AN ABSTRACT OF THE THESIS OF

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Title: Exploring The Relationship Between Engineering Design Project Characteristics and Risk Indicators

Abstract approved:

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Engineering design projects are implemented to accomplish a variety of goals in organizations. As the complexity of each project grows, the risk and uncertainty accompanying each project increases as well. As a result project managers must identify potential risks to projects and create plans to avoid realized risks leading to project failures. A risk indicator is a set of circumstances that are indicative of the strong likelihood of a risk event occurring during a project. This research was created to explore the relationship between risk indicators and various project characteristics, including project classification (the type of business goals the project was created to fill) and project type (whether the project was a first or a second attempt to solve an engineering

design problem). The results of this research are applicable to engineering managers who are responsible for the successful completion of design projects.

The research questions addressed in this study were: 1) Is there a difference in the frequency of occurrence between the 36 risk indicator codes? 2) If there is a difference, in the risk indicator frequencies, which risk indicator codes occur most often? 3) Which risk indicator codes are the most prevalent in association with certain project characteristics? These research questions were explored with the intent of discovering the risk indicators that are most important for project managers to consider in creating risk management plans based upon project characteristics.

The goal of this research is to contribute to the project management body of knowledge and to provide insight into the nature of the relationship between various project characteristics and risk indicators. To achieve this objective, eleven medium-complexity engineering design projects were selected for study. Two interview protocols were developed to elicit information about critical events occurring during the life cycles of these engineering design projects. Employees from a variety of job functions, who were directly involved in the selected projects, were interviewed. Multiple researchers coded transcripts created from the interviews. Researchers used a code scheme, developed from the literature on project success factors. The text from interview transcripts was analyzed to identify similarities and differences in the frequencies of different risk indicator codes for different project characteristics. Frequently occurring risk indicators were noted and implications for project managers were identified. The projects were divided into groups with similar project characteristics. Differences in the rates of occurrence of risk indicators were used to identify risk indicators, based on these specific project characteristics. Similarities and differences in the rates of occurrence of risk indicators in the different groups of projects were analyzed for emergent themes.

The results provided strong evidence for significant differences in the frequency of occurrence for risk indicators based on project characteristics. The most frequently occurring risk indicators differed for three project classifications (strategic, compliance, and operational). The most frequently occurring risk indicators also differed for original and rework projects. Nonparametric statistical tests were also applied to the data to test between significant differences across all risk indicators, using the same project characteristics.

Communication challenges were prevalent for all types of projects. Research has shown that inadequate communication can cause time and cost overruns on projects and can lead to rework projects. The types of communication challenges that were the most frequent differed between project classifications. For compliance projects, the most predominant communication risk was between the organization and suppliers. Communication risks between the organization and the customers occurred most often in operational projects. Finally in strategic projects, the most frequently occurring risks to communication occurred internally, between different business and engineering groups within the organization.

Another important theme was the need for standard procedures to provide adequate documentation to the different groups involved in projects. Risks associated with a lack of information provided to the different business and engineering groups working together on projects, were common among all projects. Many interviewees suggested the need for standard procedures to provide all necessary information to all groups assigned to each project, in order to facilitate the coordination of the work.

A lack of up front planning was detrimental for both original and rework projects. A lack of up front planning in original projects, at times, resulted in project failure, thereby creating the need for a rework project. In rework projects, planning at the beginning of a project was sometimes rushed due to the urgency of the project, thereby causing additional risks to the success of rework projects later on in the project life cycle.

Project managers can use the findings from this research to create more effective risk management plans tailored to the characteristics of a particular project. Knowledge of the risk indicators with the highest frequency of occurrence in each type of project can direct managers to the most effective use of risk management resources. The results of this research also add to the project management body of knowledge and provide a deeper understanding of the relationship between project characteristics and specific risk factors. The results also provide evidence that the project classification and project type are important determinants of the types of risks that will likely be faced in the course of a project. The approach used for this study can be applied to other industries and other types of projects to further extend the understanding of the relationship between project characteristics and risks. While there was evidence that some risks are typical to all design projects, a larger study is needed to generalize these findings beyond design projects and beyond the engineering organization studied.

EXPLORING THE RELATIONSHIP BETWEEN ENGINEERING DESIGN PROJECT CHARACTERISTICS AND RISK INDICATORS

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Rachel L. Yim, Author

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Exploring The Relationship Between Engineering Design Project Characteristics and Risk Indicators

1. Introduction

Projects are the means by which organizations accomplish new tasks to fulfill specific goals (Owens, Leveson, & Hoffman, 2011). Far too often projects fall short of reaching all of their goals (Lessard & Lessard, 2007). This research explored the relationship between engineering design project characteristics and risk indicators with the purpose of adding to the body of knowledge related to risk management. The practical purpose of the research is to increase the likelihood of success for medium-complexity engineering design projects. Findings from this research can be used by project managers to inform the development of risk management plans, based upon specific project characteristics.

1.1. Motivation

Projects are an integral part of organization's activities. Research has shown that over 50% of some corporation's value-adding activities are carried out through projects (Maylor, Vidgen, & Carver, 2008). For engineering design firms, new product development, redesigns, and enhancements to existing designs are accomplished through projects. Risks to projects are inherent and unavoidable (Miller & Lessard, 2001). Risk management has been acknowledged as one of the key aspects of project management (T. Raz & Michael, 2001). A risk is "a potential event that will adversely affect the ability of a system to perform its mission should the risk event take place" (Kwan & Leung, 2011, p. 635).

In the early stages of project development, potential risks to a project can be identified, allowing project managers to create comprehensive risk management plans to avoid, mitigate, or endure risks to the project as they occur (Aven & Krte, 2003). Risk indicators are circumstances that can be used to predict the likelihood of certain risk events occurring during a particular project. This research study was designed to identify risk indicators that are most often associated with different project characteristics.

1.2. Contribution

According to Vidal and Marle (2008), there is a need for a deeper understanding of the relationship between risk and project success. An opportunity exists to address this need and to contribute to the project management body of knowledge by more fully establishing the relationship between selected project characteristics and risk indicators. This study was designed to investigate the relationship between different project characteristics and risk indicators. The overall goal was to gain an increased understanding of the type of risks that most frequently accompany different types of projects.

This knowledge will provide project managers with a clearer picture of the risks to account for in risk management plans. A thorough understanding of the most important risk indicators occurring in projects can aid project managers with creating specific risk management plans for these projects. Knowledge of the most important risks to different classifications of projects can improve the success of each classification of projects.

1.3. Methodology

Qualitative and quantitative data analysis methodologies were employed in this research. The blend of both approaches allowed for a much richer analysis than simply utilizing one approach (Wolstenholme, 1999). A large engineering design company participated in this study, providing project documentation, interview participants, and general information about the company's design processes. Eleven different engineering design projects, similar in size and scope, were selected for analysis. These projects were all completed within one division of the company.

The projects were divided into different groups based upon the research question being addressed. In the study conducted to elicit the most important risk indicators based upon project classification, projects created to fulfill different organizational goals were divided into groups according to the type of goal the project was created to fulfill. Compliance projects were the projects created to fulfill requirements from regulatory agencies. Operational projects were projects requested by customers. Finally strategic projects were projects driven internally by the organization's desire to reduce cost or improve engineering designs. In the study conducted to elicit the most important risk indicators for original and rework projects, the engineering design projects were grouped according to whether the project was the first or second attempt to solve the original engineering design problem. Original projects were the first attempt, and rework projects were the second attempt.

Participants in this research were employees from various business and engineering job functions, who had participated in one or more of the eleven engineering design projects selected for analysis. A total of 70 interviews were conducted over a 28-month period. Interview notes were taken and were formatted into transcripts, which were subsequently analyzed to identify risk events encountered by the project teams during the course of the project.

Multiple researchers coded each transcript using a code schema developed from the literature on critical success factors. The code totals from each project were summed and analyzed to identify themes and patterns in occurrence and prevalence of specific types of risk events. Risk indicator codes with the highest totals were identified and provide valuable insight about important project elements to manage to help increase the likelihood of project success. Nonparametric statistical tests were also used to identify differences in the frequency of occurrence of specific risk indicators for different classifications and types of projects. The results of these analyses are described next.

1.4. Findings

The results of this study provide strong evidence that many of the most frequently occurring risk indicators differ based on two project characteristics: project classification and project type. Patterns in the frequency of risk indicator occurrences indicate that project managers should focus on different types of risks when managing plans for different classifications and types of projects. Some risks, however, were present in all projects. The most important risks identified, regardless of project characteristics, were centered around communication and planning.

The risks common to all projects are important for project managers to plan for no matter the type of project the project manager is assigned. The most prevalent risks for all project types were related to communication, documentation, and standard procedures. Communication risks were prevalent in all types of projects studied, appearing among the top ten risks in compliance, operational, strategic, original, and rework projects. The risk indicator codes for documentation and standard procedures were frequently coded in close proximity to one another, suggesting that these risks often occur concurrently. Interviewees often mentioned a desire for standard procedures to be created and for standard types of information to be available to all project team members.

The results of this research also provided evidence of significant differences in the frequencies of some risk indicators, depending on project classification. While communication risks were prevalent among all classifications of projects, the type of communication risks differed according to project classification (compliance, operational, strategic, original, or rework). Communication between groups within the organization was the most frequently occurring risk indicator for strategic projects, while communication between the company and outside entities was found to be more important in operational and compliance projects.

In rework projects, management communication of project requirements and other necessary project documentation at the beginning of the project was found to be the most prevalent type of communication risk. The three risk indicators specific to the top ten of rework projects were related to urgency, troubleshooting, and technological advances. These risks were often caused, in part, by the lack of careful up front planning. By not involving representatives from all groups involved in an original project, problems occurred during the course of a project. These problems often continued in the rework projects, created to solve the original design problem.

1.5. Conclusions

The findings from this research indicate there is a difference in types and frequency of occurrence for risk indicators. Project managers can apply the insight gained from this research to be better prepared for the risks most likely to occur based on known project characteristics. Further research is needed to extend the findings to other organizations and industries. Having provided an overview of the research motivation, contribution, methodology, and findings, a synthesis of relevant literature is presented next. The research results are then described in two different manuscripts. The first manuscript details the analysis of the impact of project classification on project risk. The second manuscript presents the analysis of the relationship between project type and project risk. The results of these two manuscripts are then discussed as a whole. The thesis concludes with a discussion of emergent themes, study limitations, and future research.

2. Literature Review

Much research has been published in the area of project management, particularly concerning the topic of project risk. Project risk has been rising in importance, as an increasingly large percentage of organizational capital is invested in accomplishing business goals through projects (Maylor et al., 2008). Although previous researchers have studied various elements of project management and risk, separately, there is a need for a greater understanding of how project characteristics can be used to improve approaches to project risk management. This research was designed to explore this relationship and to add to the current knowledge base by assessing this relationship in actual engineering design projects. This literature review provides background on a variety of topics related to organizational strategy, project management, project complexity, critical success factors, risk management, and decision-making. Research from each of these areas was reviewed and has been synthesized to provide context for this study.

2.1. Organizational Strategy

Each company has unique objectives, specific to that company's long-term business goals. Objectives need to be specific and measurable to ensure that employees and stakeholders understand the direction the company would like to go and the timeframe in which they would like to arrive (Gray & Larson, 2008). Strategies are the tangible plans, which include lists of actionable items, that are developed to reach a company's objectives (Anderson & Merna, 2003).

Detailed analysis of a company's Strengths, Weaknesses, Opportunities, and Threats (SWOT analysis) can be conducted to create a realistic assessment of a company's core competencies, vulnerabilities, risks, and opportunities in the market (Gray & Larson, 2008). This internal and external evaluation is important to ensure plans are achievable, leveraging a company's core competencies, while maintaining an acceptable range of risk and capitalizing on opportunities (Smith, 2008). Strategy is an important factor contributing to the formation of company culture, driving the way in which company objectives are achieved (Kwan & Leung, 2011). Once the objectives are stated and strategies have been formed to reach these objectives, projects are created as tangible tools to implement these strategies (Joshi, Kathuria, & Porth, 2003). The next section elaborates on the definition of projects and project management methodologies utilized to guide projects from conception to completion.

2.2. Project Management

Projects have been defined as complex, one-time, unique endeavors, constrained by time, resources, and requirements, undertaken to meet customer needs (Gray & Larson, 2008). According to Gray and Larson (2008) five major characteristics differentiate projects from regular organizational activities. The first major characteristic of projects is an established objective, a singular purpose or goal around which the entire project is focused on accomplishing. The second major characteristic is a defined life span with a beginning and an end. Projects are created with specific business goals in mind, dictating the launch and completion of a project (Lessard & Lessard, 2007). Organizational activities continue long after a project is finished. Third, a project typically requires the involvement of several departments or experts from several departments. Organizations are often times divided into separate functional departments who carry out functions insularly. To be accomplished projects may require participation and cooperation from many departments or from members of many departments (Maylor et al., 2008). Fourth, a project is a unique activity that has never been done before. The non-routine characteristics of projects present new challenges not normally found in daily operations, such as the creation or implementation of brand new technology (Project Management Institute, 2008; Tatikonda & Rosenthal, 2000). Fifth and finally, projects are constrained by specific time, cost, and performance requirements. Time, cost, and performance tend to be more closely scrutinized in projects than in daily operations. It is the job of project managers to work within these constraints to organize the human, material, and financial resources allocated to the project, to achieve the results (Nagadevara, 2012).

Project management is the formal application of established management tools, techniques, and practices to guide a project from project inception to completion (Lessard & Lessard, 2007). Project management methods are widely utilized in engineering design, as well as other industries, as an instrument to manage the accomplishment of unique tasks (Lessard & Lessard, 2007). Project management involves overseeing five main project stages: defining, planning, scheduling, implementing, and completing the project, which make up the project life cycle (Smith, 2008).

The first stage, defining, involves defining objectives of the project, the specific requirements, creating teams, and assigning general responsibilities to each group or team member. Next, during this planning stage, the constraints for the project are set in terms of scheduling, budgeting, resource allocation, and staffing. Planning is also the stage in which risk identification typically begins (Gidel, 2005). Following planning and scheduling is the implementing or execution stage. In this stage, the plans for the project are implemented. The majority of the work required to achieve project goals is conducted during the implementation phase. Resources allocated for the project are utilized during the implementation phase. The final phase is project completion and delivery. In this stage the finished product is delivered to the customer, and the resources assigned to the project are redeployed. Customer delivery can include training the customer to use the product, as well as providing the necessary documentation, along with the product. Resources used during a particular project, such as materials and equipment, are released for use in other projects during this phase (Gray & Larson, 2008).

It is the job of a project manager to direct the project through each phase of the project (Maylor et al., 2008). Since projects are, by definition, unique undertakings with low levels of repetition, typically requiring the involvement of one or more functional departments or experts, it is imperative for project managers to be adaptable in potentially complex environments (Parsons-Hann & Liu, 2005). Project managers are responsible for the performance of a project, managing limited time and resources to produce a successful outcome for the project (Bryde, 2008).

The proportion of work in companies undertaken as projects is increasing (Geraldi, Maylor, & Williams, 2011). As industry takes note of the growing importance of effective project management, the membership in professional organizations such as the Project Management Institute (PMI) is expanding (Maylor et al., 2008; Project Management Institute, 2008). According to Gray and Larson (2008), in the future companies will see an expansion in the importance and role of project management contributing to achieving the strategic business goals of an organization. This section provided an overview of projects, project stages, and project management. The next section will describe project complexity in engineering design projects. This will provide context for the industry in which this research was conducted.

2.3. Project Complexity

Although much research has been published on the topic of complexity, there is a lack of consensus on a single definition of complexity (Parsons-Hann & Liu, 2005). *The Merriam-Webster Dictionary* (1974) defines the word "complex" as "a whole made up of complicated or interrelated parts." Complexity itself is defined as "the state of being complex". According to Vidal and Marle (2008) complexity is everywhere and continually growing. Complexity is one of the main sources of unpredictability in projects leading to complications and project failures. Since complexity is an intrinsic part of projects, it is important that effects of complexity on projects are understood (Baccarini, 1996). As implied by the definition of complex, there are many interrelated parts or factors within projects. It is important to clarify the types of complexity present in a project (Geraldi et al., 2011). Table 1 summarizes descriptions of project complexity from frequently cited literature sources. An overview of two of the most frequently cited project complexity frameworks are summarized next to provide additional insight on the role of complexity on project success.

Table 1: Project Complexity Definitions from Literature

Description	**Reference**
"…it was concluded that not only the technology or technological aspects in a project determine the project's complexity….also organizational and environmental aspects play an important role." (p. 732)	Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011).
"Institutional and cultural differences between societies and organizations give rise to institutional complexity, the additional form of uncertainty in global projects when compared to projects with participants coming form a a single country and culture." (p. 12)	Koivu, T., Nummelin, J., Tukiainen, S., Tainio, R., & Atkin, B. (2004).
"In a complex system, the different elements interact and produce outcomes that are nonlinear and unpredicatable." (p. 516)	Maylor, H., Vidgen, R., & Carver, S. (2008).
"Complexity is quantity and diversity of components and relations." (p. 2)	Vesterby, V. (n.d.).
Projects requiring major modifications or new-to-the-world projects are considered complex projects. (p. 188)	Clift, T. B., & Vandenbosch, M. B. (1999).
"Complexity is treated as: (a) primarily a psychological experience, (b) am interation between task and person characteristics (c) a function of objective task characteristics." (p. 40)	Campbell, D. (1988).

2.3.1. Baccarini Project Complexity Framework

Baccarini (1996) described two types of project complexity, most frequently mentioned in project management literature, as organizational complexity and technological complexity. Each type of project complexity is further defined in terms of differentiation and interdependence. Organizational complexity will be described first, followed by technological complexity.

The functions of organizational structure are the "definition of relationships in terms of communication and reporting; allocation of responsibility for authority and decision-making; and allocation of tasks" (Baccarini, 1996, p. 202). More differentiated organizations are more complex. Organizational complexity is further differentiated into two dimensions: vertical and horizontal. Vertical differentiation is related to the hierarchical structure of the organization. Horizontal differentiation refers to the number of formal organizational units involved in the project and the task structure (i.e. whether or not the task requires specialized expertise). Organizational interdependency refers to the level in which these organizational factors are related or dependent on each other.

Technology, according to Baccarini (1996), is the transformation process utilizing materials, techniques, knowledge, and skills to change inputs into outputs. Technological complexity by differentiation stems from the number and diversity of inputs and outputs, the number of separate actions or tasks required to achieve a project, and the number of specialties required by a project. Technological complexity caused by interdependencies can stem from interdependencies between any of these characteristics.

Organizational and technological differentiation and interdependencies contribute to the project complexity. Greater differentiation or interdependence leads to greater complexity of the project. The solution to managing differentiation and interdependence proposed by Baccarini (1996) is "integration by coordination, communication, and control" (Baccarini, 1996, p. 203). The Baccarini framework is one view of complexity. A second view of complexity, proposed by Vidal and Marle (2008) is presented next.

2.3.2 Vidal & Marle Project Complexity Framework

Vidal and Marle (2008) have defined project complexity as "… the property of a project which makes it difficult to understand, foresee and keep its overall behavior, even when given reasonably complete information about a project system. Its drivers are factors related to project size, project variety, project interdependence and project context" (p. 1101). Vidal and Marle introduced a comprehensive framework for defining different types of complexity based upon four drivers: the size of a project system, variety in a project, interdependencies of project elements, and the context of a project. The four drivers are elaborated upon in more detail next.

Vidal and Marle (2008) refer to the size of a project as a “necessary condition for project complexity” stating that there should be a minimum size requirement for a system to be considered “complex” (p. 1097). Measurable factors contributing to project size include the duration of the project, number of activities, number of decisions to be made, number of departments involved, number of groups/ teams to be coordinated, and other similar categories.

Variety encompasses diversity in any project elements, including variety in project management methods and tools used, variety in information systems used, variety in organizational skills needed, etc. Variety in a project is second driver of project complexity. Variety in staffing or resources can also add to the complexity of a project (Vidal & Marle, 2008). Interactions between the variety of elements in this project complexity driver lead to the third driver of project complexity, interdependencies within project systems.

Interdependencies within project elements are considered by Maylor (2008) and Vidal and Marle (2008) to be the greatest contributors to complexity in a project. Contributors to complexity include but are not limited to availability of people, materials, and any resources due to sharing; dependencies between schedule; between sites, departments, and companies; and interdependence of objectives. It is believed that project management tools are not designed to properly manage the complexity caused by the dependencies and influence of each component of a system on the other components (Vidal & Marle, 2008).

Elements of context are the final contributor to complexity in Vidal and Marle’s (2008) project complexity framework. Context is considered to be the common denominator in any complex system. Context refers to the environment in which the project must be accomplished. This includes company culture, competition, local laws, industry regulations, and the degree of innovation within the organization. Vidal and Marle advise that project complexity should not be measured or analyzed without considering context.

According to Vidal & Marle (2008) the relationship between project complexity, project risks, project uncertainty, and project success is still somewhat indeterminate. Parsons-Hann and Liu (2005) assert that research has shown complexity contributes to failure in projects. What remains to be seen is to what extent this link between complexity and project failure holds true. The more complex a project is, the greater the potential for risk and uncertainty (Chapman, 2001). As projects grow in complexity project managers must utilize different project management techniques to bring about project success (Geraldi et al., 2011). The goal is to properly manage the uncertainty and risk that accompanies complexity to mitigate or avoid the negative aspects of risk while capitalizing on the opportunities created by uncertainty (Vidal & Marle, 2008). The tailoring of specific project management methodologies is particularly important for the management of risk and uncertainty. Thus, a comprehensive understanding of the complexities of a project is imperative for informed project planning and to achieve successful project conclusion. Defining success for projects is also relevant. The next section will synthesize various definitions of project success as proposed by previous researchers.

2.4. Project Success Factors

The successful completion of a project may be considered an obvious goal of project management, but there is little consensus between researchers on the definition of project success (Maylor et al., 2008). This ambiguity stems from differences in the interests of the stakeholders of a project. For the same project, the priorities of a customer might differ from the priorities of upper management, e.g. functionality versus cost savings (Baccarini, 1996). Thus, it is possible that the customer might consider a project successful when upper management has deemed the same project a failure. Differing values can also lead to different assessments of the outcomes of a project (Baccarini, 1996). A clear understanding of measures by which the success or failure of a project can be assessed is important. Table 2 summarizes some of the definitions of project success contained in the published project management literature from 1996-2012.

Table 2: Project Success Definitions from the Literature (1996-2012)

Definition	**Reference**
"The success is defined by a set of criteria that the outcome or the solution must meet to be considered 'successful'" (p. 19)	Babu, G. N. K. S., & Srivatsa, S. K. (2011).
Keeping to an efficient schedule will lead to a more successful project. (p. 187)	Clift, T. B., & Vandenbosch, M. B. (1999).
"Project success is an objectively measureable state describing how well the project performed." (p. 445)	De Bakker, K., Boonstra, A., & Wortmann, H. (2012).
A project is successful when the objectives are met. (p. 516)	Maylor, H., Vidgen, R., & Carver, S. (2008).
Project success is made up of how successful project management and the end product are. (p. 2)	Van der Westhuizen, D., & Fitzgerald, E. P. (n.d.)

Although authors have proposed different definitions for project success and the factors influencing project success, there is overall agreement that it is imperative for managers to identify the factors that are key to the success of a project in order to develop the best approach for managing the project (Nagadevara, 2012). These factors are called critical success factors (Chow & Cao, 2008). Critical success factors are the activities that must be completed for a project to be successful (Yaraghi & Langhe, 2011). Due to the importance of critical success factors in ensuring project success, critical success factors should be carefully monitored by project managers (Babu & Srivatsa, 2011).

A critical success framework is defined as an organized structure of critical success factors. Table 3 summarizes different definitions of critical success factors from the literature.

Table 3: Critical Success Factor Definitions

Critical Frameworks Success	
Definitions	**Author(s)**
Specific factors of a project which must be successful in order for the project goals to be considered successful (p. 962)	Chow, T., & Cao, D.-B. (2008).
It is also our intent in this paper to clarify what should be called critical success factors, and their effects (called "system responses") which lead to project success or failure. (p. 143)	Belassi, Walid, and Oya Iemeli Tukel. 1996.
Factors which affect the design and implementation stages of a project and "have influence on the inclination and readiness of a corporation" (p. 551)	Yaraghi, N., & Langhe, R. G. (2011).
"[Critical Success Factors] for any business consists of a limited number of areas in which results, if satisfactory, will ensure the organization's successful competitive performance." (p. 3434)	Zwikael, O., & Globerson, S. (2006).
Fulfilling all the project success factors will lead to a successful project. (p. 115)	Nagadevara, V. (2012).

Critical success factor frameworks contain many common elements as shown in Table 4. The most important contributors to project success, as identified in different frameworks, are influences from the external environment, influences from the internal organizational structure, elements of the project itself (size, uniqueness, degree of innovation), communication and coordination of the individuals and teams participating in the project, and factors related to the skills of company management. In Table 4, the critical success factor elements included in each framework are noted.

Table 4: Critical Success Factor Framework Elements

Authors	External Influences	Internal Organizational Structure	Company Management	Team Member Coordination	Project Elements
Belassi, Walid, and Oya Iemeli Tukel (1996).	X	X	X	X	X
Chow, T., & Cao, D.-B. (2008).		X	X	X	X
Nagadevara, V. (2012).			X	X	X
Parsons-Hann, H., & Liu, K. (2005).	X	X		X	X
Van der Westhuizen, D., & Fitzgerald, E. P. (n.d.).				X	X
Yaraghi, N., & Langhe, R. G. (2011).	X	X	X	X	X
Zwikael, O., & Globerson, S. (2006).	X	X	X	X	X

Previous research has suggested that understanding and satisfying critical success factors is an important step in achieving project success. One objective of this study was to investigate the relationship between different project characteristics and risk indicators. A review of the literature related to the project characteristics included in this research is presented next.

2.5. Project Characteristics

Organizations undertake many types of projects, and while each organization may have its own schema for classifying projects, most projects generally fall into three classifications: compliance, operational, and strategic (Gray & Larson, 2008). Compliance projects are projects that are initiated to meet regulatory requirements and are highly critical to continuing an organization's business operations. Operational projects are projects that are necessary to improve current business operations. The purpose of strategic projects is to support an organization's long-term objectives. An example of a strategic project is a project that implements novel technology into a product or manufacturing process to establish a market advantage. In addition to project classifications, the second project characteristic studied was project type. Specifically two types of projects, original projects and rework projects, were studied and are discussed next.

2.6. Project Types

Original projects are the first attempt to solve a problem or fulfill goals laid out by management (Chua & Verner, 2010). Ideally, all projects would be successful on the first try, but far too often projects fail to meet all requirements set forth at the inception of the project (Gray & Larson, 2008). Rework projects are undertaken to correct mistakes or shortcomings in original projects. Rework projects can be considered the second, or subsequent, attempt(s) to fulfill all project requirements.

Authors have used many definitions for rework. Variation of a project from the desired result can create the need to initiate rework projects. Love and Edwards (2005) defined attributes of system variation as the following: deviation, change, error, omissions, defect, failure, damage, repair, and nonconformance. Any of these listed attributes can cause an activity or task to need correction, thereby creating need for rework projects. All projects can be reduced to a sequence of activities that must be completed in order to fulfill project goals (Owens et al., 2011). Each activity has the potential to be completed correctly or incorrectly. If an error in completing a task is noted immediately, the task can be reworked as part of an original project. If errors are not caught, Owens, Levenson, and Hoffman (2011) label this undiscovered rework, and undiscovered rework can ultimately lead to unsuccessful projects and the initiation of rework projects.

The consequences of rework are often undesirable and can be avoidable if projects are properly managed at the outset. The two most prominent negative consequences of rework projects are overruns in time and budget (Love & Smith, 2003). Understanding sources of rework projects is key for project managers looking to eliminate the need for rework projects (Love & Edwards, 2005). Poor documentation and poor project management have been identified as the leading causes of rework (Love & Smith, 2003). More specifically, unclear requirements, deficiencies in communication and proper documentation, and the inability to carry out requirements as planned are contributors to the undertaking of rework projects.

Damian and Chisan (2006) conducted a study about the relationship between project requirements and management processes tied to productivity, quality, and risk management. Damian and Chisan (2006) determined that the definition and management of requirements is critical in the beginning stages of project planning, stating "Attention to up front requirement activities has been said to produce benefits such as preventing errors, improving quality, and reducing risk…" (p. 433). Up front planning early in the requirements phase of a project and clear communication of these requirements are key to preventing rework projects (Chua & Verner, 2010).

2.7. Uncertainty and Risk

Uncertainty is an unavoidable negative consequence of project complexity (Vidal & Marle, 2008). Howell et al. (2010) assert that uncertainty "encompasses not only probabilistic or undefined outcomes but also ambiguity and lack of clarity over situational outcomes" (p. 258). Pich et. al. (2002) suggest that the appropriate project management techniques and actions depend on the type of uncertainty present in a project and the complexity of the project due to the interactions and interdependence of the different factors contributing to project complexity. The interconnectivities and interdependence of factors causing project complexity can result in unintended consequences, even when the actions taken are exactly as the project manager intended (Tatikonda & Rosenthal, 2000).

One source of uncertainty in projects is ill-defined project goals or requirements (Maylor et al., 2008). One of the most significant challenges to creating clear requirements is that project stakeholders may have varying and conflicting goals for a project (Parsons-Hann & Liu, 2005). Projects with many stakeholders face the task of creating a consistent set of project requirements addressing the needs of a large set of stakeholders, where some stakeholders are internal to the organization and some stakeholders are external to the organization. Once requirements have been identified, project managers must articulate these goals in a form that is understandable to all stakeholders involved in project planning and implementation, as well as stakeholders impacted by changes resulting from the project (Parsons-Hann & Liu, 2005).

While uncertainty can cause concern for project managers looking for the best possible outcomes for the projects they are responsible for, researchers do not recommend avoiding projects with uncertainty. Complexity, which causes uncertainty, is an inherent part of all projects to some extent (Vidal & Marle, 2008). It is important for project managers to understand the types of uncertainty associated with a particular project and to choose project management strategies accordingly (Pich et al., 2002). Uncertainty can lead to opportunities for organizations that should not be overlooked (Vidal & Marle, 2008).

While there are potential positive consequences to uncertainty, risks presents potential negative impacts of uncertainty for a project (Project Management Institute, 2008). Risks are inherent in any project requiring time and resources. It is the responsibility of project managers to identify risks to a project before the project begins and to create risk management plans accordingly (Chapman, 2001a). Project complexity contributing to increased risk can be further complicated by interdependencies between risks (Wibowo & Deng, 2010). Risks are multi-dimensional, and the combination and interaction of risks can lead to unexpected or unwanted results (Miller & Lessard, 2001a).

Risk indicators are events that can predict the likelihood of a risk occurring during the lifecycle of a project. The identification of risk indicators in a project can assist project managers in creating specific risk management plans. Critical success factors are activities that must be accomplished in order for a project to be successful. If risks occur that interfere with these critical success factors, the likelihood of project success decreases.

Using critical success factor frameworks, five high-level categories of risk sources can be identified: risks related to the external environment (RTE), risks related to the organization (RTO), risks related to management performance (RMP), risks related to the project manager and team (PMT), and risks related to the project itself (RTP). Table 5 provides a snapshot of how each of these risk source categories map to nine published studies on project risk.

Table 5: Mapping of Risk Sources Included in Project Risk Studies

Authors	RTE	RTO	RMP	PMT	RTP
Babu, G. N. K. S., & Srivatsa, S. K. (2011).	X	X			X
Braaksma, A. J. J., Meesters, A. J., Klingenberg, W., & Hicks, C. (n.d.).	X	X			X
Institute of Operational Risk. (2010).	X	X	X	X	
Kloss-Grote, B., & Moss, M. A. (n.d.).	X		X	X	X
Mehr, A. F., & Tumer, I. Y. (2006).					X
Miller, R., & Lessard, D. (2001).	X	X			X
Raz, T., & Michael, E. (2001).			X	X	X
Sato, T., & Hirao, M. (2013).	X	X			X
Williams, T., Eden, C., Ackermann, F., & Tait, A. (1995).	X			X	X

A thorough understanding of the risks associated with projects early on in the project life cycle is imperative for project managers to create effective risk management plans (Gray & Larson, 2008). Managers utilize knowledge about project risks as one of the main influencers of system-level decision-making (Mehr & Tumer, 2006). The decision-making process should be impacted by the risks identified during the planning stage of the project. The next section describes risk-based decision-making and its influence on project management.

2.8. Risk Based Decision-Making

Engineering design projects are widely considered to be decision-making problems (Hazelrigg, 1998). Project managers for engineering design projects are required to find optimal solutions to complex decision-making problems that will lead to the highest-valued outcome (Gidel, 2005). The use of risk-based decision-making has been shown to minimize the overall expected risk to a project. Information about potential risks to a project can be used to prevent risk events from occurring or to minimize the overall effects of risk events on the success of a project (Miller & Lessard, 2001). Decision analysis can be broken down into three components: the identification of all available options, the determination of the expected result associated with each option, and the placement of a value on each expected result.

Similar to the components of decision-making, the risk management process begins by generating a list of all possible risks that could affect a project (Gray & Larson, 2008). The second step of the risk management process focuses on evaluating and prioritizing identified risk. One method for evaluating risks is Failure Modes and Effects Analysis (Teoh & Case, 2004). This technique begins with a brainstorming session in which stakeholders identify possible risk events. The probability and severity of each possible risk event is assigned a value. The risks with the highest values are then assigned priority by the project manager. The development of a risk response plan is the next step. Since risks can have a positive or negative effect, not all potential risk events should be avoided (Gray & Larson, 2008). The project manager must separate risks from opportunities and decide which risks to mitigate, which to avoid, and which to accept (Babu & Srivatsa, 2011). The final step is to implement risk management plans based on this evaluation of risk (Kwan & Leung, 2011).

The goal of risk-based decision-making is to select the option with the highest valued expected result, thereby minimizing the overall expected risk to a system (Mehr & Tumer, 2006). Non-optimal decision-making can be caused by failure to thoroughly examine all of the options available, incorrect expected outcomes, or assignment of improper values to each outcome (Howell, Windahl, & Seidel, 2010). Decision support tools can be used to collect and analyze data to assist with the three decision-making phases and to facilitate the selection of optimal solutions (Gidel, 2005).

The decision-making literature defines information as data that has been converted into a meaningful form, that will affect current or future activities or decisions (Perry, 2008). When information is accessible, outcomes of decisions are more likely to be desirable (March & Smith, 1995). Information availability is an influencer for individuals, such as project managers, to enable the formation of accurate beliefs about a situation. These correct assessments directly correlate to effective decisions and positive outcomes (March & Smith, 1995). It is common for organizations to compile large quantities of data from past projects, which can be converted into useful information with appropriate techniques. Though many large engineering design firms possess this data, there is often a strong need for a strategy that will produce information capable of improving project decisions and to facilitate informed, risk-based, decision-making processes.

2.9. Conclusion

Project management and the factors affecting project success are important to understand. There are many proposed frameworks in the literature intended to help researchers understand what is necessary to achieve project success. Similarly project risks and project risk management have also been studied. This research will bridge the gap between these two subjects and will help create a deeper understanding of how different project characteristics may impact the susceptibility of certain projects to certain types of risk events. The next chapter provides a detailed description of the methodology used to address the research questions.

3. Methodology

This chapter describes the research methodology developed for this study. The chapter begins with background information on qualitative data analysis and critical incident methodology. Following the discussion of these two methodological concepts is a detailed explanation of the research design, project selection, participants, data collection instruments, coding schema, code methodology, coder agreements, data screening, and analysis. This study was created to identify risk indicators associated with different project characteristics and characterize the nature of the relationship between project characteristics and risk indicators. This knowledge can be used to enhance the ability of project managers in creating risk management plans, subsequently reducing overall risk to a project. An overview of qualitative data analysis is presented first to provide a broad context for the approach used in this study.

3.1. Qualitative Data Analysis

Miles and Huberman (1994) describe qualitative data as "a source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts" (p. 1). Auerbach and Silverstein (2003) define the analysis of qualitative data as "research that involves analyzing and interpreting texts and interviews in order to discover meaningful patterns descriptive of a particular phenomenon" (p. 3).

While quantitative data analysis typically involves the systematic empirical analysis of numerical data using mathematical and statistical techniques, qualitative data are typically in the form of words rather than numbers. Qualitative data can be collected from printed text, interviews, surveys, open-ended questions, and descriptions of observations. Qualitative data are collected in close proximity to the phenomena studied, and thus can contain greater contextual detail than quantitative data (Miles & Huberman, 1994). Rather than simply gathering a snapshot in time answering questions of "what" and "how many", qualitative data can answer the questions of "why" and "how". Quantitative and qualitative data require analysis and interpretation to bring about understanding.

Basit (2003) calls data analysis the most challenging and the most crucial aspect of qualitative research. Since the reliability and validity of the findings produced by qualitative methods are dependent on the comprehensiveness of the research design, it is important for the methodology to be thorough (Wolstenholme, 1999). The rigor of qualitative research is measured by the steps taken and methods applied to show integrity and competence (Berends & Johnston, 2005). Berends and Johnston (2005) emphasize that the methods considered by funding sources and journal editors to show rigor in qualitative research are: purposive sampling, multiple coders, respondent validation, and triangulation. Many of these methods for ensuring the thoroughness and accuracy of the collection and analysis of qualitative data were employed in this research.

There are many criteria important to consider when designing the sampling methodology in a qualitative study. The sampling strategy should be relevant, likely to produce a rich and detailed data set, improve the generalizability of the discoveries, produce plausible explanations, be ethical, and most importantly, feasible (Miles & Huberman, 1994). A purposive sampling process will generate rich data content, which is a key advantage of qualitative data analysis (Curtis, Gesler, Smith, & Washburn, 2000).

In accordance with recommendations from Berends and Johnston (2005), multiple coders examined the dataset and applied codes from the code schema, where applicable. Respondent validation was completed by comparing findings from the coding process with the original transcripts. The most frequently occurring codes were compared to the context described in the transcript text to verify that codes were appropriately applied.

Triangulation involves using multiple approaches to study a phenomenon (Bekhet & Zauszniewski, 2012; Leech & Onwuegbuzie, 2007). Triangulation through gathering data from multiple sources was applied during the collection of data. Employees with different job descriptions and in varying project roles were interviewed for each project in order to obtain the most complete understanding of the circumstances surrounding the project.

Both qualitative and quantitative data analysis techniques were employed for this research project. Wolstenholme (1999) conducted a study to evaluate the strengths and weaknesses of qualitative and quantitative modeling, and concluded that both qualitative and quantitative data analysis approaches are valuable. A well-planned blend of qualitative and quantitative data analysis is beneficial in organizational research (Wolstenholme, 1999). Critical incident methodology is described in the next section.

3.2. Critical Incident Methodology

The critical incident methodology originated in the World War II Aviation Psychology program as a methodology for qualitative research, and it is currently employed in many disciplines. Flanagan (1954) defined critical incident methodology as "a set of procedures for collecting direct observations of human behavior to facilitate their potential usefulness in solving practical problems." The purpose of critical incident methodology is to determine the factors that support or hamper an activity or experience (Butterfield, Borgen, Maglio, & Amundson, 2009). According to Butterfield et al. (2009), four defining elements set apart critical incident methodology from other qualitative data collection methods. These defining elements are summarized in Table 6.

Table 6: Defining Elements of the Critical Incident Methodology

Element	Critical Incident Method (Butterfield, 2009)
1	Focus on critical events, incidents, or factors that affect (positively or negatively) the performance of an activity
2	Data collection is performed through interviews, in person or on the phone
3	Data analysis is performed through categorizing the data and searching for emerging patterns
4	Categories have operational definitions and self-descriptive titles

Flanagan (1954) proposed three general steps for implementing the critical incident methodology. First the general purpose of the activity must be specified. Second, the conditions for determining whether the activity was performed effectively or ineffectively must be identified. Last, observers are given specific measures for judging whether or not the observed behaviors in the activity met the criterion. The key component of critical incident analysis is that after the collection of a number of observations, these observations are determined to be objective or accurate if multiple independent observers made the same judgment (Chell & Pittaway, 1998). Having provided general background on both qualitative data analysis and critical incident methodology, the specific research design used for this study is described next.

3.3. Research Design

This study was designed to determine the relationship between various project characteristics and risk indicators. Qualitative data analysis techniques were used to assign risk indicator codes to interview transcripts developed from eleven different engineering design projects. Each project was also classified using various project characteristics. The data for this research were collected from medium complexity engineering design projects that were completed within a 24-month time frame within a single organization. Study participants were project managers, engineers, and other product design and certification specialists who worked directly on one or more of the selected engineering design projects.

Two surveys were developed to elicit responses from participants, identifying critical incidents, which occurred during the life of the project. The surveys were administered through interviews. The research team conducted all interviews at the site of the company. After each interview was completed, interview transcripts were written, and researchers subsequently coded interview transcripts. Codes were assigned to any line in the transcripts in which a project risk was identified. The coding framework utilized in this study was developed based on the list of critical success factors taken from Belassi and Tukel (1996) and from Chow and Cao (2008). The assigned codes represented distinctive risk indicators.

After multiple researchers had coded each interview transcript, using a defined schema of 36 risk indicator codes, risk indicator totals were calculated for each transcript and ultimately for each project. These totals were translated to percentages by project. Q-Q plots, provided in Appendix A, revealed a non-normal distribution of risk indicator code percentages. As a result nonparametric statistical analyses were determined to be appropriate in subsequent quantitative analyses. The Mann-Whitney and Kruskal-Wallis nonparametric tests were used to identify statistically significant differences in the relative frequencies of risk indicator codes for different project classifications and project types. Box plots were created to visualize variability in risk indicator code frequency by percentages. In addition, histograms of the most frequently occurring risk indicators for each project classification and type were also analyzed. Similarities and differences in risk indicator code frequencies, based on project characteristics, were identified. Patterns in the presence and frequency of risk indicators were used to identify themes and to draw conclusions about the relationship between project characteristics and risk. The next section explains the project selection process used for this study.

3.4. Project Selection

The organization participating in this study specializes in designing and manufacturing complex products made of millions of parts and multiple complex engineering systems (e.g. mechanical, electrical, software, etc.). This organization is structured into multiple divisions. Each division is responsible for the development and manufacture of a unique product, from concept through customer delivery, as well as for subsequent improvements and design of new product subsystems. Each division houses multiple departments responsible for various engineering and business functions. Hundreds of engineering design projects, of various sizes and scope, are undertaken in each division every year. A single division within the organization participated in this study. Participants in this study represented a variety of departments. Departments were typically dedicated to a specialty area (e.g. structures, electrical systems, production scheduling, etc.), and each department was responsible for specific project deliverables.

Engineering design projects are undertaken for a variety of reasons. Projects can be driven by external factors, such as changes in technology, new regulations, part obsolescence, and customer requirements. Internal priorities can also be used to initiate a project to, for example, drive cost savings. Projects selected for this study were initiated for many different reasons. The engineers and project managers responsible for project initiation constructed detailed project documentation during the initial project planning phase, specifying the rationale for initiating the project, the deliverables of the project, the job titles and names of employees who would work on the project, the total number of expected hours to complete the project, key project activities, and departments involved in the project.

Hundreds of detailed project documents were made available to the researchers to select projects for inclusion in the research. Medium-complexity engineering design projects, based on the total hours and the number of departments involved, completed within the same 24-month timeframe, were chosen for study. The selected projects were more complicated than replacing a single part in the product, but less complicated than designing an entirely new product.

Eleven projects were selected for inclusion in this research. The projects took between approximately 1,500 and 16,500 person hours to complete, involved between two and eight departments, incorporated fewer than twelve distinct activities, and had between ten and 31 engineers assigned to the project. These project characteristics are summarized in Table 7.

Table 7: Project Details for the Eleven Selected Projects

Project Number	Type of Project	Total Hours	Project Objective	Project Classification
1	Mechanical Redesign	2,728	Correct Service Related Problem	Operational
2	Mechanical Redesign	2,672	Meet Customer Requirement	Operational
3	Environmental Systems Modification	14,593	Correct Engineering Error	Operational
4	Electrical Systems Modification	2,928	Meet Additional Safety Requirements	Compliance
5	Replacing Obsolete Part	10,280	Meet Subcontractor Requirement	Compliance
6	Electrical and Software System Upgrade	16,569	Address Cost Savings	Strategic
7	Structural Redesign	15,390	Reduce Weight	Strategic
8	Electrical and Software System Redesign	5,123	Address Change in Certification Requirements	Compliance
9	Electrical and Software System Upgrade	2,292	Improve Design	Strategic
10	Electrical Systems Modification	1,477	Correct Service Related Problem	Operational
11	Software Upgrade	4,575	Meet Customer Requirement	Operational

3.5. Project Classification

Once the projects were selected, they were classified into different groups for comparison according to the objectives of this research. One of the variables of interest in this study was the project classification. The company classified each engineering design project according to the types of business goals the project was created to fulfill. The eleven projects chosen for this study were created to achieve nine different objectives (See Project Objective in Table 7). The Gray and Larson (2008) project classification framework was applied to further identify each of the eleven projects into the three project classifications: compliance, operational, and strategic. Table 8 summarizes the linkage between the project objective specified by the company and the Gray and Larson project classification framework.

Table 8: Mapping of Project Objectives to Project Classification (Number of Projects)

Compliance	Operational	Strategic
Meet Additional Safety Requirements (1)	Correct Service Related Problem (2)	Address Cost Savings (1)
Meet Subcontractor Requirement (1)	Meet Customer Requirement (2)	Reduce Weight (1)
Address Change in Certification Requirements (1)	Correct Engineering Error (1)	Improve Design (1)

Compliance projects were driven by changes in certification requirements, regulatory changes affecting the company directly, or regulatory changes affecting the company's suppliers. Operational projects were projects undertaken to improve current operations and to continue to deliver products to the customer. Operational projects were those projects undertaken to address service related problems, changing customer requirements, or the correction of problems caused by engineering redesigns. Strategic projects were management-driven projects created to reduce costs or create enhancements and design improvements to the product.

The other project characteristic of interest to this study was whether projects were original projects, defined as a first attempt to solve an engineering design problem, or whether projects were rework projects, defined as the second attempt to solve an engineering design problem. The company provided the research team with the data to identify each project as either original or rework. The participants for this study were selected from employees assigned to the eleven selected projects. The next section provides details related to the selection of participants and participant characteristics.

3.6. Participants

Participants selected for this research worked directly on one or more of the projects studied. The original project documents provided by the company to the researchers contained the name and job title of each employee assigned to each project. The researchers identified potential participants from this list based upon the type of involvement each employee had on a particular project. Some employees were directly involved in working closely with many departments in carrying out project work. Others worked entirely within their own department to accomplish a specific set of activities. Employees with a variety of job titles were selected, in order to obtain a well-rounded perspective for each project. Once the researchers compiled a list of potential research participants, a liaison from the company sent an email to potential participants, inviting them to participate in this study. The individuals who were interested in participating responded to the email. The company then worked with the employee to find a suitable interview time. The company provided participants with a charge number for the employee's time to ensure that any interested employee could participate. The company scheduled all employee interviews and provided the researchers with private conference rooms for each of the scheduled interviews.

Employees interviewed for this study served in a variety of jobs and functional areas, including engineering, project management, production scheduling, and certification. An overview of the job titles of employees interviewed for each project is provided in Table 9. The majority of participants, regardless of job title, had mechanical or electrical engineering degrees. Due to the nature of the complex systems developed in the division of the organization participating in this study, each employee had a general understanding of engineering principles, as well as project management techniques.

Table 9: Summary of Job Titles for Participants Interviewed for Each Project

Job Function	Project										
	1	2	3	4	5	6	7	8	9	10	11
Electrical Certification											X
Engineering - Air Conditioning		X									
Engineering - Electrical		X	X		X	X		X	X		
Engineering - Environmental Control Systems		X			X						
Engineering - General							X				
Engineering - Mechanical					X	X					
Engineering - Payloads	X										
Engineering - Service			X								
Engineering - Structural						X	X				
Engineering - Systems									X	X	
Engineering - Wiring Installation			X								
Production Scheduler			X								
Project Engineer	X							X			
Project Management - Engineering Change Control			X		X		X	X			
Project Management - General	X				X					X	

Individual employees and groups of employees from different departments within the organization worked together to accomplish the activities required by each project, from defining the project through project delivery. The complexity of the product made this type of teamwork essential. When necessary, experts joined together from different departments to work in partnership to create engineering design solutions. This collaborative environment provided many of these employees with a broad perspective. Some project activities were completed completely within separate departments in the organization, with each department responsible for separate deliverables. Employees participating in these project activities did not necessarily have a complete understanding of the project as a whole, but were well versed in details of a single department. The researchers selected employees with many different job titles and from different functions in order to obtain a broad view of critical incidents occurring during the project.

Each participant signed a consent form before participating in this study. Studies including human research participants are required to be approved by the Institutional Review Board (IRB) before the data collection can begin. Details related to the IRB application and research protocol are included in Appendix B. The data collection instruments and data collection processes, developed for this research, are described next.

3.7. Data Collection

In order to investigate the relationship between the identified project characteristics and risk indicators, two interview protocols were developed. The first set of interview questions, Interview A, was created using critical incident methodology. See Table 10. Critical incident methodology is utilized to obtain responses detailing first hand observations of a critical event directly from multiple observers in order to obtain an objective understanding of the event itself and the circumstances surrounding it (Butterfield et al., 2009).

At the start of each interview, the researcher team introduced themselves and answered any questions the participant had about the interview or the goals of the study. The researchers then informed the participant that questions would be asked one at a time and to answer the questions based on the employee’s knowledge of and experiences on a particular project.

Table 10: Interview A

Questions
1. What level of 'criticality' would you put the incident at, on a scale of 1 to 5? (1=important, 3=significant and 5=critical)
2. What were the events or circumstances that led to the 'critical' incident situation? The situation could have had either a positive or a negative impact.
3. When did the 'critical' incident occur?
4. When was the critical incident discovered (project phase and date)?
5. What did the 'critical' incident impact (people, technology, financial, company credibility, time line, etc.)?
6. What action was taken in response to the discovery of the 'critical' incident?
7. Was the action important, significant or critical? (How much effect on the critical incident would you say the action had?
8. What were the outcomes of the 'critical' incident as a result of the actions taken?
9. What are the possible future outcomes if the situation/process remains unchanged?
10. What are the possible future outcomes if the situation/process changes based on lessons learned?
11. What is the situation/process that needs to be changed to avoid a recurrence of this sort of incident (or to attempt to create a recurrence of this sort of incident for a positive effect)?
12. Why would this situation have taken place – is it a standard procedure, personal, management, or customer issue, organizational requirement, etc., or a deficiency in one of these?
13. Do any organizational procedures or processes need to be corrected to eliminate this sort of situation (or changed to promote this sort of situation), and if so what?
14. How likely are people to change or what would cause them to change this situation/process?
15. What else could be done to avoid (or to create) this type of situation in the future?

The second interview protocol, Interview B, was created after a first round of interviews had been completed using Interview Protocol A. The purpose of Interview Protocol B was to follow up on initial findings that emerged from the first round of interviews. The goal was to obtain a more in-depth understanding of each project and to gain a more comprehensive understanding of risks that arose during the course of each project.

Table 11: Interview B

Questions
1. What were the most frequent challenges to the successful completion of this project?
2. Were most of the risks to the project within your control (within team scheduling/ communication/ need for additional training)? Or outside the control of the team (budget/ customer complaints/ timeframe constraints)?
3. On a scale of 1 – 10, how would you rate the success of the project? (10 being very successful, all of the goals were achieved according to the specifications on time and within budget, 1 being the project was achieved but not according to plan)
4. How did the criticality of the project affect its success in completion?
5. At times there has been a large gap between the critical incident and the start of the project to address the problem. Had the project been started sooner, would the outcome have been different? Why?
6. What is the origin of most projects? (i.e. Management request, customer complaints, changes in regulations).
7. How does the source of the project affect the risks involved?
8. In your experience, what risks to engineering design projects have you encountered most often?
9. Which had the most detrimental effects to the outcome of the project?
10. When faced with important decisions in engineering design projects, what methods do you rely on to make those decisions? (Clarify: Gut feeling? Past experience? Documented knowledge?)

Seventy interviews in total were conducted during the data collection phase of this research. This data collection period took place over 28 months. The surveys were administered through interviews conducted at the site of the organization, where all of the projects had taken place. The researchers traveled to this location to conduct these interviews in person. The interviews were conducted in private conference rooms, with only the participants and the researchers in attendance. The majority of these interviews were collected with a single participant. Five percent of the total interviews were conducted with multiple participants being interviewed simultaneously. Multiple researchers were present for each interview in order to ensure that responses to interview questions were accurately recorded.

The same protocol was followed for each interview. Each participant was emailed a copy of the interview questions when the employee scheduled his or her interview. This enabled the participants to look over project documents and refresh their memory about the particular project or projects they were being interviewed for. Since some employees were directly involved in multiple projects selected for study, these individuals were given the option of being interviewed on more than one project. The researchers endeavored to obtain a full set of responses to questions from both Interview A and Interview B. Due to scheduling challenges this was not always possible.

During an interview, each question was read out loud to the participant, and clarification was provided if the participant did not understand the question. The questions were asked in the same order every time, and the interview was complete once all of the questions were asked and answered. Participants were not required to answer every question, if they did not possess relevant knowledge or chose to refrain from answering a specific question.

During each interview one researcher was assigned the primary responsibility of communicating with the participant through reading questions, clarifying, and asking follow-up questions as necessary. The other researcher(s) took detailed notes of the participant's answers to create the interview transcript. Responses were recorded as close to verbatim as possible. The researchers traded responsibilities between each interview to avoid fatigue. To ensure the accuracy of the interview transcripts, the researchers read carefully through each transcript together directly following each interview. Details were added to the transcripts wherever they had not been recorded, which occurred due to how quickly some participants spoke. Once all-important details had been added and the transcripts were finalized, the data were ready for coding. The next section describes the coding methodology developed for this study.

3.8. Coding Methodology

The analysis of qualitative data is considered to be one of the most important and difficult phases of qualitative research. Coding is one of the most common practices used to organize and examine qualitative data (Basit, 2003). The coding methodology for this research was based upon qualitative data analysis literature and recommendations from Miles and Huberman (1994). This section explains the development and structure of the code schema created for this study, the methodology used for assigning codes to the transcripts, and the analysis of coder agreement.

3.8.1 Code Schema

The unique coding schema developed for this research was based upon the critical success factor frameworks proposed by Belassi and Tukel (1996) and by Chow and Cao (2008). Chow and Cao define critical success factors as the essential areas that must be successful in order for a project to be considered successful. Risks to critical success factors are therefore factors that could cause a project to be unsuccessful in terms of meeting cost, schedule, or other requirements vital to the customer or the company (Sato & Hirao, 2013; Yaraghi & Langhe, 2011). Critical success factors therefore are important drivers of project risk management because of the role critical success factors play in project success.

The critical success factors identified by Belassi and Tukel (Belassi & Tukel, 1996) and Chow and Cao (2008) became the basis for the development of five categories of risk indicators within the code schema. Risks related to each of these five categories were defined and translated into 36 risk indicator codes. The code schema was structured using the five categories as five macro-codes. The macro-codes were (1) risks related to the external environment (RTE), (2) risks related to the organization (RTO), (3) risks related to upper management performance (RMP), (4) risks related to the functional manager and team (PMT), and (5) risks related to the project (RTP). The micro-codes, within each macro-code, defined more specific risks. The complete code schema is presented in Table 12. The processes for applying this code schema to interview transcripts to further refine the schema and to create final code assignments are presented next.

Table 12: Code Schema

Macro-Level Codes	Micro-Level Codes [abbreviation]
Related to the External Environment [RTE]	Economic Conditions **[RTE-E]**
	Customer: Safety **[RTE-CU-CS]** Customer: Change in Features / Prioritizations **[RTE-CU-CF]**
	Competitor Actions and Their Impact **[RTE-CO]**
	Technological Changes **[RTE-TE]**
	Sub-Contractors Effects **[RTE-SC]**
	Quality Conformance **[RTE-QUAL]**
Related to the Organization [RTO]	Need for Changes to Standardization of Procedures **[RTO-SP]**
	Inadequate Data / Documentation Available **[RTO-DA]**
	Model Specific Knowledge Required **[RTO-MK]**
	Experience/ Longevity in Position **[RTO-LP]**
	Budget Issues for Project (Amount or Timeliness of the Funding) **[RTO-BP]**
Related to High Level Management Performance [RMP]	Management's Skills in Scheduling and Planning **[RMP-PS]**
	Management's Skills in Communication and Coordination of Project Assignments **[RMP-CC]**
	Management's Skills in Control and Monitoring **[RMP-CM]**
	Management's Support of the Project **[RMP-SPT]**
Functional Manager and Team [PMT]	Sufficient Training/ Technical Background and Skills of Functional Manager / Team Member(s) (Sufficient Man Hours and Training Available) **[PMT-TB]**
	Communication Skills between the Functional Manager and Project Team Member(s) **[PMT-CS]**
	Ability of Functional Manager / Team Member(s) to Coordinate Tasks and Schedule **[PMT-AC]**
	Identifying and Trouble Shooting Skills of Functional Manager and Project Team Member(s) **[PMT-TS]**
	Functional Manager / Team Member(s) Commitment to the Project **[PMT-C]**
	Functional Manager / Team Member(s) Ability to Prioritize/ Trade-off Projects or Areas of Projects as Needed **[PMT-PT]**
	Frame of Reference/ Need for Understanding of How the Project fits the Big Picture **[PMT-LF]**
Related to the Project [RTP]	Urgency of Project **[RTP-U]**
	Uniqueness of Project Activities **[RTP-UQ]**
	Multiple Competing Objectives Within the Project **[RTP-MO]**
	Risk Identified Late in Project Thereby Increasing Potency **[RTP-PP]**
	Safety Issues **[RTP-S]**
	Requires Communication Between Different Groups **[RTP-CDG]**
	Project Affects Different Groups **[RTP-ADG]**
	Large Number of Actions Required to Complete the Project (Density of the Project) **[RTP-DP]**
	Timeframe Constraints **[RTP-TC]**
	Availability of Adequate Resources (General Resources) **[RTP-AR-Q]** Availability of Skills/ Experienced Staff (Project is Understaffed) **[RTP-AR-SX]**
	Needs Product Certification **[RTP-PC]**
	Delayed Start to the Project. Significant Time Between Learning of Problem and Starting the Solution that Resolves Problems **[RTP-DEL]**

3.8.2 Methodology for Coding

Two researchers practiced applying the initial code schema to interview transcripts. After numerous transcripts had been coded independently, the researchers collaborated to compare each researcher's application of the code schema to specific segments of text on selected transcripts. In accordance with recommendations by Hawes (1972) multiple discussions about discrepancies in the interpretation and application of codes results in enhanced and more precise definitions of codes. Following this recommendation, codes and definitions were refined. These improved codes and definitions were then applied. The entire cycle was repeated until a satisfactory level of agreement (80% agreement) between the two researchers was reached. A graphical representation of the code schema refinement processes is shown in Figure 1.

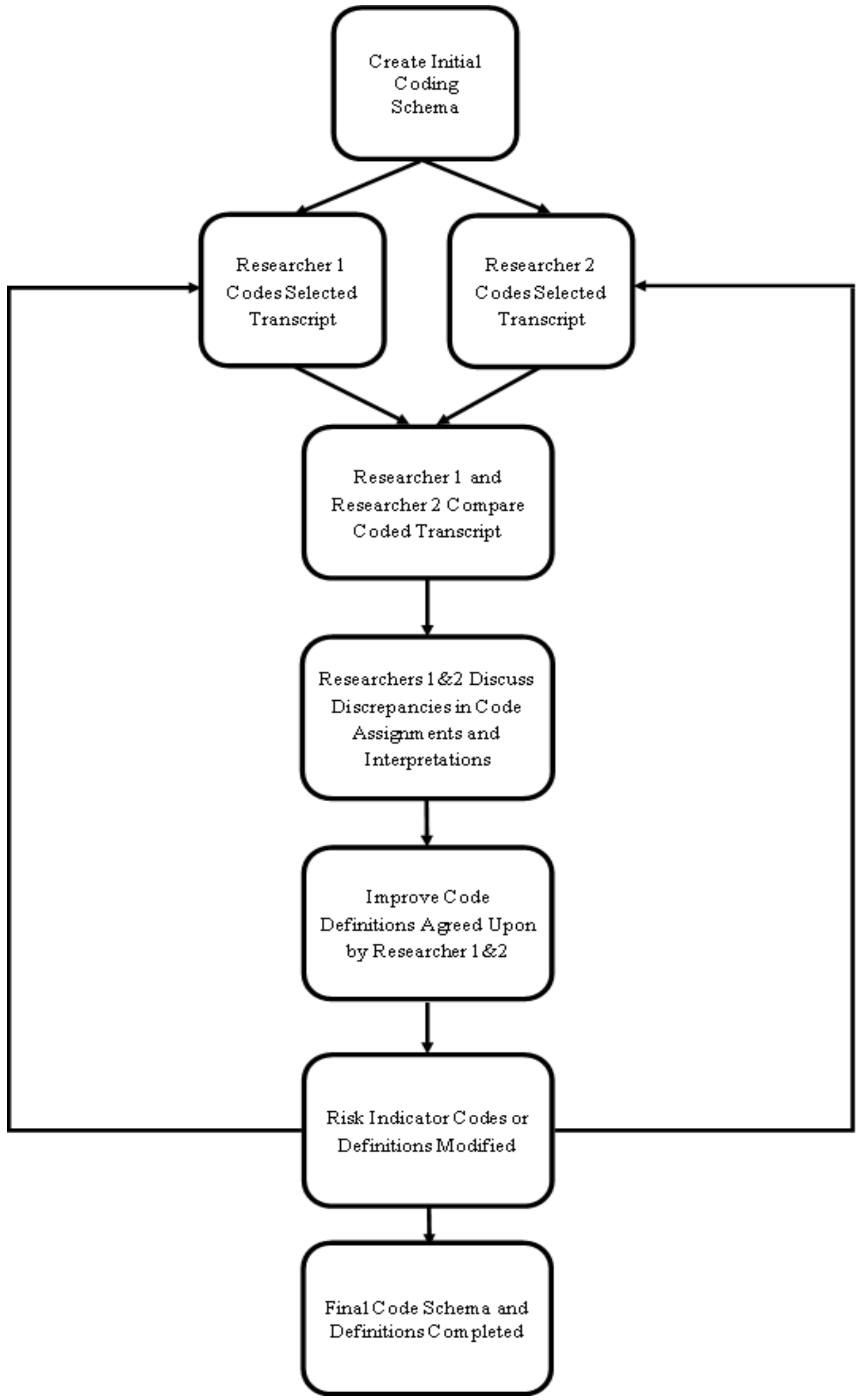

Figure 1: Refinement Process

To increase the accuracy of the coding process, transcripts were formatted to contain approximately half of a sentence on each line. Each time a risk indicator was identified in the transcript, the coder would insert the corresponding risk indicator code on the same line of text. When multiple risk indicators were mentioned on the same line, the risk indicator codes were applied in order of appearance in the text.

To enhance the validity of the coding process, additional researchers were added to the team for final coding of the complete data set. These new researchers were trained using practice interviews until they were familiar with the coding schema and were able to apply codes with an 80% rate of agreement with the original coders on these practice transcripts. The coding process used to assign final codes to each transcript is shown in Figure 2.

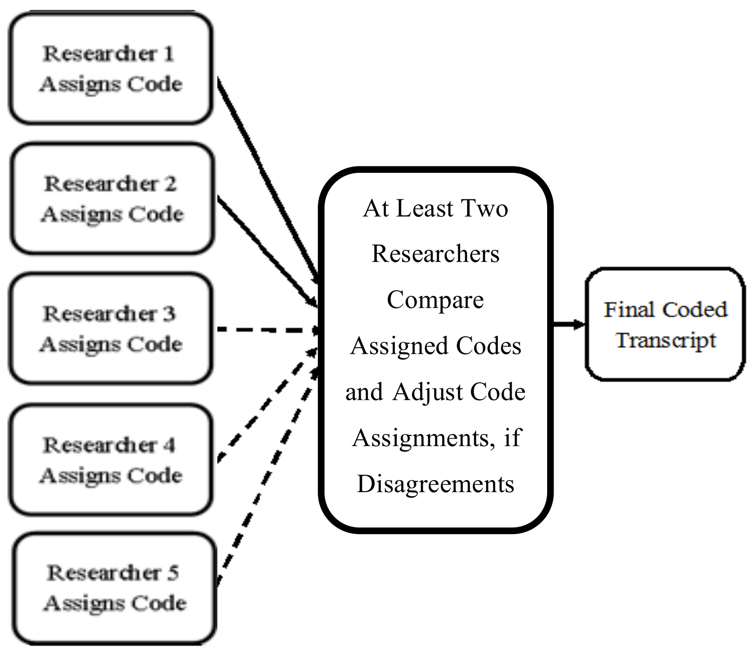

Figure 2: Process for Assigning Final Codes

For the first stage, at least two coders independently reviewed each interview transcript and assigned micro-level codes to lines of the transcript that included mention of an event that corresponded to one or more of the defined risk indicator codes. Not every line of every transcript was coded. It is normal for interview transcripts to contain portions of extraneous information that cannot be used (Miles & Huberman, 1994).

In order to prevent one researcher's codes from influencing another's interpretation of the data, each researcher would code the same transcripts using a separate document. The final coded document was formatted with the lines of transcript on the left, followed by each of the individual codes on the right. The final coders considered the words included on the transcript, the context, and the codes provided by the individual researchers when selecting final code.

The final coding step involved two researchers reading through each line of the transcript together, looking at the individually assigned codes, and discussing based upon context and all of the information available, whether or not a risk indicator was present in this line. Since the two original researchers were the most familiar with the context and the code schema, at least one of the two original research team members participated in every final coding. With the goal of preventing researcher bias from skewing the data, the second final coder was varied. Analysis of agreement levels between coders is detailed in the next section.

3.8.3 Coder Agreements

It was the goal of the researchers to ensure the reliability and validity of the coding process, thereby producing a compilation of risk indicator codes that accurately represented the risks encountered in these real engineering design projects. To be a valid representation of design project risks, it was important that the data collected fully captured and reflected the prevalence and range of events encountered during the completion of actual engineering design projects at the organization (Babbie, 2010). To ensure the validity of the final codes, Miles and Huberman (1994) recommend using multiple coders for each document. Berends and Johnston (2005) state that the use of multiple coders is an important technique to improve the validity of codes assigned to documents. Researchers have natural inclinations and tend to use certain codes (2005). Therefore to ensure the validity of the coding process for this study, multiple coders were incorporated into the design. At least one of the two researchers, who conducted the interviews and were the most familiar with the context of the projects, participated in the coding of each transcript. Additional researchers were engaged throughout the coding process to help eliminate bias that might have been present if only two coders completed the coding process for the entire set of transcripts.

Once all of the transcripts were coded, an analysis was performed to determine the agreement percentage between the codes assigned by the researchers independently and the final codes. Each row of the transcript that contained a final code was assigned a 1 if the final code matched one of the independent researcher assigned codes, or a 0 if it did not. The overall percentage of agreement per transcript was obtained by dividing the sum of the matching codes by the total number of final codes in that transcript. The average percentage of matching codes per transcript was approximately 77%. Having an agreement percentage of 77% indicated that there was, in general, consistency in code assignments, and that a reasonable number of codes were changed after both coders discussed discrepancies. Data screening techniques were applied next to further improve the validity of the data set. These data screening techniques are described in the next section.

3.9. Data Screening

Participants in this study had varying levels of involvement in the projects. Participants with limited involvement in certain projects were unable to provide detailed descriptions of events that transpired during the course of the project, leading to interview transcripts with few lines of coded text. A total of 70 interviews were originally conducted for this project. The average number of risk indicator codes per transcript for the 70 coded transcripts was 28.2 codes. When the transcripts were ranked from most risk indicator codes to least, the bottom 10% of the transcripts, those with the fewest number of codes, each contained fewer than 10 risk indicator codes. The interview transcripts with fewer than ten risk indicator codes were removed from the overall data set, leaving 63 coded transcripts for further analysis. After removing these transcripts, the average number of risk indicator codes per transcript increased to 30.5. After the data screening techniques were applied to the data set, the researchers began the analysis of the coded transcripts. These analysis techniques are introduced in the next section.

3.10. Data Analysis Process

The goal of this study was to explore the relationship between risk indicators and various project characteristics. To achieve this objective a process was created to turn the raw data, in the form of interview transcripts, into the results, in the form of research findings. A graphical representation of this process is shown in Figure 3.

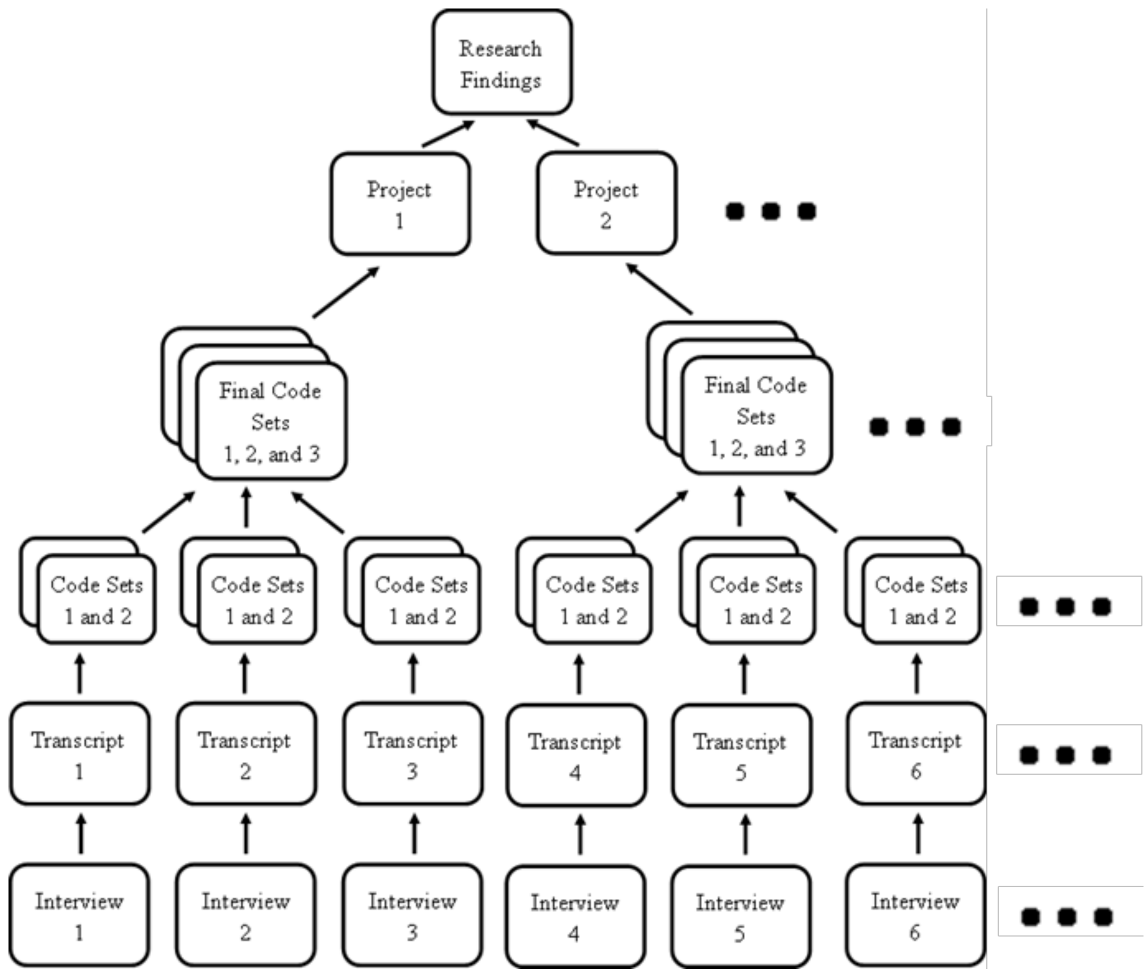

Figure 3: Data Analysis Process

The interviews were turned into transcripts. Multiple researchers coded each transcript, creating code sets. Two researchers considered each code set when selecting final codes for each project. After data screening techniques had been applied, risk indicator codes were totaled for each project. These totals were compiled for each project, and totals were compared for different subsets of projects based on the project characteristics of interest. The most frequently occurring risk indicators for different project characteristics were then compared. The findings from this research are discussed in detail within Manuscript 1 and Manuscript 2, presented next. After presenting Manuscript 1 and Manuscript 2, a high level review of the research findings was completed. This thesis concludes with a discussion of findings spanning the entire study, and a summary of the managerial implications and limitations of the research and future work.

4. Manuscript 1

EXPLORING THE RELATIONSHIP BETWEEN PROJECT CLASSIFICATION AND RISK INDICATORS

Rachel Yim, Jason Castaneda, Dr. Toni Doolen, Dr. Irem Tumer, Dr. Richard Malak

Abstract

Engineering design projects are created to fulfill different organizational objectives. Projects can be divided into three major classifications: compliance, operational, and strategic projects. Compliance projects are mandatory projects undertaken to meet regulations. Operational projects are those that are needed to sustain current operations. Strategic projects are not mandatory but are undertaken to support an organization's long-term plans. This study was undertaken to compare risks encountered in the course of undertaking all three classifications of projects within a single organization. Risks were assessed through a defined set of risk indicator codes, developed by the research team. A risk indicator was defined as a set of circumstances that has potential predictive power about the likelihood of a risk occurring during a particular design project. Interviews were conducted with employees involved in eleven engineering design projects. Interview notes were transcribed and then coded to identify the specific risk indicators for each project. The design projects were classified based on the type of project: compliance, operational, or strategic. An analysis of risk indicators by project classification was then completed to identify the relationship or lack thereof between project classifications and risk indicators. Conclusive evidence was provided that the most frequently occurring risk indicators do vary according to project classification. In addition, while some risk indicators were identified in all three project classifications, there were differences in how the risk indicators manifested themselves or in how prevalent they were for different project classifications. The results of this research, in particular, the type and prevalence of risk indicators are important and can inform the development of risk management plans. If risk management plans can be customized early in the project life cycle, higher project success rates can be realized.

Keywords

Project management, Risk management, Engineering design, Project classifications

4.1. Introduction

This section begins with an explanation of the importance of achieving project success. An overview of project management with a focus on risk management and project classification is presented next, followed by, an explanation of how this research contributes to the project management body of knowledge by characterizing the relationship between different classifications of projects and risk indicators.

The business plans of an organization are designed to fulfill the future needs of the organization's customers (Gray & Larson, 2008). An organization's business plans are accomplished via the creation and implementation of projects (Gray & Larson, 2008). Consistently delivering successful projects is something that many organizations fail to achieve far too often (Maylor et al., 2008). An unsuccessful project is one that does not meet project objectives, as measured by scope, time, cost, or other metrics important to the organization and the customer (Belassi & Tukel, 1996). The consequences of failing to meet project objectives can be significant in a competitive business environment (Maylor et al., 2008). The cost of project failures and cost overruns for the Information Technology (IT) industry alone were estimated to be approximately $150 billion in 2008 (Gray & Larson, 2008). Failed projects negatively impact businesses as a result of the financial and material resources invested in the project failing to produce anticipated returns, as well as a result of other negative consequences, including receiving poor press, losing the trust of customers, and losing competitive advantage in the marketplace. There exists a strong need for improving the likelihood of project success from both a profitability, as well as a competitive perspective.

The Project Management Institute defines project management as "The application of knowledge, skills, tools, and techniques to project activities to meet project requirements" (Project Management Institute, 2008, p. 6). Risk management is among the primary activities of project managers (Project Management Institute). The identification of risks is one of the first steps of risk management, typically begun early in the design phase. Risks to projects are unavoidable. However, project managers who understand potential project risks during the planning stages of a project have the opportunity to shape a project through the allocation of resources and risk mitigating techniques. The implementation of preemptive project management strategies has been shown to reduce overall expected risk to a project (Miller & Lessard, 2001). A good understanding of risks can help project managers create more informed risk management plans and can reduce overall project risk (De Bakker, Boonstra, & Wortmann, 2012).

Previous research has explored both project management and risk management. This study was focused on an integrated understanding of these two areas and investigated whether project classification is related to risk indicators, which are predictors of project risk. A project classification framework introduced by Gray and Larson (2008) was used to classify actual engineering design projects into one of three project classifications: compliance, organizational, and strategic. To understand and characterize the relationship between project classification and the prevalence of certain risk indicators, the researchers partnered with a large engineering design organization. Eleven design projects, undertaken to address different organizational objectives, were studied through a series of interviews with individuals who had worked directly on the selected projects. The interviews were designed to gather information about risk events that occurred in the course of a particular project. Interview transcripts were recorded and coded. Codes were analyzed to identify those risk indicators that occurred most often across specific project classifications and thus were important for project managers to be aware of when developing risk management plans.

A literature review is provided next. The literature review explores the topics of project management, organizational strategy, project success factors, and risk. These topics provide context for the design of the research as well as for interpreting the research findings. Following a review of the literature, the methodology section provides an overview of qualitative data analysis, critical incident methodology, as well as an overview of data collection and analysis techniques employed in this study. The results obtained from this study are presented and discussed following the methodology. The paper concludes with recommendations for future research.

4.2. Literature Review

4.2.1 Introduction

Project management is the conventional procedure utilized to design, implement, and complete a project (Gray & Larson, 2008). Project managers utilize different management methodologies and styles depending on the goals of the project (Srivannaboon & Milosevic, 2006). Risks are unavoidable, and project managers are tasked with developing appropriate risk management plans (Miller & Lessard, 2001). The goal of this research was to explore the relationship between projects fulfilling different organizational goals and risk indicators. This section will provide context for this research by summarizing related literature on project management, organizational strategy, project success factors, and risk management.

4.2.2. Project Management

A project is a unique one-time endeavor constrained by an allotted time period, budget, resources, and requirements (Vidal & Marle, 2008). Organizations undertake projects to accomplish short and long-term goals and to take advantage of market opportunities (Gray & Larson, 2008). Project management is a specialized management methodology utilized for achieving business goals and for implementing strategies and work tasks. Effective project management is critical to success in business (Project Management Institute, 2008). The project management strategies employed for the undertaking of each project should align with business strategies and the overall goals of an organization that are driving projects (Srivannaboon & Milosevic, 2006).

While organizations differ in how projects fit within individual corporate strategies, projects (and the goals they are designed to achieve) generally can fit into one of three classifications: compliance, operational, and strategic (Gray & Larson, 2008). Compliance projects are necessary for meeting regulatory requirements for conducting business in certain regions. For example, the purpose of a compliance project may be the modification of a product to meet new certification metrics specified by a regulatory entity. The continued production of the product, in this case, depends on successful certification. Compliance are often “must-do” projects. The second project classification, operational, includes projects that are necessary for improving current operations. Operational projects often do not have the level of urgency associated with compliance. Examples of operational projects are total quality management projects and product redesign projects. The third classification of projects, strategic, are undertaken to support the long-term goals of an organization, such as increasing the organization’s revenue or creating a market advantage. Incorporating new technology into an existing product or revamping manufacturing processes are examples of strategic design projects. Regardless of the project classification, projects are used as a vehicle to help the organization achieve its objectives, which are a part of a larger organizational strategy. This relationship between project management and organizational strategy will be discussed next.

4.2.3. Organizational Strategy

Long-range objectives express an organization’s mission in quantifiable terms. Organizations use objectives to define the high-level organization goals, i.e. the direction in which the organization would like to move and the time frame for when goals must be met. Good objectives should be clearly stated, measurable, realistic, and include a time frame (Gray & Larson, 2008). Once objectives are established, an organization can create actionable tasks to ensure objectives are met, while minimizing risks. Organizational strategy describes an organization’s plan or policy for achieving long-range objectives (Anderson & Merna, 2003). Assessments of the internal strengths and weaknesses of the company and external opportunities and threats are necessary to inform the development of strategies to capitalize on an organization’s core competencies and take advantage of opportunities, while ensuring that the organization takes on acceptable levels of risk. Organizational strategy influences how a company approaches risk management, from identifying potential risks, to implementing a risk mitigation plan (Yaraghi & Langhe, 2011; Kwan & Leung, 2011). Strategies at the business level, in theory, drive strategies at each subsequent organizational level, all the way down to individual projects (Joshi et al., 2003). Individual projects are created to fulfill organizational strategies. It is important for these projects to be successful in order for the strategies to be achieved. Definitions of what is meant by project success are provided and discussed next.

4.2.4 Project Success Factors

As projects are increasingly becoming a larger percentage of a company's overall investments of time and resources (Maylor et al., 2008), the identification of factors leading to project success and failure becomes more critical for project managers. A successful project achieves all of the objectives that make up the project's purpose (Anderson & Merna, 2003). The literature includes many definitions of what constitutes project success. Table 13 summarizes some of the frequently cited definitions for project success.

Table 13: Project Success Definitions

Definition	**Reference**
"The success is defined by a set of criteria that the outcome or the solution must meet to be considered 'successful'" (p. 19)	Babu, G. N. K. S., & Srivatsa, S. K. (2011).
Keeping to an efficient schedule will lead to a more successful project. (p. 187)	Clift, T. B., & Vandenbosch, M. B. (1999).
"Project success is an objectively measureable state describing how well the project performed." (p. 445)	De Bakker, K., Boonstra, A., & Wortmann, H. (2012).
A project is successful when the objectives are met. (p. 516)	Maylor, H., Vidgen, R., & Carver, S. (2008).
Project success is made up of how successful project management and the end product are. (p. 2)	Van der Westhuizen, D., & Fitzgerald, E. P. (n.d.)

Factors contributing to project success or failure are referred to in the literature as critical success factors (Zwikael & Globerson, 2006). Table 14 summarizes some definitions for critical success factors proposed by different researchers.

Table 14: Critical Success Factor Definitions

Definitions	Author(s)
Specific factors of a project that must be successful in order for the project goals to be considered successful (p. 962)	Chow, T., & Cao, D.-B. (2008).
Factors that affect the design and implementation stages of a project and "have influence on the inclination and readiness of a corporation" (p. 551)	Yaraghi, N., & Langhe, R. G. (2011).
"[Critical Success Factors] for any business consist of a limited number of areas in which results, if satisfactory, will ensure the organization's successful competitive performance." (p. 3434)	Zwikael, O., & Globerson, S. (2006).

Since meeting critical success factors can be the difference between project success and failure, identifying risks that prevent an organization from meeting critical success factors is important in the early stages of project planning (Yaraghi & Langhe, 2011). Risk, as it relates to project management, is further described in the next section.

4.2.5 Risk

Uncertainty is an inherent part of all design projects (Miller & Lessard, 2001). Uncertainty is defined as a state of limited knowledge where it is not possible to know a future outcome (Thunnissen 2003). Uncertainty is a lack of predictability, so it can result in either a positive or negative outcome (Stein, 1981). Uncertainty does not always lead to risk and can sometimes result in opportunity. Therefore uncertainty should not be avoided entirely. However, the uncertain nature of design projects in the conceptual planning stage often produces risk and greatly limits the effectiveness of risk mitigation methods because the most effective risk mitigation strategy cannot be predicted (Howell et al., 2010a). Kwan and Lang (2011) define risk as “A potential event that will adversely affect the ability of a system to perform its mission should the risk event take place” (p. 635). Risks in engineering design projects are one of the central causes of project failure, if they are not managed or mitigated (Royer, 2000). Project risk management is a process for systematically identifying, evaluating, and mitigating risks to improve the likelihood of project success (Maytorena, Winch, Freeman, & Kiely, 2007). Ideal risk management capitalizes on the opportunities presented by uncertainty, while simultaneously mitigating risk before it has detrimental outcomes (Stein, 1981).

Risk management techniques are limited by the information available, which is often dependent on the stage of the project. Project managers adapt the application of risk management techniques according to the stage of the project (Kwan & Leung, 2011). Project managers must take a comprehensive approach when identifying risks by utilizing input from employees, knowledge of the field and past experience, and outputs from analytical tools. Two well-known risk assessment and analysis techniques are the Failure Mode Effect Analysis (FMEA) and the Failure Mode Effect and Criticality Analysis (FMECA). In deploying these methods, a list of all potential outcomes and identified risks related to all potential effects are created (Kwan & Leung, 2011). FMEA and FMECA assess risk during certain stages of a design project. However, the usefulness of FMEA and FMECA is significantly limited in the early planning stage of a project because the level of uncertainty at the project's conceptual stage is inherently high, and project details are largely unknown (Teoh & Case, 2004; Howell et al., 2010). The application of a functional predictive risk assessment technique would vastly aid the mitigation of risks in design projects. Having discussed the topics of project management, organizational strategy, project success factors, and risk to provide context for this study, the next section details the methods used to conduct this study. The methodology begins with an overview of qualitative data analysis, which was the foundation of the research methodology used in this study, followed by a detailed description of the specific steps taken to develop and apply the code schema created for this research.

4.3. Methodology

4.3.1. Overview

This study was designed to explore the relationship between different project classifications, under which varying organizational objectives drive engineering design projects and the types of risk indicators associated with these projects. Project managers can utilize knowledge of relationships between different project classifications and specific risk indicators to develop more effective risk management plans for projects at the point in which projects are initiated. As soon as project objectives are established and project classification can be known, the results of this research can provide a basis for expecting certain types of risks. Project managers can use this information to inform risk management plans.

Eleven engineering design projects were selected for analysis in this study. Each of these projects took place within a single division of the participating engineering design organization. Two sets of interview questions were developed, with a focus on eliciting responses indicating the various challenges encountered during the life cycle of the projects. Interviews were conducted with employees, who held various functional positions and who worked on one or more of the selected projects. The researchers created a code schema of risk indicators based on critical success factor frameworks found in the project management literature. The code schema was used to classify different types of risks to engineering design projects. The code schema was applied to interview transcripts. Risk indicator codes were then analyzed to identify patterns and relationships with project classifications. Each of the eleven studied projects occurred within the same 24-month time period.

The raw data for this study were obtained through an interview process. The interviews were conducted using critical incident methodology. While the raw data for this research (interview transcripts) were qualitative, once codes were assigned, it was possible to quantitatively assess the frequency of different codes for different classifications of projects. In addition, the raw data, specifically excerpts from the transcripts, could be used to help evaluate the meaning of the quantitative findings. Before providing additional details on the specifics of project selection, data collection, participant selection, and code development, a general overview of the critical incident methodology and qualitative data analysis are provided.

4.3.2. Qualitative Data Analysis

Qualitative data analysis is defined by Auerbach and Silverstein (2003) as, "research that involves analyzing and interpreting texts and interviews in order to discover meaningful patterns descriptive of a particular phenomenon" (p. 3). Qualitative data analysis is well-suited for connecting the meanings people place on events and processes to the world around them (Miles & Huberman, 1994).

There is no single method for qualitative data analysis, yet there are characteristics that are common to most styles of qualitative research. The first characteristic is collecting textual data. Textual data can be obtained from field observation, documents, or interviews and is usually collected in close proximity to the phenomenon of interest to the study (Miles & Huberman 1994). After enough raw data is obtained, researchers have the task of recognizing patterns and extracting meaning from the words of the textual data collected, which is the second characteristic (Auerbach & Silverstein, 2003). Patterns are typically identified as a result of assigning codes to the textual data. Miles and Huberman (1994) define codes as, "Tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" (p. 56). After codes have been adequately defined and organized into a code schema, codes are assigned to phrases, sentences, or paragraphs of field transcripts that encompass a specific meaning (Miles & Huberman 1994). Coding helpfully condenses the size of the dataset into a manageable collection of information. The third key characteristic of qualitative data analysis is drawing useful conclusions from the dataset. The coding process tags relevant text, which becomes the basis for identifying recurring themes (Auerbach & Silverstein, 2003). By measuring the frequency of codes, themes can be identified, and the dataset can be converted from qualitative data to quantitative data, which is necessary for statistical analysis (Miles & Huberman, 1994).

A particular strength of qualitative data analysis is that it provides rich, grounded information that could not be understood with a purely quantitative approach (Miles & Huberman, 1994). Qualitative data analysis also has the advantage of "local groundedness" (Miles & Huberman, 1994, p. 10), meaning data is collected in close proximity to the phenomena of study. This emphasis on the specific situation (local groundedness) generates vivid description taken from real context, which makes it possible to understand underlying, nonobvious issues and form a hypothesis for complex processes (Miles & Huberman, 1994). However, qualitative data analysis also relies heavily on the competence with which the researchers carry out the analysis (Miles & Huberman, 1994). This research employed qualitative data analysis techniques to characterize the relationship between project classification and risk.

4.3.3. Critical Incident Methodology

Two sets of interview questions were developed for the study. The first set of interview questions used for this study was created using the critical incident methodology. The critical incident methodology was created as a structured method of obtaining direct observations of human behavior in order to use this information to solve real-world problems (Flanagan, 1954). The critical incident method asks interviewees to recall incidents that made the most memorable impressions on them. Critical incident methodology is designed to elicit responses detailing significant events (Butterfield, Borgen, Maglio, & Amundson, 2009). With a variety of interviewee perspectives, critical incident methodology is a strong tool for identifying the most relevant events. Details related to project selection, data collection, participant selection, code schema development, and coding are provided next.

4.3.4. Project Selection

The engineering design firm participating in this study completes hundreds of design projects each year that are initiated to meet a number of business objectives. The company designs and manufactures multiple products, each housed within its own division. To achieve consistency, all projects for this study were selected from a single division within the larger company. This division is dedicated to the design, production, and assembly of a single product. The product created in this division is very complex, composed of millions of parts and multiple interdependent systems (electrical, mechanical, software, etc.). The integration and assembly of these parts requires close coordination and communication between many functional departments.

The researchers were provided with documents containing summaries of design projects completed within the division. These summary documents were created during the initial project-planning phase. The documents contained information outlining the primary goals of the design project, the names and job titles of project team members, the resources required by the project, and the specific actions necessary to complete the project. The projects served various purposes for the organization. Some projects were redesigns of existing parts of the product. These redesigns were necessary for various reasons, including ensuring the functionality intended in the original design, part obsolescence or new technologies, changes in regulations or in certification standards, or cost savings.

To ensure that the design projects being studied could be compared to one another, the researchers limited selection of projects to medium-complexity projects. Medium-complexity projects are more complex than replacing a single part but less complex than designing an entirely new product. Medium complexity was defined in this study using four different characteristics. First, projects required 1,500 to 16,500 person-hours. Second, projects included between two and ten functional departments. Third, projects involved fewer than 15 project activities, and fourth, projects had between ten and 31 engineers on the project. Hundreds of projects fit the medium complexity criteria and were completed within the desired timeframe. The researchers selected eleven projects from the initial list of hundreds of projects based on similarity in these complexity parameters while still encompassing a variety of project types, e.g. mechanical redesign, software upgrade, and environmental systems modification, and project classifications, i.e. compliance, operational, and strategic. Details for each of the eleven projects included in this research are summarized in Table 15.

Table 15: Project Details

Project Number	Type of Project	Total Hours	Project Objective	Project Classification
1	Mechanical Redesign	2,728	Correct Service Related Problem	Operational
2	Mechanical Redesign	2,672	Meet Customer Requirement	Operational
3	Environmental Systems Modification	14,593	Correct Engineering Error	Operational
4	Electrical Systems Modification	2,928	Meet Additional Safety Requirements	Compliance
5	Replacing Obsolete Part	10,280	Meet Subcontractor Requirement	Compliance
6	Electrical and Software System Upgrade	16,569	Address Cost Savings	Strategic
7	Structural Redesign	15,390	Reduce Weight	Strategic
8	Electrical and Software System Redesign	5,123	Address Change in Certification Requirements	Compliance
9	Electrical and Software System Upgrade	2,292	Improve Design	Strategic
10	Electrical Systems Modification	1,477	Correct Service Related Problem	Operational
11	Software Upgrade	4,575	Meet Customer Requirement	Operational

For the purpose of this study, projects were sorted into three groups according to the high-level project objective, e.g. correct service related problem or meet customer requirement, etc. and were further classified using the three project classifications outlined by Gray and Larson (2008): compliance, operational, and strategic. Table 4 maps these 11 projects, based on the high-level project objectives, provided by the company and the three project classifications used in this study. The number of projects that have a given high-level objective is denoted in parentheses in Table 16. The eleven projects were undertaken to address nine different project objectives. For example, one of the eleven design projects was categorized as a cost savings design change. The company implemented this project to improve the design of an already functional product as a means to reduce the organization’s production costs. Each design project, while completed within the same division of the company, was undertaken to fulfill a unique objective.

Table 16: Mapping of Project Objectives by Project Classification (Number of Projects)

Compliance	Operational	Strategic
Meet Additional Safety Requirements (1)	Correct Service Related Problem (2)	Address Cost Savings (1)
Meet Subcontractor Requirement (1)	Meet Customer Requirement (2)	Reduce Weight (1)
Address Change in Certification Requirements (1)	Correct Engineering Error (1)	Improve Design (1)

Compliance projects were undertaken to meet mandatory regulatory requirements. The engineering projects classified as compliance projects were created to satisfy additional safety requirements, subcontractor requirements, and changes in certification requirements from governing safety boards. These projects were classified as compliance projects because these projects were undertaken to satisfy specifications created by regulatory organizations. Failure to complete the changes would halt the manufacture of the product.

Operational projects are projects that are important for maintaining regular operations. Engineering design projects placed in the operational classification included projects created to resolve service related problems, to meet customer requirements, and to correct previous engineering errors. However an organization can continue manufacturing the product in question if operational projects are not successfully completed (Gray & Larson, 2008). Strategic projects provide opportunity for expanding market share, gaining a competitive advantage in the market, and reducing long-range, future expenses, but are not vital to maintaining the organization's current business operations. The projects created by the engineering firm with the goals of cost savings, weight reduction, and design improvement, were classified as strategic projects. Next the instruments for data collection at the project level are described in greater detail.

4.3.5. Data Collection Instruments

Two interview protocols were created for the purpose of gathering first-hand accounts from employees about challenges encountered during the life cycle of the eleven engineering design projects. The first interview protocol (Interview A) was developed based on critical incident methodology. A second interview protocol (Interview B) was developed to gain a more in-depth understanding of the risks that occurred during the life cycle of each project. Interview B focused on pinpointing the challenges project managers and project team members encountered on the projects included in this study. Interview B also included questions targeted toward gaining a system-wide perspective of risks encountered across all engineering design projects within the organization. Several sample interview questions from the two interview protocols are summarized in Table 17.

Table 17: Sample Interview Questions from Interviews A and B

Sample Question	**Interview Protocol**
What did the 'critical' incident impact (people, technology, financial, company credibility, time line, etc.)?	A
What action was taken in response to the discovery of the 'critical' incident?	A
What level of 'criticality' would you put the incident at, on a scale of 1 to 5? (1=important, 3=significant and 5=critical)	A
How did the criticality of the project affect its success in completion?	B
What were the most frequent challenges to the successful completion of this project?	B
How does the source of the project affect the risks involved?	B
Why would this situation have taken place – is it a standard procedure, personal, management, or customer issue, organizational requirement, etc., or a deficiency in one of these?	A

A total of 70 interviews were conducted with project team members in private conference rooms at the company. The researchers conducted the majority of interviews with one employee at a time. Only five percent of the interviews were conducted with multiple employees simultaneously. The order of questions was always the same, and every question was always asked. The researchers took notes, typing and writing down responses as close to verbatim as possible. In order to ensure that the transcribed notes captured the full content of the interviews, the researchers read through each transcript directly after each interview and added any details that had not been captured due to the speed of the interviewee's speech. The data collection took place across a 28-month time period. The next section summarizes the process used to contact study participants, as well as study participant details.

4.3.6. Participant Selection and Details

A list of potential interview candidates with a variety of job titles (both project management and engineering positions) was created from the project documentation provided by the company for each of the eleven projects. This working list of employee names was given to a research liaison from the participating organization via email. The liaison sent an email to each employee on the list containing background information on the research study and an invitation to participate in the study as an interviewee. The liaison set up times for interviews between the researchers and the employees who responded with interest in participation.

A total of 46 employees participated. A number of engineering and management positions were represented, and eight employees were interviewed multiple times because they had a role on multiple projects. The organization being studied was organized by functional engineering departments, responsible for certain systems within the product. The major functional engineering departments working on the projects were electrical, environmental control systems, and structures. The employees in these functional departments held engineering, project management, or project scheduling positions. The majority of project managers and engineers were educated in either mechanical or electrical engineering. Employees with project scheduling roles were typically educated in an area outside of engineering, but were familiar with basic engineering functions and project management practices. Employees worked interactively with project managers to create project documentation and to develop project schedules. Job functions of each project team member interviewed are summarized by project in Table 18. The diversity of participants strengthened the study by extracting a variety of engineering, management, and process perspectives. After the completion of the interview and transcription processes, detailed interview documents were ready for coding. The next section summarizes the development of the code schema used to analyze the transcribed interview notes.

Table 18: Interviewee Job Function by Project

Job Function	Project										
	1	2	3	4	5	6	7	8	9	10	11
Electrical Certification											X
Engineering - Air Conditioning		X									
Engineering - Electrical		X	X		X	X		X	X		
Engineering - Environmental Control Systems		X			X						
Engineering - General							X				
Engineering - Mechanical					X	X					
Engineering - Payloads	X										
Engineering - Service			X								
Engineering - Structural						X	X				
Engineering - Systems									X	X	
Engineering - Wiring Installation			X								
Production Scheduler			X								
Project Engineer	X							X			
Project Management - Engineering Change Control			X		X		X	X			
Project Management - General	X				X					X	

4.3.7. Code Schema Development

The code schema created for identifying risk indicators was based upon the critical success factor frameworks developed by Belassi and Tukel (1996) and by Chow and Cao (2008). Critical success factors are indicators of areas in which risks may cause a project to fall short of its objectives in terms of schedule, cost, or functionality (Yaraghi & Langhe, 2011). Critical success factors identified by Belassi and Tukel and Chow and Cao became the basis for risk indicator categories within the code schema. The code schema was comprised of five macro-level categories including (1) risks related to the external environment (RTE), (2) risks related to the organization (RTO), (3) risks related to upper management performance (RMP), (4) risks related to the functional manager and team (PMT), and (5) risks related to the project (RTP). Specific risks within these categories were further refined by creating 36 micro-level codes. The complete code schema is summarized in Table 19. The details of the process used to identify the risk indicators associated with each of the eleven projects are described next.

Table 19: Complete Code Schema (Yim, 2013)

Macro-Level Codes	Micro-Level Codes [abbreviation]
Related to the External Environment [RTE]	Economic Conditions **[RTE-E]**
	Customer: Safety **[RTE-CU-CS]** Customer: Change in Features / Prioritizations **[RTE-CU-CF]**
	Competitor Actions and Their Impact **[RTE-CO]**
	Technological Changes **[RTE-TE]**
	Sub-Contractors Effects **[RTE-SC]**
	Quality Conformance **[RTE-QUAL]**
Related to the Organization [RTO]	Need for Changes to Standardization of Procedures **[RTO-SP]**
	Inadequate Data / Documentation Available **[RTO-DA]**
	Model Specific Knowledge Required **[RTO-MK]**
	Experience/ Longevity in Position **[RTO-LP]**
	Budget Issues for Project (Amount or Timeliness of the Funding) **[RTO-BP]**
Related to High Level Management Performance [RMP]	Management's Skills in Scheduling and Planning **[RMP-PS]**
	Management's Skills in Communication and Coordination of Project Assignments **[RMP-CC]**
	Management's Skills in Control and Monitoring **[RMP-CM]**
	Management's Support of the Project **[RMP-SPT]**
Functional Manager and Team [PMT]	Sufficient Training/ Technical Background and Skills of Functional Manager / Team Member(s) (Sufficient Man Hours and Training Available) **[PMT-TB]**
	Communication Skills between the Functional Manager and Project Team Member(s) **[PMT-CS]**
	Ability of Functional Manager / Team Member(s) to Coordinate Tasks and Schedule **[PMT-AC]**
	Identifying and Trouble Shooting Skills of Functional Manager and Project Team Member(s) **[PMT-TS]**
	Functional Manager / Team Member(s) Commitment to the Project **[PMT-C]**
	Functional Manager / Team Member(s) Ability to Prioritize/ Trade-off Projects or Areas of Projects as Needed **[PMT-PT]**
	Frame of Reference/ Need for Understanding of How the Project fits the Big Picture **[PMT-LF]**
Related to the Project [RTP]	Urgency of Project **[RTP-U]**
	Uniqueness of Project Activities **[RTP-UQ]**
	Multiple Competing Objectives Within the Project **[RTP-MO]**
	Risk Identified Late in Project Thereby Increasing Potency **[RTP-PP]**
	Safety Issues **[RTP-S]**
	Requires Communication Between Different Groups **[RTP-CDG]**
	Project Affects Different Groups **[RTP-ADG]**
	Large Number of Actions Required to Complete the Project (Density of the Project) **[RTP-DP]**
	Timeframe Constraints **[RTP-TC]**
	Availability of Adequate Resources (General Resources) **[RTP-AR-Q]** Availability of Skills/ Experienced Staff (Project is Understaffed) **[RTP-AR-SX]**
	Needs Product Certification **[RTP-PC]**
	Delayed Start to the Project. Significant Time Between Learning of Problem and Starting the Solution that Resolves Problems **[RTP-DEL]**

4.3.8. Coding Process

The coding process utilized for this study was based upon the recommendations of Miles and Huberman (1994) with the goal of completing a reliable and accurate analysis of the data. The interview transcripts were coded by at least two researchers. Risk indicator codes were assigned to individual lines of the transcripts based on the transcript content and risk indicator code definitions. The details of the coding process are described next.

The interview transcripts were formatted in such a way that each line contained approximately half of a sentence. This formatting method was performed to facilitate precision in the assignment of risk indicator codes to the transcribed text. At times multiple risks were mentioned in a single section of the transcribed text. The researchers used their understanding of the project and the code schema to select the most relevant codes to apply to each line. After all of the transcripts had been coded, the number of times each risk indicator code appeared in each transcript was summed. The sum of each risk indicator code was divided by the total number of risk indicator codes for the transcript and relative frequencies for all risk indicator codes assigned to a single transcript were calculated. The details of the procedure for assigning a final risk indicator code to text are described next.

Initially, two researchers practiced applying the code schema to a subset of the transcripts. These two researchers met together multiple times to discuss disagreements in coding and text that could not be assigned any of the codes. This work was used to refine the code schema and definitions. This process continued until both researchers agreed on a fully specified set of risk indicator codes. Miles and Huberman (1994) maintain that this approach to developing codes leads to more comprehensive code schemas.

After the code schema was finalized, three additional team members provided assistance in coding the 70 transcripts. The two original team researchers became primary coders. The primary coders instructed additional researchers on how to apply the code schema to transcripts and explained contextual complexities pertaining to the company's organizational processes. The new coders practiced coding using several transcripts until the new coders were consistently applying the coding in a similar fashion the primary coders.

Each transcript was analyzed line-by-line. Researchers searched for mention of any events that identified one or more of the risk indicators included in the code schema. When a risk indicator was identified, the researcher listed the corresponding risk indicator code on the line of text in the transcript. Only the lines corresponding to risk indicators contained codes. Some lines of text referenced events that captured multiple risk indicators. In these cases, additional risk indicator codes were assigned to the line, or directly above or below the line depending on the order that risks were mentioned. Interview transcripts also typically contain some information that is not usable for coding (Miles & Huberman, 1994). These lines of text containing extraneous information were not coded.

The best method for coding is to have more than one researcher code and then to have multiple coders review the codes together (Miles & Huberman, 1994). At least two researchers completed coding of each transcript. Each researcher followed the exact same procedure for assigning codes. Several important stipulations were put in place to ensure that each coding was original and independent. For each interview, the second coder pasted the text of the transcript into a new document to hide the codes of the first researcher, which eliminated any influence the initial codes could have on the second coder. After the second coding was completed, the second codes were pasted into the original spreadsheet containing the interview transcript. At this point in the coding analysis, a spreadsheet contained a column with the lines of transcript, two columns to the right of the text with coder 1 and coder 2 codes corresponding to lines of transcript, and one column to the right of these two columns labeled final codes that was empty.

In the final coding, two researchers read each transcript line by line and examined the codes from the first and second coding. Discussion took place when a discrepancy between the first code and the second code existed. A final code was agreed upon and inserted into the final code column. At least one of the primary researchers participated in every final coding, but the second coder was purposely changed to counteract researcher bias. Initial and final codes were analyzed to test for consistency in coding and to validate the coding process. The processes used to ensure valid and reliable codes were assigned are described next.

4.3.9. Code Validity and Reliability

The practice of having multiple researchers code each document is intended to ensure the accuracy of final codes. This practice is beneficial, but also creates challenges related to reliability. When multiple coders are used, additional time is required. In addition, each researcher has preferences in interpretation of data (Berends & Johnston, 2005). These partialities can be valid, but are often dependent on the coder's understanding of the context. Utilizing multiple coders, however, is one mechanism for increasing validity.

Once multiple coders are utilized, however, reliability can be a concern. An analysis was performed to examine consistency between initial and final codes. Each line containing a final code was assigned either a 1 or 0 based on whether or not the initial and final code matched or not, respectively. If the final code matched either of the initial assigned codes, this was assigned a value of 1. During final coding, if one line contained information corresponding to more than one code, additional codes were inserted to the transcript line above or below in corresponding order to the risk indicators mentioned. This process was taken into consideration when determining matching or non-matching codes. If a final code matched a code on the line above or below, the text on these lines were counted as a match. The sum of total matched codes in each transcript was divided by the total number of codes in that transcript to obtain the percentage agreement between initial and final codes. The average percentage of agreement between initial and final codes was approximately 77% across all transcripts. After completing this analysis, additional screening of transcripts was undertaken and is described next.

4.3.10. Data Screening

Once final codes were assigned to all transcripts, a screening process was completed to ensure that each transcript was equally represented in the dataset. In looking at each transcript individually, some transcripts had few coded lines of text. These interview transcripts were removed from the overall data set. Of the 70 total interviews, the average number of codes per transcript was 28.2. Each transcript with fewer than ten codes was eliminated from the dataset. Of the 63 remaining interviews, the average number of codes per interview increased to 30.5. Following the final coding process and after screening at the transcript level, the remaining 63 transcripts and risk indicator codes were analyzed to identify patterns and themes. Results from the analysis of the coded transcripts are presented next.

4.4. Results and Discussion

As a first step in the analysis of the coded transcripts, the top ten risk indicators appearing in each project classification were compared. The top ten risk indicators were compared for three different project classifications: compliance projects, operational projects, and strategic projects. Similarities in the top ten risk indicators for the three project classifications were identified. The risk indicators appearing in the top ten for all three classifications are noteworthy as these risks would be critical to manage, regardless of the classification of project. Figures 4, 5, and 6 present the top ten most frequently occurring risk indicator codes for each project classification. Next, specific risk indicators in the top ten for each project classification were examined. Finally, a discussion of patterns identified in risk indicator frequencies is provided.

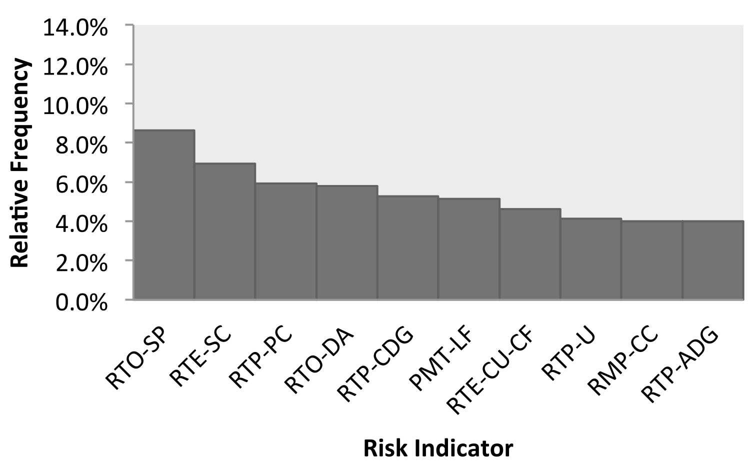

Figure 4: Top Ten Risk Indicator Codes in Compliance Projects

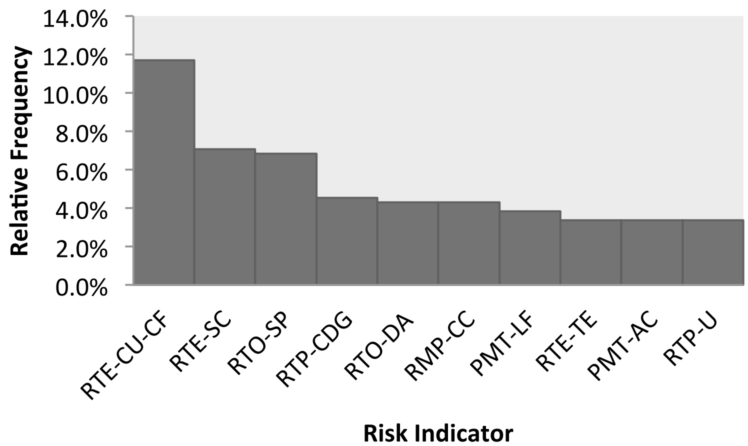

Figure 5: Top Ten Risk Indicator Codes in Operational Projects

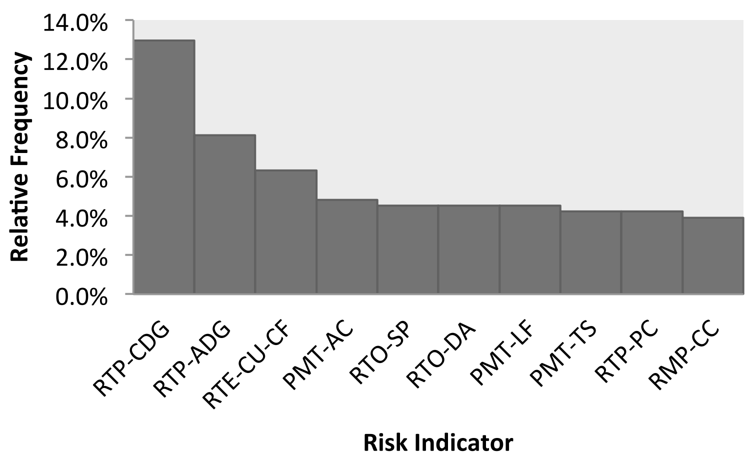

Figure 6: Top Ten Risk Indicator Codes in Strategic Projects

4.4.1. Common Risk Indicators for All Project Classifications

The goal of this research was to obtain an overall understanding of likely risks faced in different types of projects, as determined by project classification. A comparison of the most frequently occurring risk indicators associated with each project classification was conducted to identify similarities and differences in risks when project classification was taken into account. The relative frequency of each risk indicator for each project was obtained by dividing the number of times a particular risk indicator code appeared in a project by the total number of risk indicator codes for that project. The significance of each risk indicator was measured using this calculated relative frequency value. Frequently occurring risk indicator codes are indicative of likely risks, and thus of factors that require management attention when planning and carrying out risk management activities. The top ten most frequently occurring risk indicators for each project classification are discussed.

Six risk indicators out of 36 total risk indicator codes appeared in the top ten of all three project classifications. The common risk indicators were a need for changes in standard procedures (RTO-SP), inadequate data/documentation (RTO-DA), upper management's skills in communication/coordination (RMP-CC), project team need for a better understanding of project scope (PMT-LF), customer-related changes and communication (RTE-CU-CF), and communication between different functional departments (RTP-CDG). Table 20 summarizes these six common risk indicators and the occurrence percentage by classification. Three of these six common risk indicators are highlighted next.

Table 20: Common Risk Indicator Codes and Relative Frequencies

Risk Indicator Code	Compliance	Operational	Strategic
RTO-SP	8.6%	6.8%	4.5%
RTO-DA	5.8%	4.3%	4.5%
RMP-CC	4.0%	4.3%	3.9%
PMT-LF	5.1%	3.8%	4.5%
RTE-CU-CF	4.6%	11.7%	6.3%
RTP-CDG	5.3%	4.5%	13.0%

Risks related to standard procedures and documentation (RTO-SP) occurred frequently across all eleven projects. The RTO-SP code was frequently assigned to text describing circumstances when standard procedures were no longer applicable and when additional standardization would have benefitted the project or when an existing standard procedure prevented a specific task from being completed efficiently. For example, as explained by one interviewee, the need for new standard procedures was seen as a way to improve project team member understanding of project interdependencies: “It can be difficult to determine what affects what. Our evaluation process is not fantastic. If we had a better system in place to evaluate all of our impacts, it would help.” This text highlights the lack of procedures for evaluating project impact and the consequences of not having evaluation processes.

Another risk indicator common among all projects was risks related to the communication of upper management (RMP-CC). Communication of goals and priorities by upper management is important for all types of projects. RMP-CC was assigned to the following text: “We need to have management prioritization to help people know what to work on and in what order.” The objectives and tasks of strategic projects are highly dependent on management, and clear communication of the project priorities, task division, and team responsibilities are important to prevent risks to projects from occurring (De Bakker, Boonstra, & Wortmann, 2012). Inadequate management communication has also been found to cause project schedule overruns (Herroelen, 2005; Love & Smith, 2003).

The inadequate data and documentation (RTO-DA) code was assigned in three general cases: when written project requirements were unclear or vague, when employees did not have access to the information they needed to complete a task, and when documentation was inaccurate, outdated, or needed to be updated. In most cases, the documentation referred to were documents containing project requirements. For example, “[The project] might have gone better if we would have spent more time up front to make sure that everyone was on the same page about the work that needed to be done and what all of the requirements were.” In this example, the project requirements were not well-documented and, as a result, the project team encountered a number of critical incidents during the course of the project. The need for explicitly defined requirements has been well-documented in literature. Parsons-Hann and Linn (2005) found that incomplete requirements were the “biggest reason for project failure” (pg. 1).

The third risk indicator code appearing in the top ten for all three-project classifications was project team member need for a better understanding of how individual project tasks affect the whole organization (PMT-LF). The PMT-LF code was assigned to lines of interview transcripts when challenges in recognizing the impact of project tasks were noted. For example, one interviewee stated, “[The manufactured systems] are big and complex. It can be difficult to determine what affects what.” Vidal and Marle (2008) asserted that interdependencies within a project system add to the complexity of the project, and this increased complexity can threaten the success of the project. Due to both the high number of projects undertaken and the complexity of the organization’s product, project managers and project team members often did not understand how specific tasks fit within a larger frame of reference. Chow and Cao (2008) cited ill-defined project scope and ill-defined project planning as factors contributing to project failure. When the scope of a project is clearly defined, proper project planning can take place. When working on complex systems, design projects often involve making changes to one or several systems simultaneously, while maintaining other interactions within the product. Project team members may not possess the knowledge of how different subsystems currently interact. It appears that a clear understanding of such interdependencies between systems is important to reducing project risk. PMT-LF made up 5.3% of the total number of risk indicators observed in compliance projects, 3.8% in operational projects, and 4.5% in strategic projects. Variation in the relative frequency of PMT-LF between projects with each classification was also low, which suggests that PMT-LF is not dependent on project classification or other project characteristics. Thus, it appears that PMT-LF is critical to risk management strategies, regardless of the type of project. In addition to comparing the relative frequencies of the most frequently occurring risk indicator codes, a statistical comparison of risk indicator code frequency by project classification was conducted. This comparison to test for significant differences in relative frequencies is discussed next.

4.4.2. A Comparison of Risk Indicator Frequencies

This study was conducted with the goal of identifying key risk indicators in projects with different classifications. Significant differences in the relative frequencies of risk indicators would indicate risks that occur more often in one project classification than another. These differences were identified with the use of the Kruskal-Wallis H test. Q-Q plots of relative frequencies verified that the relative frequency data deviated from normality. The Kruskal-Wallis H test is the nonparametric version of the Analysis of Variance (ANOVA) (Kruskal & Wallis, 1952). The Kruskal-Wallis H test is an appropriate test when underlying population distributions are unknown (Vargha & Delaney, 1998). The null hypothesis for the Kruskal-Wallis H test is that samples come from the same or identical populations (Mahoney, 1996). For this type of nonparametric test, the data must be at least ordinal so that data may be ranked, and the rankings of different samples can be compared (Spurrier, 2003). For this research, the samples (relative frequency of risk indicator codes for different project classification) would be considered to come from the same population if the ranks of relative frequencies were similar. The Kruskal-Wallis H test was applied with a significance level of 0.05 and used to compare the relative frequencies for each of the 36 risk indicator codes based on project classification.

Two risk indicator codes, risks associated with customer requests for a change in features or changes in customer priorities (RTE-CU-CF) and risks associated with communication between groups (RTP-CDG) were found to have significant differences in the frequency of occurrence between project categories. Both of these risk indicator codes are associated with communications failures. The frequency of the risk indicator code RTE-CU-CF was 11.7% and was the most frequently occurring risk indicator for operational projects, while the frequency of RTE-CU-CF was 4.6% for compliance projects and 6.3% for strategic projects. See Figure 7. Based on these results, customer changes and communication issues occurred more frequently in operational projects. Gray and Larson (2008) define operational projects as projects that are necessary for sustaining current operations. Included in this classification are projects that were driven by customer specifications. These projects were initiated after the product was delivered to the customer, and the customer requested changes to the design of the system after using the product and identifying certain differences in functionality. Operational projects frequently require close communication with customers, thus making them more susceptible to customer-related risks (Gray & Larson, 2008).

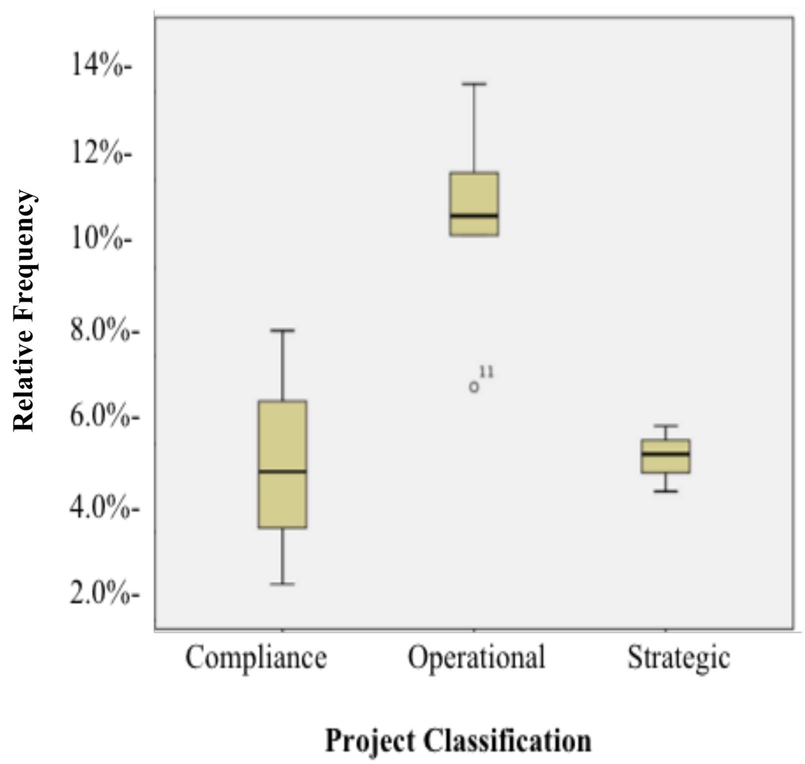

Figure 7: Boxplot of RTE-CU-CF Risk Indicator Code by Project Classification

The risk indicator, RTP-CDG, frequencies are shown in Figure 8. RTP-CDG was the most frequent risk indicator for strategic projects, making up nearly 13% of the total assigned risk indicator codes. RTP-CDG was noted much less frequently for compliance and operational projects, 4.5%, and 5.3%, respectively.

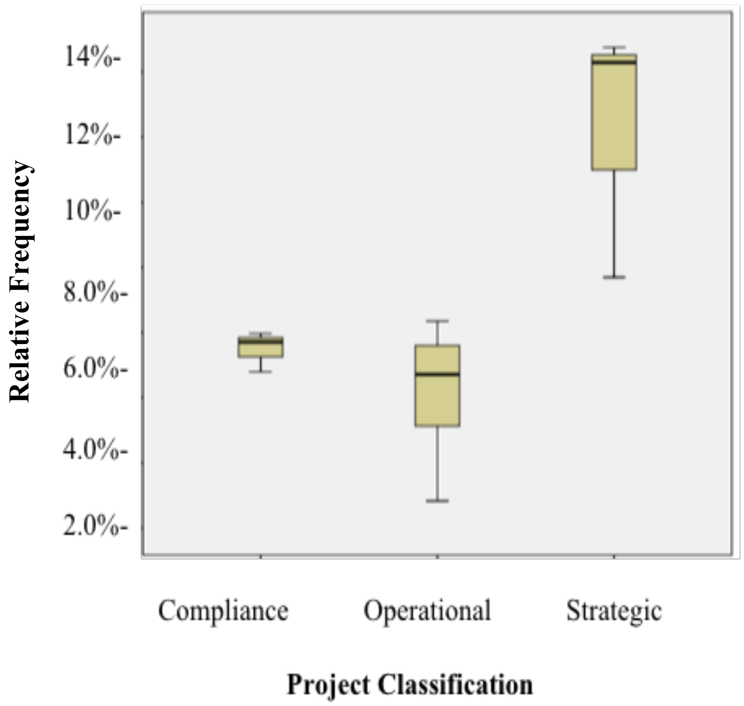

Figure 8: Boxplot of RTP-CDG Risk Indicator Code by Project Classification

Strategic projects in this study were focused on the implementation of new innovations in product designs and were primarily initiated from within the company. These projects tended to involve lesser known technologies and designs. Group communication challenges might be expected in all projects. Lessard and Lessard (2007) list group communication as one of the five most important issues for project teams to consider. Since communication is fundamental to the success of design projects, risks related to communication can be especially detrimental to project success. However, a higher frequency of RTP-CDG in strategic projects may be a result of the need for more extensive collaboration and communication among functional departments when faced with uncertainty stemming from innovation. While there were six common risk indicator codes among the three project categories, there is evidence that for at least two of these common codes, there were differences in the likelihood of these risks based on the project classification. In addition, a number of unique risk indicator codes appeared in the top ten for the different project classifications. These unique codes are discussed next.

4.4.3. Differences in Risk Indicators Between Project Classifications

Risks related to the urgency of the project (RTP-U) were prevalent in both operational and compliance projects, appearing in the top ten risk indicator list for both of these project categories. RTP-U made up only a small percentage of the total overall risk indicator codes for strategic projects and was the 22nd most frequent code out of 36 risk indicator codes total. The difference in frequencies of RTP-U appearances in different project classifications may be explainable, in part, by differences in characteristics of the three project classifications. Operational and compliance projects, for example, have strictly defined deadlines, which are frequently driven by factors outside of the organization’s control (Gray & Larson, 2008). Operational projects are often driven by customer requests, and deadlines for these projects can also be restricting. Compliance projects are made necessary by changes in regulations. Regulatory agencies set deadlines for compliance, and organizations are obligated to make the necessary design changes within specified timelines. Strategic projects are largely internally driven, and thus the organization has more flexibility in setting schedules.

Another difference noted was in risks related to certification (RTP-PC). RTP-PC codes were particularly prevalent in compliance and strategic projects. RTP-PC did not appear in the top ten list for operational projects, and was ranked 28 out of the 36 risk indicator codes. One employee who worked on a compliance project explained, “You have to define a [design] change, coordinate the requirements, verify the design change, coordinate with the [regulatory organization] and show that it still fits regulations.” RTP-PC was assigned to this excerpt of the interview transcript because the design change mentioned required interactions with the regulatory organization to certify the design. This requirement increased the complexity of the project. Project certification is a particularly important concern for projects requiring new designs (Lessard & Lessard, 2007). Compliance and strategic projects often result in designs for new systems; whereas, operational projects tend to be redesigns of existing systems or subsystems

(Gray & Larson, 2008). Thus a higher frequency of RTP-PC in compliance and strategic projects may well be the result of these project classifications encompassing projects that included completely new designs, which subsequently required some type of external certification. This characteristic increased the likelihood of the project team encountering critical incidents leading to project delays. Having presented the results for the similarities and differences in the frequency of risk indicators identified, some themes were identified and are discussed next.

4.4.4. Emergent Themes

Communication risks were one of the most common threats to project success irrespective of project classification. Communication is known to be an important component of project success as indicated by the fact that communication appears as a critical success factor in multiple frameworks developed by researchers, including Belassi and Tukel (1996), Chow and Cao (2008), Nagadevara (2012), Yaraghi and Langhe (2011), and Zwikael and Globerson (2006). The type of risk, resulting from communication challenges observed did, however, vary between classifications. Two risk indicator codes, RTE-CU-CF and RTP- CDG, were found to have statistically significant differences in relative frequencies based on project classification. Communication between the organization and outside entities, such as suppliers (RTE-SC) and regulatory agencies, appeared as two of the top three most frequently occurring risk indicator codes in compliance projects. Communication between organizations and customers (RTE-CU-CF) was the most frequently occurring risk indicator code for operational projects, and communication between departments, (RTP-CDG), was the most frequently occurring risk indicator code for strategic projects. For example, RTP-CDG was assigned when an interviewee from a strategic project stated, “It all comes down to talking among different engineering divisions. That is where we always break down.” Engineering design projects require collaboration between functional departments, which makes clear communication between the functional departments important to success.

Communication with the customer is a particularly important consideration in the implementation of customer-requested design changes because companies are typically much more familiar with the company's standard solution to an engineering design problem, than they are with specific customer needs (Gustafsson, Kristensson, & Witell, 2012). Thus it is particularly important for companies to communicate closely with customers throughout the design process to ensure the company is meeting the customer needs. Gruner and Homberg (2000) found that intensive customer communication during the development process of a product is the deciding factor in the product's ultimate success or failure. The results of this research confirm that customer communications are particularly important in engineering design projects, which are created to satisfy customer change requests.

A second common theme identified in the results of this study was that the project team encountered critical incidents when updated documentation was missing or not effective. In particular, two risk indicator codes, RTO-SP (risks associated with the need for changes to the standard procedures) and RTO-DA (risks associated with inadequate data or documentation available), consistently appeared in the top ten of all three project classifications. RTO-SP and RTO-DA were also frequently coded in close proximity to one another, suggesting that RTO-SP and RTO-DA are closely related risk indicators. For example, when asked what organizational procedures could be improved, one interviewee stated, "We need a better process for identifying what groups are going to be involved [in the project]. We need a contact list. I don't think if this document exists it has suggestions or details on how to contact affected groups." This points out both a need for standard processes and for documentation for such processes.

A third and final emergent theme was related to challenges in collaborating with suppliers (RTE-SC). In the division of the company studied, the organization designs extremely complex systems, thus many parts and subsystems are manufactured by suppliers. RTE-SC was the second most frequent risk indicator in operational and compliance projects. While RTE-SC was not in the top ten risk indicators for strategic projects, supplier challenges had a significant effect on the success of operational and compliance projects. RTE-SC was typically assigned for supplier communication challenges or when a supplier fell short of its obligations. Communication challenges often stemmed from a supplier's lack of working experience with the organization or from difficulties encountered in interacting with a non-local supplier. For example, "The supplier said it would not have these parts starting at this time. And the supplier had a sub-tier supplier, and those parts were becoming unavailable, which caused the part to become obsolete. This was a huge financial hit to the company." The organization is dependent on the performance of suppliers to meet its own objectives. Effective communication between the organization and suppliers and developing strong working relationships with suppliers was necessary to ensure project success.

Communication is essential for project success. The results from this study have shown that communication difficulties with external organizations such as suppliers and customers, can be detrimental to the success of engineering design projects. Communication risks within the organization and communication risks between the organization and outside entities are among the most frequently occurring risks in projects. The emergent themes presented in this section indicate areas for managers to pay close attention to in creating risk management plans. Specific managerial implications from these themes are presented next, along with study limitations and future work.

4.4.5. *Limitations, Conclusions, Future Work*

The limitations of this research, along with the managerial implications of the findings and suggestions for future work are presented next. Limitations to this research project stemmed from limitations in the data collected. All of the projects selected for study were completed within a single division of engineering design organization. Thus the findings from the analysis of these projects represent the risk indicators most frequently occurring within this specific division of the organization. The results from this research may not represent the most frequently occurring risk indicators for engineering design projects in other divisions of this organization or the most frequently occurring risk indicators in projects undertaken in other industries. The results from this study could be extended by applying the methodology used in this research to other divisions of the engineering design organization and to other organizations within this industrial sector as well as other industrial sectors.

Another limitation was the functional representation of project team members participating in the research. While employees from a variety of functional areas were interviewed for the research, participation in the research was voluntary, and the researchers were unable to obtain interviews from every type of employee (e.g. electrical engineers, project managers, production schedulers, etc.) for all projects. The critical incidents identified for each project were a reflection of the functional perspective of employees interviewed. A more balanced perspective of each project could be obtained if employees from every job function were interviewed.

While this research is not without limitations, the knowledge provided as a result of this research is still significant. The goal of the research was to further the understanding of risks most prevalent for different classifications of projects, thereby providing project managers with new insight to enable better project planning, and in particular planning of risk management strategies. Frequently occurring risk indicators provide a basis for managers to proactively address likely risks to projects. The managerial implications of this research are discussed next.

Communication that is clear, effective, and sufficiently thorough is important for all projects, but project managers should take care to adjust risk management plans depending on the type of project. Study results also indicated that risks caused by incomplete, inaccurate, or obsolete information pose a threat to projects, and there is a need for standard procedures to avoid the negative consequences resulting from project teams not having accurate information. Project managers should ensure that every employee involved in a project has access to the necessary information and that information is up-to-date and complete.

Third, risks associated with communication between organizations and suppliers occur frequently in operational and compliance projects, indicating that project managers working on operational or compliance projects should assign resources to establish strong relationships and communication paths with suppliers to facilitate open communication and reduce risks resulting from miscommunications related to project requirements and deadlines.

The results of this study provide evidence that different risks are associated with different project classifications. The contrasts found between the top ten risk indicators among project classification suggests that different risk management techniques should be used for maximum effectiveness. The most frequently occurring risk indicators found in this study for each project classification allow project managers to anticipate certain types of risks that will occur in future projects. Common themes across the three project categories provide insight into those areas that project managers should carefully consider in developing risk management strategies, regardless of project classification.

Future research could apply the methodology developed for this research to other project types or classifications to further refine recommendations for managers. Specifically, a different study could be conducted to explore the relationship between specific measures of project success and different risk indicators. This would help determine which risk indicators have the most detrimental effect on design projects and provide a more holistic view of the relationship between risks and project classification. Studies applying the methodology used for this research to other divisions within the engineering design firm, or even other industries could be used to extend the generalizability of the findings from this research.

4.5. References (Manuscript 1)

Anderson, D. K., & Merna, T. (2003). Project Management Strategy—project management represented as a process based set of management domains and the consequences for project management strategy. *International Journal of Project Management*, *21*(6), 387–393.

Auerbach, C. F., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*. New York, NY. New York University Press.

Belassi, W., & Tukel, O. I. (1996). A new framework for determining critical success/failure factors in projects. *International Journal of Project Management*, *14*(3), 141–151.

Berends, L., & Johnston, J. (2005). Using multiple coders to enhance qualitative analysis: The case of interviews with consumers of drug treatment. *Addiction Research & Theory*, *13*(4), 373–381.

Butterfield, L. D., Borgen, W. A., Maglio, A.S. T., & Amundson, N. E. (2009). Using the enhanced critical incident technique in counselling psychology research. *Canadian Journal of Counselling / Revue Canadienne de Counseling*, *43*(4), 265–282.

Chow, T., & Cao, D.-B. (2008). A survey study of critical success factors in agile software projects. *Journal of Systems and Software*, *81*(6), 961–971.

De Bakker, K., Boonstra, A., & Wortmann, H. (2012). Risk managements' communicative effects influencing IT project success. *International Journal of Project Management*, *30*(4), 444–457.

Gray, C. F., & Larson, E. W. (2008). *Project management*. New York, NY: McGraw-Hill/Irwin.

Gruner, K. (2000). Does customer interaction enhance new product puccess? *Journal of Business Research*, *49*(1), 1–14.

Gustafsson, A., Kristensson, P., & Witell, L. (2012). Customer co-creation in service innovation: a matter of communication? *Journal of Service Management*, *23*(3), 311–327.

Herroelen, W. (2005, Winter). Project scheduling--theory and practice. *Production and Operations Management*, *14*(4), 413-420.

Howell, D., Windahl, C., & Seidel, R. (2010). A project contingency framework based on uncertainty and its consequences. *International Journal of Project Management*, *28*(3), 256–264.

Joshi, M. P., Kathuria, R., & Porth, S. J. (2003). Alignment of strategic priorities and performance: an integration of operations and strategic management perspectives. *Journal of Operations Management*, *21*(3), 353–369.

Kruskal, W. H., & Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*, *47*(260), 583–621.

Kwan, T. W., & Leung, H. K. N. (2011). A risk management methodology for project risk dependencies. In *IEEE Transactions on Software Engineering*, 37, 635-645.

Lessard, J., & Lessard, C. S. (2007). *Project management for engineering design* (Vol. 2). San Francisco, CA. Morgan & Claypool Publishers.

Love, P., & Smith, J. (2003). Benchmarking, benchaction, and benchlearning: Rework mitigation in projects. *Journal of Management in Engineering*, *19*(4), 147–159.

Mahoney, M. (1996). Estimation of the power of the Kruskal-Wallis test. *Biometrical Journal*, *38*, 613–630.

Maylor, H., Vidgen, R., & Carver, S. (2008). Managerial complexity in project-based operations: A grounded model and its implications for practice. *Project Management Journal*, *39*(S1), 15–26.

Maytorena, E., Winch, G. M., Freeman, J., & Kiely, T. (2007). The influence of experience and information search styles on project risk identification performance. *IEEE Transactions on Engineering Management*, *54*(2), 315 –326.

Miles, M. B., & Huberman A. Michael. (1994). *Qualitative data analysis an expanded sourcebook* (2nd ed.). Newbury Park, CA: SAGE Publications.

Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management*, *19*(8), 437–443.

Project Management Institute. (2008). *A guide to the project management body of knowledge* (4th ed.). Newtown Square, PA: Project Management Institute, Inc.

Royer, P. S. (2000). Risk management: The undiscovered dimension of project management. *Project Management Journal*, *14*(9), 31-39.

Spurrier, J. D. (2003). On the null distribution of the Kruskal-Wallis statistic. *Journal of Nonparametric Statistics, 15*(6), 685–691.

Srivannaboon, S., & Milosevic, D. Z. (2006). A two-way influence between business strategy and project management. *International Journal of Project Management*, *24*(6), 493–505.

Stein, J. (1981). Contextual factors in the selection of strategic decision methods. *Human Relations*, *34*(10), 819–834.

Teoh, P. C., & Case, K. (2004). Failure modes and effects analysis through knowledge modelling. *Journal of Materials Processing Technology*, *153(1)*, 253–260.

Vargha, A., & Delaney, H. D. (1998). The Kruskal-Wallis test and stochastic homogeneity. *Journal of Educational and Behavioral Statistics*, *23*(2), 170–192.

Vidal, L. A., & Marle, F. (2008). Understanding project complexity: implications on project management. *Kybernetes*, *37*(8), 1094–1110.

Yaraghi, N., & Langhe, R. G. (2011). Critical success factors for risk management systems. *Journal of Risk Research*, *14*(5), 551–581.

Yim, R. (2013). *Exploring the relationship between engineering design project characteristics and risk indicators* (Unpublished master's thesis). Oregon State University, Corvallis, OR.

Zwikael, O., & Globerson, S. (2006). From critical success factors to critical success processes. *International Journal of Production Research*, *44*(17), 3433–3449.

5. Manuscript 2

EXPLORING THE RELATIONSHIP BETWEEN REWORK PROJECTS AND RISK INDICATORS

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Abstract

Rework projects are undertaken when projects fail to meet requirements. An original project is the first attempt to solve a problem, and a rework project is the second attempt to solve that same problem. Recent research has explored the costs and causes of rework projects, but there is a need for a greater understanding of rework project risk. To address this deficiency, this study examined the presence of risk indicators in eleven projects completed within a large engineering design organization. A risk indicator has predictive power about the likelihood of a risk occurring throughout the course of a project. The results clearly show that frequently occurring risk indicators differ between original projects and rework projects. Troubleshooting, technological advances, and urgency were the most prevalent risk indicators in the rework projects included in this study; whereas, risks related to lack of documentation available, the need for an understanding of the big picture, management communication, and product certification were the most prevalent risk indicators in the original projects studied. In addition to these findings, emergent themes from this research validate previously published studies that identify up front planning and communication as keys to project success. Insights gained from this research can be used to improve risk management plans in projects by providing managers with knowledge about specific risks likely to occur in rework projects.

Keywords

Risk management, Project management, Rework Projects, Engineering design projects

5.1. Introduction

As business becomes more globalized and industry competition increases, the success of design projects becomes more critical to a company's success (Raz, Shenhar, & Dvir, 2002). However, industries continue to lose billions of dollars to project delays and project failure each year (Gray & Larson, 2008). Project risk management is defined as a process that ‘‘systematically aims to identify, evaluate, and manage project related risks to improve project performance’’ (Maytorena, Winch, Freeman, & Kiely, 2007, p. 315). Risk management procedures are critical to successful project management. Raz et. al. (2002) observed in a study of more than 100 companies over multiple industries that those companies that incorporated risk management procedures into each project tended to have a higher project success rates. Risk indicators are events or circumstances that have the power to predict the likelihood of a risk occurring in a project. This study identified prevalent risk indicators in engineering design projects based on project characteristics with the goal of aiding managers in developing proactive risk management strategies. The ability to predict risks that will occur in a design project before project initiation would allow project managers to introduce appropriate risk management techniques and increase the likelihood of project success. In addition, such knowledge could also enable project success, resulting from fewer time delays and lower costs.

This research focused on the identification and evaluation of risk indicators in engineering design projects for two different types of projects. Specifically, projects were identified as either original or rework projects. Based upon several definitions from the project management literature, original projects were defined for this study as the first attempt to accomplish a given task or set of tasks; rework projects were defined as projects that were a second attempt to complete a task or set of tasks.

This study examined the risk indicators most likely to appear in rework projects and, as a result provides insight into the sources of risks on rework projects that can be used to inform risk mitigation and elimination strategies for rework projects. Knowledge of the most likely risks to both original and rework projects can improve the success of both types of projects by indicating the areas in which project managers should concentrate risk management resources for maximum results.

This research begins with a review of relevant literature related to the management of rework projects, project success factors, and risk management. These topics provide context for the study as well as a basis for chosen methodology. In addition previously published literature provides context for a discussion of the findings of this study. The methodology is described, following the review of the literature, followed by a summary of the research results in which details of two rework projects are discussed. An analysis of the most prevalent risk indicators in rework projects is presented next. The results section concludes with a description of risk indicators that were most prevalent in both original and rework projects. Finally the paper concludes with a discussion of some of the limitations of the research, followed by an overview of the managerial implications of the findings. The paper concludes with suggestions for future work.

5.2. Literature Review

Project management is recognized as an approach for effectively providing a new project or service within a specified timeframe (Karayaz, Keating, & Henrie, 2011). Projects are constrained by specific time, cost, and performance requirements, and it is the job of a project manager to balance these three goals (Lessard & Lessard, 2007). Projects are becoming increasingly more important to companies as over half of all work is completed within the project framework (Maylor, Vidgen, & Carver, 2008). Uncertainty can lead to risk to projects (Koltveit, Karlsen, & Gronhaug, 2005). Some of the literature relevant to project management and this study are summarized next.

5.2.1. Project Management and Rework

A project can be divided into a series of tasks or "original work" that must be accomplished (Owens, Leveson, & Hoffman, 2011). Each task has a specific objective, a set timeframe, and a budget. Tasks have the potential to be completed correctly or incorrectly. When the incorrect completion of a task is identified in a timely fashion, that task can be reworked immediately. Sometimes incorrectly completed tasks are mistakenly classified as having been correctly completed. These improperly labeled tasks are classified by Owens, Levenson, and Hoffman (2011) as "undiscovered rework."

Rework has been defined in literature in many ways. The words deviation, error, defect, failure, and nonconformance in association with the quality of a product have been used synonymously with rework (Love & Edwards, 2005). Love and Edwards define rework as "the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time" (Love, 2002). In recent years, there has been increased interest in studying the causes of rework with a goal of eliminating sources of rework. Rework is often attributed to poor initial design, brought about by unclear requirements, communication, and documentation, as well as poor workmanship, or failure to carry out requirements as specified (Love & Smith, 2003). Documentation errors and poor managerial practices have also been identified as contributing to rework. In the project environment, inadequate up front project planning during project scoping and inadequate communication and documentation have been found to lead to rework projects (Love & Smith, 2003).

The consequences of rework are numerous. Chiefly rework is regarded as the primary cause of time and schedule overruns in projects (Love & Smith, 2003). Rework can be an additional activity completed within the original project, or an entirely new project can be created to accomplish the necessary rework activities. Rework projects are costly, undesirable, and unnecessary. Companies could benefit if strategies can be implemented to mitigate the need for rework projects and to create more successful first-run projects. While some sources of rework projects have been identified in the literature, numerous studies have been published to provide practitioners with an understanding of the characteristics of successful projects. The next section describes the factors that have been identified in the literature as being drivers of project success, as well as providing a broad overview of how project success is measured.

5.2.2. Project Success Factors

Project management techniques and practices are used for the purpose of delivering successful projects (Gray & Larson, 2008). Because projects require significant investments of time, resources, and money, it is important for organizations to establish project management techniques to support the delivery of successful projects (Maylor, Vidgen, & Carver, 2008). The project environment of rework projects, often characterized by a compressed schedule and a high level of urgency, can increase the likelihood of project failure. One key to attaining project success is identifying the factors that lead to project success (Maylor et al., 2008). While there is no single definition of project success in the literature, project success metrics can be found throughout the project management literature.

One common element of the definitions of project success is that most researchers define success across multiple measures. Ten different definitions of project success, spanning 16 years of research (1996 – 2012) are summarized in Table 21. Table 21 also highlights measures of project success.

Table 21: Project Success Definition and Measures

Authors	Definition	Quality	Time	Scope	Costs
Babu, G. N. K. S., & Srivatsa, S. K. (2011).	"The success is defined by a set of criteria that the outcome or the solution must meet to be considered 'successful'" (p. 19)	X	X		X
Baccarini, D. (1996).	"...project characteristics provide a basis for determining the appropriate managerial actions required to complete a project successfully." (p. 201)	X	X	X	X
Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011).	The success of a project is affected by the complexity of the project. (p. 728)		X	X	X
Chow, T., & Cao, D. (2008)	The "overall perception of success of a particular project" (p. 963)	X	X	X	X
Clift, T. B., & Vandenbosch, M. B. (1999).	Keeping to an efficient schedule will lead to a more successful project. (p. 187)				
De Bakker, K., Boonstra, A., & Wortmann, H. (2012).	"Project success is an objectively measureable state describing how well the project performed." (p. 445)		X	X	X
Herroelen, W. (2005).	"The lack of adequate planning and control is often cited as one of the major variable that best distinguish between escalated and non-escalated projects." (p. 428)		X		X
Maylor, H., Vidgen, R., & Carver, S. (2008).	A project is successful when the objectives are met. (p. 516)	X	X	X	X
Van der Westhuizen, D., & Fitzgerald, E. P. (n.d.).	Project success is made up of how successful project management and the end product are. (p. 2)	X	X		X

While there is not consensus on how to define or measure success, there is significant overlap in the measures. Those factors leading to project success are discussed next.

Zwikael and Globerson (2006) defined critical success factors as factors that influence the failure or success of a project. Ensuring the realization of critical success factors can be the difference between project success and failure (Yaraghi & Langhe, 2011). Some examples of critical success factors include good customer communication, support from upper management, sufficient budget allocated for the project, and sufficient availability of the resources needed to complete the project (Belassi & Tukel, 1996). Since critical success factors obtainment is directly correlated with project success, identifying risks to critical success factors could be informative for project managers. To understand the formulation of risk management plans, the concept of risk and the management of project risk must be understood. These topics are discussed next.

5.2.3. Risk

Risk is defined by Kwan and Leung (2011) as a possible event that would hinder the ability of a system to complete its purpose if the event transpires. According to Lessard and Lessard (2007) one of the defining characteristics of a project is uncertainty. The amount of risk in a project increases with the amount of uncertainty in a project, and uncertainty is inherently present in all design projects (Howell, Windahl, & Seidel, 2010). Risk management processes are utilized for predicting, identifying, and mitigating project risks, ultimately increasing the likelihood of project success (Maytorena et al., 2007). The goal of risk management is to successfully identify and mitigate risks to the fulfillment of project objectives (Stein, 1981).

There are many steps in the risk management process. Risk management activities should start as soon as a project has been defined (Chapman, 2001). The most opportunity for managing risks occurs early on in the project (Gray & Larson, 2008). Changing course, due to the occurrence of risks becomes increasingly costly as the project progresses (Lessard & Lessard, 2007). The risk management process begins with the identification of potential project risks. Identifying risks requires a thorough evaluation of project attributes, gathering all relevant project information from stakeholders, and drawing from past experience and risk management techniques to create a thorough list of possible project risks. Indicators of potential project risks can be used proactively to identify project activities that should be undertaken to increase the likelihood of project success. If risk indicators can be identified before a project starts, project success is more likely.

After risks are identified, management needs to evaluate those risks and prioritize the risks so that project resources can be focused on those most likely to occur or those risks whose consequences would have the most significant negative consequences. After risks have been evaluated and prioritized, a risk management plan can be created, tailored to the specific potential risk events identified for a project and to the priorities of the company. Throughout the life cycle of a project, additional risks may be identified, thus the risk management process must be continuously applied.

Current risk identification techniques are very effective for small-scale projects, but often do not scale practically to larger projects. A common risk analysis technique is the Failure Modes and Effects Analysis (Teoh & Case, 2004). This technique is used to identify risks by outlining every part in a product and identifying all potential failures that could occur during the use of the product. Risk analysis techniques such as the Failure Modes and Effects Analysis (FMEA) are often product-oriented, rather than project-oriented. The time required to complete an FMEA for projects involving multiple functional departments and many separate activities is prohibitive (Chapanis, 1996). There is a need for predictive risk assessment techniques that can identify important risk indicators to complex products and projects.

When risks occur during the course of a project, these risks can affect critical success factors and ultimately lead to project failure. When original projects fail, rework projects can be undertaken. The purpose of the study was to determine whether or not risk indicators, associated with original engineering design projects, were the same as risk indicators associated with rework design projects. Since projects are defined as original or rework projects from the start, the knowledge gained from this research can be applied to risk management plans before the project begins. Having provided an overview the most relevant literature, the next section will discuss the methodology utilized for this research.

5.3. Methodology

5.3.1. Overview

The section begins with background on qualitative data analysis and on critical incident methodology. Next, an explanation of research design elements, including the project selection procedure, study participant identification, data collection instrument, code schema development, and coding process are provided. Coder agreement analysis and data screening processes are also presented. The section concludes with a summary of the analyses conducted.

The dataset for this research was developed from interviews with project team members from eleven design projects, completed within one division of an engineering design organization and collected over a 28-month timeframe. The dataset included 70 interview transcripts. Interviews were conducted with employees who directly contributed to one or more of the eleven selected design projects. Transcripts were created from interview notes. The code schema developed for the study was then used to assign risk indicator codes to each line of text within each transcript. Risk indictors were associated with specific challenges faced during the project, as recounted by the project team members interviewed. Risk indicator code frequencies were calculated to enable a comparison of the types and frequency of specific risks faced in the course of the two project types (original design projects and rework design projects). The next section provides an overview of qualitative data analysis techniques used as the basis for the methodological design employed in this study.

5.3.2. Qualitative Data Analysis

Forms of qualitative data collection include direct observation, interviews, and written documents (Patton, 2002). A qualitative approach to data analysis is particularly effective in capturing “real life” descriptions of naturally occurring events and processes.

Qualitative data provide vivid, rich descriptions that preserve the local context of a situation (Miles & Huberman, 1994). According to Patton (2002), qualitative data enables researchers to study issues in depth and detail.

Interview transcripts, surveys, descriptions of observations, and text are typical forms of qualitative data; whereas, quantitative data take the form of numbers, rather than words (Miles & Huberman, 1994). Due to the wide range of techniques available for the collection and analysis of qualitative data and the variety of interpretations that can stem from the same set of data, the validity of qualitative data analysis depends heavily on the construction and rigor of the analysis techniques applied. Techniques to improve the rigor of qualitative data analysis include purposive sampling, the use of multiple coders, respondent validation, and triangulation (Berends & Johnston, 2005). This study utilized these techniques to help ensure that data and analysis were both valid and reliable. To identify risks encountered and realized during real design projects, critical incident methodology was used. An overview of critical incident methodology and its appropriateness for this study are provided next.

5.3.3. Critical Incident Methodology

Critical incident methodology was created to capture important events in the study of real-life phenomenon. For this research, important events were risk events experienced by project team members during the course of project completion. Risk events were those situations that had the potential or did lead to less than ideal project performance, as measured by typical project success measures of quality, scope, budget and schedule. Critical incident methodology uses specific probes in which observers are asked to recall details about specific events (Chell & Pittaway, 1998).

Butterfield (2009) uses four factors to distinguish critical incident methodology from other qualitative data collection methods. First, critical incident methodology concentrates on critical events, incidents, or factors that can influence the outcome of an activity in a positive or negative way. Second, interviews are the primary method of data collection in critical incident methodology. Third and fourth, data analysis is accomplished through sorting the data into categories, which are used to identify emerging themes.

Critical incident methodology is most powerful when many observations are collected (Flanagan, 1954). Conclusions drawn from observations are deemed to be accurate representations of the event, if multiple independent observers have the same observation about the event. Critical incident methodology was utilized as a basis for forming the interview questions used for this study. The interview question development is described next.

5.3.4. Data Collection Instrument Development

Two different interview protocols were created to obtain project team members' observations of risks encountered and realized during the course of carrying out the eleven projects that were studied. Critical incident methodology was utilized in the development of the first interview protocol, Interview A. Interview A was developed with the goal of understanding critical incidents faced at various points during the project, actions taken by team members in response to critical incidents and outcomes experienced. The second set of interview questions, Interview B, was divided into two parts. The first half of interview probes in Interview B were designed to gain a deeper understanding of the challenges faced by the project team. The second half of the interview probes in Interview B were focused on developing an understanding of perceived system-wide risks. Table 22 provides example questions from both Interview A and Interview B.

Table 22: Sample Interview Questions

Sample Question	Interview Protocol
What were the events or circumstances that led to the ‘critical’ incident situation? The situation could have had either a positive or a negative impact.	A
What is the situation/process that needs to be changed to avoid a recurrence of this sort of incident (or to attempt to create a recurrence of this sort of incident for a positive effect)?	A
Do any organizational procedures or processes need to be corrected to eliminate this sort of situation (or changed to promote this sort of situation), and if so what?	A
What were the outcomes of the ‘critical’ incident as a result of the actions taken?	A
What are the possible future outcomes if the situation/process remains unchanged?	A
In your experience, what risks to engineering design projects have you encountered most often?	B
Which had the most detrimental affects to the outcome of the project?	B

All interviews were conducted at the site of the participating engineering design organization, over the course of 28-months. A total of 70 interviews were conducted using Interview A and Interview B. The vast majority of interviews were conducted with one employee at a time. Two interview sessions included multiple employees. Interview questions were asked in the same order for each interview. Employees were asked to recall details about the events that transpired over the entire course of the project. One researcher was responsible for asking the questions and leading the interview, while other researcher(s) took detailed notes, recording interviewee responses. After each interview was completed, researchers compiled a single complete set of notes to create an interview transcript. These interview notes were subsequently transcribed into an electronic format. The text was divided into individual lines of text containing approximately ten words. This transcription formatting was completed to support the assignment of codes to the text. Details about the selection of design projects are provided next.

5.3.5. Project Selection

The engineering design company participating in this research was organized into divisions. Each division is dedicated to the design and manufacturing of a unique product made up of hundreds of complex subsystems. To accomplish the task of creating, maintaining, and enhancing these products, the organization initiates and oversees hundreds of engineering design projects each year. The participating organization provided the research team with a list of several hundred completed engineering design projects. This list of projects contained high-level project information, including estimated hours for completion whether the project was a rework project or not.

Eleven engineering design projects were identified from this list, using different project characteristics as the basis for selection. Projects created for different purposes with similar size and scope were selected for study. Overall a diverse range of projects, with moderate variation in project size, as measured by number of project activities, created a representative subset of projects to enable a broad-based understanding of different types of risks encountered in moderately large engineering design projects. Each of the projects selected for this study were of medium-complexity. Each selected project was more complex than redesigning a single part or component, but was less complex than designing an entirely new product. Project details for the eleven selected projects are provided in Table 23.

Table 23: Project Characteristics

Project Number	Type of Project	Total Hours	Rework
1	Mechanical Redesign	2,728	No
2	Mechanical Redesign	2,672	No
3	Environmental Systems Modification	14,593	No
4	Electrical Systems Modification	2,928	No
5	Replacing Obsolete Part	10,280	No
6	Electrical and Software System Upgrade	16,569	No
7	Structural Redesign	15,390	Yes
8	Electrical and Software System Redesign	5,123	No
9	Electrical and Software System Upgrade	2,292	No
10	Electrical Systems Modification	1,477	Yes
11	Software Upgrade	4,575	No

The purpose of this study was to determine whether or not projects initiated for the first time experienced similar or different risks than projects undertaken a subsequent time, due to the failure of a previous design project to meet all technical project objectives or goals. Projects will be referred to as original projects or rework projects. Rework projects were initiated due to shortcomings in the design solution resulting from an original project. Having presented and described the project selection details, the selection of participants is described next.

5.3.6. Participants

The organization provided the researchers with very detailed project documents that included a list of employees assigned to each project, as well as the job title of each employee. The researchers identified potential participants for the study from these project documents. A list of desired participants was developed by the research team for each project and was sent to a liaison within the organization. The liaison then sent an email to the selected employees with details about the study and an invitation to participate in the study. Employees who were interested in participating responded to the liaison who then helped coordinate the scheduling of an interview. Forty-six employees with various job titles, from all eleven projects agreed to participate in the study.

The interview participants were employees from various core engineering and business departments within the organization. Each functional department was responsible for different aspects of the projects, which were undertaken to design, redesign, or modify the product. Structures, electrical, and environmental control systems engineers were the most involved functions for the projects chosen for this study.

The structures group, mainly comprised of mechanical engineers, was charged with designing physical parts and subsystems. The electrical group was comprised of electrical engineers and was responsible for designing electrical systems. The environmental control systems group was comprised of engineers representing different disciplines. The environmental control systems group developed complex heating and cooling systems required to maintain appropriate operating temperatures in the product.

Some of the selected interviewees held project management or project scheduling roles within the company. These project managers represented different engineering disciplines and were very familiar with both technical aspects of the design projects, as well as having the management skills to lead engineering teams and to coordinate with other functional groups from the division. The employees tasked with scheduling for the engineering projects held more of a business role. These employees were not required to have an engineering degree, but were required to have enough technical knowledge to understand requests for change and to create project documents outlining all of the detailed tasks necessary to complete the design. The schedulers coordinated with each engineering group to gather the necessary information to create project documents and to develop schedules that would integrate with existing commitments for each engineering group. By interviewing a wide variety of employees, a well-rounded perspective of critical incidents, which occurred in the course of project completion, was obtained. Details related to the development of the code schema used to categorize the critical incidents described by participants are provided next.

5.3.7. Code Schema Development and Code Assignment

The process used to develop the code schema for this research was based on recommendations from Miles and Huberman (1994). Interview data were formatted into transcripts. Multiple researchers coded each transcript to ensure an unbiased view of the data. Berends and Johnston (2005) assert that the use of multiple coders is necessary to obtain accurate data. The strategy of using more than one coder for every transcript is beneficial but also creates some challenges. When assigning codes, researchers often have a natural preference for applying certain codes (Berends & Johnston, 2005). Having multiple coders can counteract this type of bias.

Two researchers applied the initially developed coding schema to interview transcripts separately, then subsequently refined the coding structure until it satisfactorily described all of the different critical incidents contained in the interviews. Coding assignments were then compared, and the two researchers discussed disagreements until a complete set of risk indicators was developed. The code schema of risk indicators was comprehensive, without being redundant. Codes and code definitions become more precise through discussion of disagreements between initial coders. The code schema, code definition development process, and code assignment process is summarized in Figure 9.

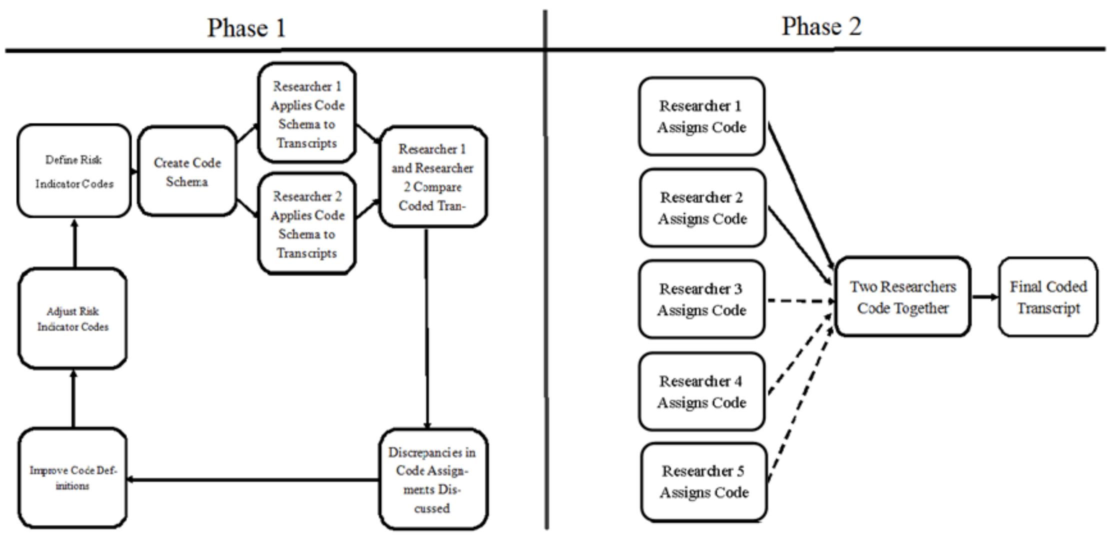


Figure 9. Code Schema Development and Code Assignment Process

After the code schema was fully developed, a larger team of researchers completed several rounds of practice coding to increase familiarization with the codes and to increase reliability of the coding process. A team of five different researchers coded transcripts individually. At minimum, two researchers coded each interview transcript. Once codes were assigned to a transcript by at least two researchers, the researchers met to compare and assign a final set of codes for each transcript. The joint process of coding involved coders reading through each transcript together line by line and discussing the assigned codes. Agreements and disagreements were examined. Ultimately a single final code was selected. When necessary, researchers referred to original project documents to garner a deeper understanding of project context. The actual code schema developed for this research is discussed next.

5.3.8. Code Schema

The basis for the code schema developed for this study was based on critical success factor frameworks found in literature. According to Yaraghi and Langhe (2011) critical success factors are those activities that must be undertaken in order for a project to be considered successful. The critical success factor frameworks developed by Belassi and Tukel (1996) and by Chow and Cao (2008) become the primary frameworks used to devise an initial code schema. Possible risk indicators were identified for each success factor. Five categories of success factors were used and formed five macro-level codes. Within the macro-level codes, each risk identified became micro-level codes. There were 36 total micro-codes in the coding schema. Definitions for each of these 36, micro-level risk indicators are summarized in Table 24. The five macro-level codes included (1) risks related to the external environment (RTE), (2) risks related to the organization (RTO), (3) risks related to upper management performance (RMP), (4) risks related to the functional manager and team (PMT), and (5) risks related to the project (RTP). Once codes were developed and assigned to transcripts, initial analyses were completed to assess the validity and reliability of code assignments.

Table 24: Code Schema (Yim, 2013)

Macro-Level Codes	Micro-Level Codes [abbreviation]
Related to the External Environment [RTE]	Economic Conditions **[RTE-E]**
	Customer: Safety **[RTE-CU-CS]** Customer: Change in Features / Prioritizations **[RTE-CU-CF]**
	Competitor Actions and Their Impact **[RTE-CO]**
	Technological Changes **[RTE-TE]**
	Sub-Contractors Effects **[RTE-SC]**
	Quality Conformance **[RTE-QUAL]**
Related to the Organization [RTO]	Need for Changes to Standardization of Procedures **[RTO-SP]**
	Inadequate Data / Documentation Available **[RTO-DA]**
	Model Specific Knowledge Required **[RTO-MK]**
	Experience/ Longevity in Position **[RTO-LP]**
	Budget Issues for Project (Amount or Timeliness of the Funding) **[RTO-BP]**
Related to High Level Management Performance [RMP]	Management's Skills in Scheduling and Planning **[RMP-PS]**
	Management's Skills in Communication and Coordination of Project Assignments **[RMP-CC]**
	Management's Skills in Control and Monitoring **[RMP-CM]**
	Management's Support of the Project **[RMP-SPT]**
Functional Manager and Team [PMT]	Sufficient Training/ Technical Background and Skills of Functional Manager / Team Member(s) (Sufficient Man Hours and Training Available) **[PMT-TB]**
	Communication Skills between the Functional Manager and Project Team Member(s) **[PMT-CS]**
	Ability of Functional Manager / Team Member(s) to Coordinate Tasks and Schedule **[PMT-AC]**
	Identifying and Trouble Shooting Skills of Functional Manager and Project Team Member(s) **[PMT-TS]**
	Functional Manager / Team Member(s) Commitment to the Project **[PMT-C]**
	Functional Manager / Team Member(s) Ability to Prioritize/ Trade-off Projects or Areas of Projects as Needed **[PMT-PT]**
	Frame of Reference/ Need for Understanding of How the Project fits the Big Picture **[PMT-LF]**
Related to the Project [RTP]	Urgency of Project **[RTP-U]**
	Uniqueness of Project Activities **[RTP-UQ]**
	Multiple Competing Objectives Within the Project **[RTP-MO]**
	Risk Identified Late in Project Thereby Increasing Potency **[RTP-PP]**
	Safety Issues **[RTP-S]**
	Requires Communication Between Different Groups **[RTP-CDG]**
	Project Affects Different Groups **[RTP-ADG]**
	Large Number of Actions Required to Complete the Project (Density of the Project) **[RTP-DP]**
	Timeframe Constraints **[RTP-TC]**
	Availability of Adequate Resources (General Resources) **[RTP-AR-Q]** Availability of Skills/ Experienced Staff (Project is Understaffed) **[RTP-AR-SX]**
	Needs Product Certification **[RTP-PC]**
	Delayed Start to the Project. Significant Time Between Learning of Problem and Starting the Solution that Resolves Problems **[RTP-DEL]**

5.3.9. Code Validity and Reliability

The process of utilizing a team of researchers to code each transcript was implemented to improve the validity of the final code assignments. According to Berends and Johnston (2005), sociological studies have shown that each researcher will have preferences for applying certain codes to certain situations. In highly contextual situations, each interpretation may be valid; therefore, it is wise to consider multiple opinions when assigning final codes.

Differences in opinion on the appropriate code assignment must be resolved to be able to complete the final code assignments. Final code assignment validity and reliability were assessed by reading through each transcript, line by line and applying a 1 when a transcript's final code matched one of the originally assigned codes, and a 0 when the final code did not match one of the original codes. The match percentage was composed of the sum of matching codes per transcript divided by the total number of codes in each transcript. The overall match percentage is the average of the matching percentages of all transcripts. An analysis of the percentage of consistency between the initial and final codes showed that the average agreement percentage across transcripts was approximately 77%.

A second stage analysis was completed to further ensure the validity of the data set and code assignments. Some participants were more deeply involved in a study project than others. Participants with little involvement in the projects for which they were being interviewed were, as a result, unable to provide detailed descriptions of critical events that transpired during the course of the project, yielding interview transcripts with very few assigned codes. These transcripts were eliminated from the overall data, eliminating seven transcripts from the dataset. Before screening out these seven transcripts, the average number of codes per interview was 28.2. After removing the seven transcripts, the number of codes per transcript increased to 30.5. The next section describes the analysis performed on the remaining 63 transcripts.

5.4. Results and Discussion

Authors have recognized many causes for rework (Chua & Verner, 2010; Love & Edwards, 2005; Owens et al., 2011). Examples of rework causes are insufficient time or resources, and insufficient information for employees who worked on the projects (Love & Edwards, 2005). When a project task has been accomplished incorrectly thereby triggering the need for rework, a project manager can either assign rework to be completed during the course of the original project, or an entirely new project can be created to resolve the issues. Two rework projects were identified in the set of eleven projects studied. These rework projects were initiated to correct engineering design limitations that existed in the solution developed in the original design project. The risk indicators identified for the rework projects were analyzed and compared to risk indicators present in the remaining nine original projects.

This research study was undertaken to gain an understanding of the risk indicators for project managers to consider when creating risk management plans for engineering design projects, with a special focus on rework projects. The risk indicators with the highest relative frequencies were considered to be the most notable due primarily to the rate of occurrence in the analyzed projects.

The details of two individual rework projects are discussed next. A description of these two projects is provided followed by several excerpts from the transcripts. These excerpts illustrate the context of the rework projects. Next, the top ten risk indicators for both rework projects and original projects are presented and examined. After examining differences in the most frequently occurring risk indicators in rework and original projects, the risk indicators common to both original and rework projects are discussed. Excerpts from interview transcripts are included throughout the discussion to provide context. Explanations for findings are provided and, where applicable, findings from the project management literature are cited to support the study results. Lastly, emergent themes related to the type of risks encountered in rework design projects are presented and discussed.

5.4.1. Rework Project Details

In this section, details on the two rework projects provide context for understanding the risk indicators identified in these projects. The first rework project (Project 7 from Table 23) will be referred to as Rework A. Employees assigned to Rework A were tasked with redesigning a structural system. The objective of the original project was to design a strong, lightweight structural system to replace a structural system that did not meet original project requirements. The originally designed product was functional, but it did not meet desired weight and strength requirements.

The goal of Rework A was to create a long-term solution by designing a structure that was functional, but lighter and stronger. According to an interviewee involved in Rework A, “there was a [project] that did a rushed solution that was really heavy and bulky. This new [project] was to take some time to make [the design] lighter and sturdier.” The first design attempt from the original project became a temporary solution because the project team pushed the design through quickly. Another interviewee involved in Rework A stated, “when you are in a rush, you don’t do all of the early steps thoroughly to make sure that the rest of the project is coordinated well and that you really understand the design concept.” Thorough planning in the early stages of a project and full commitment to a project will translate to a smooth, successful outcome (Gray & Larson, 2008). When a project team compresses a project timeline, the team’s level of understanding of project scope and objectives tends to decrease (Chapanis, 1996). Therefore, project details are more likely to be overlooked and subsequent rework projects are frequently initiated in response to having an inadequate design (Owens et al., 2011).

Excerpts from the Rework A interview transcripts also illustrate the negative consequences of Rework A on the organization. When asked about the project’s impact to the company, one interviewee explained that, “There was certainly a big financial impact, and then it involved a lot of design engineers that had to set aside their other work. It delayed other projects, because it was important, they had to focus on this instead.” According to the interviewee, there were two major implications of Rework A. The first implication was financial impact. Rework projects are unforeseen expenditures and often require additional time and resources to address work that, ideally, should have been completed (Love & Edwards, 2005). The second implication of Rework A was the unavailability of employees to work on other projects. Rework A drew employees away from other projects and priorities. This resulting reassignment of resources likely saturated the schedule, increased costs, and ultimately increased the level of risk for other impacted projects (Maylor et al., 2008).

The second rework project was Project 10 (see Table 23), referred to as Rework B. The original project preceding Rework B was created for the purpose of incorporating a new software system into a subsystem of the overall product. Unforeseen electronic glitches began to occur in other subsystems after the software was installed. Rework B was the second attempt to initiate fully functional software. The causes of Rework B were similar to Rework A. For example, an interviewee from Rework B explained, "On the first [project], if we had better evaluated the impact on systems and groups, we probably would have never had the second [project] to begin with." Rework B was the result of failing to understand interactions between systems. Additional effort at the onset of the project could have potentially generated a fuller understanding of potential interactions and prevented a rework project. Another interviewee stated, "Up front planning. That is where we have problems." This excerpt further reinforces the notion that thorough planning is a common challenge for project teams. Project teams are often forced to accelerate project tasks, which can cause project planning details to be missed and misunderstanding of project scope to occur (Wang & Ko, 2012). The consistency of causes and consequences for both Rework A and Rework B provide some evidence that accelerated timelines and inadequate understanding of project requirements can result in project failures. Having provided context for the two rework projects, the next section presents the most frequent risk indicators for these two rework projects.

5.4.2. Risk Indicators Unique to Rework Projects

The top ten risk indicator codes identified for the two rework projects made up 60% of all codes assigned to rework projects. Figure 10 summarizes the top ten risk indicator codes in descending order. Four of the rework project top 10 codes did not appear among the top ten risk indicator codes for original projects. These unique risk indicator codes are discussed next.

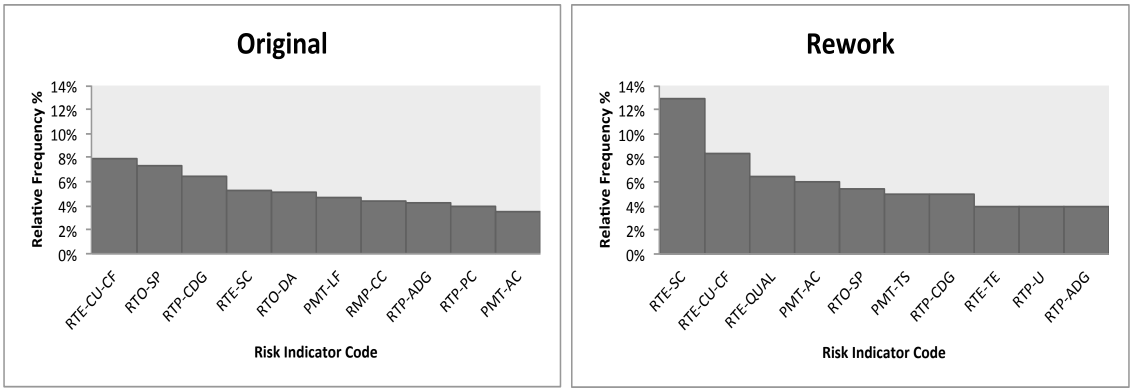


Figure 10: Top 10 Risk Indicators for Original and Rework Projects

One risk indicator code unique to the top ten of rework projects was PMT-TS. PMT-TS is the risk indicator associated with troubleshooting. This risk indicator was assigned to lines of interview transcripts that exemplified an error in troubleshooting or a need for additional troubleshooting efforts from the project team. One interviewee stated "The engineering thought it was going to work out, and they discovered during installation that it didn't work. We may have known about it before, but as you go through, there are a lot of design decisions that are made, not necessarily as a whole unit. So a lot of times with that many people or disciplines involved, there are many problems that are discovered later." A more efficient and comprehensive troubleshooting earlier in the project may have uncovered the problem before the end of Rework B. Additional troubleshooting by the project team on Rework B was needed to evaluate and solve the system issues. PMT-TS was the sixth most frequently occurring risk indicator overall in rework projects. The frequent occurrence of this risk indicator can be explained by nature of rework projects. Rework projects are initiated to resolve issues from prior projects, which requires strong troubleshooting skills. Therefore, the success of rework projects is heavily dependent on effective troubleshooting. Project managers should plan adequate time and resources to diagnose the potential effects of changes in design to mitigate the need for rework projects, as well as to ensure rework projects are successful, if undertaken.

Another risk indicator unique to the top ten of rework projects was RTE-TE, risks related to technological changes. The RTE-TE risk indicator code was assigned to text when project challenges emerged as a result of novel technology. For example, in the two rework projects analyzed in this study, it was common for additional issues to arise when new technology replaced an older, more known technology. An interviewee from Rework B described such technology challenges: “The reason we were getting these faults in service was because we had another change in software.” The project team had difficulty transitioning to the new software system. Adapting to a technology or troubleshooting technological challenges creates an additional level of risk to project success. New or especially complicated technologies cannot be completely understood at the onset, so unforeseen problems are likely to arise. In response to the question “What else could be done to avoid this type of situation in the future”, one interviewee responded “Understand the design early on and all of the impacts, so that we would not go through 20 revisions on a (product)”. From the observations made in this study, it is hypothesized that more technically complex projects are more likely to result in rework projects. In this case the technological complexity of the software upgrade resulted in the need for Rework B.

A third risk indicator unique to the top ten risk indicators in rework projects was RTP-U, risk related to project urgency. Urgency is defined for this study as the importance of the project to the company (level of criticality of a project). According to Love, Irani, and Edwards (2004), “recent research has shown that rework is the primary cause of time a schedule overruns in projects (p. 426)”. When an original project’s timeline has surpassed the timeframe allotted for that project, the urgency increases. Rework projects created to address issues in original projects may be more urgent due to the already surpassed deadlines. The rework projects analyzed in this research were second attempts to solve a design problem that had not been properly addressed in the original project. Since rework projects are follow-up projects to fix or improve upon a previous solution, the schedule can be very tight. The rework projects in this study were particularly urgent because the original projects had already overrun the deadlines agreed upon with the customer. The overall goal of this study was to discover the most prevalent risk indicators for rework projects. A variety of strategies were employed to fully characterize likely risks for rework projects. A second analysis was undertaken to identify those risk indicators that occurred at different levels of frequency between original and rework projects.

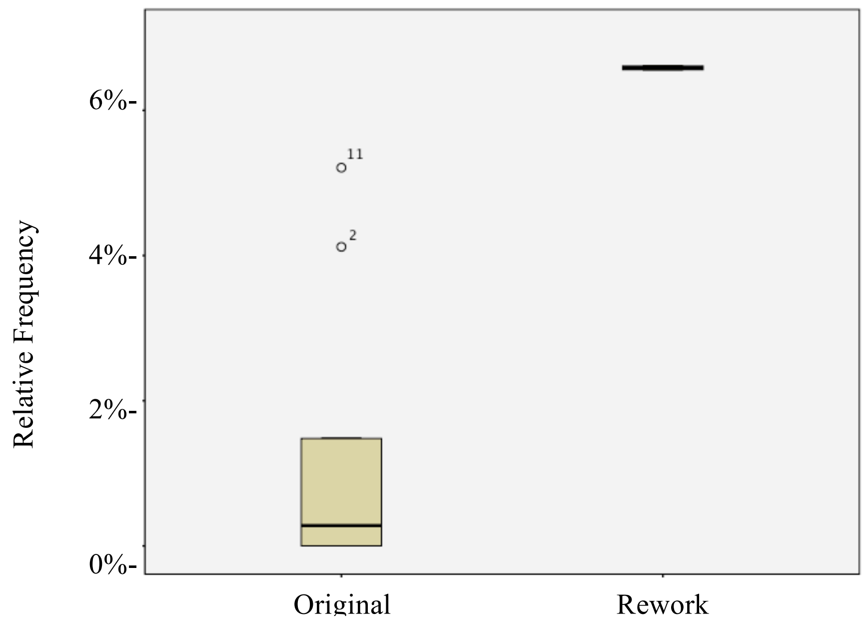


Figure 11: Box Plot of RTE-QUAL by Project Type

After final risk codes were assigned and frequencies for all codes were calculated, Q-Q plots of risk indicator code frequencies were reviewed to determine whether or not the frequency data were normally distributed. The frequency distributions did not appear to be normally distributed; therefore nonparametric tests were used to test for statistically significant differences in risk indicator code frequencies based on the type of project. Specifically, the Mann-Whitney U-test, a nonparametric statistical test for comparing two independent samples (Corder & Foreman, 2009), was used.

In this study, the null hypothesis was that there was no difference in the relative frequencies of risk indicator codes associated with original projects and the relative frequencies of the risk indicator codes associated with rework projects. A standard alpha level of 0.05 was applied. The Mann-Whitney U-test was applied to the two independent samples, and the ranked relative frequencies of the risk indicators in original projects were compared to the ranked relative frequencies of the risk indicators in rework projects. If both of the population distributions are the same, every value should occur with equal frequency between the two groups being compared. There was one statistically significant difference, with a p-value of .036, in the frequency of the risk indicator associated with the quality of the product (RTE-QUAL) as shown in Figure 11.

Previous research on rework states that rework is "doing something at least one extra time due to nonconformance to requirements" (Love & Smith, 2003, p. 148). Lack of quality conformance is one example of nonconformance to requirements. Both rework projects analyzed in this study both were initiated, in part, due to quality problems with the original design. Risks associated with quality conformance of a product were found to be statistically higher in rework projects than original projects according to the Mann-Whitney U-test. This can be explained by the fact that quality problems with the original design project would drive the need to create rework projects. Resolving quality issues then becomes an important goal of these rework projects. Having identified and discussed risk indicator codes specific to rework projects, the most prevalent risk indicator codes appearing in both original and rework projects are presented next.

5.4.3. Risk Indicator Codes Common to both Original and Rework Projects

The risk indicators with the highest relative frequencies across both categories are important for project managers to be aware of since these risk indicators have high rates of occurrence independent of type of project. The majority of risk indicator codes, common to both project types, were related to communication issues and are described and discussed in more detail next.

The risk indicator code related to customer requested changes (RTE-CU-CF) was the most frequently identified risk indicator code for original projects and was the second most frequently identified risk indicator code for rework projects. The high rate of occurrence of this risk indicator suggests that fulfilling customer requests is important to the success of all project types. The company placed a high priority on building and maintaining a good working relationship with the customer by implementing projects to satisfy customer needs. One employee stated that the most frequent challenge to the success of projects was fulfilling customer requests. “The chief [operator] of the [system] requested additional testing on the [system]. We have to do it when the customer wants it. That was a risk to the project. It was a very unusual request from a customer. So that was an additional cost and financial impact towards the end.” This was an example of how customer-requested activities during the course of the project created new challenges for the project team.

Another risk indicator code frequently identified in both original and rework projects was RTO-SP, risks associated with the need for updates or changes to standard procedures. The common theme for the requested changes to standard procedures in rework projects was the desire to create better communication and evaluation processes in order to mitigate the need for rework projects in the future. An excerpt from one transcript illustrated this theme, “Our evaluation process is not fantastic. We get the basic [design requirements document], and it is the job of the lead engineer to evaluate the impacts. But the [system] is big and complex, and it can be difficult to determine what affects what. If we had a better system in place to evaluate all of our impacts, it would probably be better.” Another employee noted, “On the first [project] if we had better evaluated the impact on systems we probably would have never had the second [project] to begin with. We caused this problem when we made that first [project]…” These two excerpts clearly outline the need for standard procedures to evaluate the impact on systems before a project begins. Research has shown that lack of clearly defined standard procedures can cause important steps to be missed or details to be overlooked in the course of a project (Clift & Vandenbosch, 1999). By implementing an update to existing standard procedures, the company may be able to improve the success of all projects by enforcing thorough up front planning.

Another frequently cited pair of risks to both project types was RTP-CDG and RTP-ADG, the risk indicators associated with the project affecting multiple groups and the need for communication between groups. The addition of multiple groups to a project adds to the project's complexity and increases risk to the project (Maylor et al., 2008b). The increased need for communication and coordination between groups may decrease the likelihood of project success when not managed well. "In engineering, tooling goes one way, engineering design goes another way, and management goes another way. Then we all get back together and go, 'How come it doesn't fit?'" Without proper communication, project teams can find themselves overlooking important details and discovering problems later, when the cost of fixing these problems is much higher (Gray & Larson, 2008). Thus proper communication between project team members is imperative (Hart & Conklin, 2006). Communication issues were identified in one of the original projects. "The [critical incident] was discovered during systems installations. Engineering thought it was going to work out, and they discovered during installation that it didn't work. We may have known about it before, but as you go through, there are a lot of design decisions that are made, not necessarily as a whole unit. So a lot of times with that many people or disciplines involved, there are many problems that are discovered later." Clearly communication between teams is a critical influencer of project success (Kennedy, McComb, & Vozdolska, 2011).

The risk indicator codes in common to original and rework projects can be used to identify fundamental risks to projects with widely ranging characteristics. Two major themes emerged from studying common risk indicator codes: communication and coordination. Up front planning and communication with everyone involved in defining and implementing the project must occur to decrease risk to both original and rework projects. Two excerpts clearly illustrate this point. "You could cause real serious money problems for [the company] if you don't have a good work statement up front, so you need to balance rushing to get a [project] started with taking too long to incorporate a [project]." Similarly, an engineer involved in overseeing the planning process of the project noted, "Other than creating a tool or a process, it is up front planning. That is where we have problems across all of our different [projects]. Improving the impact assessments, finding out who or what you are affecting, getting better information up front so we can have a better idea of who will be impacted."

The analysis of common risk indicator codes for both original and rework projects provide additional insight into those factors that must be carefully managed regardless of project type. The most prevalent unique risk indicators in rework projects were related to troubleshooting, technological advances, and project urgency. With careful planning during the beginning stages of a rework project, managers can avoid or mitigate these risks to projects. Risks associated with communication issues were the most common risks for both original and rework projects. Effective communication of project requirements and adequate standard procedures for the implementation of projects can bring about greater project success. Having discussed the most significant findings, the limitations to the study, conclusions, and future work are presented next.

5.5. Limitations, Conclusions, and Future Work

This study was conducted within a single division of a large engineering design organization. Thus the results from this research represent the most frequent risk indicator codes identified from engineering design projects undertaken within this specific segment of the organization and may not be generalizable to the entire organization or to other organizations within the field of engineering design. Similarly the findings may not be valid for other industries.

Other limitations to this study stemmed from restrictions to the types of data the researchers were able to obtain. Due to the voluntary nature of participation in this study and the busy work schedules of participants, the researchers were unable to secure the same number of participants to interview for each project. To obtain the most well-rounded perspective in which to compare projects, an even distribution of interviews and employee job functions for each project would have been ideal. Although a sizeable quantity of interview transcripts were collected for this research, the distribution of data was uneven across the different projects. According to the participants, each employee's job function influenced the employees' knowledge of the project. For example product certification specialists were most familiar with risks to the product certification, while engineering schedulers were most familiar with risks to the coordination of the schedule between different functional departments. Without full representation of employees from all job functions in the interviews, it is possible that only a subset of risks indicators were captured. For projects with fewer job functions represented, the entire range of risks to these projects may have been fully captured.

This research was created with the goal of increasing knowledge of the relationship between risk and project type, whether original or rework. The results of this study provide evidence that there are differences in the most frequently occurring risk indicator codes between original projects and rework projects. Project managers should note these differences when creating specific risk management plans based upon the type of project, whether it is the first attempt to solve an engineering design problem or the second attempt to solve the problem.

The results of this study reveal areas of potential risk to projects that would benefit the most from an investment of time and resources by project managers. The results indicated that high frequency risks, unique to rework projects are related to troubleshooting, technological advances, urgency, and quality. There are many implications for project managers based upon these findings. It is important for managers to take time at the beginning of the rework project to ensure that the root cause of the problem is identified, in order to ensure that the rework project is indeed solving the problem and not just addressing symptoms. Project managers should not let the urgency of having missed past deadlines accelerate the timeline for the rework project. Additional guidelines for ensuring the quality of the design will also help ensure that requirements are identified in a timely fashion. Finally, the effects of implementing technological advancements should be thoroughly understood before starting a rework project, in order to avoid additional, unanticipated complications.

The most frequently occurring risk indicators in common to both original and rework projects indicated that communication and coordination are the important areas of focus for project managers. Thorough communication of project goals through complete, comprehensive documentation and the use of proper project management techniques for project coordination are critical to project success. Having identified the key results and implications for project managers, opportunities for future research are outlined.

This research was created with the goal of adding to the body of knowledge related to risk management of rework projects. To verify the applicability of these findings to other fields, rework projects in other industries can be studied. Additionally, only rework projects that were a second attempt to resolve design problems were studied in this research. Future studies could focus on subsequent rework projects to discover if risk indicators associated with third or fourth attempts to resolve the same problem differ from earlier attempts. The framework created for this study also has potential application in the field of project management beyond design projects. Expanding this work to a broader range of project types and organizations would help validate the proposed critical success factor framework and could provide deeper insight for project managers in project risk management.

5.6. References (Manuscript 2)

Belassi, W., & Tukel, O. I. (1996). A new framework for determining critical success/failure factors in projects. *International Journal of Project Management*, *14*(3), 141–151.

Berends, L., & Johnston, J. (2005). Using multiple coders to enhance qualitative analysis: The case of interviews with consumers of drug treatment. *Addiction Research & Theory*, *13*(4), 373–381.

Braaksma, A. J. J., Meesters, A. J., Klingenberg, W., & Hicks, C. (2011). A quantitative method for Failure Mode and Effects Analysis. *International Journal of Production Research*, 1–14.

Butterfield, L. D., Borgen, W. A., Maglio, A.S. T., & Amundson, N. E. (2009). Using the enhanced critical incident technique in counselling psychology research. *Canadian Journal of Counselling / Revue Canadienne de Counseling*, *43*(4), 265–282.

Chapanis, A. (1996). *Human factors in systems engineering*. New York, NY: Wiley.

Chapman, R. J. (2001). The controlling influences on effective risk identification and assessment for construction design management. *International Journal of Project Management*, *19*(3), 147–160.

Chell, E., & Pittaway, L. (1998). A study of entrepreneurship in the restaurant and café industry: Exploratory work using the critical incident technique as a methodology: Prize-winning Paper from the IAHMS Conference at Sheffield Hallam University, England. *International Journal of Hospitality Management*, *17*(1), 23–32.

Chow, T., & Cao, D.B. (2008). A survey study of critical success factors in agile software projects. *Journal of Systems and Software*, *81*(6), 961–971.

Chua, B. B., & Verner, J. (2010). Examining requirements change rework effort: A study. *International Journal of Software Engineering & Applications*, *1*(3), 48–64.

Clift, T. B., & Vandenbosch, M. B. (1999). Project complexity and efforts to reduce product development cycle time. *Journal of Business Research*, *45*(2), 187–198.

Corder, G. W., & Foreman, D. I. (2009). *Nonparametric statistics for non-statisticians*. Hoboken, NJ. Wiley.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin*, *51*(4), 327–358.

Gidel, T. G. (2005). Decision-making framework methodology: An original approach to project risk management in new product design. *Journal of Engineering Design*, *16*(1), 1–23.

Gray, C. F., & Larson, E. W. (2008). *Project management*. New York, NY: McGraw-Hill/Irwin.

Hart, H., & Conklin, J. (2006). Toward a meaningful model of technical communication. *Technical Communication*, *53*(4), 395–415.

Hazelrigg, G. A. (1998). A framework for decision-based engineering design. *Journal of Mechanical Design*, *120*(4), 653–658.

Howell, D., Windahl, C., & Seidel, R. (2010). A project contingency framework based on uncertainty and its consequences. *International Journal of Project Management*, *28*(3), 256–264.

Karayaz, G., Keating, C. B., & Henrie, M. (2011). Designing project management systems. Proceedings from HICSS '11: The *Hawaii International Conference on System Sciences*. Manoa, HI: University of Hawaii at Manoa.

Kennedy, D. M., McComb, S. A., & Vozdolska, R. R. (2011). An investigation of project complexity's influence on team communication using Monte Carlo simulation. *Journal of Engineering and Technology Management*, *28*(3), 109–127.

Koltveit, B. J., Karlsen, J. T., & Gronhaug, K. (2005). Exploiting opportunities in uncertainty during the early project phase. *IEEE Engineering Management Review, 33*(1), 26.

Kwan, T. W., & Leung, H. K. N. (2011). A risk management methodology for project risk dependencies. *IEEE Transactions on Software Engineering*, 37, 635–648.

Lessard, J., & Lessard, C. S. (2007). *Project management for engineering design* (Vol. 2). San Francisco, CA. Morgan & Claypool Publishers.

Love, P. (2002). Influence of project type and procurement method on rework costs in building construction projects. *Journal of Construction Engineering and Management*, *128*(1), 18–29.

Love, P., & Edwards, D. (2005). Calculating total rework costs in Australian construction projects. *Civil Engineering & Environmental Systems*, *22*(1), 11–27.

Love, P., Irani, Z., & Edwards, D. J. (2004). A rework reduction model for construction projects. *IEEE Transactions on Engineering Management*, *51*(4), 426–440.

Love, P., & Smith, J. (2003). Benchmarking, benchaction, and benchlearning: Rework mitigation in projects. *Journal of Management in Engineering*, *19*(4), 147–159.

Maylor, H., Vidgen, R., & Carver, S. (2008). Managerial complexity in project-based operations: A grounded model and its implications for practice. *Project Management Journal*, *39*(1), 15–26.

Maytorena, E., Winch, G. M., Freeman, J., & Kiely, T. (2007). The influence of experience and information search styles on project risk identification Performance. *IEEE Transactions on Engineering Management, 54*(2), 315 –326.

Miles, M., & Huberman, A. M. (1994). *Qualitative Data Anlaysis An Expanded Sourcebook* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Owens, B. D., Leveson, N. G., & Hoffman, J. A. (2011). Procedure rework: A dynamic process with implications for the "rework cycle" and "disaster dynamics." *System Dynamics Review*, *27*(3), 244–269.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Raz, T., Shenhar, A. J., & Dvir, D. (2002). Risk management, project success, and technological uncertainty. *R&D Management*, *32*(2), 101–109.

Stein, J. (1981). Contextual factors in the selection of strategic decision methods. *Human Relations*, *34*(10), 819–834.

Teoh, P. C., & Case, K. (2004). Failure modes and effects analysis through knowledge modelling. *Journal of Materials Processing Technology*, *153–154*, 253–260.

Wang, W.T., & Ko, N.Y. (2012). Knowledge sharing practices of project teams when encountering changes in project scope: A contingency approach. *Journal of Information Science*, *38*(5), 423–441.

Yaraghi, N., & Langhe, R. G. (2011). Critical success factors for risk management systems. *Journal of Risk Research*, *14*(5), 551–581.

Yim, R. (2013). *Exploring the relationship between engineering design project characteristics and risk indicators* (Unpublished master's thesis). Oregon State University, Corvallis, OR.

6. Conclusion

This research used quantitative and qualitative research methodologies to study the relationship between various project characteristics and risk indicators. The goal was to increase knowledge of the types of risks that occur most often in different types of engineering design projects. The study elicited responses from employees about critical events occurring in the course of projects. By understanding risks encountered in completed projects, project managers can have a better understanding of how to plan for future projects. The findings of this study indicated that there are differences among the most frequently occurring risk indicators for different project categories. The most frequently occurring risk indicators across all categories are important areas for project managers to consider in designing risk management plans tailored to a project's characteristics. Overall, risks related to communication, standard procedures, and documentation were the most common threats to project success across every category of project. Other risk indicators varied, based on different project characteristics. The next section will discuss these findings and implications in further detail.

6.1. Research Findings and Implications

Companies accomplish many of their goals through the implementation of projects. One goal for industrial engineers is to improve the efficiency and effectiveness of the processes companies use to carry out projects. Uncertainty is an unavoidable characteristic of projects and can lead to potential and realized risks. Should risks materialize, they can cause a project to fall short of meeting project goals. Risk indicators are events or circumstances that can predict project risk. The results of this research provide evidence that risks are more or less likely based on certain project characteristics. Engineering project managers can utilize this knowledge of risk indicators to allocate limited resources more effectively and maximize the likelihood of project success (Miller & Lessard, 2001).

Themes identified from the data analysis were identified. Five themes were found. The first theme was related to project communication. There was strong evidence that communication risks are prevalent in all projects. Communication between the company and outside entities, such as suppliers (RTE-SC) and regulatory agencies (RTP-PC) were among the top three most frequently occurring risk indicators in compliance projects. Issues faced in customer communication were the greatest in operational projects, and communication issues between different groups or functional departments involved in a project were the greatest risk in strategic projects. The type of communication risk most frequently occurring differed based on project category, but overall communication issues were one of the most common threats to project success found in this study. Thus, project managers must carefully manage different types of communication risks, depending on the project classification.

A second theme identified in the results was that all engineering design projects struggled to provide updated standard procedures (RTO-SP) and effective project documentation (RTO-DA) to team members. Many problems faced in the eleven studied projects were caused by unclear requirements or un-communicated requirements. During the project-planning phase, managers should take care to identify the implications of making changes to the design. Managers should identify the engineering groups that will be affected by changes to the design in order to ensure that project details are communicated to the necessary individuals.

The third theme is that advances in technology can result in additional risks for rework projects. In this way the groups in charge of parts of existing systems that will be affected by the change can anticipate the changes to their part and make necessary adjustments. Technological advances, while necessary for innovation can cause unforeseen challenges due, in part, to personnel being unfamiliar with the new technology. Unanticipated consequences can result when new technologies are added to new or existing systems. The high frequency of occurrence of these risk indicators in rework projects implies that project managers should be careful to plan for these particular risks to projects. In rework projects driven by advances in technology, it is important for project managers to ensure that the affects of the technological upgrades on the system are properly understood before implementing technological changes to the system.

Elevated levels of risks caused by technological advances were also accompanied by risks in troubleshooting. Troubleshooting issues occurred when the project team failed to identify the root cause of a problem, and thus solved symptoms and not the actual problem, and when troubleshooting activities should have occurred but did not due to time constraints. Allowing adequate time for troubleshooting at the beginning of rework projects is essential to ensure the rework project is addressing the root cause of the problem and will indeed be successful.

The fifth theme identified was that risks resulting from high levels of project urgency are more typical in rework projects. The two rework projects studied were exposed to risks caused by the urgency of previously missed deadlines. Rework projects tend to have tight schedules as rework projects are initiated after an original design project failed to fully meet the project objectives. This heightened urgency led to additional mistakes. Further expediting a rework project can lead to the need for additional rework and should be avoided. Managers should take care that increased urgency does not lead to mistakes and additional rework projects caused by rushing through the initial project planning stages to meet urgent deadlines.

The five themes summarized reveal important areas for project managers to concentrate their efforts when developing risk management plans. The emergent themes from this study provide valuable insight to the management of engineering design projects. There are limitations, however, in the application and generalizability of these findings to other organizations and other industries. These limitations will be described next.

6.2. Limitations

Limitations were revealed through an assessment of the research methodology and data sources. First, this research collected data from engineering design projects that were completed entirely within one organization of a single division of a large engineering design company. This organization was dedicated to the design, development, manufacture, and maintenance of a single complex product. The results from this research are relevant to this specific organization. The risk indicators most frequently occurring in different types of engineering design projects from other organizations may be different.

The scope of the research was also limited to medium complexity engineering design projects completed within a 24-month period in this specific organization. The results of this research may not be generalizable to engineering design projects of much smaller or larger scope even within the same organization. Risks to these engineering design projects could also have been influenced by the timeframe in which the projects took place. For example, implementation of a new communication procedure, or a high turnover rate could have influenced the risks identified. The learning curve associated with adopting new procedures, or associated with new employees could negatively impact the success of projects and cause additional risks.

Another limitation was the representation of different roles and employee functions on each project. Although, overall, employees came from many different roles and functional areas, the researchers were unable to obtain interviews from every job or every function (e.g. electrical engineers, project managers, production schedulers, etc.) for all projects. The role of the employee on a project informed the view of the project, and as a result likely impacted the risks employees were aware of. The risk indicators identified in this study were a reflection of employee perspectives. A more balanced perspective of each project could be obtained if employees from every role and functional area participated in interviews for every project studied.

The reliability of the results was limited by the consistency between the researchers applying the code schema to the transcripts. After two original researchers had developed and finalized the code schema, three additional researchers were trained to apply the code schema, practicing on previously coded transcripts until the newly trained researchers consistently reached at least 80% agreement with the original codes. At this point, the newly trained researchers applied the code schema to new transcripts. The reliability of the results of this research could have been improved if a higher matching percentage was reached before starting individual coding of the transcripts.

While limitations to the validity and reliability of this research should be acknowledged, the results of this research are useful and provide project managers with important insights on where risk management resources should be concentrated. Based on these limitations, some opportunities for future research are discussed next.

6.3. Future Work

While this research provides an excellent framework for identifying risks in engineering design projects, additional research is needed to verify the results from this study and to ensure the generalizability of the results. This research was limited in scope to eleven medium complexity projects completed within a 24-month period within a single division of a large engineering design firm. While this research provides insight into the risks occurring in this specific organization, future research could apply the methodology developed for this study to other organizations and other industries to further generalize or extend the findings.

Additional studies are also needed to verify that the risks occurring in these particular engineering design projects are applicable to projects of a much smaller or larger level of complexity. In the organization studied, projects range in size from changing a single screw on the product to developing entirely new product lines. These projects span a few hours to many years. The methodology developed for this research can be adapted and applied to engineering design projects of differing levels of complexity to determine whether or not risks found most often in medium-complexity engineering design projects are consistent with the most frequently occurring risks in smaller and larger complexity projects as.

To verify the validity of the results for projects taking place in different time periods, future research can be conducted on projects completed within different time periods. Future studies can ensure that the results were accurate and not unduly influenced by other organizational or cultural phenomena occurring during the timeframe of this study.

Finally, the results of this research were obtained from eleven engineering design projects. The findings can be verified by studying additional projects, of medium complexity conducted within the same organization during the same timeframe, and comparing the new results to the results from this research study.

The goal of this research was to increase the understanding of risks to specific types of engineering design projects, thereby providing engineering project managers with insights into appropriate steps to take to mitigate or avoid such risks. The most frequently occurring risk indicators identified as a result of this study indicate risks that pose the greatest threat to project success. The results from this study, also provided evidence that risks do vary based on specific project characteristics. The contrast between the top ten risk indicators among project characteristics suggests that different risk management techniques should be used for maximum effectiveness.

7. References

Anderson, D. K., & Merna, T. (2003). Project management strategy—project management represented as a process based set of management domains and the consequences for project management strategy. *International Journal of Project Management*, *21*(6), 387–393.

Auerbach, C. F., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*. New York, NY. New York University Press.

Aven, T., & Krte, J. (2003). On the use of risk and decision analysis to support decision-making. *Reliability Engineering and System Safety*, *79*(3), 289–299.

Babbie, E. R. (2010). *The practice of social research*. Belmont, CA. Cengage Learning.

Babu, G. N. K. S., & Srivatsa, S. K. (2011). Increasing success of software projects through minimizing risks. *International Journal of Research and Reviews in Software Engineering*, *1*(1), 18-22.

Baccarini, D. (1996). The concept of project complexity—a review. *International Journal of Project Management*, *14*(4), 201–204.

Basit, T. (2003). Manual or electronic? The role of coding in qualitative data analysis. *Educational Research*, *45*(2), 143–154.

Bekhet, A. K., & Zauszniewski, J. A. (2012). Methodological triangulation: An approach to understanding data. *Nurse Researcher*, *20*(2), 40–43.

Belassi, W., & Tukel, O. I. (1996). A new framework for determining critical success/failure factors in projects. *International Journal of Project Management*, *14*(3), 141–151.

Berends, L., & Johnston, J. (2005). Using multiple coders to enhance qualitative analysis: The case of interviews with consumers of drug treatment. *Addiction Research & Theory*, *13*(4), 373–381.

Bryde, D. (2008). Perceptions of the impact of project sponsorship practices on project success. *International Journal of Project Management*, *26*(8), 800–809.

Butterfield, L. D., Borgen, W. A., Maglio, A. S. T., & Amundson, N. E. (2009). Using the enhanced critical incident technique in counselling psychology research.

Canadian Journal of Counselling / Revue Canadienne de Counseling, *43*(4), 265–282.

Chapanis, A. (1996). *Human factors in systems engineering*. New York, NY: Wiley.

Chapman, R. J. (2001). The controlling influences on effective risk identification and assessment for construction design management. *International Journal of Project Management*, *19*(3), 147–160.

Chell, E., & Pittaway, L. (1998). A study of entrepreneurship in the restaurant and café industry: Exploratory work using the critical incident technique as a methodology: *International Journal of Hospitality Management*, *17*(1), 23–32.

Chow, T., & Cao, D. B. (2008). A survey study of critical success factors in agile software projects. *Journal of Systems and Software*, *81*(6), 961–971.

Chua, B. B., & Verner, J. (2010). Examining requirements change rework effort: A Study. *International Journal of Software Engineering & Applications*, *1*(3), 48–64.

Clift, T. B., & Vandenbosch, M. B. (1999). Project complexity and efforts to reduce product development cycle time. *Journal of Business Research*, *45*(2), 187–198.

Corder, G. W., & Foreman, D. I. (2009). *Nonparametric statistics for non-statisticians*. Hoboken, NJ. Wiley.

Curtis, S., Gesler, W., Smith, G., & Washburn, S. (2000). Approaches to sampling and case selection in qualitative research: examples in the geography of health. *Social Science & Medicine*, *50*(7–8), 1001–1014.

De Bakker, K., Boonstra, A., & Wortmann, H. (2012). Risk managements' communicative effects influencing IT project success. *International Journal of Project Management*, *30*(4), 444–457.

Damian, D., & Chisan, J. (2006). An empirical study of the complex relationships between requirements engineering processes and other processes that lead to payoffs in productivity, quality, and risk management. *IEEE Transactions on Software Engineering*, *32*(7), 433–453.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin*, *51*(4), 327–358.

Geraldi, J., Maylor, H., & Williams, T. (2011). Now, let's make it really complex (complicated): A systematic review of the complexities of projects. *International Journal of Operations & Production Management*, *31*(9), 966–990.

Gidel, T. G. (2005). Decision-making framework methodology: an original approach to project risk management in new product design. *Journal of Engineering Design*, *16*(1), 1–23.

Gray, C. F., & Larson, E. W. (2008). *Project management*. New York, NY,: McGraw-Hill/Irwin.

Gruner, K. (2000). Does customer interaction enhance new product puccess? *Journal of Business Research*, *49*(1), 1–14.

Gustafsson, A., Kristensson, P., & Witell, L. (2012). Customer co-creation in service innovation: a matter of communication? *Journal of Service Management*, *23*(3), 311–327.

Hawes, L. C. (1972). Development and application of an interview coding system. *Central States Speech Journal*, *23*(2), 92.

Hart, H., & Conklin, J. (2006). Toward a meaningful model of technical communication. *Technical Communication*, *53*(4), 395–415.

Hazelrigg, G. A. (1998). A framework for decision-based engineering design. *Journal of Mechanical Design*, *120*(4), 653–658.

Herroelen, W. (2005, Winter). Project scheduling--theory and practice. *Production and Operations Management*, *14*(4), 413-420.

Howell, D., Windahl, C., & Seidel, R. (2010). A project contingency framework based on uncertainty and its consequences. *International Journal of Project Management*, *28*(3), 256–264.

Institute of Operational Risk. (2010). Key Risk Indicators. *Institute of Operational Risk*. Ware, UK.

Joshi, M. P., Kathuria, R., & Porth, S. J. (2003). Alignment of strategic priorities and performance: An integration of operations and strategic management perspectives. *Journal of Operations Management*, *21*(3), 353–369.

Karayaz, G., Keating, C. B., & Henrie, M. (2011). Designing project management systems. Proceedings from HICSS '11: The *Hawaii International Conference on System Sciences*. Manoa, HI: University of Hawaii at Manoa.

Kennedy, D. M., McComb, S. A., & Vozdolska, R. R. (2011). An investigation of project complexity's influence on team communication using Monte Carlo simulation. *Journal of Engineering and Technology Management*, *28*(3), 109–127.

Kloss-Grote, B., & Moss, M. A. (n.d.). How to measure the effectiveness of risk management in engineering design projects? Presentation of RMPASS: A new method for assessing risk management performance and the impact of knowledge management—including a few results. *Research in Engineering Design*, *19*(2), 71–100.

Koltveit, B. J., Karlsen, J. T., & Gronhaug, K. (2005). Exploiting opportunities in uncertainty during the early project phase. *IEEE Engineering Management Review, 33*(1), 26.

Kruskal, W. H., & Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*, *47*(260), 583–621.

Kwan, T. W., & Leung, H. K. N. (2011). A risk management methodology for project risk dependencies. In *IEEE Transactions on Software Engineering*, 37, 635-645.

Leech, N. L., & Onwuegbuzie, A. J. (2007). An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly*, *22*(4), 557–584.

Lessard, J., & Lessard, C. S. (2007). *Project management for engineering design* (Vol. 2). San Rafael, CA. Morgan & Claypool Publishers.

Love, P. (2002). Influence of project type and procurement method on rework costs in building construction projects. *Journal of Construction Engineering and Management*, *128*(1), 18–29.

Love, P., & Edwards, D. (2005). Calculating total rework costs in Australian construction projects. *Civil Engineering & Environmental Systems*, *22*(1), 11–27.

Love, P., Irani, Z., & Edwards, D. J. (2004). A rework reduction model for construction projects. *IEEE Transactions on Engineering Management*, *51*(4), 426–440.

Love, P., & Smith, J. (2003). Benchmarking, benchaction, and benchlearning: Rework mitigation in projects. *Journal of Management in Engineering*, *19*(4), 147–159.

Mahoney, M. (1996). Estimation of the power of the Kruskal-Wallis test. *Biometrical Journal*, *38*, 613–630.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266.

Maylor, H., Vidgen, R., & Carver, S. (2008). Managerial complexity in project-based operations: A grounded model and its implications for practice. *Project Management Journal*, *39*(S1), 15–26.

Maytorena, E., Winch, G. M., Freeman, J., & Kiely, T. (2007). The influence of experience and information search styles on project risk identification performance. *IEEE Transactions on Engineering Management*, *54*(2), 315 –326.

Mehr, A. F., & Tumer, I. Y. (2006). Risk-based decision-making for managing resources during the design of complex space exploration systems. *Journal of Mechanical Design*, *128*(4), 1014–1022.

Miles, M. B., & Huberman A. Michael. (1994). *Qualitative data analysis an expanded sourcebook* (2nd ed.). Newbury Park, CA: Sage Publications.

Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management*, *19*(8), 437–443.

Nagadevara, V. (2012). Project success factors and inter-sectoral differences. *Review of Business Research*, *12*(1), 115 – 120.

Owens, B. D., Leveson, N. G., & Hoffman, J. A. (2011). Procedure rework: A dynamic process with implications for the "rework cycle" and "disaster dynamics." *System Dynamics Review*, *27*(3), 244–269.

Parsons-Hann, H., & Liu, K. (2005). Measuring requirement complexity to increase the probability of project success. *Proceedings of the International Conference on Enterprise Information Systems*, 434–438.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Perry, B. (2008). *Organisational management and information systems*. Amsterdam, Netherlands. Elsevier Science & Technology.

Pich, M. T., Loch, C. H., & Meyer, A. de. (2002). On uncertainty, ambiguity, and complexity in project management. *Management Science*, *48*(8), 1008–1023.

Project Management Institute. (2008). *A Guide to the Project Management Body of Knowledge* (4th ed.). Newtown Square, PA: Project Management Institute, Inc.

Raz, T., & Michael, E. (2001). Use and benefits of tools for project risk management. *International Journal of Project Management*, *19*(1), 9–17.

Royer, P. S. (2000). Risk management: The undiscovered dimension of project management. *Project Management Journal*, *14*(9), 31-39.

Sato, T., & Hirao, M. (2013). Optimum budget allocation method for projects with critical risks. *International Journal of Project Management*, *31*(1), 126–135.

Smith, N. J. (2008). *Engineering project management*. Hoboken, NJ: Blackwell.

Spurrier, J. D. (2003). On the null distribution of the Kruskal-Wallis statistic. *Journal of Nonparametric Statistics, 15*(6), 685–691.

Srivannaboon, S., & Milosevic, D. Z. (2006). A two-way influence between business strategy and project management. *International Journal of Project Management*, *24*(6), 493–505.

Stein, J. (1981). Contextual factors in the selection of strategic decision methods. *Human Relations*, *34*(10), 819–834.

Tatikonda, M. V., & Rosenthal, S. R. (2000). Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management*, *47*(1), 74 –87.

Teoh, P. C., & Case, K. (2004). Failure modes and effects analysis through knowledge modelling. *Journal of Materials Processing Technology*, *153–154*, 253–260.

The Merriam-Webster Dictionary. (1974). Springfield, MA: Merriam.

Vidal, L. A., & Marle, F. (2008). Understanding project complexity: implications on project management. *Kybernetes*, *37*(8), 1094–1110.

Vargha, A., & Delaney, H. D. (1998). The Kruskal-Wallis test and stochastic homogeneity. *Journal of Educational and Behavioral Statistics*, *23*(2), 170–192.

Wang, W.T., & Ko, N.Y. (2012). Knowledge sharing practices of project teams when encountering changes in project scope: A contingency approach. *Journal of Information Science*, *38*(5), 423–441.

Wibowo, S., & Deng, H. (2010). Risk-oriented group decision making in multi-criteria analysis. In *9th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2010, August 18, 2010 - August 20, 2010* (pp. 9–14). Yamagata, Japan: IEEE Computer Society.

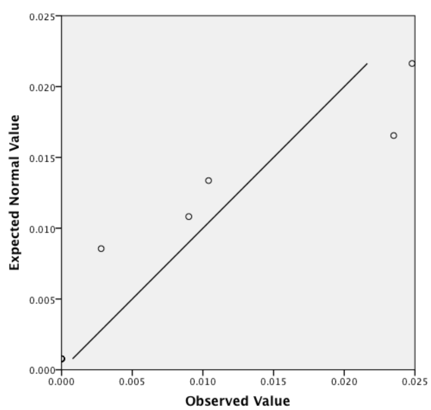
Wolstenholme, E. F. (1999). Qualitative vs quantitative modelling: The evolving balance. *The Journal of the Operational Research Society*, *50*(4), 422–428.

Yaraghi, N., & Langhe, R. G. (2011a). Critical success factors for risk management systems. *Journal of Risk Research*, *14*(5), 551–581.

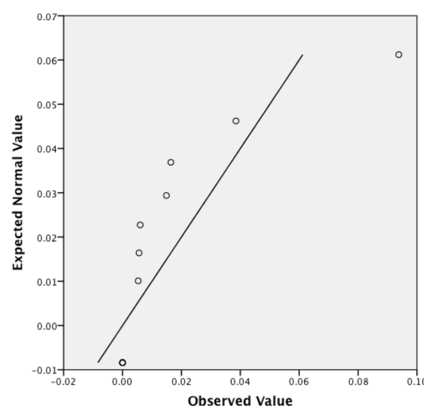
Zwikael, O., & Globerson, S. (2006). From critical success factors to critical success processes. *International Journal of Production Research*, *44*(17), 3433–3449.

Appendix A: Q-Q Plots of Relative Frequencies of Risk Indicators for All Projects

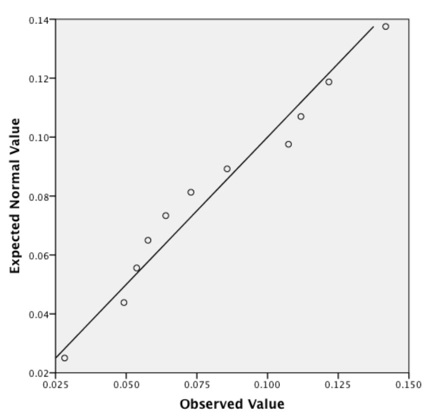
RTE-E



RTE-CU-CS



RTE-CU-CF



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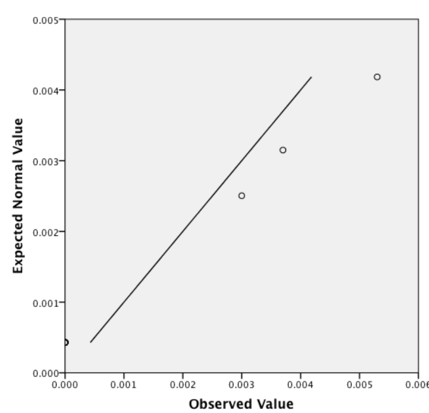

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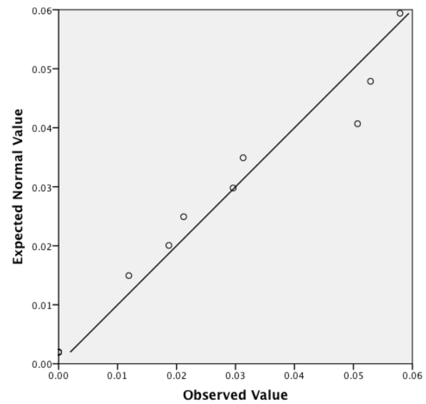
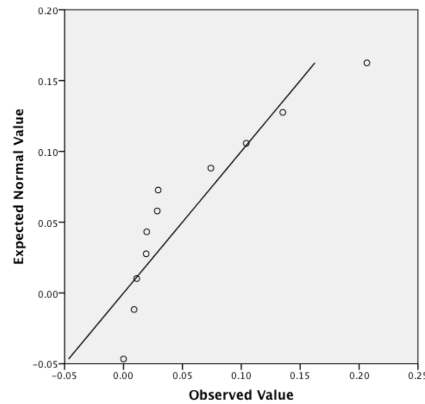
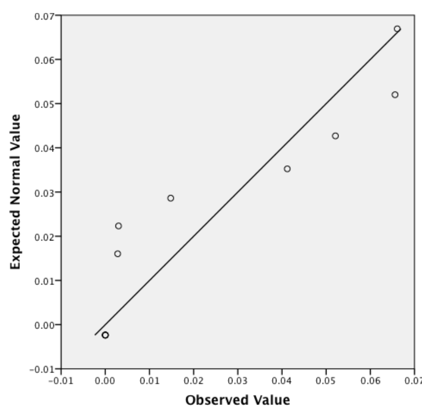


RTE-SC



RTE-QUAL



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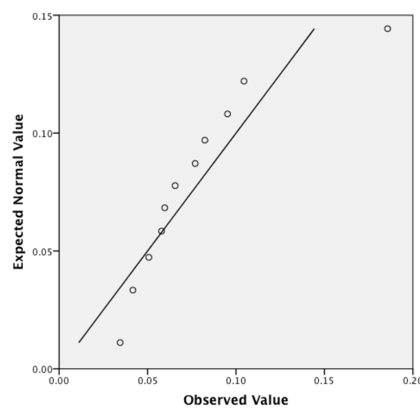

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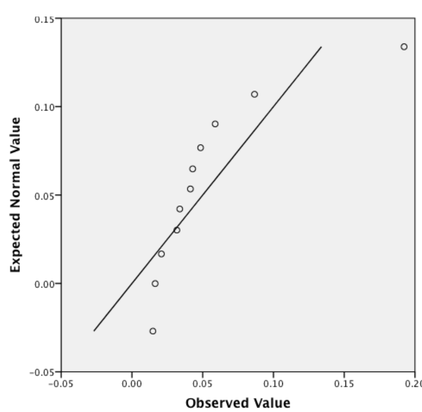

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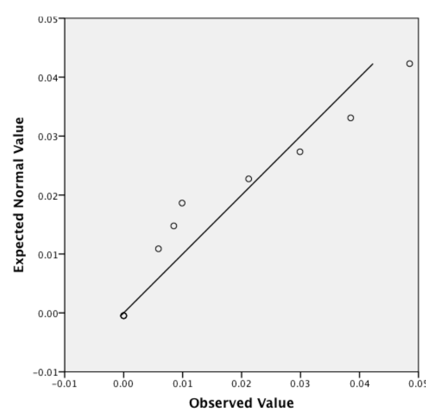

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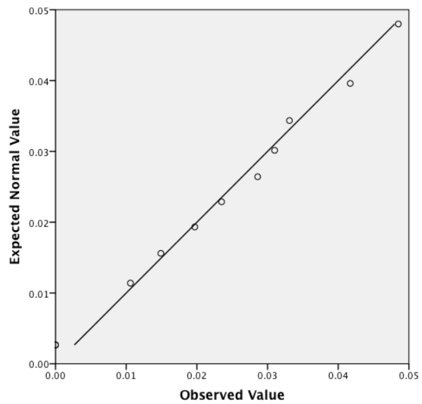

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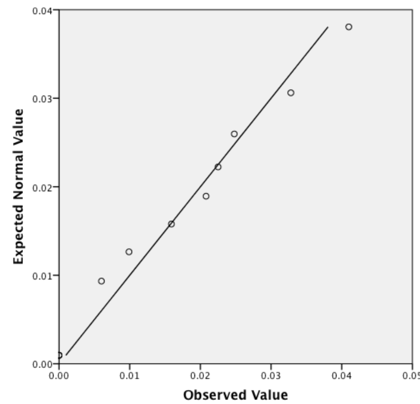
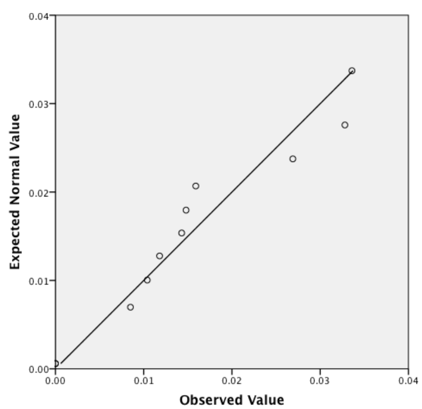
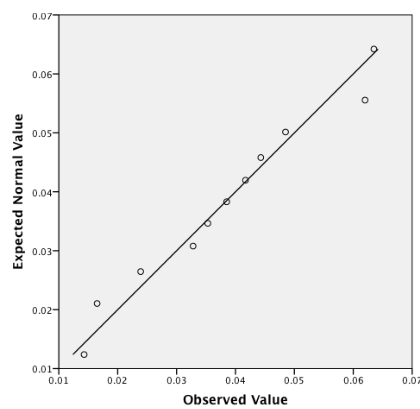


RMP-PS



RMP-CC



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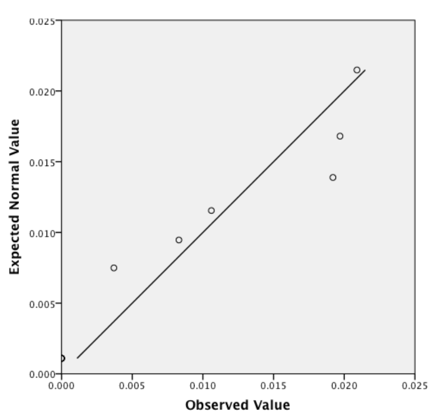
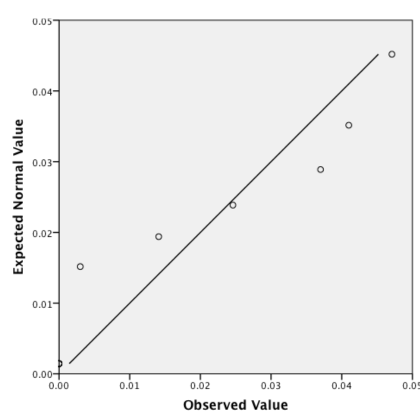
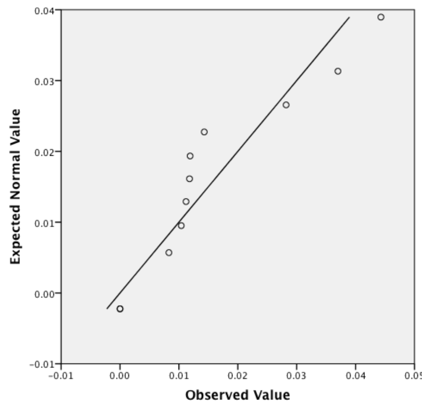


RMP-SPT



PMT-TB



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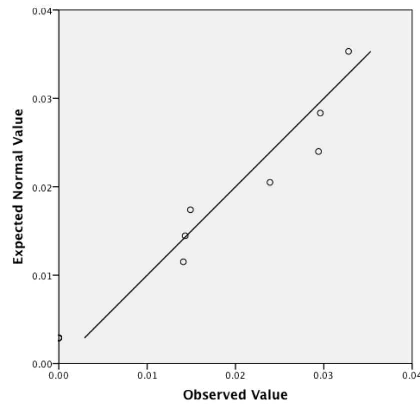

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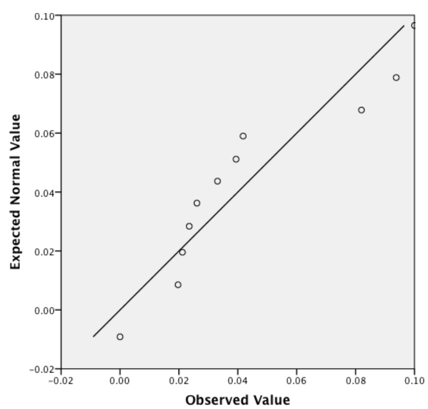

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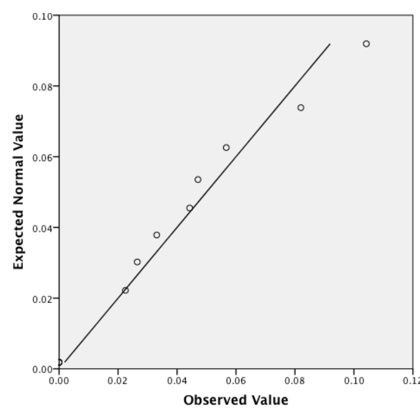
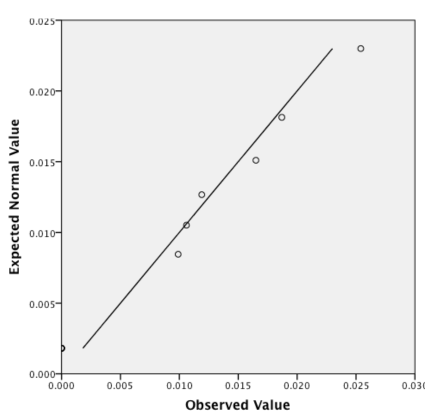


PMT-C



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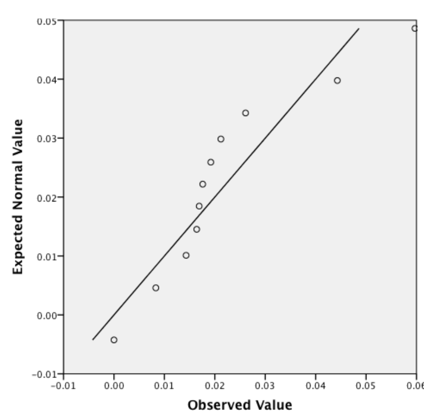

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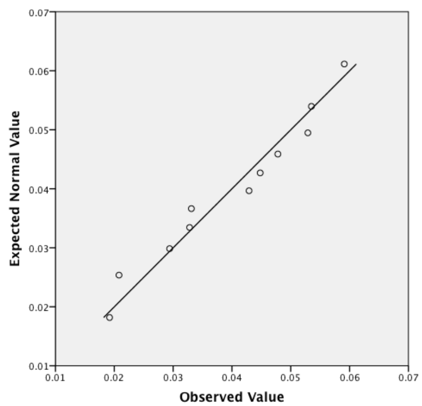

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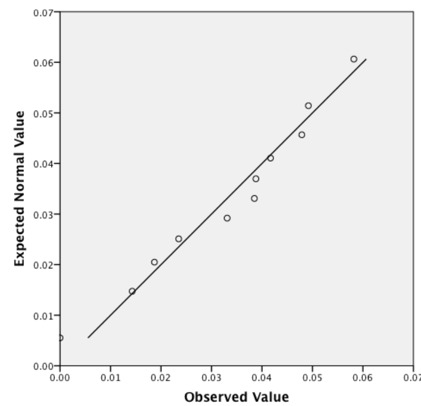

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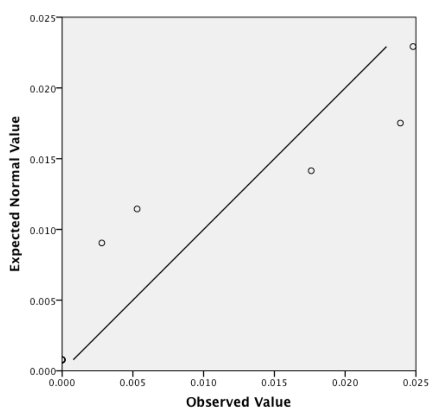

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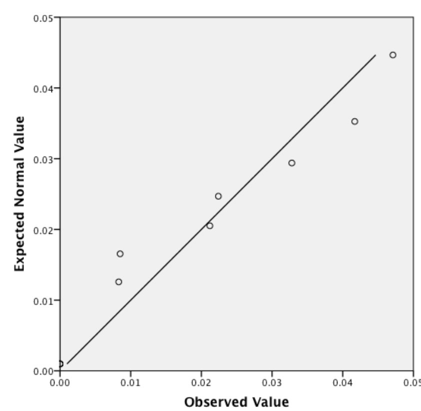
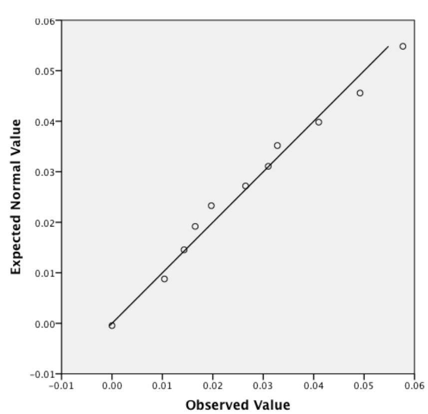
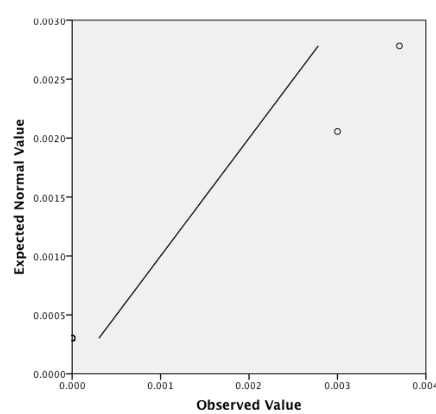


RTP-PP



RTP-S



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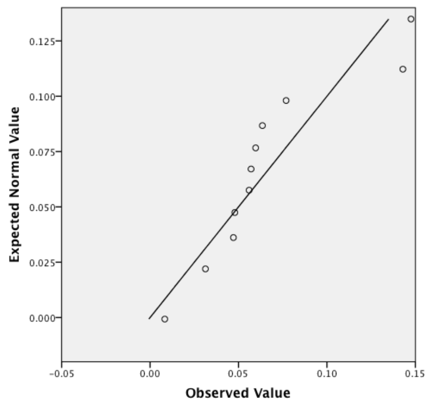

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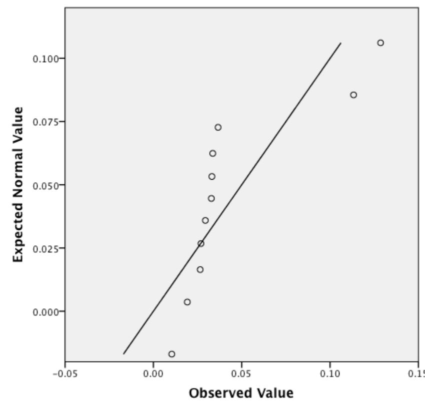

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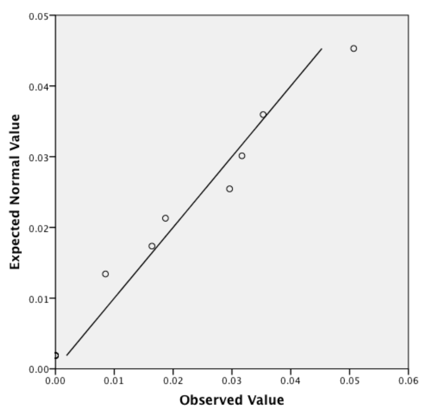
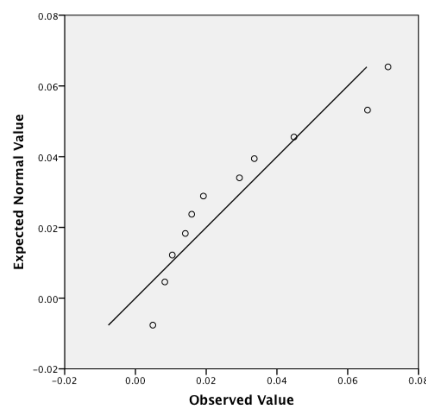
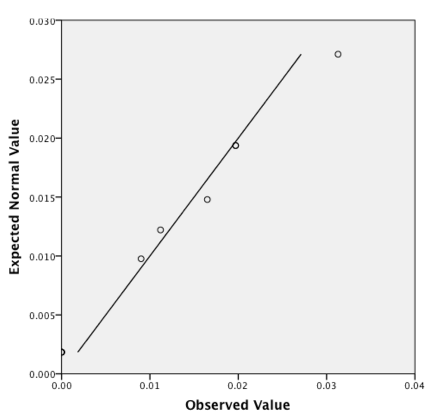


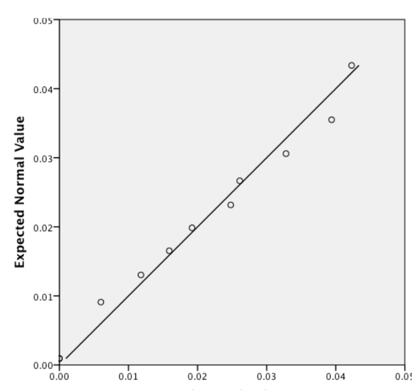
RTP-TC



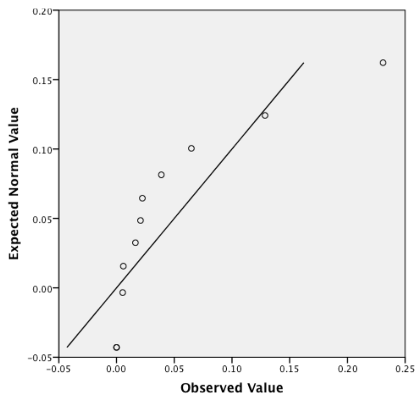
RTP-ARQ



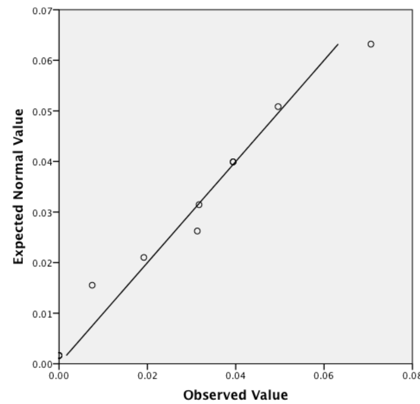
RTP-AR-SX



RTP-PC



RTP-DEL



Appendix B: IRB Documents

IRB APPLICATION

Institutional Review Board • Office of Research Integrity
B308 Kerr Administration Building, Corvallis, Oregon 97331-2140
Tel 541-737-8008 | **Fax** 541-737-3093 | IRB@oregonstate.edu
http://oregonstate.edu/research/ori/humansubjects.htm

PROJECT REVISION

Study Number:	4693		
Study Title:	A Methodology For Utility-Based Decision Making In Large Design Organizations Using Empirically-Derived Risk Indicators		
Principal Investigator:	Dr. Toni L. Doolen		
email address:	doolen@engr.orst.edu	Telephone:	541-737-5641
College, Center, or Institute:	Engineering		
If "other", indicate college:			
Department:	Other		
If "other", indicate department:	School of Mechanical and Industrial & Manufacturing Engineering		

Submit this form to request changes to an existing, approved application.

1. **Proposed change affects** (check all that apply):

   ☒ Principal Investigator or other study personnel
   ☒ Study design *(i.e., protocol, study length, study objectives)*
   ☐ Subjects *(i.e., size of population, selection criteria, recruitment method, study advertisement)*
   ☐ Consent process
   ☐ Data Collection or analysis
   ☐ Risks/Benefits
   ☐ Other

2. **Please provide the details and justification for any proposed revision(s). If adding or removing study team member(s), provide information in the table below.**

   Project funding has been confirmed so student researchers have been added to the team. Following additional review of the literature and framing of the research problem, the interview questions have been modified to be more specific to the research questions under study.

Adding/Removing Study Team Members					
Add	Remove	Study Team Member(s)	Role in Project	email Address	Ethics Training Completed
☒	☐	Rachel Yim	Student Researcher	yimr@onid.orst.edu	☒ Yes ☐ No
☒	☐	Jason Castaneda	Student Researcher	castanja@onid.orst.edu	☒ Yes ☐ No
☐	☐		Principal Investigator		☐ Yes ☐ No
☐	☐		Principal Investigator		☐ Yes ☐ No

3. **As a result of this revision, the risks of study participation have:**

   ☐ increased
   ☐ decreased
   ☒ remained unchanged

Institutional Review Board ● Office of Research Integrity
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Tel 541-737-8008 | Fax 541-737-3093 | IRB@oregonstate.edu
http://oregonstate.edu/research/ori/humansubjects.htm

PROJECT REVISION

4. **Does this revision involve a change in funding?**

☒ No changes
☐ Funding ended
☐ New or additional funding
Contract or grant title: _____
Funding source: _____
If funded, submit a copy of the grant or contract. If grant or contract and the protocol do not match, a project revision may need to be submitted for review prior to approval.

Does any member of the study team, or any of their family members, have a financial or other business interest in the source(s) of funding, materials, or equipment related to this research study?

☒ No
☐ Yes – Please describe: _____

5. **Proposed changes should be incorporated into any currently approved documents using track changes.**

Check all that are attached:

☒ Revised study protocol
☐ Revised recruitment material(s)/advertisement
☐ Revised consent(s)
☐ Revised survey/questionnaire
☐ Revised data collection form(s)
☐ Other Please specify: _____

By signing below, I certify that the information contained in this application is accurate and complete. I understand that changes may not be initiated until IRB approval has been obtained.

Name of Principal Investigator: ____

Signature____ Date__________________
Principal Investigator

The signature page must be received by the IRB before review of the revision will begin.

The signature page may be:

- **sent via mail to B308 Kerr**
- **faxed to the IRB at (541) 737-3093 or,**
- **scanned and sent via email**

RESEARCH PROTOCOL

July 7, 2010

1. Protocol Title A Methodology For Utility-Based Decision Making In Large Design Organizations Using Empirically-Derived Risk Indicators

PERSONNEL

2. Principal Investigator Toni L. Doolen, PhD
3. Student Researcher(s) NA
4. Co-investigator(s) Irem Y. Tumer, PhD
5. Study Staff: NA
6. Investigator Qualifications: Dr. Doolen has supervised multiple projects (more than one dozen) using surveys and interviews during her time at OSU. Dr. Doolen will supervise all aspects of the project related to the interview data that will be collected and used in the study. This includes data collection, analysis and summary. Dr. Tumer has completed the IRB training and has also worked with Dr. Doolen on previous studies using interviews.
7. Student Training and Oversight: NA

DESCRIPTION OF RESEARCH

8. Description of Research: The research objective of this study is to create and validate a utility-based decision methodology for large design organizations using a quantitative model based on risk indicators derived from data about prior design projects. The proposed methodology will provide designers with a formalized means to go from a qualitative understanding of what indicates risk to a quantitative model of the likely outcomes of risk-mitigating actions. Detailed studies will be conducted using engineering project data. This participation is key because it enables an industrial-scale evaluation of the methodology. The outcomes of this research will be

published in journal and conference proceedings. Results will also be shared with industrial representatives, including managers and engineers at Boeing.

9. Background Justification: If successful, this research will have a significant impact on large industrial and government organizations that design complex systems under risk. The main outcome of this research will be a validated and cohesive methodology that provides such organizations with new operational capabilities.

10. Subject Population and Recruitment

    The maximum number of participants to be recruited over the life of the study will be 35 employees from Company X. The population is not restricted to any gender or ethnic group. The only requirement for participation is that the participant is a current employee who has participated in one of the design projects selected for inclusion in the study. The PIs will work with company leaders to identify those projects that will be included in the study. Once projects have been identified, our company contact will provide the PI's with a list of project managers and project engineers names, phone numbers, and e-mail addresses. Participants will be contacted by e-mail to request their participation in an interview. If requested, a follow-up phone call to clarify the study may also occur. The interview will be scheduled to occur either over the phone or on-site at Company X at the convenience of the engineer or project manager. All questions in the interview will be related to the specific design project that the company employee worked on in the past or one that is underway at the time of the interview. The researchers will not release any personal data collected from the interviews to any company employee.

11. Consent Process

    Participation in all aspects of this research is voluntary. Participants will be informed that participation (or non-participation) in any or all of the proposed research activities will have no consequence to their employment status at Company X. Participants will be permitted to ask questions prior to making a decision on whether to participate in any portion of this research. Only aggregated data will be published.

12. Assent Process

    NA

13. Eligibility Screening: NA

14. Methods and Procedures

    14.1 Interview Questions

    All information will be collected either through a phone interview or through a face-to-face interview of the company employee at a company facility. A copy of the informed consent document and interview questions will be provided to each employee in advance by e-mail. For interviews being conducted via phone, we will schedule the interview only after a signed copy of the informed consent document has been sent to the PIs either via fax or by hard copy. A copy of the informed consent document is included in Appendix A. The interview questions used for this study are included in Appendix B. Responses will be collected by the researcher on an interview form. The interviews will not be recorded. Interview notes will be collected by hand, during the interview. Interviews will not begin unless the participant has signed a copy of the informed consent document.

    14.2 Analysis plan

    The analysis of interview data will begin with inputting each response into an electronic document, e.g. MS Word document. Each response will be tied back to a subject number. The subject number will be assigned based on the project and the role of the individual on the project. The electronic data sets will not include names of participating employees. The identification of the subject is not needed for the analysis being done. As a result, there will be no list tying the subject by name to an interview transcript. Only the project and role of the individual will be included and linked to transcribed interview notes. The only documents containing names of participants will be the signature of the participants on the informed consent form.

15. Compensation: There will be no compensation for participation in this project.
16. Cost: There will be no costs incurred by company employees to participate in this project.
17. Drugs, Biologics, Supplements, or Devices

    NA

18. Biological Samples

    NA

19. Anonymity or Confidentiality

    Individual names will not be included on any of the documents. An informed consent form will be the only document that will contain employee signatures. These documents will not be matched or linked with the data sheets containing the results of the interviews. The signed, informed consent documents will be stored in a locked file cabinet and maintained by the PI.

    All of the hard copy documents (signed informed consent documents and interview notes) created as a result of this study will be stored in a locked filing cabinet in the office of the PI. Both the file cabinet and office are locked. Electronic documents will be stored on the network drive of the PIs (maintained by OSU College of Engineering); however, these documents will not contain participant names. In accordance with regulations, documents will be securely stored in this manner during the study and for three years post-study termination.

20. Risks

    There are no discernible risks to those individuals who participate in the study. Participation is voluntary. Individuals will not be identified by name and all final documents will be kept by the research team. A copy of the analyses and summarized findings will be shared with Company X and in various professional publications. No names or other identifying titles will be used in the data summaries. There is no effect on an individual's employment status as a result of participating or not participating in any part of this study.

21. Benefits: There are no direct benefits to those individuals who participate in the study. However, it is hoped that the results of this study will help organizations be more successful in the design of complex systems.

22. Assessment of Risk:Benefit ratio: Given that the risks to Boeing employees are negligible, but the potential to improve design processes is significant, it is thought that potential to increase our understanding of how to manage risk will outweigh the small amount of time commitment required to participate in this study. Boeing has signed a Proprietary Information Agreement and agreed to participate in the project because they feel it will be valuable to the performance of their organization.

Informed Consent Document

Project Title: **A Methodology For Utility-Based Decision Making In Large Design Organizations Using Empirically-Derived Risk Indicators**

Principal Investigator: **Dr. Toni L. Doolen, School of Mechanical and Industrial & Manufacturing Engineering**

Co-Investigator(s): **Dr. Irem Tumer, School of Mechanical and Industrial & Manufacturing Engineering**

WHAT IS THE PURPOSE OF THIS STUDY?

You are being invited to take part in a research study designed to understand the role of uncertainty and risk in the design of complex systems. The purpose of this study is to obtain information regarding the mechanisms used to identify, account for, and communicate uncertainty during the design of complex engineered systems. In this research, we aim to answer the following research question: How is uncertainty dealt with in the design of complex systems? We are studying this to identify opportunities for improving the design process in large-scale complex systems, and to ultimately reduce design costs, delays, and risk.

WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you have been identified by leaders in your organization as having been recently involved in a design project.

WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?

The researchers will schedule a time to meet at your workplace or over the phone to conduct the interview. If you agree to take part in this study, your involvement will last for approximately one hour. You will be given a copy of the interview questions before the interview. During the interview, the researcher will ask you a variety of questions related to the design processes used in your organization. The researcher will take notes and record your responses during the interview. One or two researchers may be present during the interview.

WHAT ARE THE RISKS OF THIS STUDY?

We don't believe that there are any risks of participating in this study.

WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, we hope that, in the future, organizations might benefit from this study because as a result of this research we will identify "best practices" for both identifying and communicating uncertainty in the design of complex engineered systems. These best practices may be useful to organizations by improving the efficiency and effectiveness of their design processes.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for being in this research study.

WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, we will not use your name or your organizations name in any of the summary documents that are developed as a result of this study. If the results of this project are published your identity will not be made public.

DO I HAVE A CHOICE TO BE IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering. You may either refuse to participate or refuse to answer any question at any time without any impact on your employment.

You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.