	0.2063	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.0888	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.0455	∑ (ρ[j]≠ρMax)/n
N	44	n

Figure 5.13 Output from JMP for the Whole Model Test

The result of p-value<0.0001 indicates that the null-hypothesis, which is the flat model is good enough, is rejected. As a result, the specified model with the single effects as presented in Table 5.15 is required.

Lack-of-fit Test: The lack-of-fit test, sometimes called goodness-of-fit test, is the test that examines whether the fitted model is good enough, or a saturated model is required. The detailed output from JMP for the lack-of-fit test is presented in Figure 5.14.

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	35	6.7310192	13.46204
Saturated	43	0.0000000	**Prob>ChiSq**
Fitted	8	6.7310192	0.9996

Figure 5.14 Output from JMP for Lack-of-fit Test

The output shows that P-value is equal to 0.998. Therefore, there is no evidence to reject the null hypothesis that the fitted model has no lack-of-fit. The testing result supports the conclusion that there is little to be gained by introducing additional variables, such as polynomials or cross terms. As a result, the specified model is fitted correctly, and it passes the test that the model fits the data well.

5.6 Model Summary

Developing a model that helps scholars increase their understanding of project complexity can significantly contribute to the body of knowledge in the field of project management. The model that appropriately identifies project complexity levels is very important to create a basis for developing a management approach to manage project complexity and mitigate the impacts of project complexity on project performance. The developed model in this research helps scholars and practitioners in the construction field assess complexity levels of a project based on the applicably identified complexity measures. Given the identified complexity levels, project practitioners can facilitate the management process and formulate a management plan by applying an appropriate complexity management strategy.

In the model development process, the multivariable analysis is used as the method to develop the model, and the univariate method is used as an approach to selecting a subset of explanatory variables. The univariate method resulted in a set of 27 significant indicators that functioned as the measures of project complexity. To generate the required input for the proposed model, the variable reduction process called Principle Component Analysis (PCA) was applied during the model development process to reduce the number of explanatory variables. PCA process resulted in a significantly smaller number of eight principal components functioning as the moderating variables in the model. This process helped in generating a numerically stable model while the subject observations were limited.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Project complexity is a terminology that is not well understood in the area of project management, and it is a critical factor that presents additional challenges to achieving project objectives. This study developed a methodology to assess and measure project complexity including a model that helps identify the levels of project complexity. The model developed in this research is a binary logistic regression that estimates the probability of high/low complexity given the values of complexity indicators. Moreover, the research proposed a constructive way to assess and measure aspects of project complexity. The root contributors to complexity of projects defined as complexity indicators were identified, and the descriptions of those contributors from the perspective of complexity theory and complexity management were obtained to describe project complexity. In this manner, the research made a contribution to enriching the theoretical basis in the field of project management. Specifically, the analysis of survey data in this research identified 37 indicators of complexity (out of 101) that statistically differentiated low complexity projects from high complexity projects. The 37 indicators represent 23 complexity attributes within 11 categories of project complexity. The overall level of project complexity (Low Complexity vs. High Complexity) can be determined by using the developed model. The model helps project teams facilitate the complexity assessment process. This process enables project participants to develop their competencies in managing complex projects in different industry sectors. Moreover, it will lead to some suggestions for project management scholars and practitioners to leverage the positive impacts and reduce negative impacts of project complexity to manage projects in an effective way.

6.2 Research Limitation

Because complexity is an abstract concept as stated by several complexity theorists, thus collecting the data with a high level of detail was the challenge for the researcher. There were too many contributors to the complexity of a project as mentioned in the literature review, so it was difficult to collect the data with a high level of detail related to the level of impacts of project complexity on project characteristics and performance. Also, the data that was used for statistical analysis needed to be from respondents who should have good experience in project management, so obtaining a large data sample size was a challenge for the research as well.

One limitation of this research is that it focused on project complexity and not related areas such as risk and difficulty. The researcher spent considerable time to study and evaluate the differences between project complexity, risk, and difficulty. While they are related, each concept is unique as well. For example, complexity can drive a risk but a risk can create complexity. Complexity can make project execution more difficult. On the other hand, a complex project is not necessarily more difficult to execute. Another limitation is that the researcher chose not to describe complexity primarily in terms of a project's physical features (e.g., site issues related to logistics, quantities of materials, number of systems, and types of technology) but rather to address complexity as it is related to managing projects. This approach was followed to make the complexity measurement methods apply to as many different types of projects as possible. Some physical features were considered at the complexity attribute level in the assessment method. Complexity described in terms of managing project elements and their interaction was necessary to ensure that the products could be generalized across industry sectors and within an industry sector with different types of projects. However, it would be necessary to study project complexity focusing on a specific sector with the corresponding physical features. One of the well-known characteristics of any project is the uniqueness. Projects in different sectors have different physical features that more or less contribute to project complexity. Therefore, focusing more on physical features of a project could help in exploring other specific complexity aspects in the corresponding sector.

6.3 Recommendation

The recommendation for any further research is to continue efforts on improving the knowledge relevant to the research topic of project complexity. These efforts can be classified as follows:

1- Advance the developed assessment and management process of project complexity in a particular sector such as highway, industrial, or building projects. Recent research projects have focused more on exploring project complexity with respect to project management practices, but these research efforts still generalized to a broad range of project types (not for projects in a specific industry such as industrial, highway, building, and so on.) There is a need to study complexity as a separate factor influencing projects in a specific industry. It is essential to define project complexity, study the individual and most important attributes of complexity, and identify the influence of project complexity on different aspects of projects including cost, schedule, quality, and safety for each individual industry. Most attributes of complexity are known to be constantly changing variables such as project location, project team experience, interfaces within a project, logistics/market conditions, geo-political and social issues, and permitting and approvals. The presence of these changing variables depends on each specific project type and/or each specific project phase. Better understanding of project complexity in any phase for projects in a specific sector and creating a strategy plan to manage complexity will directly influence how efficiently and economically projects are planned, executed, and managed.

2- Explore the perceived link between project complexity and project performance through decision-making process. Many project scholars and practitioners believe that there should be a relationship between project complexity and projects performance and its influence on the decision-making process.

However, the data analyses in the completed complexity research has shown a weak direct relationship between project performance and project complexity. Therefore, continued examination for a direct measure between complexity and performance through the decision-making process could be useful for project teams to improve the project delivery.

3- Improved understanding of how complexity, difficulty, and risk relate. It was found that the terms complexity and difficulty are often used interchangeable, yet they are different. There is also an overlap between complexity and risk, but each of these terms is actually a different project characteristic. During the course of my completed researches, it was noted that these terms are not mutually exclusive, nor are they completely the same. There is a need to continue to look at the relationships between these terms. The research could also examine how to evaluate the tradeoffs between these three related characteristics.

4- Identify categories of interfaces between complexity attributes: in the finished researches, there were 23 attributes that were determined to indicate complexity; however, no one attribute can be used to measure complexity alone. Additionally, not all of the identified attributes are relevant on all projects. Further work is needed to evaluate best practices for how to manage interfaces and interactions of the attributes since it appears that the attributes work in harmony to describe the complexity of a project.

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APPENDIX A

DETAIL OF COMPLEXITY ATTRIBUTES

A.1 Change management (dynamics of market and environment)

- Definition: overall effort on a project to prepare for and mitigate or manage changes to project scope and/or project environment. Also considered a systematic approach or protocol to manage changes within a project
- Examples: design changes, contracting strategy changes, market driven changes, unknowns/risks that occur during project execution, regulatory changes, construction method changes
- Measures: effectiveness of change management and its mitigation, the number of changes of specific duration, timing of changes
- Impacts: cost, schedule, project objectives, resources demand
- Mitigation/management strategies: establish robust change management process/procedure early in project life. Ensure strong communication regarding changes. Establish and effectively communicate project decisions throughout project to minimize likelihood of future changes. Establish key performance indicators for project.

A.2 Clarity of business objectives

(NOTE – Similar to item 28. Level of stakeholder cohesion/alignment)

- Definition: Mutual understanding among stakeholders and team members of achievable, worthy project outcomes and tradeoffs that will make a project a success and create a comparative advantage from the viewpoint of all stakeholders
- Examples:
    - Safe Construction and Operation
    - Operating Date (Schedule)
    - Operating (Factory) Cost
    - Capital cost
    - Selling Volume
    - Price
    - Return on Investment

    - Reliability
    - Maintainability
    - Facility Life
    - Turndown/Flexibility
    - Expandability
    - Capacity
    - Quality
    - Yield
    - Sustainability
    - Job Creation
- Measures:
    - CII Alignment Tool tailored for business objectives
    - PDRI Section 1B
    - Target vs. actual for key objectives
    - Team Development Score
- Impacts:
    - Build the wrong plant or facility
    - Not fit for use
    - Not economic
    - Permitting issues
- Mitigation/management strategies:
    - Prepare a Key Principles Document stating the objectives and obtain all stakeholders signatures.
    - Conduct monthly meetings with stakeholders to review progress toward meeting the objectives

A.3 Clarity of scope definition at kick-off

- Definition: Degree to which project services, deliverables and facilities have been defined at the beginning of a project

- Examples:
    - Lack of definition due to 1st time to execute a particular project
    - Uncertainty surrounding purpose of project
    - Poor understanding of priorities of design objectives
    - Ineffective communication or insufficient understanding by key parties
    - Design entities and degree of customization
    - Lack of assigned resources at beginning of project
    - Lack of sufficient front-end planning
    - Unknown types and quantities of deliverables
- Measures:
    - Number
    - Quality of definition and planning
    - Resource loading
    - Definition of Deliverables
    - Utilization of Approved procedures
- Impacts:
    - Cost
    - Schedule
    - Staffing
    - Quality
- Management strategies:
    - Structured Planning and Execution Procedures
    - Audit to ensure utilization of Procedures
    - Independent technical review of scope and deliverables
    - Assessment of project and design team experience
    - Benchmarking against analogous project

A.4 Climate

(Consideration of project location and the affect of weather) (temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological elemental measurements in a given region over long periods

- Definition: The impact of design, equipment, construction and operating considerations required to deal with long term weather.
- Examples:
  - Temperature
  - Humidity
  - Atmospheric pressure
  - Wind
  - Precipitation
  - Atmospheric particle count
- Measure(s)/Metric:
  - Changes in weather conditions
- Impacts:
  - Schedule
    - Design additional items
    - Construction of additional items
  - Cost
    - Building
    - Elevated items
  - Operating
    - Limitation
- Mitigations/management strategies:
  - Acknowledge, understand, and assign necessary resources and build implementation strategies.

A.5 Commercial burdens

- Definition: Financial elements affecting the cost and execution requirement of a project
- Examples:
  - Financing entities
  - Currency exchange
  - Tax and interest rates
  - Sources of funding and associated terms and conditions including reporting requirements
  - Intellectual property issues
  - Procurement strategies related to vendor contracts (terms and conditions)
- Measures:
  - Number of funding entities
  - Capability of organization to handle debt (people and monetary resources)
- Impacts:
  - Cost
  - Schedule
  - Risk
  - Attractiveness for investment
- Management strategies:
  - Broker investments to hedge risk
  - Manage cash flow

A.6 Cost

- Definition: The various budget, commercial, and contractual factors that impact the number of interfaces impact cost during the execution of a project
- Examples:
  - Reimbursable or fixed price project

  - Financial factors: taxation, currency, funding sources
  - External factors: types of vendors, subcontractors. Complexity is affected with familiarity and confidence level
  - Quality of cost estimate
  - Cost definitions and knowledge hand off at each stage of the project.
  - Clarity of contingency and detailed work up of cost related to risks
  - Tracking details required on a project, especially a cost plus project
  - Availability of tools and infrastructure to track costs
  - Liquidated damages
  - Warranty
- Measure(s)/Metric:
  - Size of project (can be defined by order value)
  - Project margin
  - Contingency or risk money (ratio to the margin/ or total order value)
  - Accuracy of data/visibility of data (Level I/ II/II)
  - Robustness of processes used for cost tracking
  - Number of touch points (if multiple parties are involved project can be complex with all the data collection processes)
  - Quality of cost estimate
- Impacts:
  - Resources(people) need to track the project
    - Quantity
    - Capability
    - Availability
  - Tools/capabilities
  - Cost, Schedule, and Quality
    - Productivity
- Mitigations/management strategies:

  - Resources: development of resource planning tool, training of resources, prioritization of resources
  - Tools/capabilities: development of tracking tools/processes which take into consideration systems used for different players
  - Acknowledgement of impact, product initiation strategies and early stage planning

A.7 Design

(Number of process steps, HSE hazards, # of recycles, exotic materials)

- Definition: the depth of design and number of process steps, HSE hazards, exotic materials, type of project (LNG, power plant, offshore, onshore)
- Examples: familiar process design or unfamiliar, level of technology,
- Measures: number of process steps, number of large process equipment, large number of process interfaces,
- Impacts: design duration and effort, cost, schedule, project objectives
- Mitigation/management strategies: establish basis of design and manage changes to BOD, increase design assurance steps, involve subject matter experts,

A.8 Direct field Labor

- Definition: Skill set requirements for construction workforce and staff support assigned to a field project
- Examples:
  - Availability of specialized labor
  - Labor source relative to project location (people logistics)
  - Housing and transportation for craft labor (quality of life issues)
  - Management of labor (productivity)
- Measures:
  - Number
  - Qualifications

    - Diversity of skills
    - Labor utilization
- Impacts:
    - Cost of project
    - Schedule
    - Environment
    - Social
    - Stakeholder buy-in
- Management strategies:
    - Verify qualifications
    - Market studies of labor pools
    - Cross training to optimize labor resources

A.9 Escalation

- Definition: An unexpected increase in the cost.
- Examples:
    - Unstable economies
    - Currency fluctuations
    - Increase in costs
        - Material
            - Commodities
        - Labor
        - Equipment
- Measure(s)/Metric:
    - Planned Vs. Actuals
    - Trends of currency fluctuations
    - Trends of commodity pricing
    - Inflation rates

* Note: The longer duration of a project/extension of a schedule makes a project susceptible to schedule

- Impacts:
    - Cost
    - Schedule
    - Quality
    - Performance
- Mitigations/management strategies:
    - Fixed price pricing
    - Lock in rates at the start of the project
    - Pre-invest method
    - Defining escalation criteria in the contract to limit exposure
    - Locked in union contracts

A.10 Fiscal planning/financing (funding stream, uncertain political environment)

- Definition: project's funding plan can introduce project complexity through number of partners, fiscal/economic climate, political environment (stakeholders, government regulations)
    - Examples: financing through a financial institution, joint venture partners include foreign entities/governments
- Measures: robust economics, commodity/product prices, project metrics (ROR, NPV)
- Impacts: schedule delay, project funding, project decisions
- Mitigation/management strategies: develop alternate funding plans, try to ensure project has strong economics, alignment with business strategies

A.11 Interfaces within the project

(Number of subs, number of disciplines within subs, # of offices executing project, # of software systems being used and if they can interact or standalone, internal, level)

a. *Quantity*
b. *Location*
c. *Interdependency*
d. *Importance*

- Definition: An interaction, in the form of a discussion or deliverable, between people, teams and/or organizations for the purpose of communicating (handoffs/ approvals/decisions), to influence and advance the project.
- Examples:
    - Stage Gates
    - Milestones
    - Progress meetings / presentations / etc.
    - Deliverable handovers
    - Workshops
    - Peer reviews and audits
    - Various kickoff meetings
    - Vendor selection
    - Etc.
- Measures: Define all interfaces, quantity and timing, using integrated CPM schedule as basis of reference.
    - Rank interface criticality , importance and interdependency
    - Deliverable hand-off /validation
        - Who
        - When
        - Where
        - How
- Impacts:
    - Size of team(s)
    - Authority of decision making
    - Interfaces

        - Number of
        - Types
        - Timing
        - Un-foreseen
    - Delay of critical interfaces impacting:
        - Schedule
        - Cost
        - Quality
        - Safety
        - Etc.
- Mitigation/management strategies:
    - Assign project "interface managers" and delegate authority
        - Develop a team rooster with roles and responsibilities
        - Continuous management of activities with AR's and status

A.12 Joint Ventures

- Definition: The cooperation of two or more individuals or businesses in which each agrees to share profit, loss and control in a specific enterprise.
- Examples:
    - Partnership with resource holder
- Measures:
    - The number of parties
    - Equity positions
    - Existence of key technologies or trade secrets
    - Duration to negotiate contract
    - Number of supply agreements
- Impacts:
    - Longer duration for decision making
    - Changes after FEL3 (if FEL3 was done without partner involvement)

- Changes to execution strategy (if not defined in JV Articles)

- Mitigation/management strategies:
    - Have a majority partner
    - Include execution strategy (Contracting, procurement plans, staffing, roles) included in the JV Articles
    - Understand the partner project champion and their position, identify opponents
    - Alignment of partners approach to capital project execution
    - Due diligence on reputation, financial strength.

A.13 Legal (region, authorities, binding agreements with vendors or clients)

- Definition: The amount of behavior that a body of law attempts to regulate
- Examples:
    - US Tax Code
    - Environmental Regulations
    - Obamacare
    - Lump Sum EPC Contracts
- Measures:
    - Number of agreements
        - Financial
        - Real Estate, right of ways
        - Services
        - Supply
        - IP (Partners, suppliers)
    - Allocation of Contract Risk
    - Existence of trade secrets
    - Export Control
    - Level of Environmental Permits (Minor/Major/PSD)
- Impacts:

- Resources
- Time
- Lawsuits

- Mitigation/management strategies:
    - Definitions of what is and is not a change should be provided. Examples may be included. Also, the understanding that change orders will not be issued for contractor errors should be included.
    - The change order process should be clearly described, especially regarding issues of review responsibilities and timeliness. Procedures should be established on how and how quickly notice will be served on change orders. A method for determining the cost of a change should also be stated. This should include agreed upon unit rates for common items.
    - A procedure for resolving disputes should be included.
    - Supporting/Included Documents will often serve as the standard for measuring changes and are helpful in determining whether an event represents a change. A complete and clear list of the supporting documents should be included. A list of the hierarchy of the documents will help with disputes.
    - Workmanship requirements should be clearly specified in the contract. A time limit for the contractor to correct defects should be specified.
    - To reduce Work Scope Definition clause problems, preplanning or alignment meetings with the contractor with an emphasis on communications will help clarify the scope, roles, and expectations. A clear list of services to be provided should be a part of the contract. A clear, well-developed project execution plan should be agreed upon as soon as possible in the contracting process.
    - Consult with the contractor prior to the specification of a reporting and control system. Agree on a system and how often cost and schedule

reporting will be done. Define the minimum reporting requirements and metrics.

  - Clearly define the risk allocation on the project including any shared risk.
  - Provide clear site safety requirements and expectations
  - Provide site security procedures
  - Include contract language that permits Eastman to retain control of third party subcontractor's qualifications, monitoring, interface, procedures, and policies.
  - Provide clear documentation requirements for packaged equipment
  - Include turnover, check-out, and start-up system requirements
  - Develop a payment schedule based on percent complete

A.14 Level of authorizing approvals and duration of receiving approvals

(Flat or hierarchical)

- Definition: efficiency in making project decisions (organizational structure design for making project decisions, stakeholder management)
- Examples: size of the organization, project decision review board, established decision making process,
- Measures: time taken for project decisions, decision quality (spider diagram), delegation of authority structure
- Impacts: cost, schedule, project objectives
- Mitigation/management strategies: establish a clear decision making process for the project (staged gate approval process), use decision review board for key project decisions, develop decision support packages,

A.15 Level of Control (Change management)

- Definition: The degree of authorization to enact changes through a lifecycle of a project.

- Examples:
    - Identification of variance or Scope Change
        - Lack of recognition
    - Mutually beneficial changes
    - Delegation of authority
    - Quantity of individuals required to approve changes
        - How
        - Who (Field office, home office, operators, executive mngt)
        - How many organizations/interface points
        - Timing
        - Value
    - Change of ownerships
- Measure(s)/Metric:
    - Quantity of Changes in each phase
    - Value of Changes
    - Quantity of rework and new work
- Impacts:
    - Interface points
    - Cost
    - Schedule
        - Due to rework
        - Time to reach alignment
        - Materials
        - Construction
            - Labor
            - Material
- Mitigations/management strategies:
    - Detailed agreed to change management procedures

A.16 Level of stakeholder cohesion/alignment

- Definition: The effort to meet and maintain the original business objective and scope intent identified by the original sponsorship through current project activities.
- Examples: Lack of scope clarity, misaligned project to business objectives, outdated project to business needs, unclear sponsorship(s)
- Measures:
    - Geographic Location of Project to Sponsor (Decision making, involvement)
    - Quantity of Owner initiated Changes
    - Defined Roles and Responsibilities
    - Quantity of Structured Project Documents
    - Duration of Project Document review and Approvals
- Impacts:
    - Quality
    - Scope
    - Schedule
    - Cost (Rework, Abandoned Investments)
    - Engineering design
    - Personnel Resources
- Mitigation/management strategies:
    - Project Documentation endorsement
    - Project Governing Models
    - Project Visibility (portfolios, summaries)
    - RACI Matrix

A.17 Local content requirements

- Definition: The local regulations, restrictions or requirements enforced on the project resulting from physical jobsite location and project type.
- Examples:

- Open shop vs. union requirements
- Environmental regulations / permits
- MSHA / CalMSHA (if a subsurface or surface mine)
- Special licensing for engineering or construction
- Requirements to use local workforce (common for international work)

- Measures / Metrics:
  - Number of individual permits required for project execution
  - Number of government oversight agencies
  - Number of organizations required for project development
  - Additional local fees / taxes
- Impacts:
  - Costs – labor rates
  - Team selection – additional staffing, training requirements, etc.
  - Management – oversight of multiple organizations
  - Schedule – ability to compensate for schedule recovery
  - Procurement strategy
  - Risk
  - Environmental
  - Safety
  - Engineering
- Mitigation/management strategies:
  - Early identification of local requirements
  - Use of personnel familiar with local requirements
  - Perform early risk assessment
  - Identify unavoidable cost impacts and include in project budget

A.18 Logistics with purchasing, fabrication, transportation to site, and installation at site

- Definition: The effort required to physically procure, transport, install and integrate materiel and personnel for the purpose of completing a project
- Examples: materiel shipments; supplier sourcing (remote vs. local); team travel; construction site organization and staging
- Measures:
    - Project-specific travel budgets
    - Number of purchase orders
    - Steps in supply chain
    - Number of modes of transportation
    - Distance/number of boundaries through which materiel & personnel travel
- Impacts:
    - Schedule
    - Cost
    - Engineering design
    - Procurement strategy
    - Risk
    - Environment
    - Quality of components
    - Personnel sourcing
    - Security
- Mitigation/management strategies:
    - Local/in-country procurement
    - Local personnel sourcing
    - Early coordination discussions
    - Devoted logistics personnel
    - Selected modes of transportation

- Enhanced packaging

A.19 Number of locations

- Definition: Distinct geographical locations of project team members
- Examples:
    - # of contract offices
    - # of owner offices
- Measures:
    - # of contract offices
        - Engineering / Architect
        - Procurement
        - Construction
    - # of licensor offices
    - # of owner offices
    - Time zone differences
- Impacts:
    - Miscommunications
    - Errors
    - Extended review durations
    - Re-work
    - Travel cost
    - Information Protection
- Mitigation/management strategies:
    - File Shares
    - Video Conferencing Tools
    - Routine centralized meetings

A.20 Number of Participants (Stakeholders)

- Definition: This complexity attribute relates to the number of stakeholders associated with a project. It is important to note that these stakeholders can be internal and external to the owner company and internal and external to the project team. The definition of stakeholder can be found in the PMI PMBOK [1]. (Level of stakeholder cohesion/alignment was identified as a separate attribute in the brainstorming exercise.)
- Examples:
    - Customers, sponsors, partners, contractors, subcontractors, landowners, regulatory agencies, operations, etc.
    - Internal/External
    - High/Medium/Low Influence
    - Highly/Moderately Impacted by the project
    - New development stakeholders versus revamp/sustaining project stakeholders
    - Obvious versus hidden or shadow stakeholders
- Measures:
    - Determine number of stakeholders, categorize (e.g., internal, external, sponsor, public) and group based on degree of alignment with the project.
    - Determine degree of influence of each stakeholder and degree of project impact to each stakeholder.
    - Determine phases in the project life cycle in which each stakeholder has influence. This would allow for determination of the number of stakeholders with influence during each project phase.
    - Determine phases in the project life cycle in which each stakeholder is impacted by the project. This would allow for determinations of the number of stakeholders impacted by the project during each project phase.
    - Determine availability and expected involvement of each stakeholder.

    - Determine the potential number (or percentage) of hidden/shadow stakeholders that could significantly influence the project throughout the life cycle.
- Impacts:
    - Number of stakeholders impacts the number of interfaces that the project team will be required to manage. This will impact the amount of work required to communicate with stakeholders and manage their expectations.
    - Number of stakeholder can impact the type of regulatory requirements, permits required, land agreements required.
    - Degree of influence of key stakeholders, and degree of project impact to key stakeholders will influence the amount of effort required to communicate with them and manage their expectations.
    - Greater number of stakeholders could increase the probability of misalignment between different stakeholders.
    - Not engaging enough and/or very influential stakeholders in the planning phases of a project life-cycle can increase project complexity during project execution.
    - In revamp or sustaining projects, the operations functions have high influence late in the project. Not engaging operations early in the project development can add complexity during construction, commissioning and start-up.
    - Inadequate engagement of stakeholders that have low visibility but high impact on the project can increase project complexity.
- Mitigation/management strategies:
    - Projects with less stakeholders will most likely have less stakeholder interfaces to be managed by the project team.
    - Assessing stakeholder related considerations (regulatory, permitting, land, etc.) when selecting project locations could lead to a less complex project.

- Having support from many influential stakeholders could simplify many aspects of the project.
- Categorization of stakeholders could simplify communication and simplify the development of stakeholder management strategies.
- Teambuilding, alliance building, and partnering can help decrease stakeholder driven complexity.

- References:

[1] Project Management Institute, A Guide to the Project Management Body of Knowledge (PMBOK Guide) – Fourth Edition, 2008.

A.21 Number of suppliers, subcontractors, contractors

- Definition: This complexity attribute relates to the quantity of supplier, subcontractors and contractors associated with a project. The total count is independent of who holds the contract; it may be the owner, general contractor or multiple general contractors. The total count is also independent upon whether the supplier, subcontractor and/or contractor physically participates in activities on site, solely delivers supplies, equipment or materials to the site or ships supplies, equipment or materials to the site.
- Examples:
    - Material suppliers
    - Service vendors
    - Specialty contractors
    - First, second and third tier subcontractors under one or more general contractors
    - Multiple prime contractors under owner or Construction Manager
    - Owner – when they are supplier of materials or services
- Measures:
    - Determine total number of suppliers supporting project and categorize/group based on criticality of scope on project.

- Determine degree of project impact.
    - Determine areas/phases of influence on project success.
    - Determine degrees of interdependency of supplier, subcontractor, or contractor with other suppliers, subcontractors and contractors.
- Impacts:
    - Number of suppliers, subcontractors and contractors impacts coordination efforts required for project success
    - Number of suppliers, subcontractors and contractors impacts communication efforts
    - Number of suppliers, subcontractors and contractors impacts volume of contractual relationships at various levels.
    - Number of suppliers, subcontractors and contractors may impact complexity of dispute resolution based on levels to contractual relationships and interconnection of project coordination efforts.
    - Coordination of suppliers, subcontractors and contractors with client/owner O&M staff may impact startup and turnover.
    - High number of suppliers, subcontractors and contractors may have significant impact on schedule, quality and cost.
- Mitigation/management strategies:
    - Pre-project planning by key decision makers that includes procurement strategy.
    - Standardization of agreement at all levels
    - Strong subcontracting strategies and processes.
    - Strong and early schedule development
    - Clear scopes of work with delineation between parties
    - Effective Interactive Planning before and during project
    - Clear and effective project progress meetings.

A.22 Owner, partnerships

- Definition: Governance structure sponsoring a given project
- Examples:
    - Sole Ownership
    - Equity divisions
    - Joint venture
    - Consortiums
- Measures:
    - Number
    - Cultural affinity
    - Balance of strength
- Impacts:
    - Cost
    - Schedule
    - Make-up of Management team structure
- Management strategies:
    - Governance models
    - Risk Tolerance (Distribution)
    - Decision making processes and authority
    - Financial authorization limitations

A.23 Permitting and regulatory requirements (construction and long term)

- Definition: Building, environmental, and code compliance required for initial site construction access, construction phase, and facility / location startup and operation.
- Examples:
    - Right of way to access site
    - Transportation of large equipment overland (rural freeze restrictions)
    - Greenfield - Initial environmental permit for facility (local, state, federal)
    - Brownfield – major or minor source review / update of existing permit

- Operating permits (hazard waste generation, water, air emission permits)
- Electrical/structural/mechanical

- Measures:
  - Number of regulatory bodies (EPA, DEC, local building codes, etc.)
  - Greenfield or brownfield
  - Domestic or foreign
  - Number of types of processes and emission points
  - Type of insurance (self-insured, etc.)
- Impacts:
  - Schedule delay – time spent waiting for and negotiating / aligning with regulatory bodies
  - Community perception
  - Legal cost
  - Team resource time spent handling permitting challenges – meeting documentation (opportunity cost)
  - Contingency planning difficult – inconsistent / unknown time required to obtain permits
- Mitigation/management strategies:
  - Develop permitting plan during project inception
  - Engage regulatory bodies early in the process
  - Communicate via community meetings, new briefs, flyers etc. to align support during planning phase
  - Pursue lobbying efforts for government challenges
  - Leverage similar construction activities for other facilities as a starting point
  - Identify highest risk permitting areas to establish management contingency allocation (both schedule and cost) – (rate 1 to 5)

A.24 Physical location

(Location of suppliers and project, density of population, urban vs. rural, new jurisdiction vs. known jurisdiction)

- Definition: This complexity attribute relates to geographic location of the final constructed asset, the physical location of project activities (e.g., engineering, fabrication, construction), and the physical location of key stakeholders including project team members (e.g., sponsors, partners, suppliers, contractors, etc.). It is important to note that perceived complexity associated with a specific project may be dependent on whether the company has experience working in the project's geographic region or in similar locations.
- Examples:
    - Arctic, Offshore, Desert, Muskeg, Remote, Urban / Rural.
    - Engineering in US, Drafting in India, Construction in Africa.
    - Owner in Europe, Partner in North America, EPC Contractor in South America.
    - Geographic region is new to the owner, new to the industry.
    - Technical, logistical, regulatory complexities due to physical location.
- Measures:

  Sample questions:
    - Has the company previously constructed a project in this geographic region? Has the industry previously constructed a project in this geographic region?
    - Are there special climate considerations?
    - Will new technologies be required to construct in this physical location?
    - What are the land and regulatory impacts of this physical location? How does it impact the number of stakeholders?
    - How does the physical location impact project logistics? How do these logistics impact cost and schedule?

- Are project activities taking place in multiple time zones (e.g., engineering, fabrication, construction)?
- How does the physical location impact safety and security?
- Will language or cultural differences increase project complexity?
- Could develop a map or list of construction project regions that are traditionally complex from technological, regulatory, logistical, etc. perspectives.

- Impacts:
    - Projects in new geographic regions may be more complex because many project requirements are not yet in place (e.g., field staff, international accounting requirements, regional office).
    - Projects in new geographic regions may be more complex due to unfamiliarity of regional requirements.
    - Extreme and/or unfamiliar climates add complexity to design, construction execution and operation.
    - Project location may lead to use of a technology that the owner is unfamiliar with or that is new to the industry.
    - Projects in urban locations may have many more directly impacted stakeholders than in remote locations. This could increase the regulatory complexity.
    - Logistics for field activities may be more complex for projects in very remote areas and for projects in very urban areas.
    - Extensive travel to and from different locations (e.g. engineering location and site location) can add complexity to a project.
    - Having project activities occurring in many different geographic locations (e.g., different time zones) can complicate communication.
    - Physical location can complicate design with respect to safety and security.
    - Language and cultural differences can complicate communication.

    - Availability of existing operations and maintenance staffing and the time requirement for them to travel to engineering and vendor sites can be problematic and add complexity to the project. Additional staffing may be required.
- Mitigation/management strategies:
    - Partnerships with companies more familiar with a new region. Partnership and Alliance methodologies should be considered.
    - Co-locating staff or using video-conferencing.
    - Conducting very good front-end planning when developing projects in challenging project locations.
    - Consider logistics when selecting equipment and material suppliers.
    - Assess stakeholder related considerations (regulatory, permitting, land, etc.) when selecting project locations.
    - Teambuilding at a common location during the early stages of the project.
    - Cultural training in the early stages of the project.
    - Development of common goals, rewards or incentives that could be shared by the different contributors and that would decrease complexity related to physical location.

A.25 Productivity

- Definition: This seems like a subset of scoping effort with an affect to schedule and costs.
- Examples: Examples of items that could affect productivity

A.26 Project Size

- Definition: This complexity attribute relates to the size of a project in monetary value. As suggested in the text, Industrial Mega Projects, "projects in the neighborhood of a billion dollars is where we see project outcomes begin to deteriorate sharply," the large size of these projects tend to increase complexity and decrease probability of success. This text also notes that complexity drives team size. MORROW E [1] The inverse could also be inferred that team size drives complexity because the communication channels increase at a rapid rate of [n * (n-1) / 2]. PMI PMBOK [2]

- Examples:
    - Size of project stakeholder group
    - Size of project capital
    - Size of external stakeholder group.
    - Highly/Moderately Impacted by the project
    - Environmental and Political footprints of project
    - Number of co-owners/partners in project
- Measures:
    - Number of environment and regulatory permits required.
    - Stress on Local Communities, i.e. local labor, infrastructure, traffic patterns.
    - Determine how projects are impact by turnover during different phases in the project life cycle in which each stakeholder has influence.
    - Competition for resources (Internal and External).
    - Amount of outsourcing required to execute project.
    - Stability of political environment.
    - Alignment with co-owners and partners. Number of joint venture partners.
    - Number of sub-projects.
    - Size of core team.
    - Time required to develop and execute the project.
    - Number of stakeholders impacted.
    - Degree of media coverage.
- Impacts:

- Poorly informed decision making.
- Short term focus.
- Competitive contracting environment.
- Outsourcing of key resources.
- Accelerating schedules
- Multiple conflicting contracting strategies
- Having more stakeholders, environmental and regulatory requirements, subprojects, and joint venture partners increases the number of interfaces that need to be managed by the project.
- Larger projects tend to take longer to develop and execute. This increases the probability of key team member turnover. It can also lead to changes in key external stakeholders (e.g. national, regional or local politics)
- Very large projects require numerous resources from the owner organization. Finding resources to fill these roles can be difficult. Proceeding without key roles can add complexity to a project.
- Very large projects can drain the engineering and construction resource pool in a geographic area. Finding resources can be difficult and expensive.
- High profile projects need to be very carefully managed from a media / community relations standpoint.
- Smaller projects are sometimes underestimated in terms of complexity and sometimes not provided with enough resources. Some small projects can be very technically complex and have a significant impact to the business. (E.g. upgrade in an operating facility).

- Mitigation/management strategies:
    - Early alignment with business and technical engineering objectives.
    - Co-owner and partner alignment.
    - Informed decision making by executive sponsor.
    - Alignment with both host government and local communities.

- Avoid fast tracking and uninformed *executive forced* downward estimate revisions and scope deletions. Ensure that schedule is realistic and that planning activities are completed properly.
- Consider different types of organizational models that may better suit the size of the project (“traditional” [1], “hub and satellite”[1], “organic”[1]). An appropriate organizational model can help teams manage interfaces.
- Having integrated teams for large projects can decrease the number of interfaces.

- References:

[1] Industrial Megaprojects, Edward W Merrow, John Wiley and Sons, 2011.

[2] Project Management Institute, A Guide to the Project Management Body of Knowledge (PMBOK Guide) – Fourth Edition, 2008.

A.27 Public Profile

- Definition: how the project/company is perceived by the public, how the project is impacting local community or geographical area
- Examples: Economic/environmental impact to community, example: Keystone pipeline project (effects many communities)
- Measures: share price, special reports
- Impacts: project approvals, regulatory approvals, cost, schedule, design
- Mitigation/management strategies: early definition of public relation risks - develop risk management plan including mitigation, stakeholder management plans, regulatory permit approval plans

A.28 Quality of suppliers, subcontractors, contractors

- Definition: This complexity attribute relates to the quality of suppliers, subcontractors and contractors who participate in the completion of a project. A variety of contributing factors can affect quality such as experience, size, and market conditions however, it is the measurement of quality that is being measured and assessed as a factor in project complexity here; i.e. the ‘What’; not the‘Why’. Quality can be assessed in a number of areas as shown in the example list below.

- Examples:
  - Quality of bid or proposal
    - Responsive to request
    - Complete
  - Quality of schedule or schedule input
    - Adequate detail
    - Logic
    - Coordinated with others or master schedule, as needed
  - Meeting timeline requirements
    - Submittal dates
    - Deliveries
    - Site Activities
    - Closeout
  - Change Management
  - Coordination, Communication, Responsiveness – overall collaboration with team
  - Quality of materials
  - Quality of craftsmanship
  - Quality of supervision
  - Meeting project/design performance requirements
  - Accuracy and timeliness of invoices
  - Ability to acquire and retain resources
- Measures:
  - Categorize suppliers, subcontractors and contractors by level of impact each has on project.
  - Measure quality of suppliers, subcontractors and contractors on pre-determined criteria (examples above).

- Determine weighted factors for each quality measurement as related to supplier's criticality to project success (category)
- Determine impact of quality score versus dispute resolution history.
- Compare quality scores with overall project cost.
- Measure capacity of suppliers to procure/obtain materials to complete their obligations to project timely.
- Measure capacity of factory/shop to manufacture
- Resource pool and ability to retain for duration of project

- Impacts:
  - Quality of Suppliers, subcontractors and contractors impacts ability to meet project design requirements.
  - Quality of Suppliers, subcontractors and contractors impacts ability of team to effectively collaborate and resolve project challenges (i.e. an impact on time, quality and cost)
  - Quality of Suppliers, subcontractors and contractors impacts overall cost of project.
  - Quality of Suppliers, subcontractors and contractors may impact cash flow if invoicing is incorrect and/or late or if changes are not efficiently managed.
  - Quality and quantity of craft to meet project schedule can greatly impact overall success
- Mitigation/management strategies:
  - Early project planning to establish project success metrics
  - Set wide range of key project criteria and pre-qualify Contractors using criteria (more than financial stability and experience).
  - Establish and evaluate suppliers on key criteria for project.
  - Pre-qualify subcontractors using a wide range of criteria to ensure selection of subs takes into account key requirements for success

  - Create and use procedure to track quality of suppliers, subs and contractors early in project and periodically throughout project to enable leadership to step in and support/correct poor performance before it greatly impacts project

A.29 Resource availability

- Definition: The cost of resources compared to the project budget
- Measures:
  - Actual unit rates compared to budget unit rates
- Impacts:
  - Cost
  - Schedule
- Mitigation/management strategies:
  - Firm Bid Contracting

A.30 Schedule

- Definition: The steps/activities identified to meet time objectives
- Examples:
  - Type of schedules
    - Software used
    - Level of schedule (details of activities)
      - Level 1: Milestones
      - Level 2: Summary of activities
      - Level 3: Details
      - …..
      - Level 10
    - Interdependencies between steps/activities
- Measure(s)/Metric:
  - Number of steps and activities

    - Number of critical paths
    - Number of interfaces
    - Number of total constraints
- Impacts:
    - Resources(people) need to track the project
        - Quantity
        - Capability
        - Availability
    - Tools/capabilities
    - Productivity
    - Interfaces
    - Reporting cycles and decision making
    - Need to recover
- Mitigations/management strategies:
    - Critical path analysis and ability to build a path to reduce delays
    - Assigning/commitment of task owners and clear definition of responsibilities
    - Management support for schedule as a tool as compared to a report
    - Establishment of a clear communication mechanism between all parties involved
    - Assigning expeditors for all critical activities
    - Clear scope definition
    - Productive internal/external kickoff meetings
    - Maintaining as issue resolution log

A.31 Social and political influences surrounding project location

(Impact of mega project on environment)

- Definition: Project impact on local social and political groups (stakeholders)
- Examples:

    - Disturbance of wetlands
    - Competition for resources increases labor rates / turnover
    - Deep water drilling
- Measures:
    - Number of impacted stakeholders
        - Positive Impacts
        - Negative Impacts
    - Corruption Perceptions Index
- Impacts:
        - Environmental Impact
            - Air/Water/Land/Noise/Light/Dust
        - Jobs Impact
        - Traffic Impact
        - Infrastructure Impact
        - Governmental Incentives
        - Resource availability impact
- Mitigation/management strategies:
        - Understand the project context (big rock, small pond)
        - Define local content requirements
        - Identify competing projects
        - Identify and understand the stakeholders
            - Allocation of project value to stakeholders (Ceding value to others)

A.32 Strategic importance of the project to organization (amount of profit)

- Definition: Impact of the project on the organization's overall profitability, growth, future industry position, and internal strategic alignment

- Examples: high-profile, large budget projects; projects of national or international significance; projects executed for a change in mission; projects that take a technological risk
- Measures:
  - Project value as a percent of overall project portfolio
  - Scale of public interest/visibility (scale of 1 to 5 or similar)
  - Number of new technologies implemented
  - Number of external stakeholders
  - Scale of senior leadership involvement (scale of 1 to 5 or similar)
- Impacts:
  - Cost
  - company assets devoted to project
  - corporate risk/exposure
  - profit margin
  - learning curve
  - stockholder interests
  - personnel sourcing
- Mitigation/management strategies:
  - Hire consultants/specialists
  - public relations and media control
  - leadership involvement/vision for project
  - project team selection
  - Post-construction performance (corporate "brand" protection)

A.33 Project team experience

(Relative to type of project, size, location, communication, performance)

- Definition: Depth of expertise and knowledge in areas required for the project execution, in the locality (cultural and language consideration) and are familiar with the implicit and explicit customer expectations of performance.

- Examples:
    - Knowledge of tailoring the project processes to the correct scope size – use abridge project processes for small brownfield projects, and rigorous systems for larger scope and regulated (government) project
    - Deploying a small polymer production line in China vs. large multi-line version in the US
    - Experienced team trying to deploy a new innovative technology
    - Communication styles totally different with experienced members and new members – hardcopy vs. IM, txt, email
- Measures:
    - Number of years of experience of key team members
    - Number of new team members
    - Number of similar projects previously executed by team
    - Number of languages in correspondence
    - Size of direct and indirect project team (number of people on each)
- Impacts:
    - Schedule impact – longer time for communication
    - Change orders increase in number and magnitude – requirements more difficult to define / understand
    - Safety risks may not be apparent to less experienced team members
    - HR management – roles many not be well understood by team
    - Team frustration – not knowing how to solve the new problems without previous experience with similar challenges
- Mitigation/management strategies:
    - Identify key roles and fill with experienced resources
    - Clearly define rolls of new members and provide mentoring as needed
    - Benchmark on other similar projects – incorporate best practices early
    - Provide local cultural review of project plan – review with interpreter or other cultural expert familiar with new location

A.34 Technology

(New or innovative design, resolution of issues, project process, and evolution vs. revolution)

- Definition: The application of technical processes, methods, components, and/or knowledge to execute the project.
- Examples:
    - New or innovative design/product to the organization or industry
    - Resolution of issues, new approaches/tools
    - Process design (Building systems, LNG plants)
    - Evolution (step change) vs. revolution (dramatic change)
- Measure(s)/Metric:
    - Proven, developing, new to organization, new to industry or
    - Number of process equipment or building systems
    - Number of new innovative methods, or other
    - Use scale/range such as low use of technology to high use of technology (1 to 5)
- Impacts: Note not measuring impact on project performance (e.g., schedule, cost, etc.)
    - Schedule – number of activities or number of near critical paths (less than five days float)
    - Cost – dollar size of project
    - Team selection (resources, training, skill requirements)
    - Functional objectives – impact on ROI
    - Risk – number of key risks
    - Use of best practices – level of use of constructability reviews or level of use of Front End Planning
    - Stakeholder's buy in – alignment with use of technology
    - Engineering design, procurement, operability, maintainability – degree of improvement in these processes

- Environment
- Opportunity

- Mitigations/management strategies:

A.35 Time Scale of the project

- Definition: The overall duration of the project encompassing early design to project completion, including any multiple phase requirements.
- Examples:
  - Projects with unusually long durations (LNG, Nuclear)
  - Projects which require multiple phases (sports stadium modifications)
  - Projects with compressed schedules due to unmovable completion dates (EPA compliance)
  - Projects which have multiple construction mobilizations (Projects located in areas with weather constraints)
- Measures:
  - How many years is the project duration
  - The number of individual phases
  - Fast track project
  - Number of long lead procurement items
  - Number of construction mobilizations
- Impacts:
  - Cost
  - Schedule
  - Procurement sequencing / logistics
  - Risk
  - Turnover in project team members
  - Multiple construction shifts (for compressed schedule)
  - Engineering design
- Mitigation/management strategies:

- Early procurement discussions
- Early constructability reviews
- Modularization studies
- Dedicated senior project management team

A.36 Turn Over

- Definition: This complexity attribute relates to the turnover of stakeholders associated with a project. It is important to note that these stakeholders can be internal and external to the owner company and internal and external to the project team. The definition of stakeholder can be found in the PMI PMBOK [1]. (Level of stakeholder cohesion/alignment was identified as a separate attribute in the brainstorming exercise.)
- Examples:
    - Customers, sponsors, partners, contractors, subcontractors, landowners, regulatory agencies, operations, etc.
    - Internal/External
    - High/Medium/Low Influence
    - Highly/Moderately Impacted by the project
    - New development stakeholders versus revamp/sustaining project stakeholders
    - Obvious versus hidden or shadow stakeholders
- Measures:
    - Determine impact of stakeholder turnover by categorizing (e.g., internal, external, sponsor, public, project leadership, core team, support resource).
    - Determine how projects are impacted by turnover based on size.
    - Determine how projects are impact by turnover during different phases in the project life cycle in which each stakeholder has influence.

- Examine the norm for project turnover on typical types of projects. New Construction versus Brownfield, Internal Projects versus External Projects.
    - Determine the areas of influence that may drive stakeholder turnover positively and negatively.
    - Compare the change in the degree of project complexity when turnover occurs in projectized versus matrix project organizational structures.
- Impacts:
    - Amount of stakeholder turnover may directly impact the complexity of the project. This measurement could be included in the leadership metrics/KPI's for the project.
    - Turnover of key stakeholder i.e. Project Manager, has been associated with negative outcomes in several academic studies.
    - Examine existing research on the correlation between stakeholder turnover and project success.
    - Loss of project resource continuity can lead to the need to train new resources, loss of information, loss of background or context on why decisions were made.
    - In heated labor markets it may be difficult to find replacement resources.
    - Change in stakeholders can lead to other project changes and the need to re-build relationships.
- Mitigation/management strategies:
    - Projects with expected turnover could limit turnover to strategic project gates and phases.
    - Some large engineering and construction firms are able to mitigate turnover impact by having standardized work processes.
    - Gaining commitment from upper level management on support for consistent staffing of the project.

    - Have in place clear transition requirements and expectations required for exiting and onboarding.
    - Teambuilding, alliance, and partnering strategies have complexity mitigation potential.
    - Invest in training and competency of personnel in key project roles to ensure that replacements are available when turnover takes place.
    - Diligently maintain project documentation to simplify the transition to new resources.
    - Changes in key project personnel could be limited contractually.
- References:

[1] Project Management Institute, A Guide to the Project Management Body of Knowledge (PMBOK Guide) – Fourth Edition, 2008.

A.37 Type of project (conceptual, FEED, EPC, grassroots, revamp)

- Definition: too broad define. This is described with the other attributes (see others)
- Examples:
- Measures:
- Impacts:
- Mitigation/management strategies:

A.38 Types or risks that are being managed (within your control, types)

- Definition: high impactful risks projects encounter, these can vary during each project phase from Conceptual – FEED – Execution – Operations
- Examples: contracting strategy risks, stakeholder mis-alignment risks, regulatory risks, market risks,
- Measures: number of risks, impact from risks, quantitative/qualitative assessments
- Impacts: cost, schedule, project objectives

- Mitigation/management strategies: establish a risk management plan early including risk register, risk assessment, mitigation plan, etc., continuous monitoring, change management

A.39 Unfamiliar procurement

- Definition: Purchasing equipment or services in a new region or business sector
- Examples:
    - Understand culture and compatibilities
    - Assess new commercial, technical and logistic issues
- Measures:
    - Ability to specify requirements
    - Evaluation of qualifications and capabilities
- Impacts:
    - Increase in number of buyers, expeditors and inspectors
    - Cost
    - Additional communication requirements
- Management strategies:
    - Develop rigorous candidate list and qualification process
    - Mutual orientation, team building and alignment

A.40 Visibility internally and externally

- Definition: Relative importance of project within corporate portfolio
- Examples:
    - Projects with political implications
    - Significant financial exposures
    - Potential impact to public sector
    - New ventures into new regions or new business sectors
- Measures:
    - Size

- Location
- Strategic importance and value
- Involvement of above-normal management levels

- Impacts:
  - Personnel assigned to project
  - Personal and organizational reputations
  - Cost
  - Schedule
- Management strategies:
  - Stakeholder analysis
  - Strategy development
  - Rigorous communications plan (more details and categories reported to higher levels)
  - Project Management resource loading

APPENDIX B

COMPLETE SURVEY QUESTIONNAIRE

SURVEY REQUEST

Dear CII Company Member:

Complexity is a term often used in the construction industry to describe a project. However, there appears to be a limited understanding of project complexity, and no standard definition of what it means or how to measure it. Intuitively, the construction industry knows that project complexity has an impact on project delivery, project management practices, and project performance. Research Team 305 is tasked with assessing project complexity by addressing questions such as:

- What is an appropriate definition of project complexity?
- How is complexity of a project described?
- How can project complexity be measured?
- What impact does complexity have on projects?
- How can project complexity be managed?

The RT 305 research method includes three data collection strategies: survey, interviews, and workshops. This memo is requesting your help on the survey data collection effort. CII's on-line survey software is used for the questionnaire. The questionnaire requires that your company complete the same questionnaire for **two** projects, **one** that is considered **low in terms of project complexity** and **one** that is considered **high in terms of project complexity**. The respondent is free to judge the level of complexity for each project. The project should be completed within the last three years or one that is almost complete where the final cost and duration will not change. The majority of the survey questions are constructed so that they can be completed without considerable effort to find information relevant to the project. This assumes that the person completing the survey is very familiar with the project such as the project manager. Moreover, different people can complete the survey for each project or the same person can complete several surveys on different projects.

The following URL will take you to the on-line survey – **URL:**

https://survey.construction-institute.org//TakeSurvey.aspx?EID=981B8o4B038BMKml7B39mB3459B082

When opened, the survey is tied to the respondent's computer IP address to ensure confidentiality. The respondent must complete the survey using his or her computer.

RT 305 requests that the survey be completed by **October 14, 2013**. Based on pilot tests, the survey should take about 1 to 2 hours to complete per each survey depending on the availability of some project data.

The respondent can preview the survey using the following link to CII's website:

https://www.construction-institute.org/MC_Resources/survey/CII_RT_305_Survey_Questionaire_2013-09-18.pdf

RT 305 will hold the data collected as strictly confidential in line with CII's confidentiality requirements as described in the on-line survey. There is no risk to the individual completing the survey.

While participation in this survey is voluntary RT 305 thanks you in advance for your participation. If you have questions, please contact the principal investigators, Stuart Anderson, Texas A&M University, 979-845-2407, s-anderson5@tamu.edu or Jennifer Shane, Iowa State University, 515-294-1703, jsshane@iastate.edu.

NAVIGATION TIPS

- At the end of each page click on the SAVE button. This will bring you back to the top of the page. Scroll down to the bottom of the page and click on the NEXT button. As you scroll down the page you can check your answer.
- You can click on the BACK button to return to the previous page.
- If you leave the survey before completing it be sure you have clicked on the SAVE button. You can close the survey and come back into the survey using the same link, from the same computer and the same browser. However, you will have to click on the NEXT button on each page to return to the place in the survey where you left off.
- On the second to last page you should click on the DONE button. This brings you to a page with two buttons: PRINT RESPONSE and CONTINUE. The DONE button does not submit the survey. Click on the PRINT RESPONSE button. You may have to do this twice to print. You can print a hard copy or a pdf of your responses.
- Once you print your survey, click on the CONTINUE button. This button actually submits the survey.

The Knowledge Leader for Project Success
Owners • Contractors • Academics

RT 305 Measuring Project Complexity and Its Impact

Survey Questionnaire

September 17, 2013 Revision 6

Table of Contents

Background

Complexity is a term often used in the construction industry to describe a project. However, there appears to be limited understanding of project complexity, and no standard definition of what it means or how to measure it. Intuitively, the construction industry knows that project complexity has an impact on project delivery, project management practices, and project performance.

Research Team 305 is currently studying project complexity in an attempt to define, measure, and assess the impact of complexity on projects. Dr. Stuart Anderson, Texas A&M University, is the Principle Investigator for this study. Dr. Jennifer Shane, Iowa State University, is the Co-Principle Investigator. Their contact information is 979-845-2407, s-anderson5@tamu.edu and 515-294-1703, jsshane@iastate.edu, respectively.

RT 305 requests that the survey be completed for two projects by **October 11th, 2013**. This survey is voluntary and RT 305 will hold the data collected as strictly confidential in line with CII's confidentiality requirements as follows:

- Participating in this survey is voluntary.
- The data provided by participating companies in this survey will be confidential and used only for research purposes.
- The provided data will not be communicated in any form to any organization other than CII authorized academic researchers and designated CII staff members.
- To protect the confidentiality of companies submitting data, only aggregated data will be presented and published.

Survey Instruction

Every project is complex to some degree. Some projects are more complex than others. RT 305 team wants to measure project complexity with respect to this continuum. Please select **two projects** that have been completed within the last three years or are almost complete such that the actual cost and actual schedule duration is known with almost certainty. One project should represent a project with low complexity and one project should represent a project with high complexity. Select the projects based on your perspective of complexity or the perspective of your organization.

1- Please identify whether the project covered in this survey is considered low or high in terms of project complexity (check one box only)?

☐ Low Level of Complexity

☐ High Level of Complexity

This survey has three parts: 1) General Project Description; 2) Project Complexity Metrics; and 3) Best Practice Implementation. The survey questions are constructed so that they can be completed without considerable effort to find information relevant to the project. This assumes that the person completing the survey is very familiar with the subject project. Based on the pilot tests, the survey should take about one to two hour(s) to complete per each survey. The information data in the General Project Description of the survey might be best completed by the project controls lead or business manager.

Key Definitions

Stakeholders: "Person or organization (e.g. customer, sponsor, performing organization, or the public) that is actively involved in the project, or whose interests may be positively or negatively affected by the execution or completion of the project. A stakeholder may also exert influence over the project and its deliverable." (PMBOK, 4th edition, 2008)

Internal Stakeholders: Persons or Organizations within the Owner Company or Joint Venture Company or within the Designer/ Contractor Company that can exert influence on the outcomes of the project.

External Stakeholders: Partners, Governments, Public Agencies, Investors, NGOs that can exert influence on the outcomes of the project.

Interface: A common boundary or interaction between individuals or organizations.

Project Execution: Specific phases included under project execution include detailed engineering/design, procurement of permanent facility equipment and materials, construction, and start up.

Project Execution Plan: A formal document that defines in detail the proposed scope, schedule, budget, systems, methods and processes for executing the project. Some descriptors of a project execution plan include:

- Project schedule and budget
- Resources to be utilized
- Contracting strategy
- Drawing and modeling requirements
- Identification of design deliverables,
- Deliverable review and approval process
- Project controls and reporting plans
- Safety review requirements
- Process for reliability and maintenance inputs

Please proceed to the **Respondent Information** section to start the survey.

Respondent Information

2- **Respondent Data**

Name:____

Company Name: ____

Email Address: ____

Years of Experience in Design and/or Construction: ___________________

Describe Relationship to Project (e.g., project team member, sponsor, etc.)

____

For Owners:

3- **What was your average Annual Capital Project Budget for the past three years?**

☐ 0 to $100 million

☐ $100 million to $1.0 billion

☐ Greater than $1.0 billion

For Contractors

4- **What was your average Annual Contract Revenue for the past three years?**

☐ 0 to $100 million

☐ $100 million to $1.0 billion

☐ Greater than $1.0 billion

I. General Project Description

This section of the survey covers general characteristics about the project, factors that influence project execution (e.g., project delivery approach, project management team, etc.), and project performance information.

5- General Information

Project Name: ____

Project Owner(s): ____

Primary Designer: ____

Primary Contractor: ____

Owner Location (in relation to project location):
City:________________, (State or Province):______________, Country: _____

Project Construction Location:
City:________________, (State or Province):______________, Country: _____

Lead Design Office Location:
City:________________, (State or Province):______________, Country: _____

When was construction completed? ______Year

6- **What was your company's responsibilities for this project?**
Non-owners, please check all that apply.

- ☐ Front End Planning (Pre-construction)
- ☐ Detail Design/Engineering
- ☐ Procurement
- ☐ Construction
- ☐ Commissioning and Startup

COMPLETING THE REMAINING QUESTIONS:

PLEASE ANSWER ALL QUESTIONS BASED ON YOUR COMPANY'S RESPONSIBILITIES ON THIS PROJECT (IF QUESTION DOES NOT APPLY DO NOT ANSWER THE QUESTION OR CHECK THE "NOT APPLICABLE" (N/A) BOX)

7- Which of the following best describes the industry group for this project (Check one group only)?

☐ Heavy Industrial	☐ Light Industrial
- Chemical Manufacturing - Electrical (Generating) - Environmental - Metals Refining/Processing - Mining - Tailing - Natural Gas Processing - Oil/Gas Exploration/Production (well-site) - Oil Refining - Oil Sands Mining/Extraction - Oil Sands SAGD - Oil Sands Upgrading - Cogeneration - Pulp and Paper - Other Heavy Industrial	- Automotive Manufacturing - Consumer Products Manufacturing - Foods - Microelectronics Manufacturing - Office Products Manufacturing - Pharmaceutical Manufacturing - Pharmaceutical Labs - Pharmaceutical Warehouse - Clean Room (Hi-Tech) - Other Light Industrial
☐ Buildings	☐ Infrastructure
- Communications Center - Courthouse - Dormitory/Hotel/Housing/Residential - Embassy - Low rise Office (≤3 floors) - High rise Office (>3 floors) - Hospital - Laboratory - Maintenance Facilities - Movie Theatre	- Airport - Central Utility Plant - Electrical Distribution - Flood Control - Highway (including heavy haul road) - Marine Facilities - Navigation - Process Control - Rail - Tunneling

- Parking Garage	- Water/Wastewater
- Physical Fitness Center	- Telecom, Wide Area Network
- Prison	- Pipeline
- Restaurant/Nightclub	- Tank farms
- Retail Building	- Gas Distribution
- School	- Other Infrastructure
- Warehouse	
- Other Buildings	

8- From the list below, please select the category that best describes the primary nature of this project.

Check one category only

☐ Grass Roots, Greenfield

☐ Brownfield (co-locate)

☐ Modernization, Renovation, Upgrade (Existing Facility)

☐ Addition, Expansion

☐ Environmental

☐ Other ____

Project Cost (Budget amounts include contingency and correspond to funding approved at time of authorization. This is the original baseline budget, and should not be updated to include any changes since change data are collected in the next question)

9- Please complete the following table.

Project Phases	**Baseline Budget**	**Actual Cost**	**Don't Know**
Total Project Cost	$____________	$____________	☐
Detailed Engineering/Design	$____________	$____________	☐
Procurement	$____________	$____________	☐
Construction	$____________	$____________	☐

10- Please complete the following table with respect to Change Orders after authorization.

	Total Number of Change Orders	**During Engineering/Design Phase**	**During Construction Phase**
Owner Driven	Number________; Value: $_______________	Number__________; Value: $_________________	Number: _______; Value: $_______________
Engineering Driven	Number________; Value: $_______________	Number__________; Value: $_________________	Number: _______; Value: $_______________
Contractor Driven	Number________; Value: $_______________	Number__________; Value: $_________________	Number: _______; Value: $_______________

11- Project Schedule

(Schedule corresponds to approved schedule at time of authorization. This is the original baseline schedule and should not be updated to include any changes)

Project Phases	**Baseline Schedule**	**Actual Schedule**	**Don't Know**
Total Project Schedule	______Months	______Months	☐
Detailed Engineering/Design	______Months	______Months	☐
Procurement	______Months	______Months	☐
Construction	______Months	______Months	☐

12- Please select the primary driver of project execution for this project.

(Assume safety is a given on all projects.)

Check only one driver

☐ Cost

☐ Schedule

☐ Performance

13- Was this primary driver communicated to the project team?

☐Yes ☐No

14- What was the primary business driver for this project?

(Assume safety is a given on all projects.)

Check only one driver

☐ Quality

☐ Capacity

☐ Risk

☐ Operability

☐ Environmental

☐ Social

☐ Others______________________

15- Was this driver communicated to the project team?

☐Yes ☐No

16- Did your project contract contain any of the following provisions?

A. Liquidated damages: ☐ Yes ☐No

B. Penalties for late completion: ☐ Yes ☐No

C. Bonuses for on time or early completion: ☐ Yes ☐No

17- Project Delivery Method

Please choose the project delivery method from those listed below that most closely characterizes the delivery method used for this project. If more than one delivery method was used, select the primary method.

Delivery Method		Description
☐	Design-Bid-Build	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
☐	Design-Build (EPC)	Owner contracts with Design-Build (EPC) contractor.
☐	CM at Risk	Owner contracts with designers and construction manager (CM). CM holds the contracts.
☐	Multiple-Primes	Owner contracts separately with designer and multiple prime constructors.
☐	Other	Please describe: ______________________________ ______________________________________

18- Contract Type

Please indicate below the contract types that were used on this project. If you had multiple contractors for a particular function, please answer the questions below in terms of what was most common.

Project Phase	Lump Sum	Cost Reimbursable (including unit price, Guaranteed Maximum Price)
Detailed Engineering/Design	☐	☐
Procurement	☐	☐
Construction	☐	☐

19- Project Scope

Please provide a brief description of the project scope (what was actually being designed / constructed), limit your response to 200 words.

____

____

____

____

20- Project Management Team

Project Management Team (PMT) Size and Experience

Please indicate the peak and average number of participants on the Project Management Team (PMT) during the execution phases of the project. The execution phase of the project is defined to include detail engineering through mechanical completion. To account for individuals responsible for multiple projects, your response should reflect Full Time Equivalents (FTE's). FTE's represent the number of participants and the percent of time each is allocated to the project. For example, if one team member responsible for procurement works ½ time on the project, then the procurement contribution to the FTE measure is 0.5. Likewise, if two project controls specialists work on the team full time, they contribute 2.0 to the FTE.

For owners, the participant count should include owner or owner representative members of the PMT, but only those participants whose labor is accounted by the Owner as part of the cost of the project.

For contractor, participants do not include craft. Typical PMT participants are listed in the table below.

Typical Project Management Team Participants (PMT)

Project Manager	Contract Administrator
Engineering Manager / Project Eng.	Project Controls Engineer (Cost and Schedule)
Business Manager	QA / QC Administrator
Construction Manager	Safety Supervisor
Operations Manager	Operations Manager
Discipline Engineering Leads	Maintenance Manager
Procurement Manager	Consultants

Project Phase	**Estimated PMT Size**		**Estimated Years of Industry Experience**
	Peak	Average	Average
Detailed Engineering/Design	_____FTEs	_____FTEs	_______Years
Procurement	_____FTEs	_____FTEs	_______Years
Construction	_____FTEs	_____FTEs	_______Years

II. Project Complexity Metrics

The following section focuses on indicators of project complexity. Some questions are quantitative (i.e., a number) and some questions are qualitative (i.e., a categorical scale one to seven). Please answer the following questions.

21- What was the influence of this project on the organization's overall success (e.g., profitability, growth, future industry position, public visibility, and internal strategic alignment)?

Limited Contributor to Organization's Success		Moderate Contributor to Organization's Success			Substantial Contributor to Organization's Success	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

22- How many stakeholders had an active role (i.e., monthly input) in decision making on the project?

	Number of Decision makers
Internal stakeholders	Number:______________
External stakeholders	Number:______________

23- How well aligned were these stakeholders?

	Extremely aligned			Moderately aligned			Not at all aligned
	1	2	3	4	5	6	7
Within Internal Stakeholders	☐	☐	☐	☐	☐	☐	☐
Within External Stakeholders	☐	☐	☐	☐	☐	☐	☐

24- How clear were the owner's project goals and objectives at kick-off of project execution?

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

25- What was the impact of required approvals from internal stakeholders on the original project execution plan?

No Impact on Project Execution Plan			Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

26- What was the impact of required approvals from external stakeholders on the original project execution plan?

No Impact on Project Execution Plan			Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

27- What was the impact of required inspection by external (regulatory) agencies/entities on original project execution plan?

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

28- How many executive oversight entities above the project management team had decision-making authority on your project execution plan?
(Please do not include project management team members shown in Table 1)

Number:___________

29- How many financial approval authority thresholds existed on your project?
(Example: the project manager can approve purchase orders up to $100K, the division director can approve purchase orders up to $1M, etc.).

Number:___________

30- What was the maximum number of authority levels above the Project Manager needed for change order approval?

Number:___________

31- How many times on this project did a change order need to go above the Project Manager for approval?

Number:___________

For Owner:

32- How many total sponsoring entities, or joint venture partners with an equity position, existed on this project?

Number:__________

For Contractors:

33- How many total joint-venture partners were there in this project?

Number:__________

34- Approximately how many regular status reports were completed in six months by the project team that are intended for executive management?

Number:__________

35- How many total permits were required?

Permits required by regulatory agencies to legally <u>start site construction work</u> (e.g. government environmental permits, Corps of Engineers permits)

Number:__________

36- What was the difficulty in obtaining permits?

Not at all difficult		Moderately difficult			Extremely difficult	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

37- How many external (regulatory) agencies/entities were required to <u>approve the design</u>?

Number:__________

38- What was the difficulty in obtaining design approvals?

Not at all difficult		Moderately difficult			Extremely difficult	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

39- Please indicate the impact of external agencies on the project execution plan.

Caused No Problems Meeting the Execution Plan		Caused Some Problems Meeting the Execution Plan			Caused Substantial Problems Meeting the Execution Plan	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

40- What was the number of funding phases (gates) from concept to project completion?

Number:_____________

41- Did the project experience any delays or difficulties in securing project funding?

☐ Yes ☐No ☐Don't Know

42- Was the funding process well understood during the Front End Planning phase?

Extremely Clear		Somewhat Ambiguous				Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

43- Did project economics (ability to meet desired rate of return or benefit to cost ratio greater than 1.0) have an impact on the ability to obtain funding?

☐ Yes ☐No

44- Please complete the following table regarding the number of organizations and number of project management leadership team members.
Leadership team member would be the same as those shown in Table 1.

Project Participants	Number of Organizations	Number of Project Management Leadership Team members
Owner	Number:____	Number:_____
Prime Designer/ Engineer Organizations	Number:_____	Number:_____
Prime Contractor Organizations	Number:_____	Number:_____
Subcontractors to Prime Contractor Organizations	Number:_____	NA
Vendors to Prime Contractors or Subcontractors	Number:_____	NA
Permitting Agencies (for construction)	Number:_____	Number:_____

45- How effective was the communication within each participant group?

Project Participants	Effectiveness of communication						
	Extremely Effective			Moderately Effective			Not at all Effective
	1	2	3	4	5	6	7
Owner	☐	☐	☐	☐	☐	☐	☐
Prime Designer/ Engineer Organizations	☐	☐	☐	☐	☐	☐	☐
Prime Contractor Organizations	☐	☐	☐	☐	☐	☐	☐

Subcontractors to Prime Contractor Organizations	☐	☐	☐	☐	☐	☐	☐
Vendors to Prime Contractors or Subcontractors	☐	☐	☐	☐	☐	☐	☐
Permitting Agencies (for construction)	☐	☐	☐	☐	☐	☐	☐

46- Have the owner and the primary designer/engineer worked together before this project?

☐ Yes ☐ No ☐ N/A

If yes, how many times have they worked together? ____________

47- Have the owner and the primary contractor worked together before this project?

☐ Yes ☐ No ☐ N/A

If yes, how many times have they worked together? ____________

48- Have the primary designer/engineer and the primary contractor worked together before this project?

☐ Yes ☐ No ☐ N/A

If yes, how many times have they worked together? ____________

49- Was the process for defining the project's scope understood during the selection of designers and contractors?

Extremely clear		Somewhat Ambiguous				Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

50- What percentage of design was completed prior to project budget authorization?

☐	☐	☐	☐	☐	☐	☐
0-5%	6-14%	15-24%	25-34%	35-44%	45-50%	>50%

51- Did the TIMING of the change orders impact project execution?

No Impact			Some Impact			Highly Impacted (required replanning of project execution plan)
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

52- Did the MAGNITUDE of the change orders impact project execution?

No Impact			Some Impact			Highly Impacted (required replanning of project execution plan)
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

53- Was the scope at the time of completion substantially the same as it was at authorization?

Exactly the Same			Some Changes in Scope			Significant Changes in Scope
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

54- Was the change management process clear to key project team members (see Table 1)?

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

55- Was the change management process followed by key project team members (see Table 1)?

Completely Followed			Somewhat Followed			Not Followed
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

56- How effective was the change management process in controlling cost and schedule growth?

Very Effective			Moderately Effective			Not Effective
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

57- To what extent did Request for Information (RFIs) drive project design changes?

No Impact on Design Changes			Moderate Impact on Design Changes			Caused a High Level of Design Changes
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

58- How remote (distance from highly-populated areas) was the project location?

Not at All Remote			Moderate			Highly Remote
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

59- In general, how populated (rural vs. urban) was the project location?

Low Density (rural environment)			Moderate			High Density (urban environment)
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

60- What level of infrastructure existed at the site to support the project (e.g., infrastructure is existing utilities (water, electricity, natural gas, etc.) and roads)**?**

Available Infrastructure			Limited Infrastructure			No infrastructure/ Greenfield
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

61- What impact did the project location have on the project execution plan?

No Impact on Meeting the Execution Plan			Moderate			Substantial Impact on Meeting the Execution Plan
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

62- Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost. Include all costs for transportation, setting and hooking-up field connections.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

63- How many different countries worked on the detailed engineering/design phase of the project?

Number: ________ ☐Don't Know

64- How many different countries worked on the construction phase of the project (include both field staff and craft labor)?

Number: ________ ☐Don't Know

65- Were project documents translated into a different language?

☐ Yes ☐No

If yes, how many different languages did the official project documents have to be translated into?

Number: ________

66- What were the security requirements for accessing the project construction site?

Low Security Requirements to Enter and Protect the Site		Some Specialized Clear Needed to Enter and Protect the Site			Specialized Clearance to Enter the Site and Protect the Site		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

67- How many execution locations were used on this project?

Project Phases	Number of Locations
Detailed Engineering/Design	Number: _______
Fabrication (bulk materials and equipment)	Number: _______
Construction (including modular assembly yards)	Number: _______

68- What was your company's degree of familiarity with technologies that were involved in each of the following project phases?

Project Phases	Completely Familiar with All Technologies		Somewhat Familiar with Technologies			Not Familiar with Many Technologies	
	1	2	3	4	5	6	7
Detailed Engineering/ Design	☐	☐	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐	☐	☐
Operating facility	☐	☐	☐	☐	☐	☐	☐

69- Compared to a typical project for your company, what was the difficulty in system design and integration on this project?
(System is the combination of several pieces of equipment to perform in a particular manner)

	Difficulty						
	Not at all Difficult			Moderately Difficult			Extremely Difficult
	1	2	3	4	5	6	7
Systems	☐	☐	☐	☐	☐	☐	☐

70- How many new systems were tied into existing systems?

Number:__________ ☐N/A

71- What percentage of project/construction management staff actually worked on the project compared to planned project/construction management staff?

☐	☐	☐	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

72- What percentage of field craft labor was actually on the payroll at project peak compared to the plan at peak?

☐	☐	☐	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

73- What percentage of the time were facility/operations personnel available for the project compared to the plan for the project?

☐	☐	☐	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

74- Was the delivery of permanent facility equipment delayed?

☐ No Delay
☐1 week
☐2-4 weeks
☐5-8 weeks
☐9-12 weeks
☐>12 weeks

75- What was the frequency of workarounds (work activities out of sequence to continue) because materials were not available when needed to support construction?

No Workarounds			Moderate Number of Workarounds			High Number of Workarounds
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

76- Please rate quality issues with field craft labor during project construction.

No Quality Issues			Moderate Level of Quality Issues			Substantial Number of Quality Issues
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

77- Please rate quality issues with bulk materials during project execution.

No Quality Issue			Moderate Level of Quality Issues			Substantial Number of Quality Issues
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

78- Please rate quality issues with the permanent (tagged) equipment during project execution.

No Quality Issue			Moderate Level of Quality Issues			Substantial Number of Quality Issues
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

79- What was the percentage of craft labor turnover?

☐	☐	☐	☐	☐	☐
0-9%	10-19%	20-29%	30-39%	40-49%	>50%

80- What was the percentage of project/construction management staff turnover?

☐	☐	☐	☐	☐	☐	☐
0-4%	5-9%	10-14%	15-19%	20-24%	24-28%	>28%

81- What percentage of Bulk Materials were sourced within the project country? (% of Bulk Material Cost)

☐	☐	☐	☐	☐	☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

82- What percentage of Permanent (Tagged) Equipment was sourced within the project country? (% of Tagged Equipment Cost)

☐	☐	☐	☐	☐	☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

83- What percentage of craft labor was sourced locally? (within 100 mile radius of Job Site)

☐	☐	☐	☐	☐	☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

84- What percentage of the scope was involved with the reuse of existing installed equipment?

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

85- Degree of additional quality requirements?

Construction tolerances exceeded standard practice (industry standard or accepted standard) for the type of project.

Tolerances consistent with Standard Practice			Some Deviations from Standard Practice			Many Tight Tolerances Relative to Standard Practice
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

86- Degree of additional quality requirements?

Specifications for materials exceeded standard practice for the type of project.

No Deviations from Standard Practice			Some Deviations from Standard Practice			Many Deviations from Standard Practice
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

87- At project authorization how did the cost and schedule targets compare to industry/internal benchmarks?

	Target						
	Lower than industry standard benchmark			At industry standard			Very aggressive
	1	2	3	4	5	6	7
Cost target at authorization	☐	☐	☐	☐	☐	☐	☐
Schedule target at authorization	☐	☐	☐	☐	☐	☐	☐

88- What percentage of engineering/design was planned to be completed at the start of construction?

__________ % Engineering/Design

89- What was the actual percentage of engineering/design completed at the start of construction?

__________ % Engineering/Design

90- Please identify any other factors or attributes on this project that contributed to its complexity that may not have been covered in the survey.

____

____

____

Project Complexity

91- Please rate the overall complexity of this project on the scale below:

Very Low Complexity		Moderate Complexity				Very High Complexity
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

92- How does this project's overall complexity compare to the complexity of other projects that your company executes?

Lower Level of Complexity Compared to Other Projects		Same Level of Complexity Compared to Other Projects				Higher Level of Complexity Compared to Other Projects
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

III. Best Practice Implementation

The intent of this section is to assess relationships between Project Complexity Metrics and their impact on implementation of select industry Best Practices. Each Best Practice is defined by one or three sentences taken from IR 166-3 V2.0, CII Best Practice Guide: Improving Project Performance. The scale is seven-point categorical with 1 being "Not Implemented at All" and 7 "Very Extensively Implemented."

93- Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

Based on the definition, to what extent was Constructability implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

94- Team Building

Team building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members' problem-solving skills.

Based on the definition, to what extent was Team Building implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

95- Alignment

The purpose of alignment is to focus the energy and talent of the team on a common purpose by developing a common vision of project success and placing personal goals subservient to overall project success. Alignment is defined as "The condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project priorities."

Based on the definition, to what extent was an Alignment process implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

96- Partnering

Companies may partner in order to achieve specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is built on trust, dedication to common goals and the understanding of each other's individual expectations and values. Partnering may be a long term commitment between two or more organizations, as in an alliance, or it may be applied to a shorter period of time, such as the duration of a project.

Based on the definition, to what extent was Partnering implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

97- Front End Planning

Front end planning (FEP) is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. This process provides a comprehensive framework for detailed project planning. FEP is a gated process that focuses on feasibility, concept and detailed scope phases of project development.

Based on the definition, to what extent was a Front End Planning process implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

98- Change Management

Change management is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes.

Based on the definition, to what extent was Change Management implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

99- Material Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management system combines and integrates takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

Based on the definition, to what extent was Materials Management implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

100-Zero Accident Techniques (i.e., Safety)

Zero accident techniques include the site-specific safety programs and implementation, auditing, and incentive efforts to create a project environment and a level of training that embraces the mindset that all accidents are preventable and that zero accidents is an obtainable goal.

Based on the definition, to what extent was Zero Accident Techniques implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

101- Planning for Start Up

Startup is defined as the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Critical steps within the startup phase include systems turnover, check-out of systems, commissioning of systems, introduction of feed stocks, and performance testing.

Based on the definition, to what extent was planning for Start Up implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

102- Dispute Prevention and Resolution

Dispute resolution techniques include the use of a Disputes Review Board as an alternate dispute resolution process to eliminate the necessity to take disputes to litigation. The Dispute Review Board technique provides a process for addressing disputes in their early stages before the dispute affects the progress of the work, creates adversarial positions, and leads to litigation.

Based on the definition, to what extent was Dispute Review implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

103- Quality Management

Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects.

Based on the definition, to what extent was Quality Management implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

104- Lessons Learned

A lesson learned is knowledge gained from experience, successful or otherwise, for the purpose of improving future performance. Examples are: a lesson that is incorporated in a work process; a tip to enhance future performance; a solution to a problem or a corrective action; a lesson that is incorporated into a policy or a guideline; an adverse situation to avoid; and collective knowledge of "soon to retire" employees. Lessons learned programs (LLP) involve the people, processes, and tools that support an organization's collection, analysis, and implementation of validated lessons learned.

Based on the definition, to what extent was a Lessons Learned Process implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

105- Project Risk Assessment

The process to identify, assess, and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

Based on the definition to what extent was a Risk Assessment implemented on this project?

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

106- Are you willing to participate in the follow-up Interview?

☐**Yes** ☐**No**

Please send your completed survey to Dr. Stuart Anderson, Texas A&M University, or Dr. Jennifer Shane, Iowa State University, at s-anderson5@tamu.edu or jsshane@iastate.edu.

THANK YOU FOR PARTICIPATING IN THIS STUDY

APPENDIX C

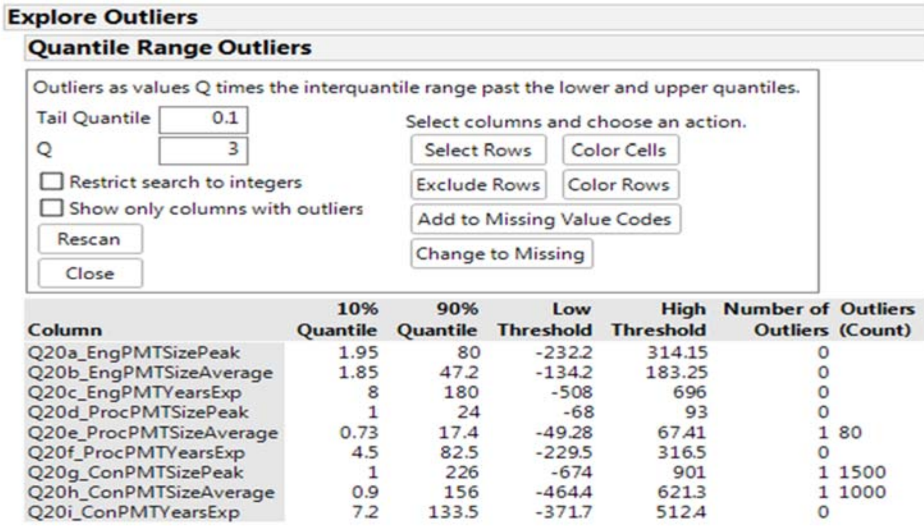
USE OF JMP STATISTICAL SOFTWARE FPR DATA ANALYSIS AND MODEL DEVELOPMENT

1. Applicability of JMP

JMP (originally stood for John's Macintosh Program) is a statistical software initially created in 1989 by SAS Institute (Statistical Analysis System) to empower scientists and engineers to explore data visually. This is the tool that can be used for scientists, engineers and any other data explorers in almost every industry and government sector. JMP combines interactive statistics with dynamic and visual graphics, in memory and on the desktop. Because everything is linked – the graphics, statistics, and data – JMP can improve the chance of making breakthrough discoveries in any data. For the analysis purpose, JMP can fully perform the data analyses to meet the research requirements including data cleanup, basic data analysis, and statistical modeling.

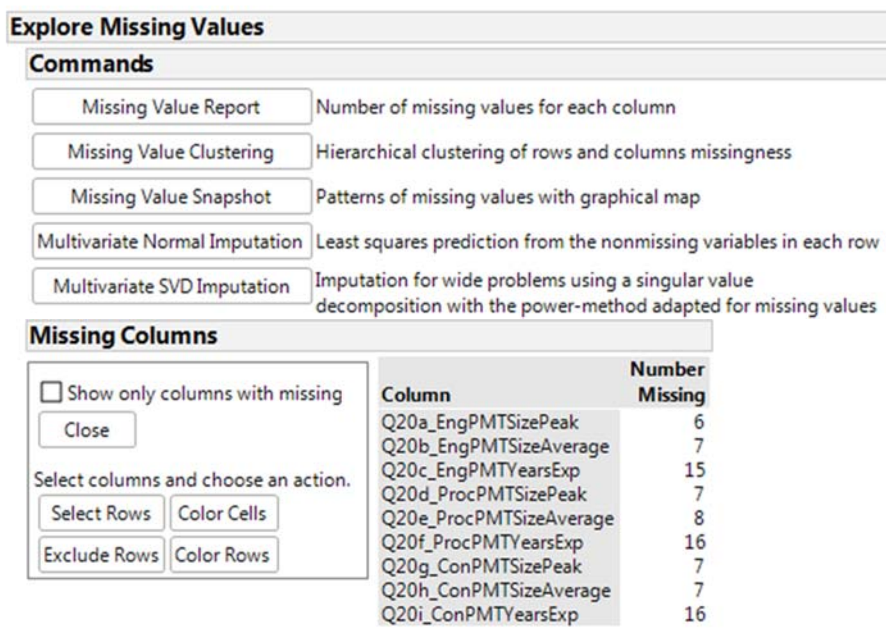
2. Data Cleanup

JMP is highly valued in preparing data for analysis to make data preparation easier, faster, and more reliable. In case the data cannot be cleaned up directly, JMP includes methods to minimize the impact of data problems on the analysis, often eliminating the need (and effort required) to make the data pristine. Before being analyzed, the data needs to be checked to make sure it is clean, that the values are consistent and encoded well. JMP offers many ways to do this. One of the best approaches is with the Distribution platform. For example, if outliers are identified, JMP simply grab them, and they are selected in the table. Figure C.1 and Figure C.2 provide examples of using JMP for screening the data for data cleanup purpose.



Column	10% Quantile	90% Quantile	Low Threshold	High Threshold	Number of Outliers	Outliers (Count)
Q20a_EngPMTSizePeak	1.95	80	-232.2	314.15	0	
Q20b_EngPMTSizeAverage	1.85	47.2	-134.2	183.25	0	
Q20c_EngPMTYearsExp	8	180	-508	696	0	
Q20d_ProcPMTSizePeak	1	24	-68	93	0	
Q20e_ProcPMTSizeAverage	0.73	17.4	-49.28	67.41	1	80
Q20f_ProcPMTYearsExp	4.5	82.5	-229.5	316.5	0	
Q20g_ConPMTSizePeak	1	226	-674	901	1	1500
Q20h_ConPMTSizeAverage	0.9	156	-464.4	621.3	1	1000
Q20i_ConPMTYearsExp	7.2	133.5	-371.7	512.4	0	

Figure C.1 Use of JMP for Outlier Screening



Column	Number Missing
Q20a_EngPMTSizePeak	6
Q20b_EngPMTSizeAverage	7
Q20c_EngPMTYearsExp	15
Q20d_ProcPMTSizePeak	7
Q20e_ProcPMTSizeAverage	8
Q20f_ProcPMTYearsExp	16
Q20g_ConPMTSizePeak	7
Q20h_ConPMTSizeAverage	7
Q20i_ConPMTYearsExp	16

Figure C.2 Use of JMP for Missing Data Screening

The following data cleanup tools are included in JMP:

- Screening for outliers
- Screening for entry errors, error codes or missing values/missing value codes that might not have been accounted for in the data
- Data property cleanup
- Binning continuous data into discrete categories

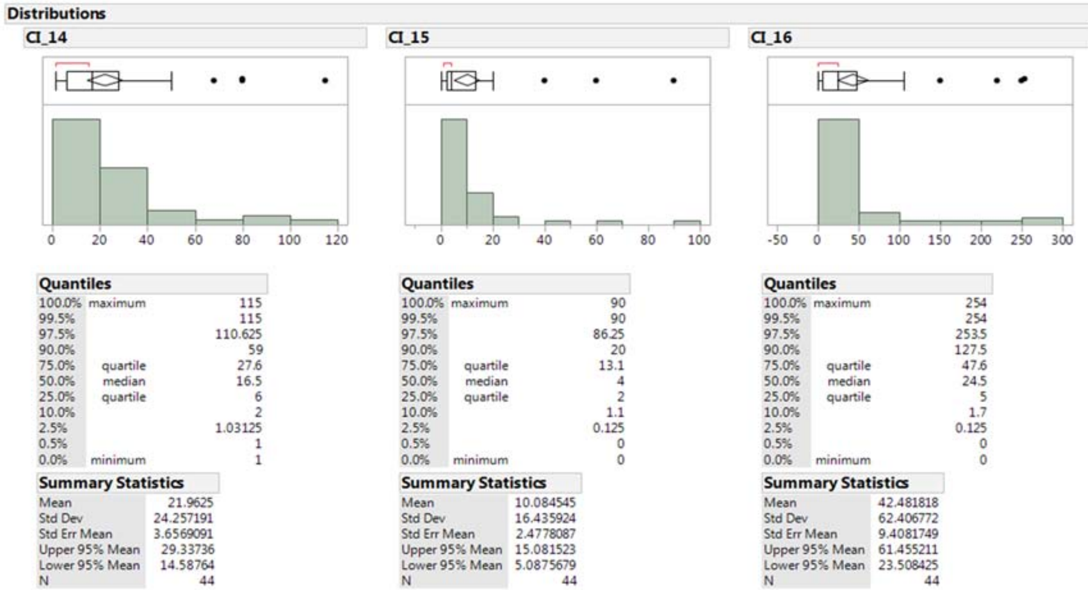
3. Basic Data Analysis

Employing basic statistical tools for visual analysis is often the best way to communicate the results. And frequently, the first step in a statistical data inquiry consists of investigating variables one at a time, a process known as univariate analysis. In JMP, after identifying the interested variables, the Distribution platform automatically provides graphs and statistics based on the variables defined by the modeling type. The distribution platform can quickly generate histograms, summary statistics, box plots and quantiles for continuous data, capability analysis, distribution fitting and frequencies for nominal or ordinal values.

Key capabilities in JMP for basic statistical analysis include:

- Histograms, box plots
- Descriptive statistics
- One- and two-sample t-tests, ANOVA, regression, nonparametric test
- Distribution fitting
- Fitting splines and curves to data
- Statistical calculators and simulators; power and sample size calculation

Figure C.3 provides an example of basic data analysis from JMP including histograms, box plots, and descriptive statistics for continuous data. Figure C.4 shows the example of basic data analysis including distribution and frequencies for ordinal data.



CI_14 — Quantiles

100.0%	maximum	115
99.5%		115
97.5%		110.625
90.0%		59
75.0%	quartile	27.6
50.0%	median	16.5
25.0%	quartile	6
10.0%		2
2.5%		1.03125
0.5%		1
0.0%	minimum	1

CI_14 — Summary Statistics

Mean	21.9625
Std Dev	24.257191
Std Err Mean	3.6569091
Upper 95% Mean	29.33736
Lower 95% Mean	14.58764
N	44

CI_15 — Quantiles

100.0%	maximum	90
99.5%		90
97.5%		86.25
90.0%		20
75.0%	quartile	13.1
50.0%	median	4
25.0%	quartile	2
10.0%		1.1
2.5%		0.125
0.5%		0
0.0%	minimum	0

CI_15 — Summary Statistics

Mean	10.084545
Std Dev	16.435924
Std Err Mean	2.4778087
Upper 95% Mean	15.081523
Lower 95% Mean	5.0875679
N	44

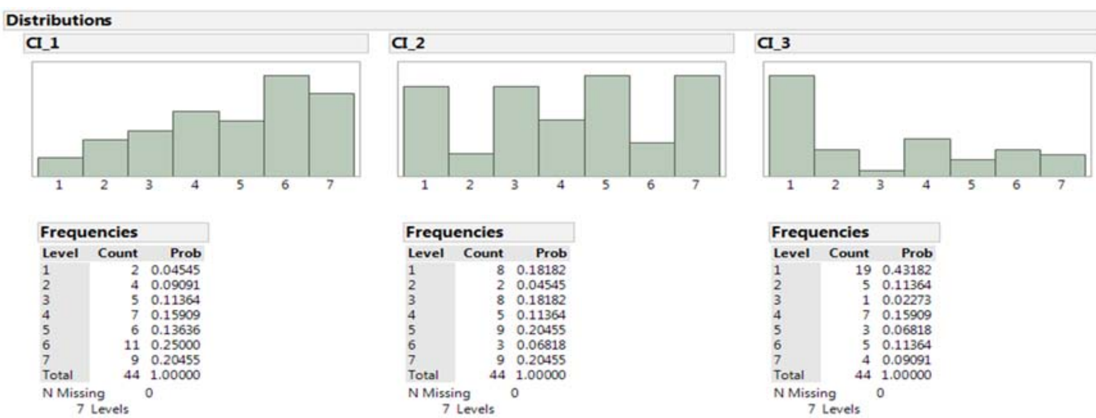
CI_16 — Quantiles

100.0%	maximum	254
99.5%		254
97.5%		253.5
90.0%		127.5
75.0%	quartile	47.6
50.0%	median	24.5
25.0%	quartile	5
10.0%		1.7
2.5%		0.125
0.5%		0
0.0%	minimum	0

CI_16 — Summary Statistics

Mean	42.481818
Std Dev	62.406772
Std Err Mean	9.4081749
Upper 95% Mean	61.455211
Lower 95% Mean	23.508425
N	44

Figure C.3 Distribution Analysis for Continuous Data



CI_1 — Frequencies

Level	Count	Prob
1	2	0.04545
2	4	0.09091
3	5	0.11364
4	7	0.15909
5	6	0.13636
6	11	0.25000
7	9	0.20455
Total	44	1.00000

N Missing 0
7 Levels

CI_2 — Frequencies

Level	Count	Prob
1	8	0.18182
2	2	0.04545
3	8	0.18182
4	5	0.11364
5	9	0.20455
6	3	0.06818
7	9	0.20455
Total	44	1.00000

N Missing 0
7 Levels

CI_3 — Frequencies

Level	Count	Prob
1	19	0.43182
2	5	0.11364
3	1	0.02273
4	7	0.15909
5	3	0.06818
6	5	0.11364
7	4	0.09091
Total	44	1.00000

N Missing 0
7 Levels

Figure C.4 Distribution Analysis for Ordinal Data

4. Statistical Modeling

Building useful models is part science and part art, and JMP includes an array of statistical platforms to help in building useful models based on the collected data set. With methods for revealing relationships among variables in a process, JMP allows not only making predictions but also identifying settings for factors that yield the best performance. JMP includes a variety of ways to fit linear and nonlinear models, and these diverse fitting tools help in making correct decisions, whatever relationships the data shows.

The heart of the JMP model-fitting toolkit is the Fit Model platform. Fit Model lets modelers construct model terms and select from different methods, including standard least squares fitting, nominal/ordinal logistic fitting, stepwise, or all possible models depending on the type of data measurement units. Figure C.5 presents JMP fit model platform used to develop the target model.

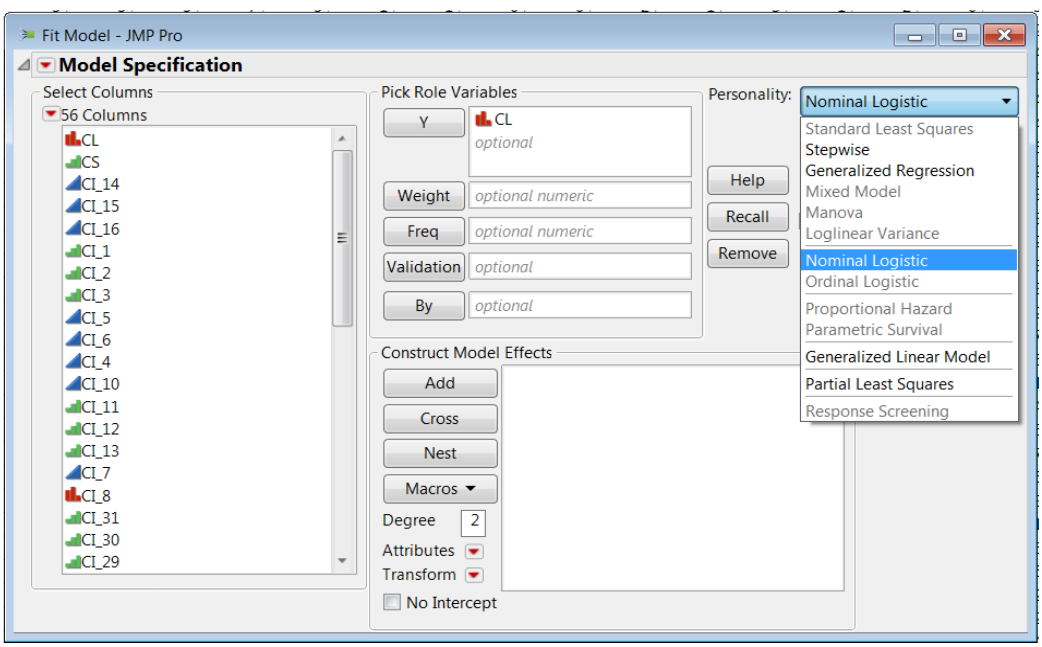
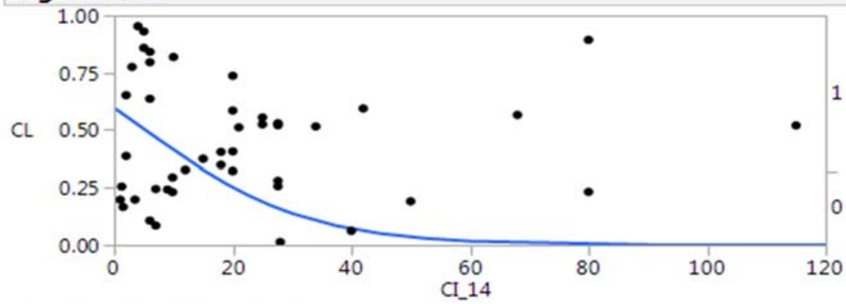


Figure C.5 JMP Fit Model Platform for Specifying the Target Model

The Fit Y by X platform is intended for modeling dependencies between a single input and a single response or outcome. This platform supports simple linear regression, logistic regression, ANOVA, ANOM and contingency analyses. When the target model is specified from the fit model platform, JMP results in the model fit that includes model plots, model parameters, relevant model tests, and other necessary model information. Figure C.6 shows an example of JMP model fit result.

Nominal Logistic Fit for CL

Logistic Plot



Converged in Gradient, 6 iterations

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	4.225679	1	8.451359	0.0036*
Full	23.295940			
Reduced	27.521620			

RSquare (U)	0.1535
AICc	50.8846
BIC	54.1603
Observations (or Sum Wgts)	44

Measure	Training	Definition
Entropy RSquare	0.1535	1-Loglike(model)/Loglike(0)
Generalized RSquare	0.2448	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.5295	∑ -Log(ρ[j])/n
RMSE	0.4208	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.3586	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.3182	∑ (ρ[j]≠ρMax)/n
N	44	n

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	26	19.660305	39.32061
Saturated	27	3.635635	Prob>ChiSq
Fitted	1	23.295940	0.0454*

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	0.39171203	0.546048	0.51	0.4732
CI_14	-0.0740316	0.0346823	4.56	0.0328*

For log odds of 0/1

Effect Likelihood Ratio Tests

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
CI_14	1	1	8.45135897	0.0036*

Figure C.6 Model Fit and Related Model Tests

The JMP nonlinear platform allows fitting a large number of models to the data. The software's built-in library makes it particularly simple to fit popular bioassay and pharmacokinetic models. By defining appropriate formula columns, any nonlinear model can be virtually fitted.

In addition to the model features as shown in Figure C.6, JMP model fit also results in the corresponding model function. Figure C.7 presents a model equation generated from model fit process using JMP

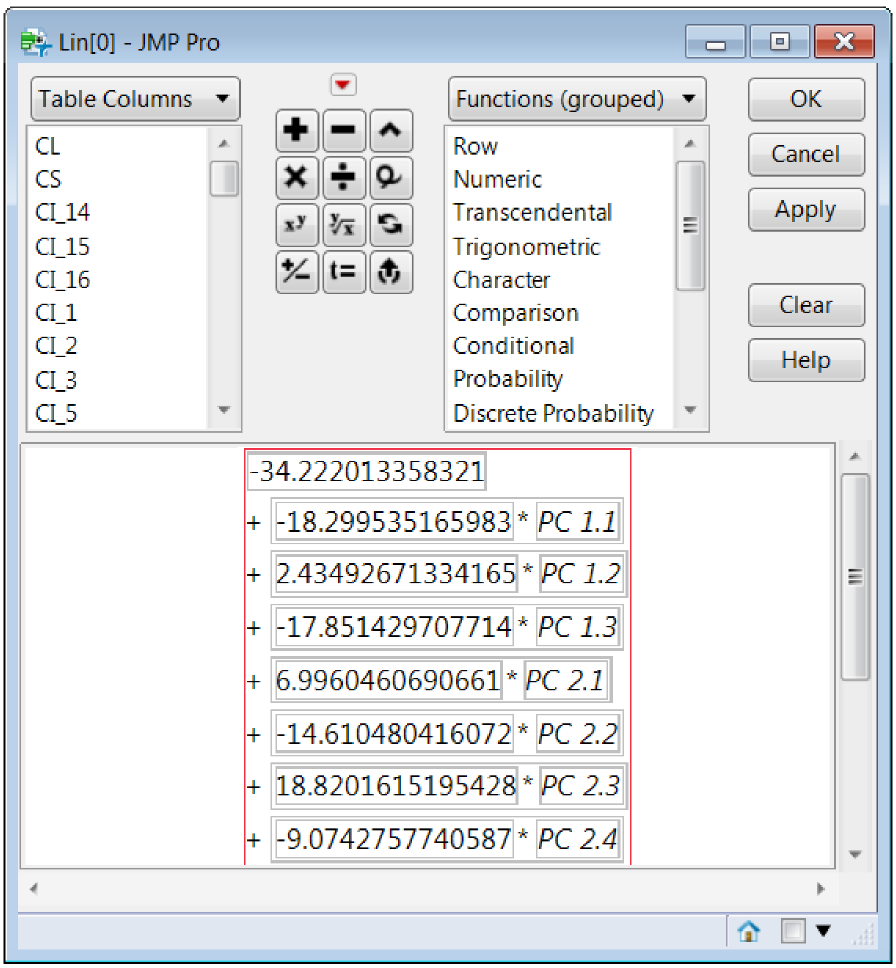


Figure C.7 Corresponding Model Equation

JMP also fits mixed models with random effects and includes advanced multivariate modeling techniques: principal components, multiple correspondence analysis, partial least squares, cluster, item analysis, partition models and more. One significant advantage of JMP used for this research is the advanced multivariate technique of Principal Component Analysis. This JMP feature and the analysis process are presented in Chapter 5 of this research. Figure C.8 shows an example of the result of principal component analysis using JMP multivariate modeling techniques.

Renumbered PCA Output - Principal Components - JMP Pro

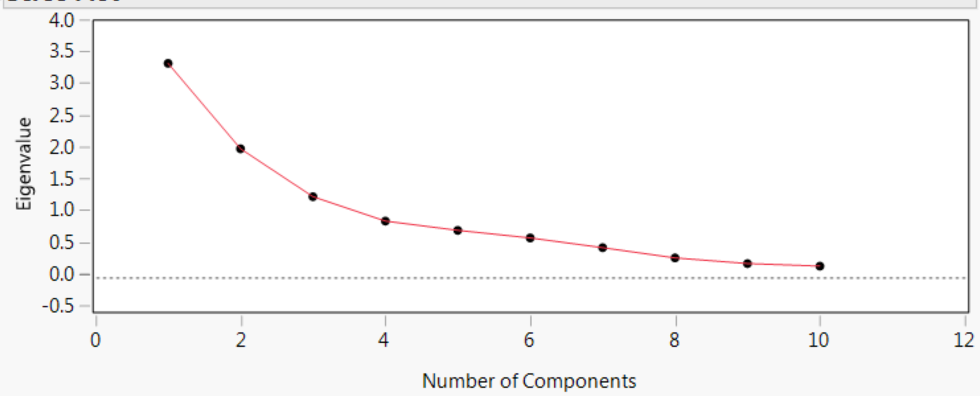
Principal Components: on Correlations

Summary Plots

Eigenvalues

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	3.3626	33.626		33.626
2	2.0171	20.171		53.797
3	1.2625	12.625		66.422
4	0.8784	8.784		75.206
5	0.7318	7.318		82.524
6	0.6125	6.125		88.649
7	0.4591	4.591		93.240
8	0.2984	2.984		96.224
9	0.2092	2.092		98.315
10	0.1685	1.685		100.000

Scree Plot



Loading Matrix

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10
CI_1	0.30480	-0.01008	0.66757	0.52763	0.25444	-0.32029	0.09057	-0.07728	0.00727	-0.03742
CI_2	0.44290	-0.28432	0.61754	-0.10943	0.06825	0.54750	0.04667	0.14056	-0.02226	0.05317
CI_3	0.84504	-0.00761	0.06989	-0.25702	-0.21985	0.01280	0.13129	-0.28292	0.25289	-0.07191
CI_10	0.47166	-0.05209	-0.39645	0.67351	-0.18420	0.31199	-0.16680	-0.03385	0.02474	-0.05649
CI_11	0.77733	0.00569	-0.33056	0.07785	-0.05862	-0.08442	0.47485	0.09802	-0.12846	0.13505
CI_12	0.85554	0.00448	-0.01117	-0.11704	0.09314	-0.14803	-0.39447	-0.08404	-0.06880	0.23711
CI_13	0.86316	-0.03735	-0.12028	-0.16920	0.14726	-0.16678	-0.12997	0.30040	0.00897	-0.23184
CI_14	0.23510	0.88517	0.09453	-0.10715	0.02084	0.14645	0.00059	-0.18321	-0.26267	-0.12785
CI_15	-0.01790	0.79661	-0.19365	0.05169	0.49258	0.14570	0.05047	0.06786	0.21746	0.08134
CI_16	-0.01375	0.71679	0.32118	0.07640	-0.55069	-0.11439	-0.05584	0.21543	0.08037	0.06855

Figure C.8 Principal Components Multivariate for the Model Basis

APPENDIX D

SURVEY RESPONSE RESULT

RT 305 Measuring Project Complexity and Its Impact

Survey Questionnaire

September 17, 2013 Revision 6 – Added Project Attribute Buckets

Survey Result for Low Complexity vs. High Complexity Projects

Table of Contents

Background

Complexity is a term often used in the construction industry to describe a project. However, there appears to be limited understanding of project complexity, and no standard definition of what it means or how to measure it. Intuitively, the construction industry knows that project complexity has an impact on project delivery, project management practices, and project performance.

Research Team 305 is currently studying project complexity in an attempt to define, measure, and assess the impact of complexity on projects. Dr. Stuart Anderson, Texas A&M University, is the Principle Investigator for this study. Dr. Jennifer Shane, Iowa State University, is the Co-Principle Investigator. Their contact information is 979-845-2407, s-anderson5@tamu.edu and 515-294-1703, jsshane@iastate.edu, respectively.

RT 305 requests that the survey be completed for two projects by **October 14, 2013**. This survey is voluntary and RT 305 will hold the data collected as strictly confidential in line with CII's confidentiality requirements as follows:

- Participating in this survey is voluntary.
- The data provided by participating companies in this survey will be confidential and used only for research purposes.
- The provided data will not be communicated in any form to any organization other than CII authorized academic researchers and designated CII staff members.
- To protect the confidentiality of companies submitting data, only aggregated data will be presented and published.

Survey Instruction

Every project is complex to some degree. Some projects are more complex than others. RT 305 team wants to measure project complexity with respect to this continuum. Please select **two projects** that have been completed within the last three years or are almost complete such that the actual cost and actual schedule duration is known with almost certainty. One project should represent a project with low complexity and one project should represent a project with high complexity. Select the projects based on your perspective of complexity or the perspective of your organization.

1- **Please identify whether the project covered in this survey is considered low or high in terms of project complexity (check one box only)?**

☐ Low Level of Complexity **14 Responses**
☐ High Level of Complexity **30 Responses**

This survey has three parts: 1) General Project Description; 2) Project Complexity Metrics; and 3) Best Practice Implementation. Most survey questions are constructed so that they can be completed without considerable effort to find information relevant to the project. This assumes that the person completing the survey is very familiar with the subject project. Based on the pilot tests, the survey should take about one to two hours to complete per each survey depending on the availability of some project data. The quantitative data in the General Project Description of the survey might be best completed by the project controls lead or business manager.

Key Definitions

Stakeholders: "Person or organization (e.g. customer, sponsor, performing organization, or the public) that is actively involved in the project, or whose interests may be positively or negatively affected by the execution or completion of the project. A stakeholder may also exert influence over the project and its deliverable." (PMBOK, 4th edition, 2008)

Internal Stakeholders: Persons or Organizations within the Owner Company or Joint Venture Company or within the Designer/ Contractor Company that can exert influence on the outcomes of the project.

External Stakeholders: Partners, Governments, Public Agencies, Investors, NGOs that can exert influence on the outcomes of the project.

Interface: A common boundary or interaction between individuals or organizations.

Project Execution: Specific phases included under project execution include detailed engineering/design, procurement of permanent facility equipment and materials, construction, and start up.

Project Execution Plan: A formal document that defines in detail the proposed scope, schedule, budget, systems, methods and processes for executing the project. Some descriptors of a project execution plan include:

- Project schedule and budget
- Resources to be utilized
- Contracting strategy
- Drawing and modeling requirements

- Identification of design deliverables,
- Deliverable review and approval process
- Project controls and reporting plans
- Safety review requirements
- Process for reliability and maintenance inputs

Please proceed to the **Respondent Information** section to start the survey.

Respondent Information

2- Respondent Data

Name:____

Company Name: _______________________________________

Email Address: ____

Years of Experience in Design and/or Construction: _**23.38 vs. 24.5**________

Describe Relationship to Project (e.g., project team member, sponsor, etc.)

____

For Owners:

3- What was your average Annual Capital Project Budget for the past three years? 11 responses 23 responses

☐0 to $100 million **(1/11)** **(5/23)**

☐$100 million to $1.0 billion **(8/11)** **(9/23)**

☐Greater than $1.0 billion **(2/11)** **(9/23)**

For Contractors

4- What was your average Annual Contract Revenue for the past three years?

15 responses 9 responses

☐0 to $100 million **2/5** **1/9**

☐$100 million to $1.0 billion **2/5** **1/9**

☐Greater than $1.0 billion **1/5** **7/9**

I. General Project Description

This section of the survey covers general characteristics about the project, factors that influence project execution (e.g., project delivery approach, project management team, etc.), and project performance information.

5- General Information

Project Name: ____

Project Owner(s): ____

Primary Designer: ____

Primary Contractor: ____

Owner Location (in relation to project location):
City:______________, (State or Province):____________, Country: ___

Project Construction Location:
City:______________, (State or Province):____________, Country: ___

Lead Design Office Location:
City:______________, (State or Province):____________, Country: ___

When was construction completed? ______Year

6- What was your company's responsibilities for this project?

Non-owners, please check all that apply.

14 responses **30 responses**

- ☐ Front End Planning (Pre-construction) **6/14** **24/30**
- ☐ Detail Design/Engineering **6/14** **20/30**
- ☐ Procurement **5/14** **21/30**
- ☐ Construction **3/14** **22/30**
- ☐ Commissioning and Startup **7/14** **23/30**

COMPLETING THE REMAINING QUESTIONS:

PLEASE ANSWER ALL QUESTIONS BASED ON YOUR COMPANY'S RESPONSIBILITIES ON THIS PROJECT (IF QUESTION DOES NOT APPLY DO NOT ANSWER THE QUESTION OR CHECK THE "NOT APPLICABLE" (N/A) BOX)

7- Which of the following best describes the industry group for this project (Check one group only)? 13 responses 30 responses

☐ Heavy Industrial **9/13** **21/30**	☐ Light Industrial **1/13** **2/30**
- Chemical Manufacturing - Electrical (Generating) - Environmental - Metals Refining/Processing - Mining - Tailing - Natural Gas Processing - Oil/Gas Exploration/Production (well-site) - Oil Refining - Oil Sands Mining/Extraction - Oil Sands SAGD - Oil Sands Upgrading - Cogeneration - Pulp and Paper - Other Heavy Industrial	- Automotive Manufacturing - Consumer Products Manufacturing - Foods - Microelectronics Manufacturing - Office Products Manufacturing - Pharmaceutical Manufacturing - Pharmaceutical Labs - Pharmaceutical Warehouse - Clean Room (Hi-Tech) - Other Light Industrial
☐ Buildings **2/13** **5/30**	☐ Infrastructure **1/13** **2/30**
- Communications Center - Courthouse - Dormitory/Hotel/Housing/Residential - Embassy - Low rise Office (≤3 floors) - High rise Office (>3 floors) - Hospital - Laboratory - Maintenance Facilities - Movie Theatre	- Airport - Central Utility Plant - Electrical Distribution - Flood Control - Highway (including heavy haul road) - Marine Facilities - Navigation - Process Control - Rail - Tunneling

- Parking Garage - Physical Fitness Center - Prison - Restaurant/Nightclub - Retail Building - School - Warehouse - Other Buildings	- Water/Wastewater - Telecom, Wide Area Network - Pipeline - Tank farms - Gas Distribution - Other Infrastructure

8- From the list below, please select the category that best describes the primary nature of this project. **12 responses** **30 responses**

Check one category only

☐ Grass Roots, Greenfield **2/12** **8/30**

☐ Brownfield (co-locate) **2/12** **4/30**

☐ Modernization, Renovation, Upgrade (Existing Facility) **7/12** **9/30**

☐ Addition, Expansion **1/12** **8/30**

☐ Environmental **0** **0**

☐ Other ____**1** (Primarily Greenfield, some Brownfield to tie into existing facilities.)__

1 (Energy Reductions/Modernization/Upgrade.)

Project Cost (Budget amounts include contingency and correspond to funding approved at time of authorization. This is the original baseline budget, and should not be updated to include any changes since change data are collected in the next question)

9- Please complete the following table. **13 responses** **23 responses**

Project Phases	**Baseline Budget**	**Actual Cost**	**Don't Know**
Total Project Cost	$129,722,995 $366,030,240	$140,034,172 $405,623,480	☐
Detailed Engineering/Design	$7,543,131 $46,408,498	$8,084,371 $51,740,300	☐
Procurement	$9,184,755 $207,692,543	$9,118,685 $221,488,706	☐
Construction	$68,357,055 $174,342,124	$84,074,730 $193,204,009	☐

10- Please complete the following table with respect to Change Orders after authorization. 10 responses 21 responses

	Total Number of Change Orders	During Engineering/Design Phase	During Construction Phase
Owner Driven	Number: 6 30 Value: $307,189 $16,016,055	Number: 3 9 Value: $67,223 $14,423,722	Number: 3 21 Value: $239,966 $1,592,333
Engineering Driven	Number: 3 43 Value: $46,578 $1,644,689	Number: 1 12 Value: $27,703 $857,932	Number: 2 31 Value: $18,875 $806,757
Contractor Driven	Number: 2 35 Value: $13,875 $788,733	Number: 0 1 Value: $0 $22,988	Number: 2 34 Value: $13,875 $765,745

11- Project Schedule (13 responses) (27 responses)

(Schedule corresponds to approved schedule at time of authorization. This is the original baseline schedule and should not be updated to include any changes)

Project Phases	**Baseline Schedule**	**Actual Schedule**	**Don't Know**
Total Project Schedule	23 Months 30 Months	28 Months 33 Months	☐
Detailed Engineering/Design	11 Months 9 Months	15 Months 13 Months	☐
Procurement	9 Months 11 Months	10 Months 14 Months	☐
Construction	10 Months 18 Months	13 Months 20 Months	☐

12- Please select the primary driver of project execution for this project.

(Assume safety is a given on all projects.)
Check only one driver

13 Responses 30 Responses

☐Cost 3/13 5/30

☐Schedule 6/13 20/30

☐Performance 4/13 5/30

13- Was this primary driver communicated to the project team?

	13 Responses	30 Responses
☐ Yes	13/13	29/30
☐ No	0/13	1/30

14- What was the primary business driver for this project?

(Assume safety is a given on all projects.)

Check only one driver

	11 Responses	30 Responses
☐ Quality	01/11	5/30
☐ Capacity	2/11	12/30
☐ Risk	2/11	1/30
☐ Operability	4/11	7/30
☐ Environmental	2/11	3/30
☐ Social	0/11	0/30
☐ Others___	0	2/30

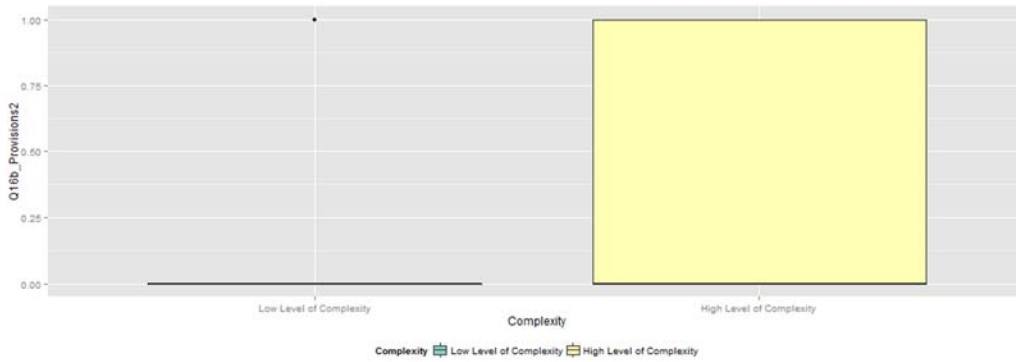
15- Was this driver communicated to the project team?

	13 Responses	30 Responses
☐ Yes	13/13	30/30
☐ No	0/13	0/30

16- Did your project contract contain any of the following provisions?

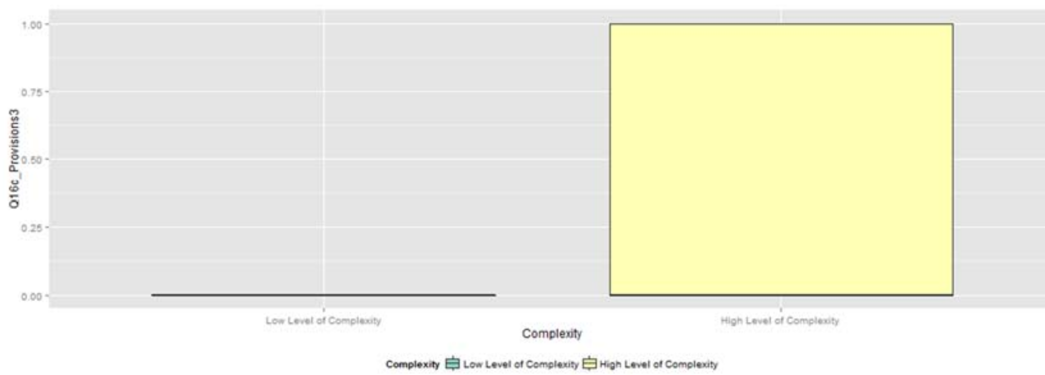
	13 Responses	27 Responses		
A. Liquidated damages:	☐ Yes 5/13	16/27	☐ No 8/13	11/27
B. Penalties for late completion:	☐ Yes 2/13	13/27	☐ No 11/13	14/27

The p-value for a test of difference in the means is 0.0288



C. Bonuses for on time or early completion: ☐ Yes 0/13 9/27 ☐No13/13 18/27

The p-value for a test of difference in the means is 0.0013



17- Project Delivery Method

Please choose the project delivery method from those listed below that most closely characterizes the delivery method used for this project. If more than one delivery method was used, select the primary method.

13 Responses **30 Responses**

Delivery Method		**Description**
☐	Design-Bid-Build 5/13 9/30	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
☐	Design-Build (EPC) 3/13 12/30	Owner contracts with Design-Build (EPC) contractor.
☐	CM at Risk 0/13 2/30	Owner contracts with designers and construction manager (CM). CM holds the contracts.

☐	Multiple-Primes 4/13 7/30	Owner contracts separately with designer and multiple prime constructors.
☐	Other 1/13 0/30	Please describe: **Design build using different alliance contractors for EP, and C**

18- Contract Type

Please indicate below the contract types that were used on this project. If you had multiple contractors for a particular function, please answer the questions below in terms of what was most common.

Project Phase	Lump Sum	Cost Reimbursable (including unit price, Guaranteed Maximum Price)
Detailed Engineering/Design **11 Responses 29 Responses**	**4/11☐13/29**	**7/11☐16/29**
Procurement **11 Responses 27 Responses**	**4/11☐16/27**	**7/11☐11/27**
Construction **12 Responses 30 Responses**	**5/12☐14/30**	**7/12☐16/30**

19- Project Scope

Please provide a brief description of the project scope (what was actually being designed / constructed), limit your response to 200 words.

____

____

____

____

20- Project Management Team

Project Management Team (PMT) Size and Experience

Please indicate the peak and average number of participants on the Project Management Team (PMT) during the execution phases of the project. The execution phase of the project is defined to include detail engineering through mechanical completion. To account for individuals responsible for multiple projects, your response should reflect Full Time Equivalents (FTE's). FTE's represent the number of participants and the percent of time each is allocated to the project. For example, if one team member responsible for procurement works ½ time on the

project, then the procurement contribution to the FTE measure is 0.5. Likewise, if two project controls specialists work on the team full time, they contribute 2.0 to the FTE.
For owners, the participant count should include owner or owner representative members of the PMT, but only those participants whose labor is accounted by the Owner as part of the cost of the project.
For contractor, participants do not include craft. Typical PMT participants are listed in the table below.

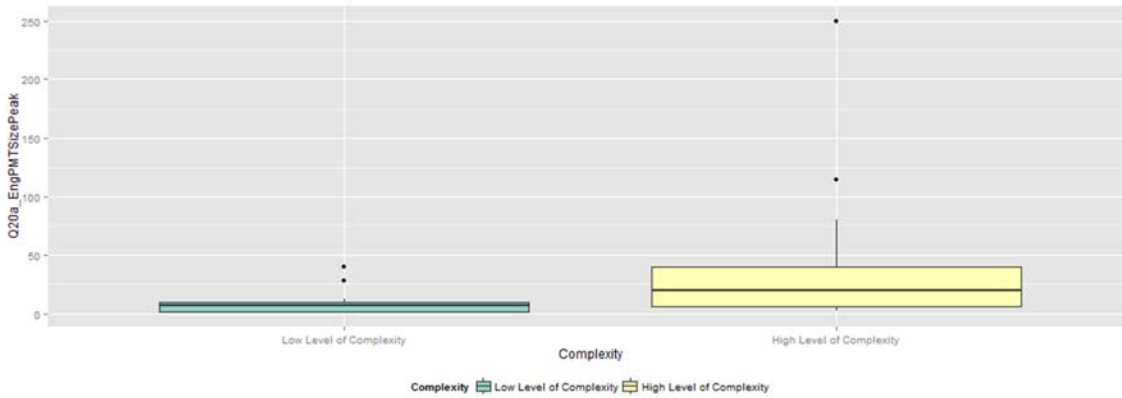
Table 1. Typical Project Management Team Participants (PMT)

Project Manager	Contract Administrator
Engineering Manager / Project Eng.	Project Controls Engineer (Cost and Schedule)
Business Manager	QA / QC Administrator
Construction Manager	Safety Supervisor
Operations Manager	Operations Manager
Discipline Engineering Leads	Maintenance Manager
Procurement Manager	Consultants

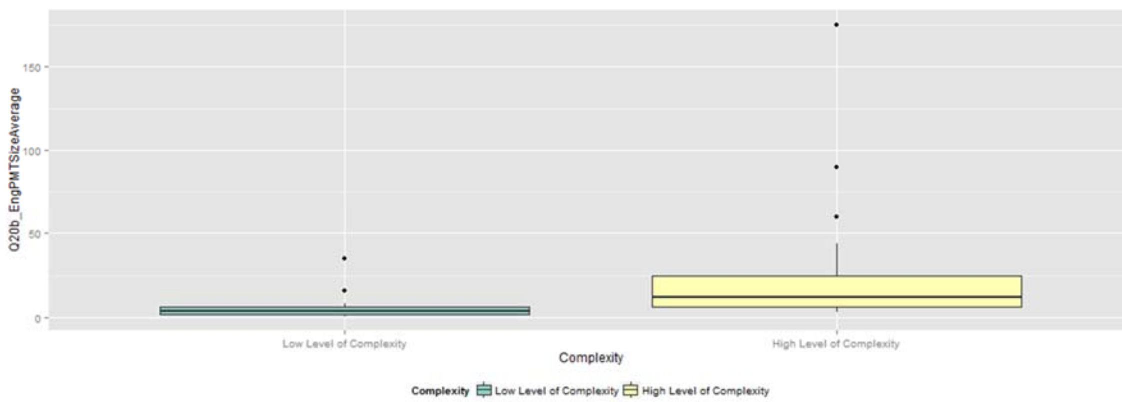
12 Responses **26 Responses**

Project Phase	Estimated PMT Size		Estimated Years of Industry Experience
	Peak	Average	Average
Detailed Engineering/Design	9.85 36.27 **a.** FTEs	7.00 25.68 **b.** FTEs	28.18 50.28 Years
Procurement	3.29 13.12 **d.** FTEs	2.17 10.00 e. FTEs	28.00 29.24 Years
Construction	28.44 97.56 FTEs	19.41 71.06 FTEs	21.20 73.56 Years

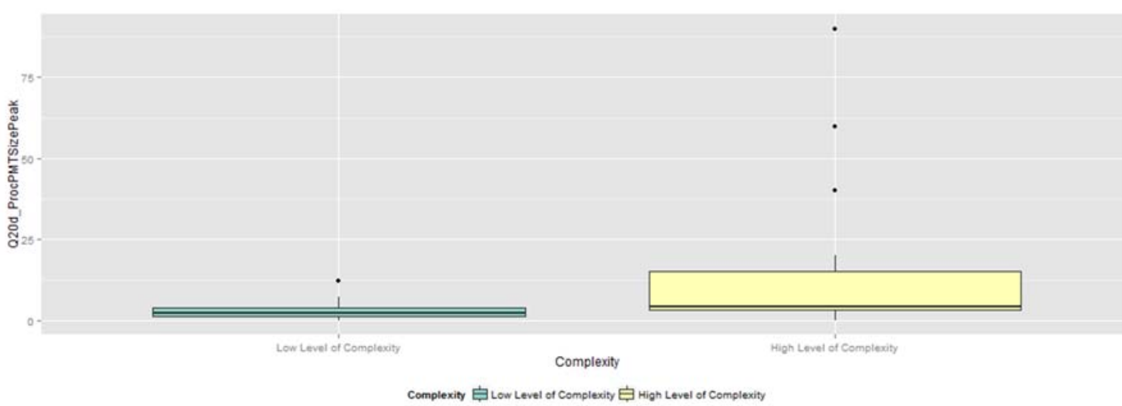
a. The p-value for a test of difference in the means is 0.0207



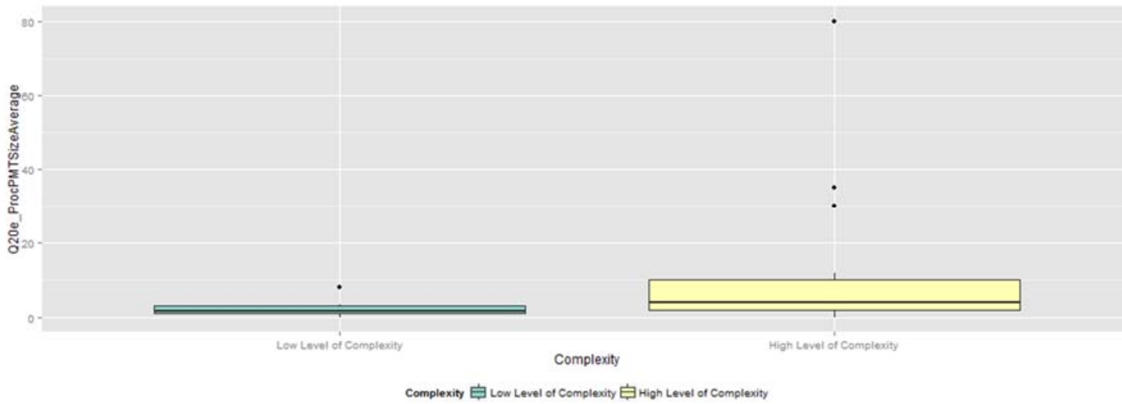
b. The p-value for a test of difference in the means is 0.0258



d. The p-value for a test of difference in the means is 0.0313



e. The p-value for a test of difference in the means is 0.0379



II. Project Complexity Metrics

The following section focuses on indicators of project complexity. Some questions are quantitative (i.e., a number) and some questions are qualitative (i.e., a categorical scale one to seven). Please answer the following questions.

STAKEHOLDER MANAGEMENT

21- What was the influence of this project on the organization's overall success (e.g., profitability, growth, future industry position, public visibility, and internal strategic alignment)?

14 Responses **30 Responses**

Limited Contributor to Organization's Success		Moderate Contributor to Organization's Success			Substantial Contributor to Organization's Success	
1	2	3	4	5	6	7
☐	☐	☐	**4.00** ☐	☐	**6.00**☐	☐

22- How many stakeholders had an active role (i.e., monthly input) in decision making on the project? 14 Responses 29 Responses

	Number of Decision makers
Internal stakeholders	Number:__**6.64** **10.34**
External stakeholders	Number:___**2.57** **5.72**

23- How well aligned were these stakeholders?

11 Responses 29 Responses

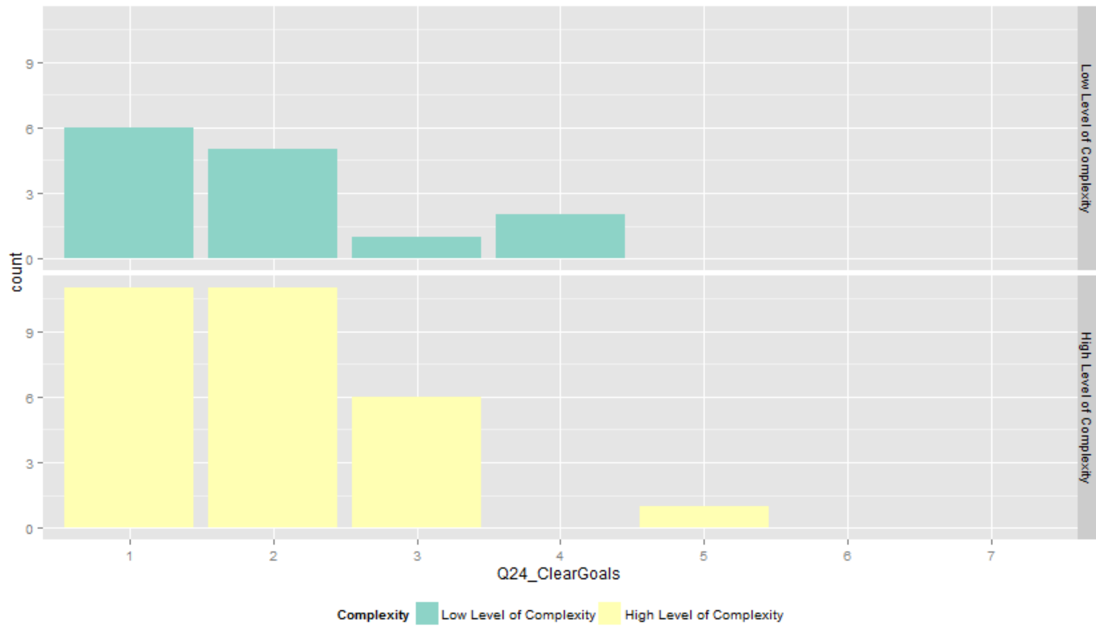
	Extremely aligned		Moderately aligned				Not at all aligned
	1	2	3	4	5	6	7
Within Internal Stakeholders	☐	**2**☐ **2**	☐	☐	☐	☐	☐
Within External Stakeholders	☐	**2**☐	**3**☐	☐	☐	☐	☐

24- How clear were the owner's project goals and objectives at kick-off of project execution? 14 Responses 29 Responses

Extremely Clear		Somewhat Ambiguous			Completely Ambiguous	
1	2	3	4	5	6	7
☐	**2**☐**2**	☐	☐	☐	☐	☐

No Significant difference

The p-value for a test of difference in the distributions is 0.8577



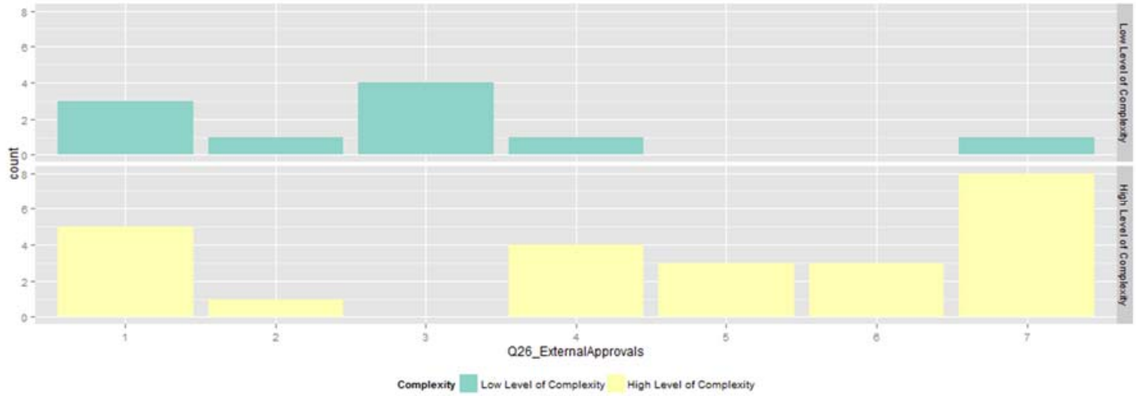
25- What was the impact of required approvals from internal stakeholders on the original project execution plan? **14 Responses** **29 Responses**

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)	
1	2	3	4	5	6	7
☐	☐	☐ 3.5	☐ 4.0	☐	☐	☐

26- What was the impact of required approvals from external stakeholders on the original project execution plan? **10 Responses** **24 Responses**

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)	
1	2	3	4	5	6	7
☐	☐	3.0 ☐	☐	5.0 ☐	☐	☐

The p-value for a test of difference in the distributions is 0.0341

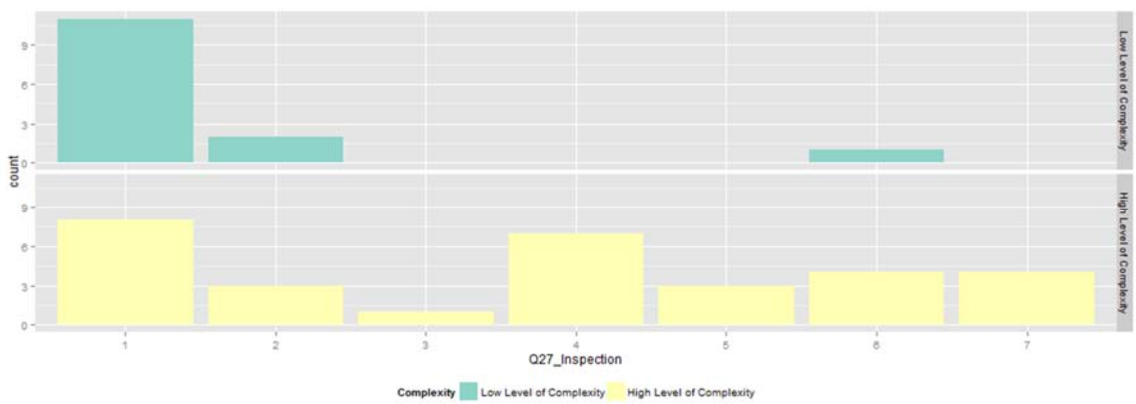


27- What was the impact of required inspection by external (regulatory) agencies/entities on original project execution plan?

14 Responses **30 Responses**

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required replanning)	
1	2	3	4	5	6	7
☐**1.0**	☐	☐	**4.0**☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0012



GOVERNANCE

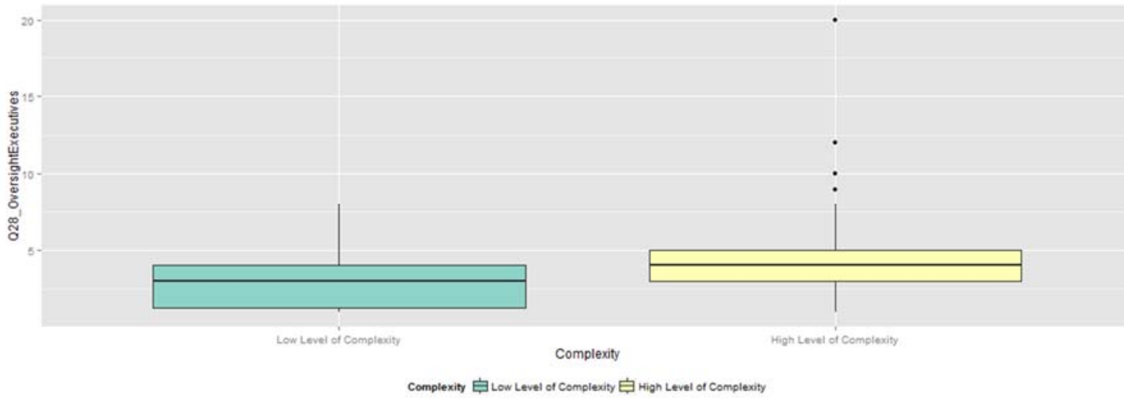
28- How many executive oversight entities above the project management team had decision-making authority on your project execution plan?

(Please do not include project management team members shown in Table 1)

14 Responses **29 Responses**

Number:__**3.07** **4.96**

The p-value for a test of difference in the means is 0.047



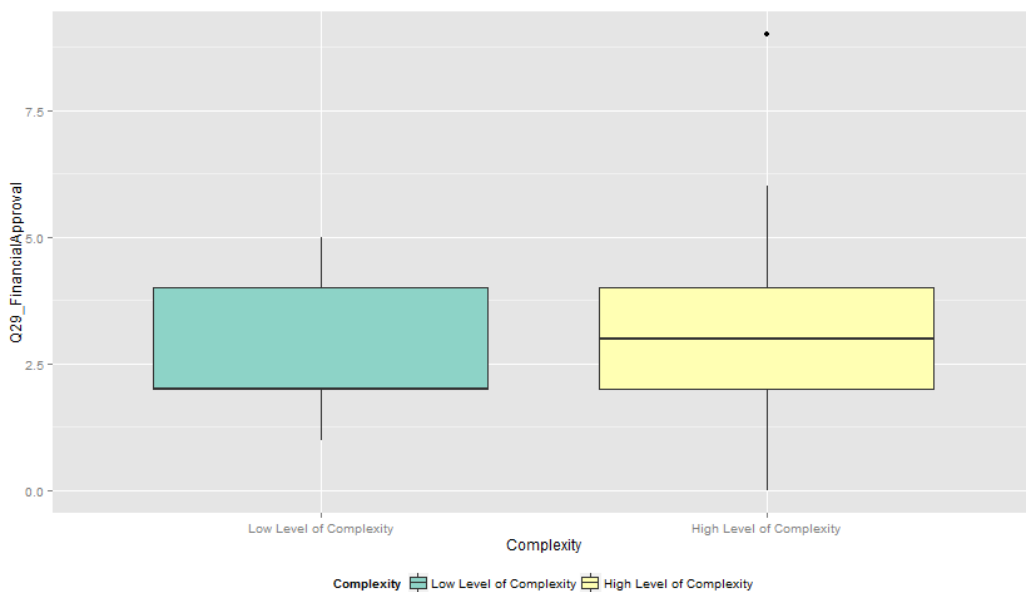
29- How many financial approval authority thresholds existed on your project? (Example: the project manager can approve purchase orders up to $100K, the division director can approve purchase orders up to $1M, etc.).

13 Responses **29 Responses**

Number:______**3.0** **3.03**

No Significant difference

The p-value for a test of difference in the means is 0.9481



30- What was the maximum number of authority levels above the Project Manager needed for change order approval?

13 Responses **29 Responses**

Number:______**1.69** **1.90**

31- How many times on this project did a change order need to go above the Project Manager for approval? **13 Responses** **28 Responses**

Number:____**1.62** **10.75**

For Owner:

32- How many total sponsoring entities, or joint venture partners with an equity position, existed on this project? **11 Responses** **24 Responses**

Number:____**0.73** **1.38**

For Contractors:

33- How many total joint-venture partners were there in this project?

10 Responses **16 Responses**

Number:____**0.3** **0.88**

34- Approximately how many regular status reports were completed in six months by the project team that are intended for executive management?

14 Responses **29 Responses**

Number:___**7.86** **12.45**

LEGAL

35- How many total permits were required?

Permits required by regulatory agencies to legally start site construction work (e.g. government environmental permits, Corps of Engineers permits)

13 Responses **25 Responses**

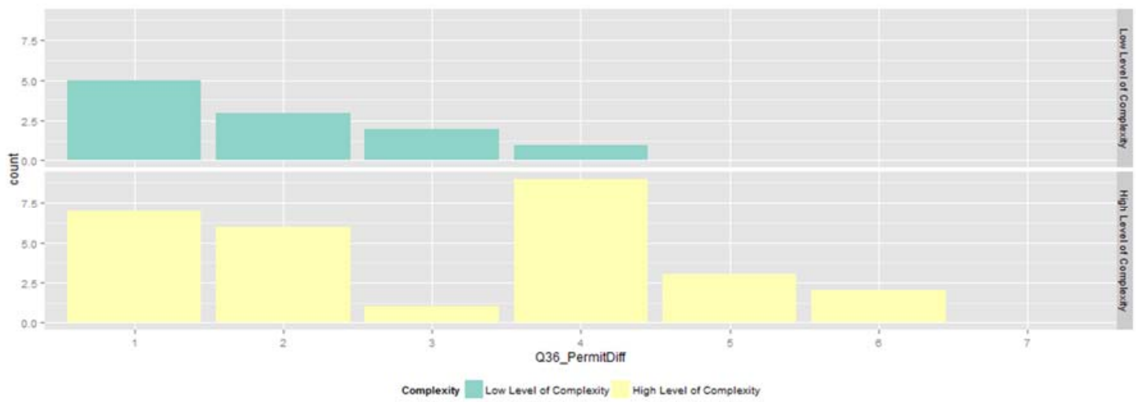
Number:_____**1.54** **8.36**

36- What was the difficulty in obtaining permits?

11 Responses **28 Responses**

Not at all difficult			Moderately difficult			Extremely difficult
1	2	3	4	5	6	7
☐	2.0☐	☐3.5	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0497



37- How many external (regulatory) agencies/entities were required to <u>approve the design</u>? **11 Responses** **25 Responses**

Number:___**1.00** **1.88**

38- What was the difficulty in obtaining design approvals?

10 Responses **25 Responses**

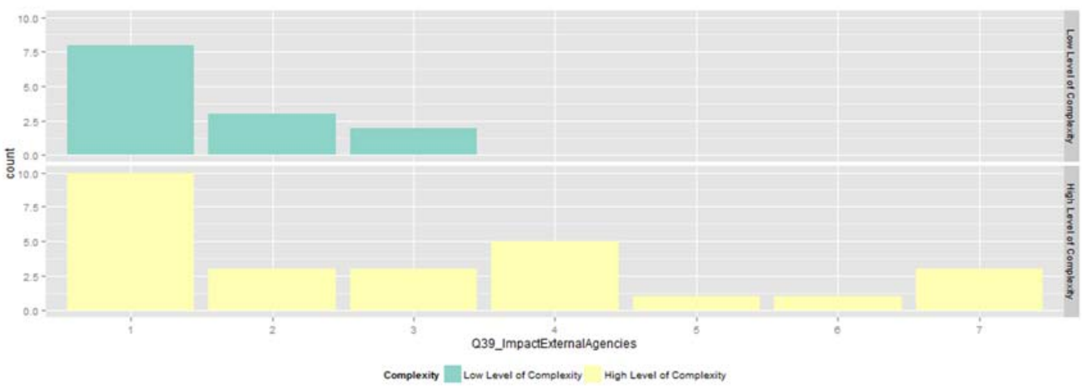
Not at all difficult			Moderately difficult			Extremely difficult
1	2	3	4	5	6	7
☐1.50	☐	3.0☐	☐	☐	☐	☐

39- Please indicate the impact of external agencies on the project execution plan.

13 Responses **26 Responses**

Caused No Problems Meeting the Execution Plan		Caused Some Problems Meeting the Execution Plan			Caused Substantial Problems Meeting the Execution Plan	
1	2	3	4	5	6	7
☐**1**	☐**2.5**	☐	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.039



FISCAL PLANNING

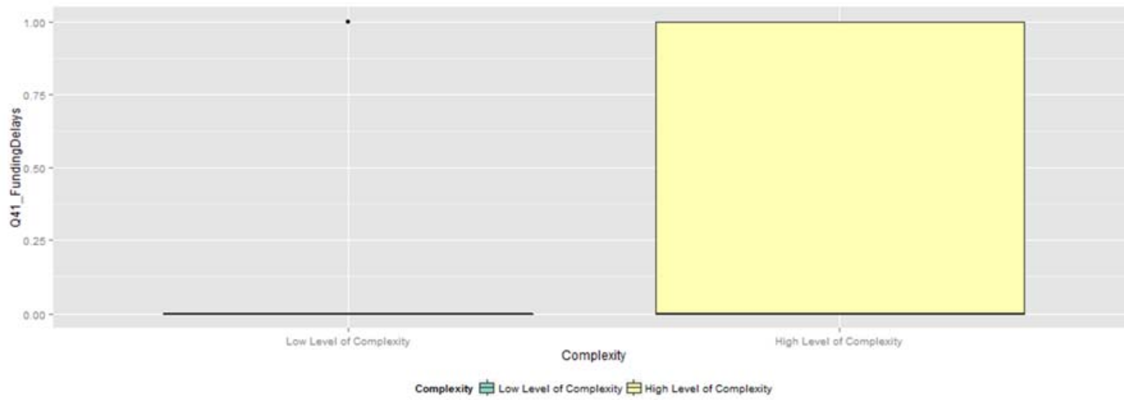
40- What was the number of funding phases (gates) from concept to project completion? **13 Responses** **23 Responses**

Number:___**2.23** **3.00**

41- Did the project experience any delays or difficulties in securing project funding? **14 Responses** **30 Responses**

1/14 ☐ Yes **10/30** **12/14** ☐ No **15/30** **1/14** **5/30** ☐ Don't Know

The p-value for a test of difference in the means is 0.0148



42- Was the funding process well understood during the Front End Planning phase? **13 Responses** **29 Responses**

Extremely Clear		Somewhat Ambiguous			Completely Ambiguous	
1	2	3	4	5	6	7
☐ **1.0**	☐ **2.0**	☐	☐	☐	☐	☐

43- Did project economics (ability to meet desired rate of return or benefit to cost ratio greater than 1.0) have an impact on the ability to obtain funding?

14 Responses **25 Responses**

4/14 ☐ Yes **10/25** **10/14** ☐ No **15/25**

INTERFACES

44- Please complete the following table regarding the number of organizations and number of project management leadership team members.

Leadership team member would be the same as those shown in Table 1.

Project Participants	Number of Organizations	Number of Project Management Leadership Team members
Owner **14 Responses** **24 Responses**	Number:__**2.00** **1.79**	Number:__**5.17** **5.60**
Prime Designer/ Engineer Organizations **14 Responses** **25 Responses**	Number:___**1.43** **1.64**	Number:___**4.92** **9.14**
Prime Contractor Organizations **13 Responses** **25 Responses**	Number:___**1.62** **1.68**	Number:___**4.55** **11.79**
Subcontractors to Prime Contractor Organizations **13 Responses** **18 Responses**	Number:___**6.15** **7.61**	NA
Vendors to Prime Contractors or Subcontractors **10 Responses** **18 Responses**	Number:__**19.30** **17.44**	NA
Permitting Agencies (for construction) **10 Responses** **18 Responses**	Number:__**1.09** **1.06**	Number:__**0.33** **1.27**

45- How effective was the communication within each participant group?

Project Participants	Effectiveness of communication						
	Extremely Effective			Moderately Effective		Not at all Effective	
	1	2	3	4	5	6	7
Owner 14 Responses **27 Responses**	☐	**2.0**☐**2.0**	☐	☐	☐	☐	☐
Prime Designer/ Engineer Organizations 14 Responses **29 Responses**	☐	**2**☐**2**	☐	☐	☐	☐	☐
Prime Contractor	☐	☐**2**	**3.0**☐	☐	☐	☐	☐

Organizations 13 Responses 30 Responses							
Subcontractors to Prime Contractor Organizations 11 Responses 24 Responses	☐	2.5☐	3☐	☐	☐	☐	☐
Vendors to Prime Contractors or Subcontractors 10 Responses 22 Responses	☐	☐	3☐3	☐	☐	☐	☐
Permitting Agencies (for construction) 6 Responses 20 Responses	☐	2☐2.5	☐	☐	☐	☐	☐

46- Have the owner and the primary designer/engineer worked together before this project? 13 Responses 30 Responses

11/13 ☐ Yes 22/30 2/13☐No 7/30 0/13☐N/A 1/30

If yes, how many times have they worked together? ____________

47- Have the owner and the primary contractor worked together before this project? 14 Responses 30 Responses

12/14 ☐ Yes 22/30 1/14☐No 6/30 1/14☐N/A 2/30

If yes, how many times have they worked together? ____________

48- Have the primary designer/engineer and the primary contractor worked together before this project? 14 Responses 30 Responses

10/14 ☐ Yes 19/3 4/14☐No 9/30 0/14☐N/A 2/30

If yes, how many times have they worked together? ____________

SCOPE DEFINITION

49- Was the process for defining the project's scope understood during the selection of designers and contractors? 14 Responses 29 Responses

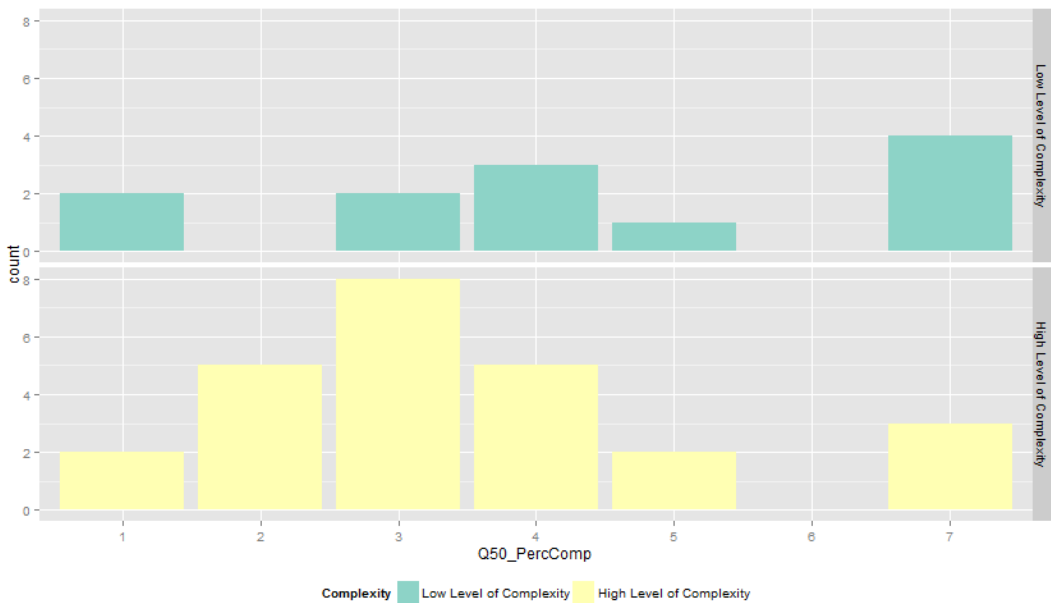
Extremely clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	2.0 ☐2.0	☐	☐	☐	☐	☐

50- What percentage of design was completed prior to project budget authorization? 12 Responses 25 Responses

☐	☐	☐	4.0☐ 3.0	☐	☐	☐
0-5%	6-14%	15-24%	25-34%	35-44%	45-50%	>50%

No Significant difference

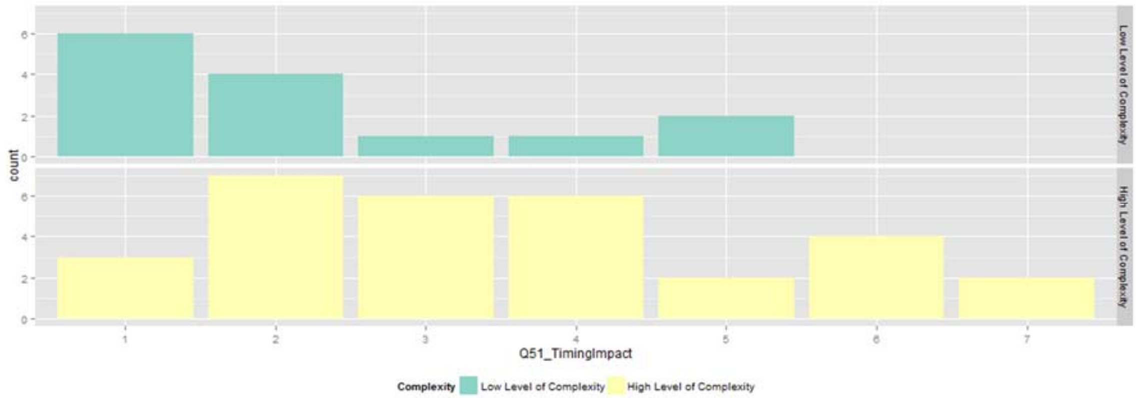
The p-value for a test of difference in the distributions is 0.1693



51- Did the TIMING of the change orders impact project execution?
14 Responses 30 Responses

No Impact			Some Impact			Highly Impacted (required replanning of project execution plan)
1	2	3	4	5	6	7
☐	2.00☐	3.00☐	☐	☐	☐	☐

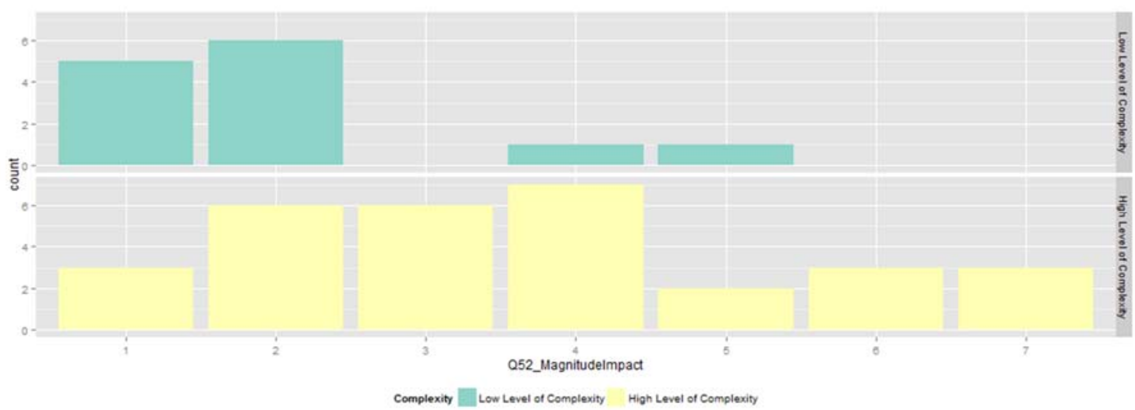
The p-value for a test of difference in the distributions is 0.0129



52- Did the MAGNITUDE of the change orders impact project execution?
13 Responses **30 Responses**

No Impact			Some Impact			Highly Impacted (required replanning of project execution plan)
1	2	3	4	5	6	7
☐	2.00☐	☐3.50	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.003



53- Was the scope at the time of completion substantially the same as it was at authorization? 13 Responses 30 Responses

Exactly the Same			Some Changes in Scope			Significant Changes in Scope
1	2	3	4	5	6	7
☐	☐	3.0☐3.0	☐	☐	☐	☐

54- Was the change management process clear to key project team members (see Table 1)? **13 Responses** **28 Responses**

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	2.0☐2.0	☐	☐	☐	☐	☐

55- Was the change management process followed by key project team members (see Table 1)? **14 Responses** **30 Responses**

Completely Followed			Somewhat Followed			Not Followed
1	2	3	4	5	6	7
☐	2.0☐2.0	☐	☐	☐	☐	☐

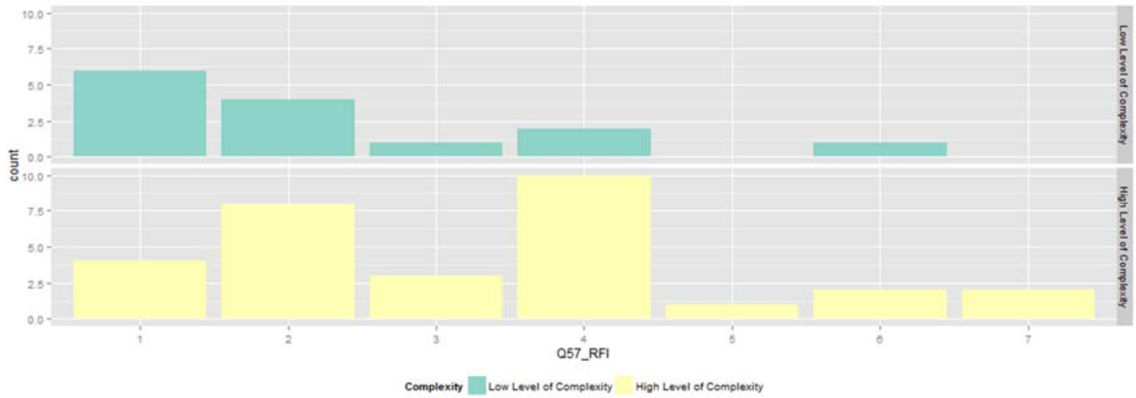
56- How effective was the change management process in controlling cost and schedule growth? **14 Responses** **30 Responses**

Very Effective			Moderately Effective			Not Effective
1	2	3	4	5	6	7
☐	☐2.00	3.00☐	☐	☐	☐	☐

57- To what extent did Request for Information (RFIs) drive project design changes? **14 Responses** **30 Responses**

No Impact on Design Changes			Moderate Impact on Design Changes			Caused a High Level of Design Changes
1	2	3	4	5	6	7
☐	2.0☐	3.5☐	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0268



LOCATION

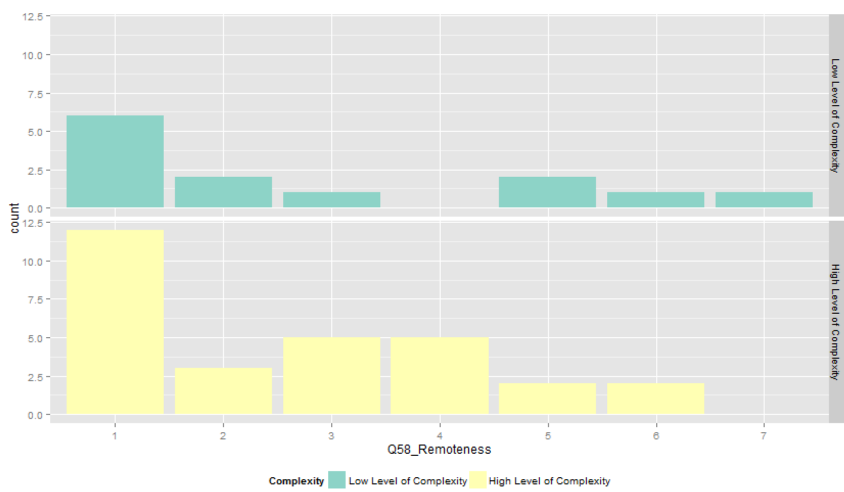
58- How remote (distance from highly-populated areas) was the project location?

13 Responses **29 Responses**

Not at All Remote			Moderate			Highly Remote
1	2	3	4	5	6	7
☐	2 ☐ 2	☐	☐	☐	☐	☐

No Significant difference

The p-value for a test of difference in the distributions is 0.9773



59- In general, how populated (rural vs. urban) was the project location?

14 Responses **29 Responses**

Low Density (rural environment)			Moderate			High Density (urban environment)
1	2	3	4	5	6	7
☐	☐	☐**3.5**	**4.0**☐	☐	☐	☐

60- What level of infrastructure existed at the site to support the project (e.g., infrastructure is existing utilities (water, electricity, natural gas, etc.) and roads)**?**

14 Responses **29 Responses**

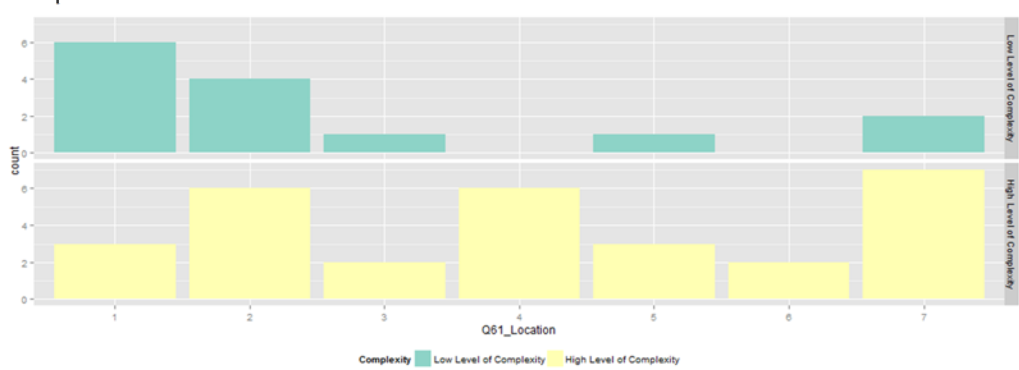
Available Infrastructure			Limited Infrastructure			No infrastructure/ Greenfield
1	2	3	4	5	6	7
1.0☐**1.0**	☐	☐	☐	☐	☐	☐

61- What impact did the project location have on the project execution plan?

14 Responses **29 Responses**

No Impact on Meeting the Execution Plan			Moderate			Substantial Impact on Meeting the Execution Plan
1	2	3	4	5	6	7
☐	☐**2.00**	☐	**4.00**☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.017



62- Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost. Include all costs for transportation, setting and hooking-up field connections.

13 Responses **27 Responses**

☐	☐	☐	**28%**☐**27%**	☐	☐	☐	☐	☐	☐	☐
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

63- How many different countries worked on the detailed engineering/design phase of the project? 14 Responses **25 Responses**

Number: _**1.14** **3.96** ☐Don't Know

64- How many different countries worked on the construction phase of the project (include both field staff and craft labor)?

14 Responses **28 Responses**

Number: ___**1.75** **4.57** ☐Don't Know

65- Were project documents translated into a different language?

14 Responses **28 Responses**

1/14☐ Yes **3/28** **13/14**☐No **25/28**

If yes, how many different languages did the official project documents have to be translated into?

Number: ________

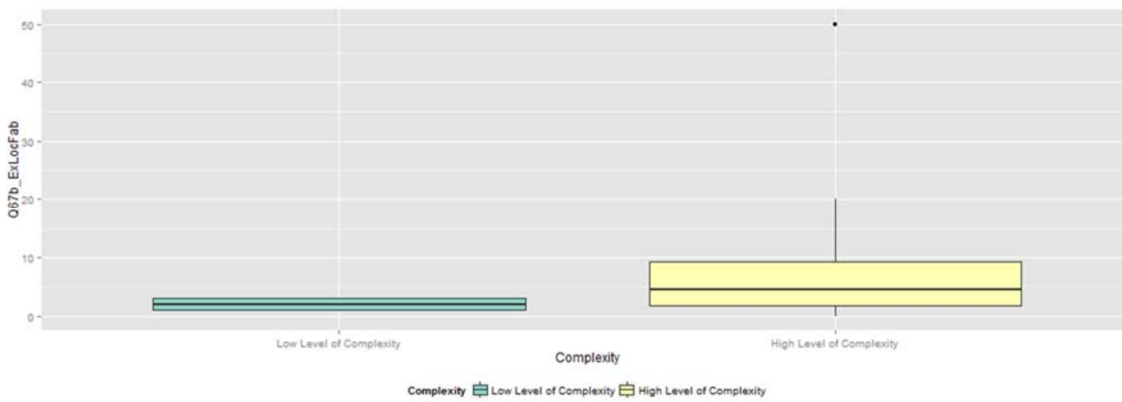
66- What were the security requirements for accessing the project construction site? 14 Responses **29 Responses**

Low Security Requirements to Enter and Protect the Site		Some Specialized Clear Needed to Enter and Protect the Site			Specialized Clearance to Enter the Site and Protect the Site		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐**4.0**	**5.0**☐	☐	☐	☐

67- **How many execution locations were used on this project?**

Project Phases	Number of Locations
a. Detailed Engineering/Design 14 Responses 27 Responses	Number: __1.5 2.23
b. Fabrication (bulk materials and equipment) 13 Responses 25 Responses	Number: __1.85 7.83
c. Construction (including modular assembly yards) 13 Responses 25 Responses	Number: _1.69 2.12

b. The p-value for a test of difference in the means is 0.0114



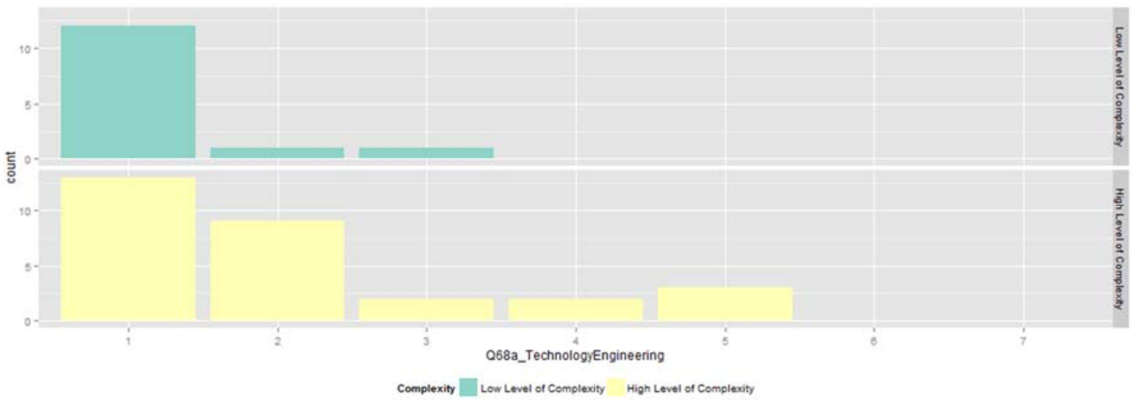
DESIGN AND TECHNOLOGY

68- **What was your company's degree of familiarity with technologies that were involved in each of the following project phases?**

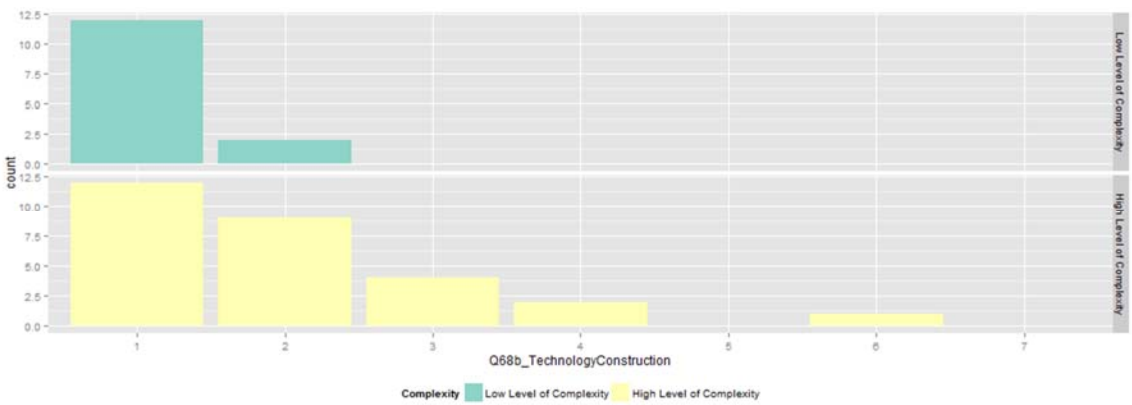
Project Phases	Completely Familiar with All Technologies		Somewhat Familiar with Technologies			Not Familiar with Many Technologies	
	1	2	3	4	5	6	7
a. Detailed Engineering/ Design 14 Responses 29 Responses	1.0☐	2.0☐	☐	☐	☐	☐	☐

b. Construction 14 Responses **28 Responses**	1.0☐	2.0☐	☐	☐	☐	☐	☐
c. Operating facility **14 Responses 28 Responses**	1.0☐1.0	☐	☐	☐	☐	☐	☐

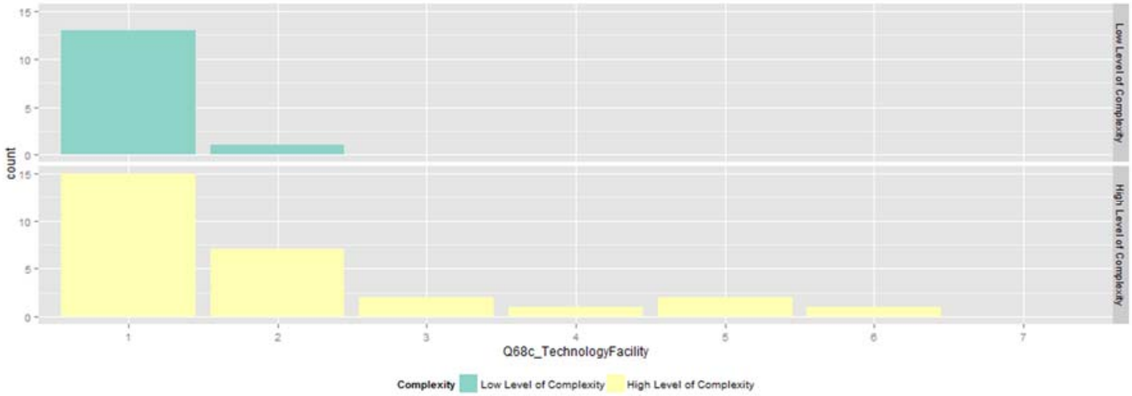
a. The p-value for a test of difference in the distributions is 0.0138



b. The p-value for a test of difference in the distributions is 0.0065



c. The p-value for a test of difference in the distributions is 0.0106

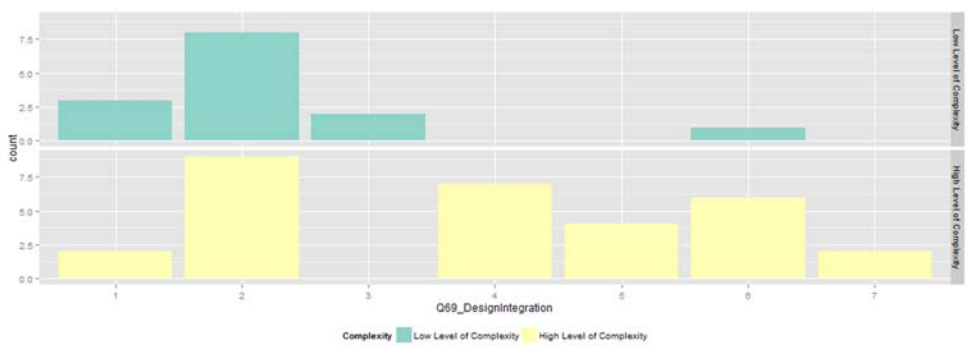


69- Compared to a typical project for your company, what was the difficulty in system design and integration on this project?

(System is the combination of several pieces of equipment to perform in a particular manner) **14 Responses** **30 Responses**

	Difficulty						
	Not at all Difficult			Moderately Difficult			Extremely Difficult
	1	2	3	4	5	6	7
Systems	☐	**2.0**☐	☐	**4.0**☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0048



70- How many new systems were tied into existing systems?

13 Responses **26 Responses**

Number:___**3.67** **8.31** ☐N/A

PROJECT RESOURCES

71- **What percentage of project/construction management staff actually worked on the project compared to planned project/construction management staff?**

13 Responses **30 Responses**

☐	☐	**3.00** ☐ **3.00**	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

72- **What percentage of field craft labor was actually on the payroll at project peak compared to the plan at peak?** **11 Responses** **27 Responses**

☐	☐	**3.00** ☐ **3.00**	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

73- **What percentage of the time were facility/operations personnel available for the project compared to the plan for the project?**

13 Responses **27 Responses**

☐	☐ **2.00**	**3.00** ☐	☐	☐
70-84%	85-99%	100-114%	115-129%	140-145%

74- **Was the delivery of permanent facility equipment delayed?**

14 Responses **27 Responses**

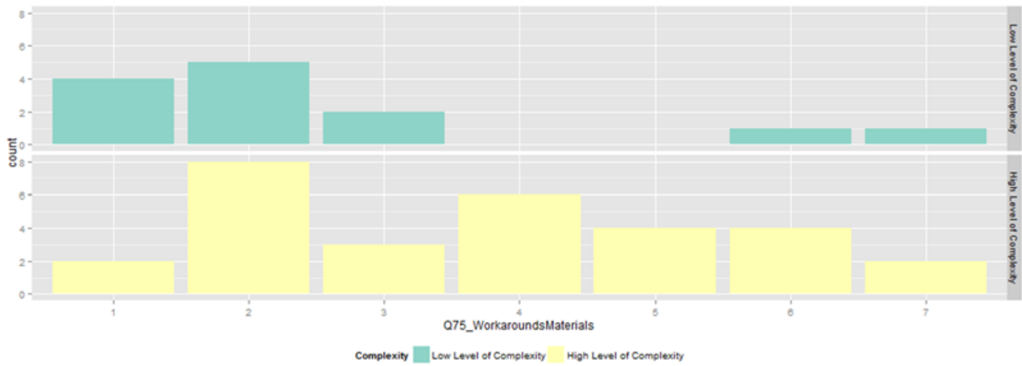
☐ No Delay **6/14** **12/27**
☐1 week
☐2-4 weeks
☐5-8 weeks
☐9-12 weeks
☐>12 weeks

Mean: 6.88 weeks **7.4 weeks**

75- **What was the frequency of workarounds (work activities out of sequence to continue) because materials were not available when needed to support construction?** **13 Responses** **29 Responses**

No Workarounds			Moderate Number of Workarounds			High Number of Workarounds
1	2	3	4	5	6	7
☐	☐**2.0**	☐	**4.00**☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0293

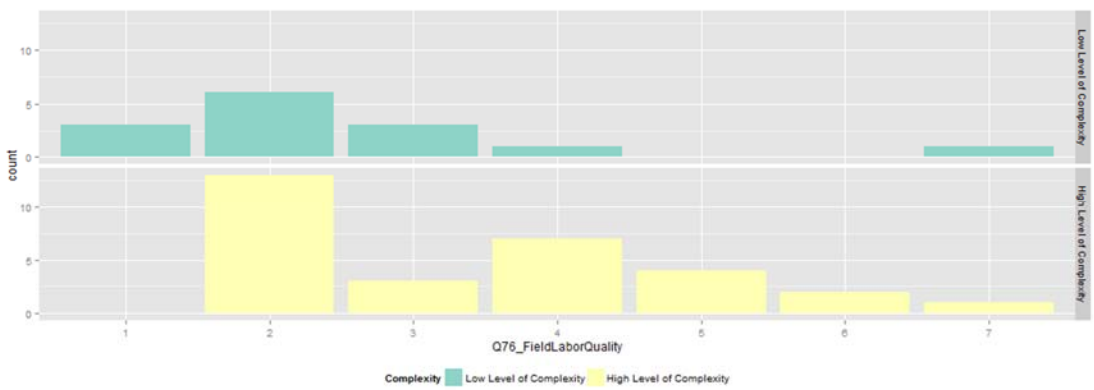


76- Please rate quality issues with field craft labor during project construction.

14 Responses **30 Responses**

No Quality Issues		Moderate Level of Quality Issues				Substantial Number of Quality Issues
1	2	3	4	5	6	7
☐	☐2.0	☐3.0	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0381

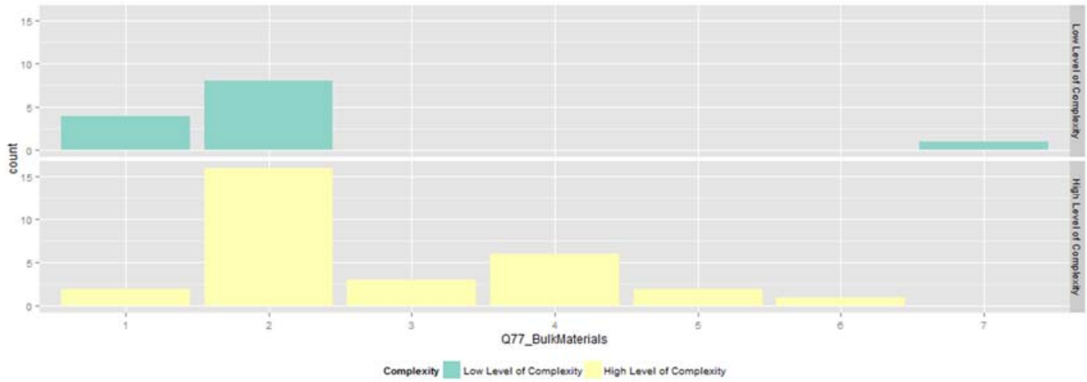


77- Please rate quality issues with bulk materials during project execution.

13 Responses **30 Responses**

No Quality Issue		Moderate Level of Quality Issues				Substantial Number of Quality Issues
1	2	3	4	5	6	7
☐	2.0☐2.0	☐	☐	☐	☐	☐

The p-value for a test of difference in the distributions is 0.0181



78- Please rate quality issues with the permanent (tagged) equipment during project execution.

14 Responses **28 Responses**

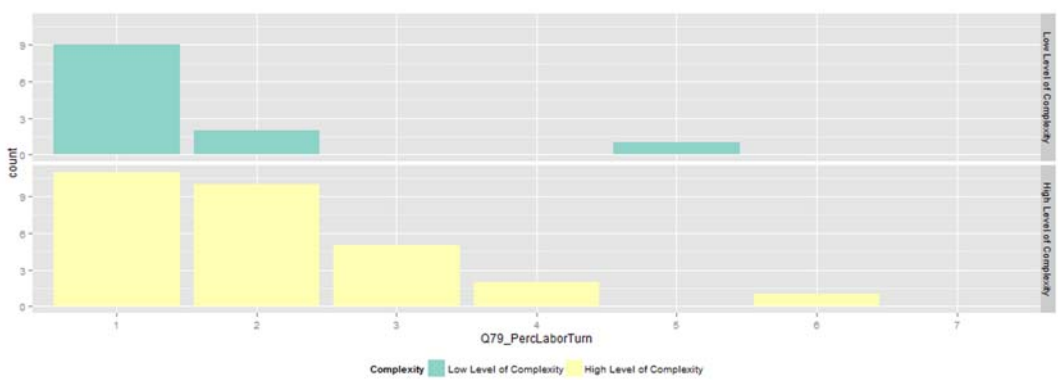
No Quality Issue		Moderate Level of Quality Issues			Substantial Number of Quality Issues	
1	2	3	4	5	6	7
☐	☐2.0	3.0☐	☐	☐	☐	☐

79- What was the percentage of craft labor turnover?

12 Responses **30 Responses**

☐ 1.0	2.0☐	☐	☐	☐	☐
0-9%	10-19%	20-29%	30-39%	40-49%	>50%

The p-value for a test of difference in the distributions is 0.0459



80- **What was the percentage of project/construction management staff turnover?**

13 Responses **30 Responses**

☐ 1.0	☐ 2.0	☐	☐	☐	☐	☐
0-4%	5-9%	10-14%	15-19%	20-24%	24-28%	>28%

81- **What percentage of Bulk Materials were sourced within the project country? (% of Bulk Material Cost)** **13 Responses** **28 Responses**

☐	☐	☐	☐	5.0☐ 5.0	☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

82- **What percentage of Permanent (Tagged) Equipment was sourced within the project country?** (% of Tagged Equipment Cost)

14 Responses **27 Responses**

☐	☐	☐	☐	5.0☐ 5.0	☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

83- **What percentage of craft labor was sourced locally? (within 100 mile radius of Job Site)** **13 Responses** **29 Responses**

☐	☐	☐	4.5☐	☐	6.0☐
0-19%	20-39%	40-59%	60-79%	80-99%	100%

84- **What percentage of the scope was involved with the reuse of existing installed equipment?** **13 Responses** **29 Responses**

☐	☐ 1.0	2.0☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

QUALITY

85- **Degree of additional quality requirements?**

Construction tolerances exceeded standard practice (industry standard or accepted standard) for the type of project. **13 Responses** **28 Responses**

Tolerances consistent with Standard Practice		Some Deviations from Standard Practice			Many Tight Tolerances Relative to Standard Practice	
1	2	3	4	5	6	7
1.0☐	☐	3.0☐	☐	☐	☐	☐

86- Degree of additional quality requirements?

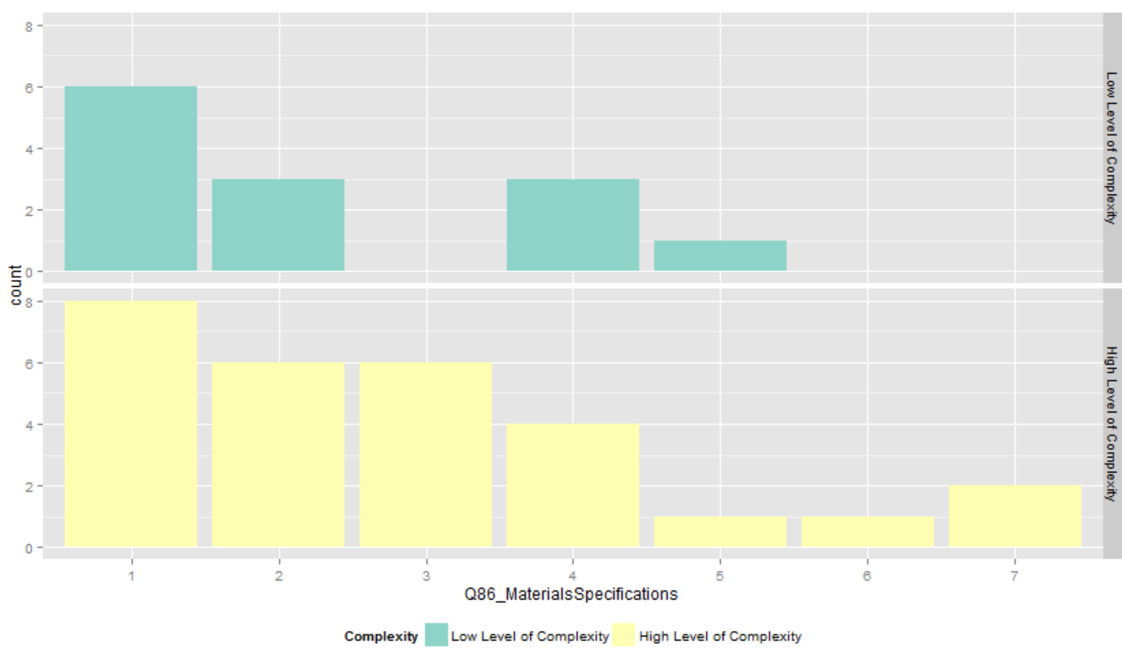
13 Responses **28 Responses**

Specifications for materials exceeded standard practice for the type of project.

No Deviations from Standard Practice		Some Deviations from Standard Practice			Many Deviations from Standard Practice	
1	2	3	4	5	6	7
☐	2.0 ☐2.5	☐	☐	☐	☐	☐

No Significant difference

The p-value for a test of difference in the distributions is 0.3193

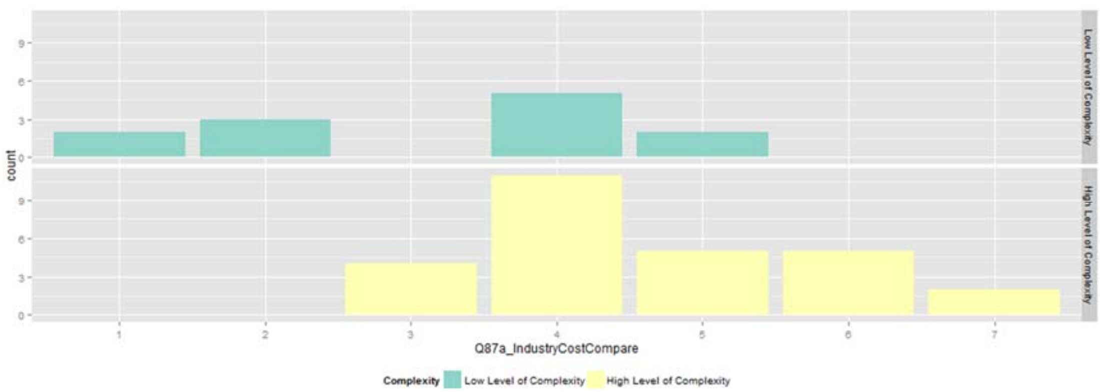


EXECUTION TARGETS

87- At project authorization how did the cost and schedule targets compare to industry/internal benchmarks? **12 Responses** **28 Responses**

	Target						
	Lower than industry standard benchmark			At industry standard		Very aggressive	
	1	2	3	4	5	6	7
a. Cost target at authorization	☐	☐	☐	**4.0**☐ **4.0**	☐	☐	☐
b. Schedule target at authorization	☐	☐	☐	**4.0**☐	☐	**6.0**☐	☐

a. The p-value for a test of difference in the distributions is 0.0118



88- What percentage of engineering/design was planned to be completed at the start of construction? **11 Responses** **26 Responses**

___**64.09** **59.58**____ % Engineering/Design

89- What was the actual percentage of engineering/design completed at the start of construction? **11 Responses** **26 Responses**

___**67.73** **50.31**____ % Engineering/Design

90- Please identify any other factors or attributes on this project that contributed to its complexity that may not have been covered in the survey.

___

___

___

Project Complexity

91- Please rate the overall complexity of this project on the scale below:

14 Responses **29 Responses**

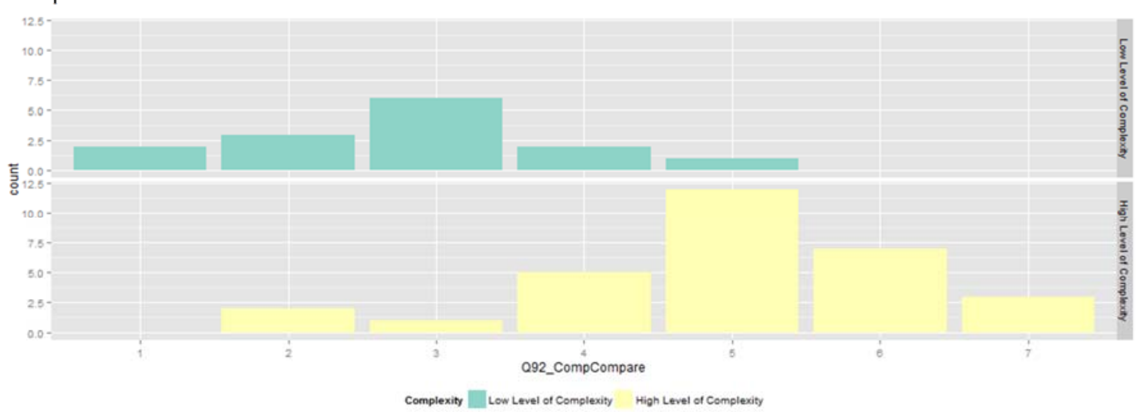
Very Low Complexity			Moderate Complexity			Very High Complexity
1	2	3	4	5	6	7
☐	☐**2.79**	☐	☐	**5.24**☐	☐	☐

92- How does this project's overall complexity compare to the complexity of other projects that your company executes?

14 Responses **30 Responses**

Lower Level of Complexity Compared to Other Projects			Same Level of Complexity Compared to Other Projects			Higher Level of Complexity Compared to Other Projects
1	2	3	4	5	6	7
☐	☐	**3.0**☐	☐	**5.0**☐	☐	☐

The p-value for a test of difference in the distributions is 0



III. Best Practice Implementation

The intent of this section is to assess relationships between Project Complexity Metrics and their impact on implementation of select industry Best Practices. Each Best Practice is defined by one or three sentences taken from IR 166-3 V2.0, CII Best Practice Guide: Improving Project Performance. The scale is seven-point categorical with 1 being "Not Implemented at All" and 7 "Very Extensively Implemented."

93- Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

Based on the definition, to what extent was Constructability implemented on this project?
14 Responses **29 Responses**

Not Implemented at All		Partially Implemented				Very Extensively Implemented	Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	5.0☐5.0	☐	☐	☐

94- Team Building

Team building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members' problem-solving skills.

Based on the definition, to what extent was Team Building implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented				Very Extensively Implemented	Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	4.0☐	5.0☐	☐	☐	☐

95- Alignment

The purpose of alignment is to focus the energy and talent of the team on a common purpose by developing a common vision of project success and placing personal goals subservient to overall project success. Alignment is defined as "The condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project priorities."

Based on the definition, to what extent was an Alignment process implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	4.0☐	5.0☐	☐	☐	☐

96- Partnering

Companies may partner in order to achieve specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is built on trust, dedication to common goals and the understanding of each other's individual expectations and values. Partnering may be a long term commitment between two or more organizations, as in an alliance, or it may be applied to a shorter period of time, such as the duration of a project.

Based on the definition, to what extent was Partnering implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	4.0☐	☐	6.0☐	☐	☐

97- Front End Planning

Front end planning (FEP) is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. This process provides a comprehensive framework for detailed project planning. FEP is a gated process that focuses on feasibility, concept and detailed scope phases of project development.

Based on the definition, to what extent was a Front End Planning process implemented on this project? 14 Responses 29 Responses

Not Implemented at All			Partially Implemented			Very Extensively Implemented	Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	5.0☐5.0	☐	☐	☐

98- Change Management

Change management is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes.

Based on the definition, to what extent was Change Management implemented on this project? 14 Responses 29 Responses

Not Implemented at All			Partially Implemented			Very Extensively Implemented	Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	6.0☐6.0	☐	☐

99- Material Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management system combines and integrates takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

Based on the definition, to what extent was Materials Management implemented on this project? 14 Responses 29 Responses

Not Implemented at All			Partially Implemented			Very Extensively Implemented	Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	6.0☐6.0	☐	☐

100- Zero Accident Techniques (i.e., Safety)

Zero accident techniques include the site-specific safety programs and implementation, auditing, and incentive efforts to create a project environment and a level of training that embraces the mindset that all accidents are preventable and that zero accidents is an obtainable goal.

Based on the definition, to what extent was Zero Accident Techniques implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	7.0☐7.0	☐

101- Planning for Start Up

Startup is defined as the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Critical steps within the startup phase include systems turnover, check-out of systems, commissioning of systems, introduction of feed stocks, and performance testing.

Based on the definition, to what extent was planning for Start Up implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	6.0☐6.0	☐	☐

102- Dispute Prevention and Resolution

Dispute resolution techniques include the use of a Disputes Review Board as an alternate dispute resolution process to eliminate the necessity to take disputes to litigation. The Dispute Review Board technique provides a process for addressing disputes in their early stages before the dispute affects the progress of the work, creates adversarial positions, and leads to litigation.

Based on the definition, to what extent was Dispute Review implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐1.0	2.0☐	☐	☐	☐	☐	☐	☐

103- Quality Management

Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects.

Based on the definition, to what extent was Quality Management implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐ **5.0**	**6.0** ☐	☐	☐

104- Lessons Learned

A lesson learned is knowledge gained from experience, successful or otherwise, for the purpose of improving future performance. Examples are: a lesson that is incorporated in a work process; a tip to enhance future performance; a solution to a problem or a corrective action; a lesson that is incorporated into a policy or a guideline; an adverse situation to avoid; and collective knowledge of "soon to retire" employees. Lessons learned programs (LLP) involve the people, processes, and tools that support an organization's collection, analysis, and implementation of validated lessons learned.

Based on the definition, to what extent was a Lessons Learned Process implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	**4.0** ☐	**5.0** ☐	☐	☐	☐

105- Project Risk Assessment

The process to identify, assess, and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

Based on the definition to what extent was a Risk Assessment implemented on this project? 14 Responses 29 Responses

Not Implemented at All		Partially Implemented			Very Extensively Implemented		Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	**6.0** ☐	**7.0** ☐	☐

106- Are you willing to participate in the follow-up Interview?

☐ **Yes** ☐ **No**

Please send your completed survey to Dr. Stuart Anderson, Texas A&M University, or Dr. Jennifer Shane, Iowa State University, at s-anderson5@tamu.edu or jsshane@iastate.edu.

THANK YOU FOR PARTICIPATING IN THIS STUDY