ANALYSES OF HIGHWAY PROJECT CONSTRUCTION RISKS, PERFORMANCE, AND CONTINGENCY

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Mohamed Fahmy Diab

In Partial Fulfillment of the Requirements
for the Degree of
DOCTORAL OF PHILOSOPHY

Major Department:
Civil Engineering

November 2010
Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Mohamed Fahmy Diab, Ph.D., Department of Civil Engineering, College of Engineering and Architecture, North Dakota State University, November 2010. Analyses of Highway Project Construction Risks, Performance, and Contingency. Advisor: Dr. Amiy Varma.

Past studies have highlighted the importance of risk assessment and management in construction projects and transportation industry, and have identified cost and time as the most important risks that transportation professionals want to understand and manage. The main focus of this study is to comprehensively analyze transportation construction risk drivers and identify the correlation of the significant risk drivers with project characteristics, cost growth, schedule growth, and project contingency. This study has adopted 31 relevant and significant programmatic and project-specific risk drivers from different past studies. These risk drivers have been analyzed and evaluated using survey responses from professionals in the context of highway transportation projects. Risk assessments including rating of the encountered risk drivers and their correlation with project characteristics have been carried out within the context of highway construction projects in the United States. Correlations of the construction project performance or risk measures, cost growth percentage, and schedule growth percentage, with the rating values of identified risk drivers values have enabled a better understanding of the impacts of risks and the risk assessment process for highway transportation projects. The impact of significant risk drivers on reported construction cost contingency amounts has also been analyzed. The purpose of this effort was to assess impact of ratings for cost impact, schedule impact, and relative importance of the identified risk drivers on contingency amounts. Predetermined method is the common way to calculate contingency amount in transportation projects. In this study parametric modeling has been used to analyze the relationship between predetermined contingency amounts in transportation projects with perceived risk rating values in order to understand how the expert judgments regarding risk ratings can be used in determination of contingency amounts.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Amiy Varma, for his great support and knowledge, which contributed to my success in the civil engineering program. I also would like to thank Dr. Denver Tolliver for funding my research study and for the opportunity to work at the Upper Great Plains Transportation Institute. Special thanks to my committee members, Dr. Donald Andersen, Dr. Donna Dietz, and Dr. Rhonda Magel, for their time and great input.

I would like to thank Mr. Curt Doetkott for being a great statistical consultant. I would like to acknowledge the civil engineering department for giving me the opportunity to do my PhD degree at North Dakota State University. Finally, I would like to thank everyone who helped me to complete my degree successfully.

DEDICATIONS

To My Parents

and my Sons

Amr & Karim

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS v

DEDICATIONS vi

LIST OF TABLES xii

LIST OF FIGURES xvii

CHAPTER 1. INTRODUCTION 1

1.1. Background 1

1.2. Problem Statement 3

1.3. Objectives 4

1.4. Scope 5

1.5. Dissertation Organization 6

CHAPTER 2. LITERATURE REVIEW 7

2.1. Highway Risk Management 7

2.2. Identification of Construction Risks 10

2.3. Project Performance and Success Indicators 13

2.4. Risk Assessment and Evaluation 16

2.5. Risk Assessment and Analysis Techniques 18

2.5.1. Qualitative Techniques 19

2.5.2. Quantitative Techniques 19

2.6. Contingency Studies 21

2.7. Contingency Estimating Methods 23

2.7.1. Expert Judgment ... 23

2.7.2. Predetermined Guidelines ... 24

2.7.3. Simulation Analysis ... 24

2.7.4. Parametric Modeling ... 25

2.7.5. Hybrid Methods ... 25

2.8. Summary ... 25

CHAPTER 3. METHODOLOGY AND HYPOTHESES ... 28

3.1. Overall Approach ... 28

3.2. Identifying Risks ... 30

3.3. Designing and Conducting Survey ... 32

3.4. Hypotheses ... 35

3.4.1. Using Risk Assessment ... 36

3.4.2. Ratings of Cost Impact and Schedule Impact and the Use of Risk Assessment ... 39

3.4.3. Cost Growth ... 40

3.4.4. Schedule Growth ... 45

3.4.5. Owner's Contingency ... 50

3.4.6. Contractor's Contingency ... 51

3.5. Analyses ... 52

3.5.1. Sorting the Results ... 52

3.5.2. Risk Ranking ... 53

3.5.3. Defining Models Indicators ... 53

3.6. Summary ... 55

CHAPTER 4. ANALYSIS OF SURVEY RESPONSE 56
4.1. Responses and Response Rate 56
4.2. Descriptive Statistics 57
4.2.1. Survey – Part I 58
4.2.2. Survey – Part II 61
4.2.3. Survey – Part III 73
4.3. Analyzing Dependency Correlations 73
4.3.1. Types of Organization and the Use of Risk Assessment in Projects and Program 75
4.3.2. Types of Organization and the Use of Risk Assessment in Specific Project .. 78
4.3.3. Project Delivery Methods and the Use of Risk Assessment in Project 79
4.3.4. Total Planned Project Costs (TPCs) and Use of Risk Assessment in Project . 80
4.3.5. Total Planned Durations (TPDs) and the Use of Risk Assessment in Project. 82
4.3.6. Cost Impact Rating (CI) and the Use of Risk Assessment in Project 83
4.3.7. Schedule Impact Rating (SI) and the Use of Risk Assessment in Project 91
4.4. Summary 100
CHAPTER 5. RISK RATING AND RANKING 104
5.1. Risk Rating 104
5.2. Risk Ranking for All Projects 105
5.3. Risk Ranking for Different Types of Projects 109
5.3.1. New or Expansion Projects (PT-1) 110
5.3.2. Rehabilitation or Reconstruction Projects (PT-2) 111
5.3.3. Bridge or Tunnel Projects (PT-3) 114

5.3.4. Complex Projects (PT-5) ... 114

5.4. Summary ... 116

CHAPTER 6. IMPACT ON PROJECT PERFORMANCE MEASURES ... 121

6.1. Cost Growth ... 122

6.2. Cost Growth Dependency Correlations ... 124

6.2.1. Cost Growth and Project Type ... 126

6.2.2. Cost Growth and Project Delivery Method ... 129

6.2.3. Cost Growth and Total Planned Project Cost ... 131

6.2.4. Cost Growth and Total Planned Project Duration ... 133

6.2.5. Cost Growth and the Use of Risk Assessment ... 134

6.2.6. Cost Growth and Schedule Growth ... 135

6.2.7. Cost Growth and Risk Ratings ... 136

6.3. Schedule Growth ... 139

6.4. Schedule Growth Dependency Correlations ... 141

6.4.1. Schedule Growth and Total Planned Project Duration ... 142

6.4.2. Schedule Growth and the Use of Risk Assessment ... 143

6.4.3. Schedule Growth and Project Delivery Method ... 144

6.5. Summary ... 146

CHAPTER 7. CONTINGENCY ... 150

7.1. Owner's Contingency ... 151

7.1.1. Owner's Contingency and Relative Importance of Risks (RI) ... 151

7.1.2. Owner's Contingency and Cost Impact of Risks (CI) ... 155

7.1.3. Owner's Contingency and Schedule Impact of Risks (SI) ... 155

7.2. Contractor's Contingency 157

7.2.1. Contractor's Contingency and Relative Importance of Risks (RI) 157

7.2.2. Contractor's Contingency and Cost Impact of Risks (CI) 159

7.2.3. Contractor's Contingency and Schedule Impact of Risks (SI) 161

7.3. Summary 163

CHAPTER 8. CONCLUSIONS AND RECOMMENDATION 165

8.1. Conclusions 165

8.2. Significance of the Study 170

8.3. Recommendations 171

REFERENCES 174

APPENDIX A. STUDY ABBREVIATIONS 177

APPENDIX B. THE SURVEY FORM 179

APPENDIX C. DETAILED DESCRIPTIVE FREQUENCY TABLES 186

APPENDIX D. DETAILED RISK RATINGS 211

LIST OF TABLES

Table Page

2.1. Performance Metrics 15

3.1. Construction Risk Drivers 31

4.1. Frequencies of Locations of Responders 59

4.2. Frequencies of Types of Organization 59

4.3. Frequencies of Use of Risk Assessment in Chosen Projects 60

4.4. Importance of Risk Management in Highway Project Performance 61

4.5. Frequencies of Location of Projects 62

4.6. Frequencies of Project Types 62

4.7. Frequencies of Highway Types 63

4.8. Frequencies of Project Delivery Methods 63

4.9. Frequencies of Procurement Methods 64

4.10. Frequencies of Payment Methods 64

4.11. Frequencies of Total Planned Costs of Projects 65

4.12. Frequencies of Project Start Years 66

4.13. Frequencies of Total Planned Durations (TPDs) of Projects 66

4.14. Frequencies of Owner's Contingency Percentages 67

4.15. Frequencies of Contractor's Contingency Percentages 68

4.16. Frequencies of Cost Growth (CG) Percentages 70

4.17. Frequencies of Schedule Growth (SG) Percentages 71

4.18. Roles of Responders in the Projects Reported 72

4.19. Use of Risk Assessment in Project 73

4.20. Type of Organization and the Use of Risk Assessment 77

4.21. Types of Organization and the Importance of Risk Management 77

4.22. Types of Organization and the Use of Risk Assessment in Project 79

4.23. Project Delivery Methods and the Use of Risk Assessment in Project 81

4.24. Total Planned Cost (TPC) and the Use of Risk Assessment in Project........................ 82

4.25. Total Planned Duration (TPD) and the Use of Risk Assessment in Project.................... 84

4.26. CI-3 and the Use of Risk Assessment in Project 86

4.27. CI-10 and the Use of Risk Assessment in Project 87

4.28. CI-12 and the Use of Risk Assessment in Project 88

4.29. CI-17 and the Use of Risk Assessment in Project 89

4.30. CI-21 and the Use of Risk Assessment in Project 90

4.31. CI-29 and the Use of Risk Assessment in Project 91

4.32. CI-30 and the Use of Risk Assessment in Project 92

4.33. SI -3 and the Use of Risk Assessment in Project.. 94

4.34. SI-10 and the Use of Risk Assessment in Project.. 95

4.35. SI-12 and the Use of Risk Assessment in Project.. 96

4.36. SI-15 and the Use of Risk Assessment in Project.. 97

4.37. SI-21 and the Use of Risk Assessment in Project.. 98

4.38. SI-29 and the Use of Risk Assessment in Project.. 99

4.39. SI-30 and the Use of Risk Assessment in Project... 100

5.1. Significant Risk Drivers for All Projects.. 107

5.2. Significant Risk Drivers for New or Expansion Projects (PT-1) 111

5.3. Significant Risk Drivers for Rehabilitation or Reconstruction Projects (PT-2) 113

5.4. Significant Risk Drivers for Bridge or Tunnel Projects (PT-3) 115

5.5. Significant Risk Drivers for Complex Projects (PT-5) 116

5.6. Summary of Significant Risk Drivers for Different Types of Projects 118

6.1. Frequencies of Different Cost Growth Levels 123

6.2. Frequency Table for Five Cost Growth Levels 123

6.3. Frequency Table for Two Cost Growth Levels 124

6.4. Type of Organization and Cost Growth 125

6.5. Project Location and Cost Growth 125

6.6. Project Type and Cost Growth at Two Levels 127

6.7. Project type and Cost Growth at Eleven Levels 128

6.8. Project Type and Project Delivery Method 129

6.9. Project Type and Planned Project Cost 130

6.10. Project Delivery Method and Cost Growth at Two-Levels 131

6.11. Project Delivery Method and Cost Growth at Eleven Levels 132

6.12. Total Planned Project Cost and Cost Growth at Two Levels 133

6.13. Use of Risk Assessment and Cost Growth at Two Levels 135

6.14. Schedule Growth and Cost Growth at Two Levels 136

6.15. CI-9 and Cost Growth at Two Levels 138

6.16. CI-9 and Use of Risk Assessment 138

6.17. CI-14 and Cost Growth at Two Levels 140

6.18. CI-14 and Use of Risk Assessment 140

6.19. Frequency Table of Schedule Growth at Two Levels 141

6.20. Use of Risk Assessment and Schedule Growth at Five Levels 144

6.21. Use of Risks Assessment and the Schedule Growth at Two Levels........................ 145

6.22. Project Delivery Method and Schedule Growth at Eleven Levels 146

7.1. Stepwise Regression of Owner's Contingency with Relative Importance Ratings.... 153

7.2. Stepwise Regression of Owner's Contingency with Schedule Impact Ratings 157

7.3. Stepwise Regression of Contractor's Contingency with RI Ratings of Risks........... 159

7.4. Stepwise Regression of Contractor's Contingency with CI Ratings of Risks........... 161

7.5 Stepwise Regression of Contractor's Contingency with SI Ratings of Risks 162

C.1. Frequency Table of Location of Organization of Survey Responders...................... 186

C.2. Frequency Table of Types of Organization of Survey Responders 187

C.3. Frequency Table of the Use of Risk Assessment... 187

C.4. Frequency Table on Importance of Risk Management for Project Performance....... 187

C.5. Frequency Table of Experience of Organization of Survey Responders.................. 188

C.6. Frequency Table of Location of Survey Responders... 189

C.7. Frequency Table of Regional Location of Survey Responders 190

C.8. Frequency Table of Project Types in Responses 190

C.9. Highway Type Frequency.. 190

C.10. Frequencies of Different Project Delivery Methods.. 191

C.11. Frequencies of Different Procurement Methods.. 191

C.12. Frequencies of Different Payment Methods 191

C.13. Frequencies of Different Total Project Planned Cost Ranges................................. 192

C.14. Frequencies of Different Project Start Year... 192

C.15. Frequencies of Different Project Planned Duration Ranges 193

C.16. Frequencies of Different Owner's Contingency Percentages 193

C.17. Frequencies of Different Contractor's Contingency Percentages 194

C.18. Frequencies of Different Cost Growth Levels 194

C.19. Frequencies of Different Schedule Growth Levels 195

C.20. Frequencies on Use of Risk Assessment 195

C.21. Relative Importance Ratings Frequency 196

C.22. Cost Impact Ratings Frequency 203

C.23. Schedule Impact Ratings Frequency 207

D.1. Relative Importance Ratings for All Projects 211

D.2. Cost Impact Ratings for All Projects 212

D.3. Schedule Impact Ratings for All projects 213

D.4. Relative Importance Ratings for New or Expansion Projects (PT-1) 214

D.5. Cost Impact Ratings for New or Expansion Projects (PT-1) 215

D.6. Schedule Impact Ratings for New or Expansion Projects (PT-1) 216

D.7. RI Ratings for Rehabilitation or Reconstruction Projects (PT-2) 217

D.8. Cost Impact Ratings for Rehabilitation or Reconstruction Projects (PT-2) 218

D.9. Schedule Impact Ratings for Rehabilitation or Reconstruction Projects (PT-2) 219

D.10. RI Ratings for Bridge or Tunnel Projects (PT-3) 220

D.11. Cost Impact Ratings for Bridge or Tunnel Projects (PT-3) 221

D.12. Schedule Impact Ratings for Bridge or Tunnel Projects (PT-3) 222

D.13. Relative Importance Ratings for Complex Projects (PT-5) 223

D.14. Cost Impact Ratings for Complex Projects (PT-5) 224

D.15. Schedule Impact Ratings for Complex Projects (PT-5) 225

LIST OF FIGURES

Figure Page

2.1. Project Development Process and Projected Cost 8

2.2. Caltrans Risk Management Process 10

2.3. Risk Management and Cost Validation in the WSDOT CEVP Process 11

2.4. Risk Assessment Process 17

2.5. The C4CE's DBM Method Integrates Best Practices 22

4.1. Census Regions and Division of the United States 58

7.1. Linear Regression Model for Owner's Contingency 152

7.2. Stepwise Regression of Owner's Contingency with Schedule Impact Ratings 156

7.3. Stepwise Regression of Contractor's Contingency with RI Ratings of Risks 158

7.4. Stepwise Regression of Contractor's Contingency with CI Ratings of Risks 160

7.5. Stepwise Regression of Contractor's Contingency with SI Ratings of Risks 162

CHAPTER 1. INTRODUCTION

1.1. Background

The construction industry and its clients are associated with high degree of risk due to the complex nature of the construction process. Cost overruns and late completion times in large infrastructure projects have been widely recognized as risks impacting project performance (Flyvbjerg et al. 2002). Controlling project budgets over project construction life cycle for the mega infrastructure projects is a major challenge for both the public and the private sectors. Accurately estimating cost is an important factor for a successful project cost management from the start of planning phase to the completion of construction (Akintoye and MacLeod 1997).

The Association for Advancement of Cost Engineering (AACE) has developed a cost estimate classification system with five classifications for cost estimate (Christensen and Dysert 2005). The projects with the lowest level of project definition are classified as Class 5, while projects with full and mature project definition are classified as Class 1. The different cost estimation techniques and tools range from stochastic to deterministic to a combination of the two, depending on project definition level. The closer a project is to Class 1 cost estimate, the more preferable and effective is the deterministic method.

One of the strategies to reasonably estimate the project construction costs is to assign contingencies to the different project cost components or to the total base cost of project in order to accommodate project uncertainties and risk. Estimators have been always trying to estimate the adequate amount or percent of project contingencies so that cost growth can be avoided and the unused contingency at project's completion can be minimized. Managing risks, especially in the construction phase, is the most effective strategy that will help control cost and time escalations. Identifying, analyzing and assessing different construction risks at the planning phase may be used to effectively calculate the project contingency. Different techniques and tools that can be used in this regard are simulation, parametric modeling, expert judgment, and others. Parametric modeling is simple, understandable, and empirical by nature.

Design-Build (DB) project delivery method is an alternative for Design-Bid-Build (DBB) project delivery method in many countries around the world, including the United States. In DB project delivery method, the design and construction phases of a project are combined into one contract. In a Federal Highway Administration (FHWA) sponsored design-build effectiveness study (SAIC et al. 2006), the data analysis has shown the following:

1) In both building and highway projects, duration of the projects were found to be 4 to 60 percent lower for projects using DB project delivery method compared to those using DBB project delivery method.

2) In both building and highway projects, DB method has typically resulted in lower project cost compared to that for DBB method. However, there has been anywhere from an 18-percent reduction to a 23-percent increase in cost when using DB method instead of DBB method.

3) The increased use of DB method in public sector and the need to improve the performance and quality of public highway projects require more familiarity with all performance and risks indicators in this method.

Molenaar (2005) emphasized the importance and the effectiveness of using risk management and other cost control processes in lowering the expected costs of projects. Akintoye and MacLeod (1997) studied the perceived risks and found that contractors and project managers in the UK use perceived risk as the likelihood of unforeseen factors occurring, which could adversely affect the successful completion of a project in terms of cost, time, and quality, and concluded that analyzing and controlling risks are the key to improving profit.

1.2. Problem Statement

Most of the transportation megaprojects have experienced significant cost overruns or project delays and schedule growth. Adding contingency to the project's base cost is a common practice to deal with these growths in cost and schedule resulting from any underestimating of cost components, other risks and uncertainties encountered during the project's construction life cycle.

The level of development of project's definition and scope will dictate the choice of estimating method, which can be stochastic, deterministic, or some combination of the two. This choice, in turn, naturally depends on the available information regarding design and engineering of the project. The federal and state highway agencies typically rely on deterministic method and estimates in the conceptual phase for the unit cost estimate. Estimating project construction contingency has been a great challenge in highway megaprojects because of the project's complexity and the difficulty in quantifying the project's associated risks in preconstruction phase. In DB project delivery method the contingency calculation is very critical because of the nature of its implementation, which needs to integrate design with construction under one party. The key concern for risk management in DB project delivery method is the shifting of risks, especially for design risks, from the owner or public sector to the design-builder.

Base construction cost may be up to 80% of total project cost. Identifying and analyzing the critical risk indicators, which occur in construction phase, are crucial requirements by all parties involved in a project. By identifying these risks, which have great impact on construction cost growth and schedule growth, the project estimators can determine the adequate amount or percentage of construction contingency, which in turn helps them deal with project associated risks and uncertainties, while not tying up valuable funds that can be used for other activities. Highway departments and project companies use the traditional percentage method to calculate the project contingency or some simulation software to give a range and probability distribution for project cost and duration.

Developing prediction model for cost growth, schedule growth, and contingency can be more effective tool in preconstruction phase for future highway projects. Parametric modeling has been used in previous research to develop total project costs or tender prices of projects by taking into account the project variables. Testing of regression models for cost growth, schedule growth, and contingency as dependent variables against risk rating values as independent variables have not been researched adequately for highway projects.

1.3. Objectives

The primary objectives of this study are:

1) To identify the critical construction risks in highway construction projects in the US;

2) To understand and analyze the correlation between project characteristics and project performance measures for highway construction projects;

3) To assess the identified risks with respect to their relative importance on the occurrences of other risk drivers for highway construction projects;

4) To analyze and evaluate the effect of relative importance and severity of impact of identified risks on project cost growth for highway construction projects;

5) To analyze and evaluate the effect of relative importance and severity of impact of identified risks on project schedule growth for highway construction projects; and

6) To analyze and model cost growth percentage, schedule growth percentage, and contingency percentage for highway construction projects.

1.4. Scope

The scope of this study is in identifying and evaluating the construction risks in highway projects in the US with respect to each risk's importance and its impact on cost and schedule growth. Project information and characteristics as well as project risks' cost and schedule impact ratings has been used in this study to test and understand the impact on project's cost growth, schedule growth, and contingency percentages. The analyses are carried out based on the responses from professionals, who responded based on their experience related to past several highway construction projects.

1.5. Dissertation Organization

This dissertation is organized in eight chapters. This chapter provided background, problem statement, objectives, and scope of the research. Chapter 2 presents a review of related and relevant past studies related to risk management, cost growth, schedule growth, and contingency for highway construction projects. Chapter 3 details the methodology, including survey design and hypotheses of interest in this research. Chapter 4 analyzes the survey responses and identifies dependency correlations. Risk rating and ranking design for all projects as well as by project types are provided in Chapter 5. Project performance measures such as cost growth and schedule growth and their dependency correlations have been analyzed and discussed in Chapter 6. Important analyses related to owner's and contractor's contingency are discussed in Chapter 7. Significant conclusions from this study and recommendations for further research are presented in Chapter 8. A list of references follows Chapter 8. Explanations of the abbreviations used (Appendix A), documentation of the survey form (Appendix B), detailed descriptive frequency tables (Appendix C), and detailed risks' ratings (Appendix D) are given in four appendices.

CHAPTER 2. LITERATURE REVIEW

In this chapter different past research studies in the area of construction management and highway transportation project risk management have been reviewed and examined. Identification of risk indicators, risk assessment and evaluation, risk assessment techniques, and contingency and estimating methods have been identified, reviewed, and discussed.

2.1. Highway Risk Management

Construction project involves a variety of activities among different organizations. These activities are implemented by a large number of people for a specific period of time and under various constraints. This construction process carries numerous uncertainties and risks, which increase with the size and the complexity of a project. Risk has been defined in different ways. Project Management Institute (PMI) defines project risk as an uncertain event or condition and that its occurrence has a positive or negative effect on at least one project objective, such as time, cost, scope, or quality. Risk might have one or more causes and if it occurs, has one or more impacts (PMI 2004)

In another reference the history of the word risk is given as follows: "*the word risk is quite modern; it entered the English language in the mid 17th century, coming from the French word (risqué). In the second quarter of the 18th century the Anglicized spelling began to appear in insurance transaction.*" (Flanagan and Norman 1999).

Project risk management might be formal or informal process, and it is defined by PMI as: "*Project Risk Management includes the process concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project; most of these processes are updated throughout the project*" (PMI 2004).

Ashley et al. (2006) emphasizes the importance of including risk assessment, risk allocation, and risk management in highway construction projects. Risk management must be forward looking and identify potential problems. Contingency is greatest in the beginning of a project and is gradually reduced as the project is designed, risks are resolved, or the contingency is spent. The range of project cost and its associated contingency is reduced as the project moves through the development process as it is shown below in Figure 2.1.

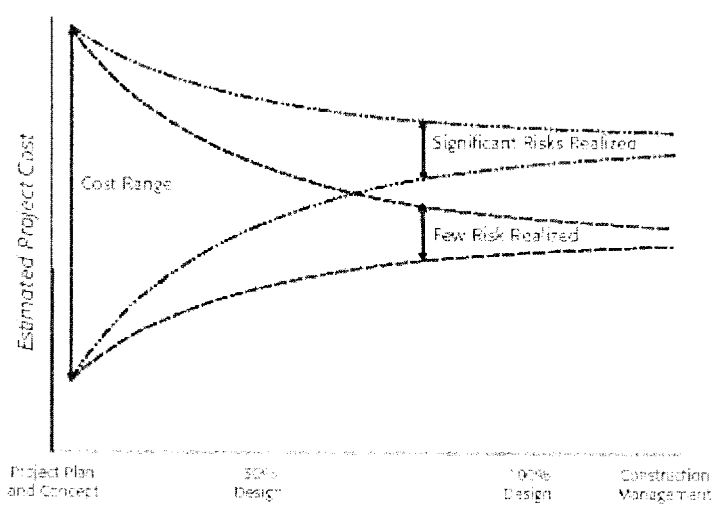


Figure 2.1. Project Development Process and Projected Cost
Source: (Ashley et al. 2006)

According to Ashley et al. (2006), risk management process has the following six primary steps:

1) Identification: It is the process of identifying, categorizing, and documenting risks that could affect the project.

2) Assessment: It is the process of quantifying the risk events documented in the preceding identification stage.

3) Analysis: It is the process of conducting additional quantitative analysis to combine the effects of the various identified and assessed risk events into an overall project risk estimate, and to determine cost and schedule contingency values.

4) Mitigation and Planning: It is the process of exploring risk response strategies for the high risk items identified in the qualitative and quantitative risk analyses.

5) Allocation: It is the process of allocating the risks to the party best able to manage them.

6) Tracking and Updating: It is the process to systematically track the identified risks, identify any new risks, effectively manage the contingency reserve, and capture lessons learned for future risk assessment and allocation efforts.

Not many departments of transportation (DOTs) have developed a comprehensive risk management process. A good example of risk management process is the one followed by Caltrans (see Figure 2.2), which includes all of the aforementioned six steps.

The risk management process of Washington State Department of Transportation (WSDOT) (see Figure 2.3) indicates how its steps vary throughout the project development period. It demonstrates how the relative importance of the risk management activity corresponds to project cost verification and validation activities as part of the cost estimating and validation process (CEVP).

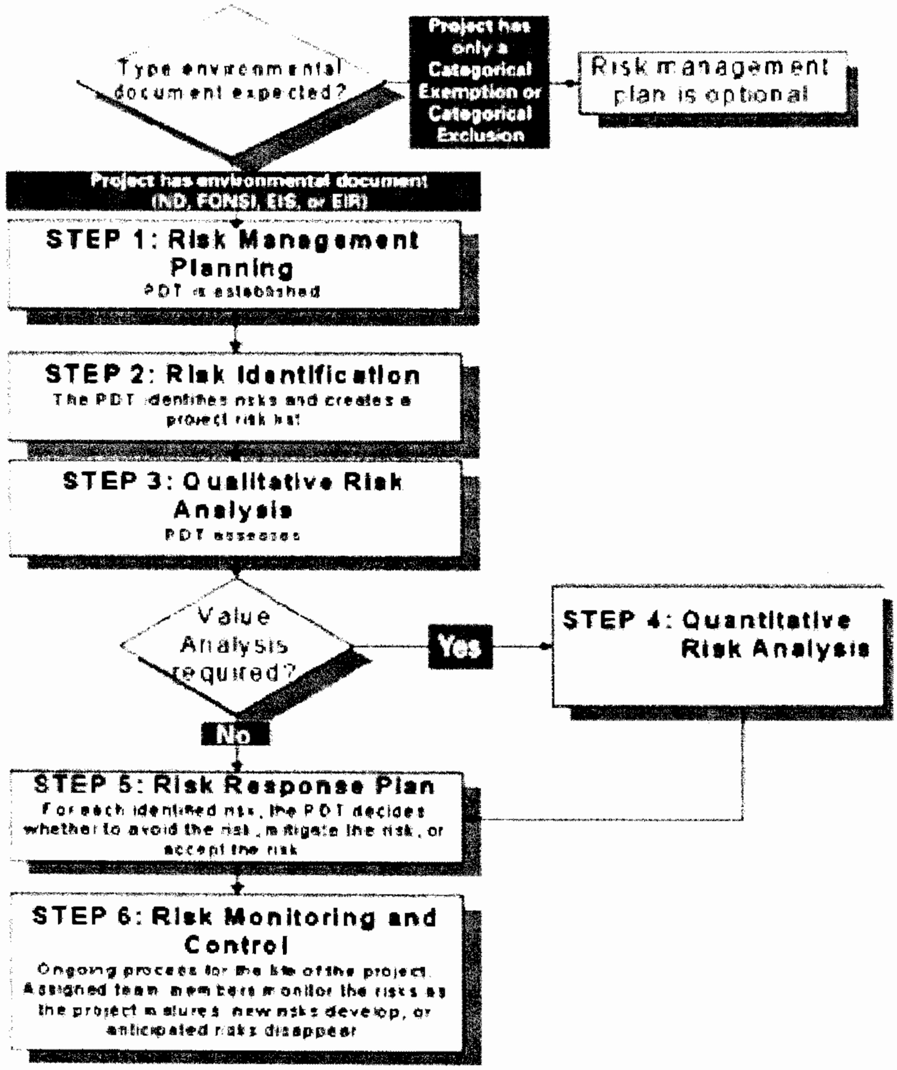


Figure 2.2. Caltrans Risk Management Process
Source: (Ashley et al. 2006)

2.2. Identification of Construction Risks

Lam (1999) studied different infrastructures megaprojects in different parts of the

Figure 2.3. Risk Management and Cost Validation in the WSDOT CEVP Process
Source: (Ashley et al. 2006)

world. Risks of infrastructure projects have been identified under a sectoral classification scheme and demonstrating their effects. The study showed that mega projects have some impact on the environment in one way or the other which require conducting environment impact analyses and implementing environmental mitigation measures. The study also emphasized that the residual risks, which cannot be covered or mitigated, stem from the government side, and the issue of privatization is politically sensitive. The pattern of risks inherent in projects is largely influenced by the financial structure of the projects. Road projects usually don't involve very sophisticated technology, but can require very large investment because of the size and scope. Toll road cases have shown that inadequate traffic volumes is the critical risk for project sponsor in the operation phase and the accuracy of traffic forecast is critical issue in project risk identification process.

Zayed et al. (2007) identified two levels of risk areas in Chinese highway projects: company (macro) and project (micro) levels. A risk model, using the analytical hierarchy process (AHP), was used to facilitate risk assessment and to prioritize the examined projects based upon risk. The political risk was found to be the most critical and financial risk the second most critical risk at the macro level. Emerging technology and resource risks had the highest rating for criticality at the micro level.

El-Sayegh (2007) identified and ranked the critical risks for the construction industry in United Arab Emirates (UAE) industry and allocated these risks to the owner, the contractor, or to be shared between them. The most critical risks were inflation and sudden changes in prices, shortage in resources supply, and availability of material, labor, and equipment. Other major risks related to owner were tight construction schedule, improper invention and change of design. Performance and management of subcontractors and delay of material supply by suppliers were among the ten most critical risks in UAE construction industry.

Risk in construction project is normally assumed by the owner unless it is transferred to another party. One of the risk management objectives is to allocate risk to the party best able to manage the risk effectively with the lower cost. Kangari (1995) identified the contractors' attitude for allocation of construction risks and examined the importance of different risk categories based on the survey of the top 100 US construction companies. The study found that the contractors' views regarding risk allocation have changed since the 1970s. In the 1990s contractors were willing to assume risks such as change order negotiations, third-party delays, contract delays resolutions, and indemnification and hold harmless, which accompany contractual and legal problems in the form of risk sharing with the owner. For the economic condition related risks, the study showed that the lower the inflation rate, the more risk a contractor was willing to assume, and during periods of higher number of business failures, the contractor was less willing to assume risk. The contractor should assume risks related to labor, equipment, and material availability, labor and equipment productivity, and quality of work. On the other hand, owner should assume the risks related to permits and ordinances, site access and right of way, defective design, changes in work scope, and changes in government regulations. Depending on the change in attitude as industry changes and with the passage of time the allocation of other risks shifts from one party to the other.

American Association of State Highway and Transportation Officials (AASHTO) have identified the critical highway risks in design-build projects in the US. These critical risks are: design related, environmental approval and permitting, right-of-way, local agency, utility, railroad issues, construction, force majeure, different site conditions, and warranty related risks (AASHTO 2008).

2.3. Project Performance and Success Indicators

Songer and Molenaar (1997) conducted a research study on Design-Build projects in public sector. The five critical project characteristics out of fifteen that were identified in this study are: well-defined scope, shared understanding of scope, owner's construction sophistication, adequate owner staffing, and established budget. The findings have been identified by project owners and project experts. The study also identified the critical success factors from the public agency perspective, and found that the most important criteria were staying on budget, conforming to user's expectations, and staying on schedule.

A comparison between three most common project delivery methods (design-bid-build, design-build, and construction management at risk) has been conducted based on data collected from 351 building projects in the U.S. (Konchar and Sanvido 1998). In this study cost, schedule, and quality performance of the three project delivery methods were analyzed against 100 explanatory and interacting variables using multivariate linear regression analysis. The results indicated that using design-build project delivery method can provide significant cost and schedule advantages and result in more desirable quality performance.

Lam et al. (2008) used the key project performance indicators of time, cost, quality, and functionality to measure the success of DB projects in Hong Kong. The study identified project nature, the effective project management action, and the adoption of innovative management approaches as the critical success factors for Design-Build projects in Hong Kong through multiple regression models. Ling et al. (2004) developed models to predict performance of DB and DBB projects for 11 performance metrics based on data from 87 building projects. The 11 performance metrics used in this study as dependent variables (Yi) are listed in Table 2.1 on the next page.

Shane et al. (2009) identified transportation construction project cost escalation factors through literature review and triangulation of data from interviews with more than 20 state highway agencies in the U.S. The study categorized these factors in two groups: external and internal factors. External factors include: local concerns and requirements related to societal environment as well as the natural environment, effects of inflation,

Table 2.1. Performance Metrics

ID	Performance metrics (Dependent variable)	Definition
Cost		
Y1	Unit cost ($/m2)	(Final project cost/area)/index
Y2	Cost growth (%)	[(Final project cost - contract project cost)/contract project cost] x 100
Y3	Intensity [($/m2)/month]	Unit cost/total time
Time		
Y4	Construction speed (m2/month)	Area/(as built construction end date - as built construction start date/30)
Y5	Delivery speed (m2/month)	Area/total time
Y6	Schedule growth (%)	[(Total time -total as planned time)/total as planned time]x 100
Quality		
Y7	Turnover quality	Ease of starting up and extent of call backs (5 = exceed owner's expectation; 1 = not satisfactory)
Y8	System quality	Performance of building elements, interior space and environment (5 = exceed owner's expectation; 1 = not satisfactory)
Y9	Equipment quality	Performance of equipment (5 = exceed owner's expectation; 1 = not satisfactory)
Others		
Y10	Owner's satisfaction	5= exceed owner's expectation; 1 = not satisfactory
Y11	Owner's administrative burden	5 = minimum burden; 1 = very heavy burden

scope changes and creep which are not controllable by the project's sponsoring agency/ owner, unforeseen events, and unforeseen conditions. Internal factors are directly controlled by the project's sponsoring agency/owner. These factors include: bias of underestimation of project cost, delivery/procurement approach and allocation of risk, project schedule changes, engineering and construction complexities, scope changes, scope creep, poor estimating, faulty execution, and ambiguous contract provisions.

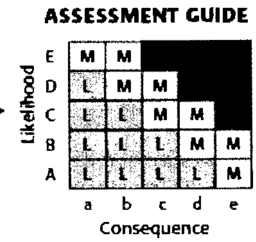
Using data from Norwegian road construction within the period from 1992 to 1995, Odek (2004) found that the smaller projects encountered cost overruns more than larger ones. Other factors found to influence the size of cost overruns included completion time and the regions of these projects. However, neither project type nor work force type influenced the level of cost overruns.

2.4. Risk Assessment and Evaluation

According to a National Cooperative Highway Research Program (NCHRP) report (Anderson et al. 2007) *"Risk analysis can be used throughout the project development process. At the earliest stages of project development, risk analysis will be helpful in developing an understanding of project uncertainty and in developing an appropriate project contingency."* Ashley et al. (2006) revealed that awareness of risk assessment and allocation techniques is more advanced in Europe than in the U.S., and also presented the risk assessment process guide developed by Department of Energy (DOE) (see Figure 2.4), which can be used for highway transportation projects.

Akintoye and MacLeod (1997) found that the construction industry in the UK has approached risk management in terms of individual intuition, judgment, and experience gained from previous contracts. Contractors have tendency to contract out all the work packages in a project to sub-contractors and undertake contract management as part of strategy to reduce or eliminate their risk. The more powerful and sophisticated the risk

Level	Likelihood
A	Remote
B	Unlikely
C	Likely
D	Highly Likely
E	Near Certainty



RISK ASSESSMENT

High (Red)
Unacceptable. Major disruption likely. Different approach required. Priority management attention required

Moderate (Yellow)
Some disruption. Different approach may be required. Additional management attention may be needed

Low (Green)
Minimum impact. Minimum oversight needed to ensure risk remains low

Level	Schedule	and/or	Cost
a	Minimal or no impact		Minimal or no impact
b	Additional resources required; able to meet		<5%
c	Minor slip in key milestones; not able to meet need date		5-7%
d	Major slip in key milestone or critical path impacted		7-10%
e	Can't achieve key team or major program milestone		>10%

Figure 2.4. Risk Assessment Process
Source: (Ashley et al. 2006)

assessment techniques, the more time and data are required, and since the construction industry is constrained by time, most of contractors are reluctant to use risk analysis and management techniques.

Construction Industry Institute (CII) formed the International Project Risk Assessment Project Team (PT 181) to develop a management tool to identify and assess the risks associated with international capital projects. PT 181 developed a structured risk identification and assessment process known as the International Project Risk Assessment (IPRA). The team developed risk checklist, which covers all potential international construction project risks in different sectors. This list was modified at the end of the study, which reflects the differences between domestic and international construction risks.

Vines et al. (2004) assessed these risks and it has been found that the most critical risks in terms of level of relative impact on project objectives are: source and form of funding, estimate uncertainty, business case, insurance, economic model, currency, relationship with government/owner, market/product, traditions and business practices, and contract type and procedures.

According to AACE, the level of project definition, inherently addressed in AACE's estimate and schedule classifications, is a predominant risk driver and a good starting point for most risk analysis (Christensen and Dysert 2005). The risk of utility conflicts has been recognized as a common occurrence on many roadway projects. Goodrum et al. (2008) studied and analyzed the cost, frequency, and severity of utility conflicts from 45 different state transportation agencies, and developed four in-depth case studies by both type and location (urban versus rural roadway projects). Existing underground telecommunication utilities are the most frequent and most severe utility conflicts on roadway projects.

2.5. Risk Assessment and Analysis Techniques

There are many qualitative and quantitative risk analysis techniques which can be used. The choice of a particular technique would be based on the project, its determining factors, and the type of analysis needed with respect to profitability, time, cost, and other factors. Cano and Cruz (2002) evaluated numerous studies and identified and listed several qualitative and quantitative techniques.

2.5.1. Qualitative Techniques

The commonly used qualitative techniques are:

1) Checklists;

2) Brainstorming and Delphi, which can by conducted among group decision-makers;

3) Assumption analysis or data precision ranking, which can be done to examine the risk data and evaluate the degree to which the data are useful to understand the risk;

4) Probability and impact description, which can be done to describe parameters in qualitative terms (such as very high, high, moderate, and so on);

5) Probability-impact risk rating tables, which can be based on combining probability and impact qualitative scales;

6) Cause-and-effect diagrams or fishbone diagrams, which are graphs that presenting the interrelations between risks and their causes;

7) Flowcharts and influence diagrams, which can be graphs presenting the interrelations between activities, risks, and responses; and

8) Event and fault trees, which can be used in engineering systems and project management.

2.5.2. Quantitative Techniques

The commonly used quantitative techniques are:

1) Sensitivity analysis to test the criticality of different project parameters;

2) Expected value tables to compare expected values for different risk responses;

3) Triple estimate and probabilistic sums, which could be applied to cost estimating;

4) Monte Carlo simulation to obtain the cumulative likelihood distributions of the project's objectives (net present value, cost, time) using probabilistic estimation of the input parameters;

5) Decision trees, which can be used among choices with uncertain outcomes;

6) Probabilistic influence diagrams, which combine influence diagrams with probability and Monte Carlo theory to simulate aspects of project risk;

7) Multi criteria decision-making support methods (MCDMSMs), like Analytical hierarchy process (AHP), which can be used for multi criteria selection among different risk responses by mixing qualitative and quantitative criteria;

8) Process simulation, using a variety of techniques to simulate specific project process;

9) System dynamics, which combines influence diagrams with a more complex mathematical framework to dynamically simulate specific aspects of project parameters with feedback loops, and has the ability to simulate the selection among different alternative actions; and

10) Fuzzy logic, with potential application to scheduling, cost control, and multi criteria selection among several alternatives.

Hollmann (2007) identified the challenges and shortcomings of using Monte-Carlo simulation determining contingency and highlighted that the best practice for estimating contingency should include the following features:

1) Identifying and understanding the risk drivers;

2) Recognizing the differences between systemic and project specific risk drivers;

3) Addressing systemic risk drivers by using empirically-based stochastic models;

4) Addressing project specific risk drivers using methods that explicitly link risk drivers and cost outcomes; and

5) If the method uses Monte Carlo, address dependencies.

Hollmann and the Center for Cost Engineering ($C^{+}CE$) have developed tools that apply these best practices. Basic parametric contingency estimating model for systemic risks, and expected value template for modeling project specific risk drivers, has been incorporated in Monte Carlo simulation modeling. Figure 2.5 presents this combined approach, which has been called as DBM. For early estimates the parametric model can be used alone.

2.6. Contingency Studies

Project uncertainties create potential for cost and time escalation due to the developed risks resulting from such uncertainties. Contingency is a value allowance to cover the cost escalation and recover from risk. It has been defined by PMI (2004) as *"The amount of funds, budget or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization."*

On the importance of risk assessment in contingency calculations, Anderson et al. (2007) explains that *"The standard state highway agency method for assigning contingency has been to either follow standard percentage for the varying stages of project development or to rely solely on the project estimator's experience. The enumeration and qualitative* *assessment of a project's contributor risks offers a more effective method for determining project contingency than does the standard state highway agency practice of broad-based percent add-on contingency amount, and the macro environment focuses estimator attention on project risks."*

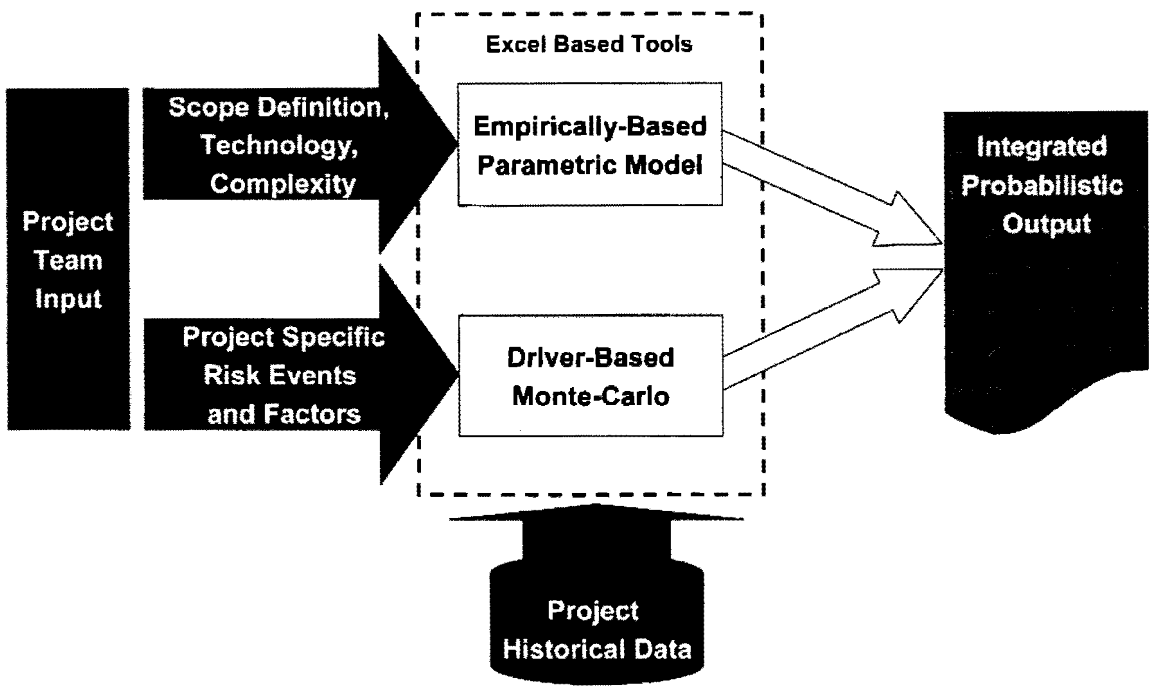


Figure 2.5. The C4CE's DBM Method Integrates Best Practices
Source: (Hollmann 2007)

Hamburger (1990) identified contingency categories as: (a) budget contingency, which consists of the performance elements and the economic elements; (b) schedule contingency; and (c) specification or technical contingency, which should not be treated as a part of the project budget but should be held separate from the budget in a management reserve account. The performance elements include an estimate quality contingency and an adjustment or fix-it contingency. The economic elements include price protection and escalation contingency.

Gunhan et al. (2007) conducted a research study by analyzing the number and magnitude of change orders which were filed for five and half years in school building projects at a school district to determine the main causes for these changes. The results revealed that the majority of change orders were caused by owner-direct changes and the changed conditions. The study revealed that the occurrence rate can be reduced if right construction management firm was chosen and contingency funds were effectively used. The right choice of construction management firm has potential to improve the preconstruction activities such as conducting diligent site investigation, realistic project schedule, well defined project scope, and value engineering and constructability reviews.

2.7. Contingency Estimating Methods

According to Hollman (2008), the classes of methods used to estimate cost/time contingency are expert judgment, predetermined guidelines, simulation analysis, parametric modeling, and hybrid methods.

2.7.1. Expert Judgment

This method depends on experience and good judgment and it is highly subjective. The bias of this method can be minimized by obtaining the consensus of multiple experts or an experienced team, provided there is varied, independent opinion. Most methods are usually hybrid combinations with expert judgment method.

2.7.2. Predetermined Guidelines

It is simple to understand and use, and it is basically providing a single contingency or float value to cost and risk elements. A disadvantage of this method is that it cannot effectively address risks that are unique to a specific project or risks that are common, but may have inordinate impacts on a given project.

2.7.3. Simulation Analysis

This method combines expert judgment with an analytical probabilistic model in a simulation routine. The advantage of this method is that it provides probabilistic output, and can be used for project-specific risks. The disadvantage of this method is that its outcomes are not highly consistent and its complexity requires expertise in application and choice of the alternate estimates and schedules to estimate the impact if risk happens. The most common methods used in this analysis are Range Estimating and Expected Value.

Range estimating method is based on the cost elements ranges and distribution based on team understanding of the risks. The significant correlations amongst cost elements are incorporated into the analysis. The simulation model uses these data as input and the output will provide total cost distribution along with other data like contingency distribution and probability curves.

The expected value method uses direct estimates of the cost (or schedule) impact of each significant risk and their probability of occurrence. The product of their multiplication is the expected value for each risk. The simulation uses the calculated expected value distributions as the model inputs and the program run to develop total cost distribution along with other data like contingency distribution and probability curves.

2.7.4. Parametric Modeling

This method is generally an algorithm, which is derived from multiple-regression analysis of quantified risk drivers with cost growth, schedule growth, or contingency outcomes for historical projects. The advantage of this method is that it is simple to use, understandable, consistent, and empirical by nature. The disadvantage of parametric modeling is the complexity of developing the model, which requires statistical skills and historical data with a range of risks and outcomes. The method cannot effectively address risks that are unique to a specific project, or risks that are common, but may have unusual impacts on a given project. It is most useful for early estimates when systemic risks are dominant.

2.7.5. Hybrid Methods

Since each of previous methods has advantages and disadvantages, the best approach is use two or more methods to estimate risk cost/time or contingency. The most common combination is to use expert judgment with any other method. Another combination is to use a parametric model for systemic risks and simulation analysis for project-specific risks.

2.8. Summary

This chapter has presented review of different studies, which highlighted the importance of risk assessment and management in construction project and transportation industry. Previous studies have identified cost and time as the risks that most transportation professionals are interested in understanding and managing. Different risk drivers in construction industry have been defined and identified in previous studies. However, risk drivers have not been adequately analyzed. This study is motivated by the need for and the lack of comprehensive examination of transportation construction risk drivers and the correlation among the significant risk drivers and project characteristics. The study has adopted 31 risk drivers based on different literature reviewed in this chapter. These risk drivers are presented and discussed further in Chapter 3. The literature reviews and interaction with construction industry related professionals allow appropriate identification of programmatic- and project-specific construction risk drivers for highway projects. Qualitative risk assessment, which has been conducted in previous studies by rating the encountered risk drivers in the reported projects, has also been used in this study. However, the previous studies have not correlated project characteristics to the different construction risk drivers in highway projects in quantitative assessment.

The key construction project performance or risk measures, adopted from literature reviews, are cost and schedule growth percentages, which most transportation professionals are familiar with. In this study there is research interest to test these metrics against the identified risk drivers' rating values to assess or quantify the impact of these risk drivers on project performance measures in order to better the understanding of risk assessment process in highway projects in the US.

The impact of significant risk drivers on reported construction cost contingency amounts and percentages is also of significant interest to the construction industry. Hence, the need and interest to test statistically the interrelationship of the ratings for relative importance, cost impact, and schedule impact of different risk drivers with the contingency percentages used by owners and contractors. As predetermined method is the common way to calculate contingency amount in transportation projects, parametric models have been used to develop model for contingency percentages used in highway projects. The combination of expert judgment and parametric modeling has potential to be more effective in determining contingency amounts or percentages.

CHAPTER 3. METHODOLOGY AND HYPOTHESES

This chapter presents and discusses the overall approach for the research used in this dissertation, which includes risk identification and rating, formulation and evaluation of hypotheses, analyses of survey of responses, and the related modeling of performance measures such as cost growth percentages, schedule growth percentages, and contingency percentages.

3.1. Overall Approach

A comprehensive understanding of the impact of construction risks on project construction performance and management in highway projects in the U.S. is intended to be developed by identifying and analyzing the encountered construction risks through collection of quantitative and qualitative data related to completed highway construction projects. Such data is collected from transportation professionals based on their experiences and expectations in the chosen completed projects.

The focus was on collecting project specific data, which can be easy to quantify and obtain from project records. In addition, data on construction risk information related to these projects was also of primary interest. However, the risk information such as likelihood of occurrence, severity, and impacts of risks are not clearly documented and available in records of past highway projects in the US. It was a challenge to develop risk related data to be used in this research. Other studies for building construction projects, facing similar challenge, studied and analyzed the construction risks using scales for relative importance, cost impact, and schedule impact for different relevant risk drivers. Similar data were collected and evaluated in the analysis of risks in highway construction projects in this research.

The overall approach of this research involved the following twelve steps:

1) Step I -- Identifying relevant project characteristics information and critical risk drivers;

2) Step II -- Devising a draft survey;

3) Step III -- Seeking input regarding the devised survey;

4) Step IV -- Finalizing the survey;

5) Step V -- Seeking Institutional Review Board (IRB) approvals;

6) Step VI -- Conducting survey;

7) Step VII -- Formulating hypotheses of interest;

8) Step VIII -- Analyzing survey responses;

9) Step IX -- Evaluating and testing formulated hypotheses; and

10) Step X -- Identifying influencing project characteristics and risk drivers impacting cost growth, schedule growth, and contingency.

11) Step XI -- Documenting and discussing results

12) Step XII – Developing conclusions and recommendations

These steps are discussed further in this chapter under different sections and in Chapters 4 to 7. The discussions related to these steps are provided in this Chapter under broad categories such as risk identification (includes Step I), designing and conducting survey (involving Steps II to VI), hypotheses (Steps VII and IX), and analyses (Step VIII, IX, and X). The evaluation and testing of hypotheses have been carried out in Chapters 4, 6 and 7.

Similarly, other analyses, modeling, and discussion of related results have been carried out in Chapters 4, 5, 6, and 7. The conclusions and recommendations, based on analyses, modeling, and the related discussion of related results, are provided in Chapter 8.

3.2. Identifying Risks

Step I was identifying and categorizing the highway construction risks and related project characteristics from literature that were reviewed. This information was also discussed with transportation professionals from public and private sectors at many related professional conferences in past couple of years. The aim was to focus on those risks that pose the greatest threat on projects' goals and on construction performance measures such as cost and time. It also involved specifying the required project characteristics information that should be collected through the survey. The significant risk drivers were chosen based past research work that were documented in the literature review, interactions with professionals in public and private sectors, and personal construction management and engineering experience.

A total of 31 risk drivers were identified and grouped in following five broad categories: project scope, right of way, utility conflicts, architectural/engineering (A/E) services, and project construction management. The risk drivers are listed in Table 3.1. The responders were asked to provide project-specific information as well as rate the pre-identified common critical risks encountered in completed highway construction projects they were involved with. They were also given the opportunity to provide information on other risks which the project had encountered, but were not listed in the questionnaire.

Table 3.1. Construction Risk Drivers

I	Project Scope
R1	Project purpose is poorly defined
R2	Changes by owner's request
R3	Changes to unforeseen site environment requirements
II	**Right of Way**
R4	Right of Way analysis in error
R5	Land acquisition delay
III	**Utility Conflicts**
R6	Inadequate plan reviews by designers and contractors/ design errors
R7	Poor involvement of utility companies in planning stage
R8	High number of utilities in the site
R9	Inaccuracy of existing utility locations and survey data
R10	Poor coordination among utility agencies, designers, and contractors
R11	Increased utility relocation costs
R12	Poor engineering practice within the state
R13	Utility damages by contractors/subcontractors faults in construction
IV	**A/E Services**
R14	Surveys late and/or surveys in error
R15	Inexperienced professionals for this type of project
R16	Design errors and omissions
R17	Inadequate Constructability reviews
R18	Delay in Quality Assurance/Quality Control (QA/QC) services
R19	Poor preliminary soil information and investigations
R20	Unforeseen and/or different geotechnical conditions
R21	Unforeseen hazard conditions
R22	Inaccurate structures design
V	**Project Construction Management**
R23	Poor communication with owner and contractor
R24	Delay of permits
R25	Constraints in construction work window
R26	Material availability and price inflation
R27	Subcontractors errors and delays
R28	Maintenance of traffic/staging/auxiliary lanes
R29	Inexperienced project manager
R30	Safety issues
R31	Warranty issues
R32	Other
R33	Other

3.3. Designing and Conducting Survey

Design of survey involved steps II to V. In Step II a draft survey was devised, which was based on literature review, interaction with professionals from the industry, and relevance of considerations to risks encountered in highway construction projects. In Step III, input was sought regarding both the content of the survey and how to conduct it. For the content and structure of the survey input was sought from colleagues and professionals in the highway construction industry as well as in academia conducting construction risk related research. For the conduct of the survey assistance of the North Dakota State University (NDSU) Group Decision Center was sought. The professionals from industry also helped in identifying potential responders and provided advice on the mechanism for conducting an effective and successful survey. Transportation professionals were called to get their feedback on the structure of the survey and the feasibility of obtaining required information. In addition, personal interviews were conducted with transportation professionals to evaluate the relevance of including the identified risks and to discuss the importance of the study for the future of transportation professionals.

A test of developed survey was carried using couple of survey respondents to identify any problems in conducting the survey, and to address them before sending the survey out to all potential responders. Different professional associations were contacted to send out this survey to their members. The professional associations that provided assistance in this effort were Associated General Contractors, American Road and Transportation Builders Association, and Construction Management Association of America. The survey was conducted on line. The tests were carried out to see that survey transmission and responses obtained were collated correctly here at NDSU. In addition, few industry professionals were asked to test the online survey for any problems in understanding the content of the survey and in providing responses. Thus, in Step IV, survey was finalized taking into account all the useful and important input and feedback.

In Step V, an IRB approval (IRB Protocol #: EN09155) was obtained, before conducting the survey, as it involved survey of construction professionals from academia, consulting, and industry. In Step VI, the survey was conducted online. An email message with brief introduction, explanation of responders' rights, and the survey link was sent to transportation professionals randomly via the listserv. This listserv was created with assistance from the Information Technology Services (ITS) at NDSU, to include all potential participants' emails. The main goal of this survey was to collect specific data related to the completed projects that the responders were been involved in.

The finalized survey (see Appendix B for the entire survey) used in this research had three parts. Part I included general information about responder's job title, experience in using risk assessment, and location and type of organization he/she worked for. Part II allowed responders to choose up to three completed projects and provide specific information about the characteristics of these projects. Part III sought responses on thirty-one construction risk drivers arranged in five risk driver categories. The responders were asked to evaluate relative importance, cost impact, and schedule impact of encountered risks in the chosen projects. The responders were asked to describe the encountered risks in more detail and then rate the relative importance, cost impact, and schedule impact.

Relative importance (RI) of each risk measures how the evaluated risk is critical to the occurrence and severity of other risks and the project objectives. The responder is asked to rate the criticality level of each encountered and identified risk on a scale from 1 to 5, with 1 representing very low importance and 5 representing very high importance with regard to how critical this risk is on other assessed risks in the chosen project. The severity of cost impact (CI) of each risk was assessed on a scale from 1 to 3, with 1 representing low impact on cost growth and 3 representing high impact on cost growth. The severity of schedule impact (SI) of each risk was assessed on a scale from 1 to 3, with 1 representing low impact and 3 representing high impact on schedule growth.

As has been mentioned before, the responder is asked to rate the different risk drivers for the chosen project. In this study the risk rating represents the uncertainty level of risk driver's impact on total project cost growth and total project schedule growth. The different assessment levels depend on responders' perceptions of how much these risk drivers contributed to changes in project performance measures. The rating data carries some uncertainty and subjectivity of responder's perception based on his/her previous experiences. In addition to the pre-defined construction risks in the survey, the responder has the opportunity to add any other risks, which are not listed in the survey but was encountered in the project responder was involved with. The responder was also asked to assess relative importance, cost impact, and schedule impact of these non-listed risks.

For this study purposes, the probability or occurrence rate of each risk is assumed to be either 1 (100%) or zero (0%). For each chosen project, if the responder gives any rating for a risk with respect to its relative importance, cost impact or schedule impact, it is considered as being encountered in the project, and hence its probability is taken as 1 (or 100%). If no ratings are provided for a risk, then it was assumed that it was not encountered in the project, and hence its probability is taken as zero (or 0%).

3.4. Hypotheses

A set of hypotheses was formulated for this research in Step VII. These hypotheses are mentioned and outlined in this chapter. These hypotheses were evaluated through different statistical analysis techniques by using SAS® statistical program in Step IX and the evaluations are discussed in Chapters 4, 6, and 7. The discussion of results from such evaluations led to several findings and formed the bases for conclusions and recommendations provided in this study, which was part of Steps XI and XII.

Twenty six initial hypotheses were the main focus of statistical analyses. Attempts were made to analyze the different significant correlations between specific project related characteristics, project cost growth, project schedule growth, owner's contingency amount/percentage, contractor's contingency amount/percentage, and the encountered construction risks. In an effort to minimize the bias of subjective risk rating data from the survey, other quantitative data about the project total cost, duration and contingency were used to develop meaningful findings about the impact of risk on highway construction projects. The main hypotheses were developed based on what was considered to be of significant interest from literature review, relevance to construction industry, and personal curiosity to better understand the different attributes affecting project performance effectiveness. These hypotheses were tested using Chi-Square, likelihood ratio Chi-Square, and Fisher's exact tests. The individual hypotheses are identified and explained in following sub-sections.

3.4.1. Using Risk Assessment

Risk assessment is playing a big role in understanding the different project risks as was evident from the literature review. It is important to investigate whether organizations are actually using any form of risk assessment in their highway construction projects, and if they understand the importance of using risk assessment in their highway construction projects. A related research need is to understand if there is any correlation between using risk assessment in a specific project and the different characteristics of the project. The following hypotheses have been developed to test these initial research needs or questions, and to compare the different perception and practices among the public and private organizations.

Hypothesis 1: Type of organization and the use of risk assessment in highway construction projects.

H_0: There is no dependency correlation between type of organization and the use of risk assessment in highway construction projects.

H_a: There is dependency correlation between type of organization and the use of risk assessment in highway construction projects.

There is a debate among the transportation professionals whether public and/or private organizations are investing their resources adequately in risk assessment process. There is also a perception that public sector is more concerned and willing to use risk assessment in their construction program, perhaps more than the private sector, in order to become more accountable regarding using the tax payer's money and realizing the best value. Hence, it is important to test this hypothesis about dependency correlation between use of risk assessment and types of organizations in their construction program to understand if there are differences in perceptions and practices.

Hypothesis 2: Type of organization and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between type of organization and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between type of organization and the use of risk assessment in the chosen highway construction project.

This hypothesis is intended to answer the research question as to how prevalent the use of risk assessment is by different type of organizations in individual chosen projects. A related interest is to know if there are significant differences in perception and practices between public and private organizations at project level. These differences could pose certain challenges as we transition from projects with DBB project delivery method to those with DB project delivery method, particularly related to risk allocation and management.

Hypothesis 3: Project delivery method and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between project delivery method and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between project delivery method and the use of risk assessment in the chosen highway construction project.

The interest in this hypothesis is tied to hypothesis 2 as there is interest in industry to know if use of risk assessment and management more prevalent in DBB or DB project delivery method.

Hypothesis 4: Total planned project cost and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between total planned project cost and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total planned project cost and the use of risk assessment in the chosen highway construction project.

The relevance and importance of this hypothesis comes from the argument that only large project uses risk assessment because only when the project size and scale reaches a certain level there is adverse impact on project performance and there are resources available to conduct risk assessment. In addition, large scale projects are more prone to risks.

Hypothesis 5: Total planned project duration and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between total planned project duration and the use of risk assessment in the chosen highway project.

H_a: There is dependency correlation between total planned project duration and the use of risk assessment in the chosen highway project.

The importance of this hypothesis comes from the argument that if the project is subjected to a tight schedule, it is very important to conduct risk assessment to prevent any risks and resulting consequence which might delay project completion. So the research interest is if the total planned duration is small is there more use of risk assessment for the project.

3.4.2. Ratings of Cost Impact and Schedule Impact and the Use of Risk Assessment

As project is in planning phase, a team of professionals explore the type and number of risks a project may encounter. In addition, the team may assess the level of cost and schedule impact for those risks, based on past experience or some quantitative analyses, including simulation. The hypotheses 6 and 7 are related to that need of having a risk assessment and management process in place given the cost and schedule impact related to different risks. Hence, there is interest in knowing if there is a dependency correlation between cost impact or schedule impact and the use of risk assessment in chosen projects.

Hypothesis 6: Rating for Cost Impact (CI) and the use of risk assessment in the chosen highway project.

H_0: There is no dependency correlation between CI and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between CI and the use of risk assessment in the chosen highway construction project.

Hypothesis 7: Rating for Schedule Impact (SI) and the use of risk assessment in the chosen highway project.

H_0: There is no dependency correlation between SI and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between SI and the use of risk assessment in the chosen highway construction project.

3.4.3. Cost Growth

Cost growth (CG) is usually expressed as follows:

$$CG = \frac{(FC - TPC)}{TPC} \times 100 \qquad 3.1$$

CG = Cost Growth

TPC = Total Planned Construction Cost

FC = Final Total Construction Cost

In the cost growth question, the survey provided 11 levels of cost growth percentage ranges to choose from. Analyses were carried out to test cost growth levels for the chosen projects against the projects' characteristics and risk rating data to evaluate if there was any correlation dependency. The prediction models of cost growth (CG) were also tested, to see if the independent variables (project's characteristics and risk ratings) could help predict CG. Hypotheses 8 to 16 were formulated to test the dependency correlations related to CG.

Hypothesis 8: Total cost growth and project type for highway construction projects.

H_0: There is no dependency correlation between total cost growth and project type for highway construction projects.

H_a: There is dependency correlation between total cost growth and project type for highway construction projects.

Project types, as shown in the survey (see Appendix B), include: New road construction or expansion (PT-1), road rehabilitation or reconstruction (PT-2), bridge or tunnel (PT-3), intelligent traffic systems (PT-4), and complex projects (PT-5). There is some perception and related arguments that CG is more in complex projects than in any other types. Complex projects tend to have more uncertainties related context, design, and construction. This hypothesis helps test the dependency correlation of cost growth with different project types.

Hypothesis 9: Total cost growth and project delivery method for highway construction projects.

H_0: There is no dependency correlation between total cost growth and project delivery method for highway construction projects.

H_a: There is dependency correlation between total cost growth and project delivery method for highway construction projects.

Project delivery methods considered in this research include: Design Bid Build (DBB), Design Build (DB), and others. Others included some that were reported by responders when they filled the survey. Some professionals argue that DB project delivery method reduces the CG. This hypothesis tests this correlation dependency between total cost growth and different project delivery methods.

Hypothesis 10: Total cost growth and total planned cost for highway construction projects.

H_0: There is no dependency correlation between total cost growth and total planned cost for highway construction projects.

H_a: There is dependency correlation between total cost growth and total planned cost for highway construction projects.

Here the premise is that total planned cost may have a bearing on what the total cost growth may result in highway construction projects. The relevance and importance of this hypothesis comes from the argument that some transportation professionals have found that small-size project are more prone to cost growth, while others believe the contrary.

Hypothesis 11: Total cost growth and total planned duration for highway construction projects.

H_0: There is no dependency correlation between total cost growth and total planned duration for highway construction project.

H_a: There is dependency correlation between total cost growth and total planned duration for highway construction project.

The relevance and importance of this hypothesis comes from the argument that whenever the project has tight schedule, the project would be subjected to cost growth. To avoid cost growth, it is important to have a realistic schedule and budget.

Hypothesis 12: Total cost growth and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between total cost growth and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and the use of risk assessment in the chosen highway construction project.

This hypothesis tests the correlation between the use of risk assessment and its impact on CG reduction. Some argue that use of risk assessment reduce CG.

Hypothesis 13: Total cost growth and total schedule growth in the chosen highway construction project.

H_o: There is no dependency correlation between total cost growth and schedule growth in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and schedule growth in the chosen highway construction project.

This hypothesis is intended to answer the research question if increased in schedule growth results in increase cost growth. In other words, is there any dependency correlation between total cost growth and total schedule growth?

Hypothesis 14: Total cost growth and owner's contingency amount in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and owner's contingency amount in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and owner's contingency amount in the chosen highway construction project.

The relevance and importance of this hypothesis comes from the premise that the higher the contingency amount the owner assigns to the chosen project the lower would be CG of the project. If the consequences are reversed then there is potential for considerable amount of underutilization of resources, which could have been used elsewhere for other productive uses.

Hypothesis 15: Total cost growth and contractor's contingency amount in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and contractor's contingency amount in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and contractor's contingency amount in the chosen highway construction project

The relevance and importance of this hypothesis comes from the premise that the higher the contractor's contingency amount for the chosen project the lower would be CG of the project. If reverse were true then the amount of contingency dollar tied up in a project could be higher than was needed and that would be unproductive.

Hypothesis 16: Total cost growth and ratings for relative importance (RI), cost impact (CI), and schedule impact (SI) for risks in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and ratings for RI, CI, and/or SI for any of the 31 risks in highway construction projects.

H_a: There is dependency correlation between total cost growth and ratings for RI, CI, and/or SI for some of the 31 risks in highway construction projects.

The relevance and importance of this hypothesis comes from the intuitive understanding that the higher the risk rating related to the 31 risk drivers the higher the CG will be for the chosen project. It is also important to understand which risks are more significant in their impact on project's cost growth.

3.4.4. Schedule Growth

Schedule growth is usually expressed as follows:

$$SG = \frac{(FD - TPD)}{TPD} \text{ X } 100 \qquad 3.2$$

SG = Schedule Growth

TPD = Total Planned Construction Duration

FD = Final Duration

In the schedule growth question, the survey provided 11 levels of schedule growth percentage ranges to choose from. Analyses were carried out to test schedule growth levels for the chosen projects against the projects' characteristics and risk rating data to evaluate if there was any correlation dependency. The prediction models of total schedule growth (SG) were also tested, to see if the independent variables (project's characteristics and risk ratings) could predict total schedule growth. Hypotheses 17 to 24 were formulated to test the dependency correlations related to total schedule growth.

Hypothesis 17: Total schedule growth and project type for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and project type for highway construction projects.

H_a: There is dependency correlation between total schedule growth and project type for highway construction projects.

There is some perception and related arguments that SG is more in complex projects than in any other types of projects. This hypothesis helps test the correlation dependency of schedule growth with different project types.

Hypothesis 18: Total schedule growth and project delivery method for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and project delivery method for highway construction projects.

H_a: There is dependency correlation between total schedule growth and project delivery method for highway construction projects.

Does project delivery method affect project schedule growth is of interest to the construction industry. The importance of this hypothesis is that some professionals argue that DB project delivery reduces the SG of highway construction duration. This hypothesis tests this correlation dependency.

Hypothesis 19: Total schedule growth and total planned cost for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and total planned cost for highway construction projects.

H_a: There is dependency correlation between total schedule growth and total planned cost for highway construction projects.

The importance of this hypothesis comes from the argument of that only small size project are subjected to SG, which could be the case if the schedule delays were primarily related to weather. On the other hand complex projects may have several conditions which are not well known and could impose delays when those unknown conditions do occur.

Hypothesis 20: Total schedule growth and total planned duration for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and total planned duration for highway construction project.

H_a: There is dependency correlation between total schedule growth and total planned duration for highway construction project.

The importance of this hypothesis comes from the argument of that whenever the project has tight schedule, the project would be subjected to SG, and to reduce SG the project total duration should be increased or more realistically estimated with better project schedules.

Hypothesis 21: Total schedule growth and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between total schedule growth and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total schedule growth and the use of risk assessment in the chosen highway construction project.

This hypothesis attempts to answer if use of risk assessment allows one to avoid or mitigate the impact of risks on schedule, and thus prevent SG. This hypothesis tests the correlation between the use of risk assessment and its impact on SG reduction. Some professionals support the use of risk assessment to reduce SG.

Hypothesis 22: Total schedule growth and owner's contingency amount in the chosen highway construction project.

H_0: There is no dependency correlation between total schedule growth and owner's contingency amount in the chosen highway construction project.

H_a: There is dependency correlation between total schedule growth and owner's contingency amount in the chosen highway construction project.

The importance of this hypothesis comes from the argument of that if the owner assigns more contingency to the chosen project then one can accelerate certain activities after encountering delays, and as a result end up with a lower SG in the project than would have been possible otherwise.

Hypothesis 23: Total schedule growth and contractor's contingency amount in the chosen highway construction project.

H_o: There is no dependency correlation between total schedule growth and contractor's contingency amount in the chosen highway construction project.

H_a: There is dependency correlation between total schedule growth and contractor's contingency amount in the chosen highway construction project.

This hypothesis follows the same argument and basis as hypothesis 22, but contractor's contingency percentage would be considered instead of owner's contingency.

Hypothesis 24: Total schedule growth and ratings for relative importance (RI), cost impact (CI), and schedule impact (SI) for risks in the chosen highway construction project.

H_o: There is no dependency correlation between total schedule growth and ratings for RI, CI, and/or SI for any of the 31 risks in highway construction projects.

H_a: There is dependency correlation between total schedule growth and ratings for RI, CI, and/or SI for some of the 31 risks in highway construction projects.

The importance of this hypothesis comes from the premise that the higher risk ratings of 31 risks the higher total schedule growth the chosen project would have. It is also important to test the significance of impact of all risks on project's schedule growth.

3.4.5. Owner's Contingency

Several considerations are taken into account when deciding on a contingency amount by an owner. Among the considerations are total planned cost, total planned duration, and existence of risks. If the budget or schedule is tight it may create conditions where both cost and time overruns may occur. Similarly, existence of potential risks can impact too. The owner may consider increasing owner contingency if the project had risks that had more severe impact on cost and schedule of a project and also had high relative importance. However, this if this is the case in current practice is not clear.

Hypothesis 25: Owner's contingency amount and rating of RI, CI, and SI of different risks for the chosen highway project.

H_o: There is no dependency correlation between owner's contingency amount and ratings of RI, CI, and/or SI for any of the 31 risks for the chosen highway project.

H_a: There is dependency correlation between owner's contingency amount and ratings of RI, CI, and/or SI for some of the 31 risks for the chosen highway project.

The importance of this hypothesis comes from the argument that to manage the different high risk rating of risk drivers the owner should assign larger contingency percentage to the project cost.

3.4.6. Contractor's Contingency

Several considerations are taken into account when deciding on a contingency amount by a contractor. Among the considerations are total planned cost, total planned duration, what other projects the contractor is involved in, and existence of risks. If the budget or schedule is tight it may create conditions where both cost and time overruns may occur. If contractor is working on several projects then there might not be enough resources to put in for contingency. Similarly, existence of potential risks can impact too. The owner may consider increasing owner contingency if the project had risks that had more severe impact on cost and schedule of a project and also had high relative importance. However, this if this is the case in current practice is not clear.

Hypothesis 26: Contractor's contingency amount and rating of RI, CI, and SI of different risks for the chosen highway project.

H_0: There is no dependency correlation between contractor's contingency amount and ratings of RI, CI, and/or SI for any of the 31 risks for the chosen highway project.

H_a: There is dependency correlation between owner's contingency amount and ratings of RI, CI, and/or SI for some of the 31 risks for the chosen highway project.

The importance of this hypothesis comes from the argument that to manage the different high risk rating of risk drivers the contractor should assign larger contingency percentage to the project cost.

3.5. Analyses

Several qualitative and quantitative analyses were carried out as part of Steps VIII to X. Demographic data provided in the survey responses were collated, sorted, organized to identify the nature of responders and their responses and to understand if there were any differences or common trends, which might be useful highlight. After analysis of risk data, critical risks were identified and ranked. Numerous hypothesis testing were carried out to evaluate dependency correlations. In addition, regression was used to identify the influencing project characteristics and risk data that impact cost growth percentage, schedule growth percentage, and contingency percentages.

3.5.1. Sorting the Results

The demographic data about different organizations and responders were analyzed and are discussed in Chapter 4. The frequency tables were developed to understand the common characteristics of highway construction projects in the US. This also helped in identifying and reducing the number of independent variables that impact project cost and time performance measures. In addition, analysis of demographic data helped develop better understanding of the nature of construction risks and what project attributes have more influence on project risk rating and in turn on project cost and time performance. Mean, standard deviation, maximum, mode, and minimum values of ratings for relative importance, cost impact, and schedule impact for different risk drivers were calculated. The pre-defined risks in the survey and the new risks identified by survey respondents were also sorted. These parameters were used to rank the significant risks for different types of projects.

3.5.2. Risk Ranking

Another interest in this research was to determine critical risks and rank them. This was carried out as part of Step VIII, which dealt with analyses of survey responses. For the purpose of ranking risks with the regard to its relative importance, cost impact, or schedule impact, the study used mean and mode as the main parameters, which helped rank the most significant risks encountered in the chosen projects based on responder's perceptions. The main purpose of risk ranking was to identify the most significant risk which had the largest impact on project performance. This was done using the risk rating results by using the mean of responses for each risk driver with respect to relative importance, cost impact, and schedule impact, and then sort them starting from the highest to the lowest value. After ranking using the mean, the study also looked at the mode as the second step to identify the most significant risk among the highest mean values. At the end of this process, the study determined up to five critical risks for each type of project. Type of project represents the context of any specific project and these contexts have a bearing on which risks become more important to control and manage. The risk ranking effort by project type helps and guides construction industry and professionals focus on the identified critical risks and pay attention to controlling and managing them in future planning for these types of projects.

3.5.3. Defining Models Indicators

A set of hypotheses was formulated to be evaluated through different statistical analysis techniques by using SAS® statistical program. The findings were drawn from results and discussion of results, which in turn formed the bases for the conclusions and recommendations of the research.

The assumptions made in the statistical analyses are as follows:

1) Chi-square and likelihood ratio chi-square (LR) statistic tests were used in assessing goodness-of-fit independence in contingency tables. Since all variables are categorical, according to most questions in the survey, the independence of two categorical variables were used in the analyses in this study.

2) Chi-square test has been used to test the null hypothesis, which was that there was no dependency between the categorical variables.

3) In the case when the count in a cell of a contingency table was less than 5, the LR chi-square test was more appropriate. Ozdemir and Eyduran (2005) proposed the power of test as a tool to choose which one is better. Fisher (1970) proposed exact test whenever the expected values are less than 1 in the contingency table and there are small samples. Fisher test was been used in the study to test the frequencies extreme values have among the different cells. All the three tests were used to support the analysis of dependency correlation in this study.

4) Alpha (α) = 0.05 has been used in most tests as a conservative approach, but α = 0.10 has been used in few tests for the purpose of highlighting the observed dependency correlation at this level.

The contingency amount/percentage was regressed as dependent variable against ratings of relative importance (RI), cost impact (CI), and schedule impact (SI) for different risk drivers. The correlation dependency and prediction capability were statistically analyzed. The main goal of developing correlation dependency models was identify the most significant contributors among the ratings of relative importance, cost impact, schedule impact of different risk drivers that have perceptible impact on project performance measures of time and cost, and contingency values. The analyses and discussion of related results also help improve the understanding of project construction performance and management of highway construction projects.

3.6. Summary

The survey results were analyzed in numerous ways to identify and rank significant construction risk drivers, to test twenty six hypotheses of dependency correlations among qualitative and quantitative data related to project characteristics, ratings of relative importance (RI), cost impact (CI), schedule impact (SI) for different risk drivers, project performance measures of cost growth and schedule growth, and project contingency. In addition, regression modeling using risk rating data was done to predict the impact on owner's and contractor's contingency percentages. All these analyses have provided useful insights that can be helpful in better understanding risk assessment, impact of risks on project performance, and use of contingency values for highway construction projects.

CHAPTER 4. ANALYSIS OF SURVEY RESPONSE

This chapter presents some of the analyses of survey responses. Some additional details of survey and the conduct of survey are also discussed in this chapter. The type and number of responses, the analyses of the descriptive data, and the related results have been provided in this chapter as well. In addition, the dependency correlations of relationships relevant to the first seven hypotheses (mentioned in Chapter 3) have been tested and the results related to those have been presented in this chapter. Furthermore, the trends and insights related to highway construction projects and the considerations of 31 risk drivers are highlighted through analysis and documentation and discussion of results.

4.1. Responses and Response Rate

The study conducted the survey online to collect the required information for meaningful analysis about the impact of risk on cost and time performance in highway construction projects. About 660 email messages were sent to transportation professionals in both the public and private sectors in May, 2009, and the survey remained open for 6 months till November, 2009. The messages to take the survey went to transportation professionals at Federal Highway Administration, State DOTs, other public agencies, A/E Consultants, Design Firms, Contractors, and Subcontractors. Total number of responses received was 246 (about 37 % of all emails sent), some of which contained responses for more than one project. Out of these responses, 98 responses ((about 40 % of all responses received) had Part I of the survey fully completed, but had partially completed Part II and Part III of the survey. The number of responses that fully completed all parts of the survey was 48 (about 20 % of all responses received). For testing any parameter, only responses that reported an observation for that parameter were considered.

It was very challenging to get highway construction related professionals to complete this survey. First, it was the first time in a decade that such a survey about rating relative importance, cost impact, and schedule impact of construction risks in highway projects was being conducted. Second, most of the highway construction related professionals were busy at the time of the year the survey was sent out; they were working on fast-track projects associated with the federal government stimulus package. Third, providing ratings for relative importance, cost impact, and schedule impact for 31 risk drivers requires more in-depth examination, reflection, and time than would be necessary to get other project characteristics data such as location, extent, cost, or duration. Highway construction related professionals found it hard to allocate the time needed. As a result, many did not go beyond Part I of the survey. Despite data challenges, a meaningful set of important data was obtained, several analyses were conducted, and numerous insights were obtained that could be useful for consideration of risks in highway construction projects.

4.2. Descriptive Statistics

Descriptive statistics have been provided in this chapter in form of frequency tables for responses to different questions in three parts of the survey. The insights that these frequency tables provide are also discussed.

4.2.1. Survey – Part I

There were six questions in Part I of the survey pertaining to responders and related to their job title, organization location, type of organization, years of experience in risk analysis, perception related to the importance of risk management in cost and time performance of highway project, and the frequency of use of risk analysis within their organization. The responders' organizational location was spread over the entire nation. The Census delineates the U.S. into four regions as Northeast (Region 1), Midwest (Region 2), West (Region 3), and South (Region 4). The frequencies of organizational location of responders in the Census delineated regions are shown in Figure 4.1 and Table 4.1, with majority responders working for organizations located in South (Region 4).

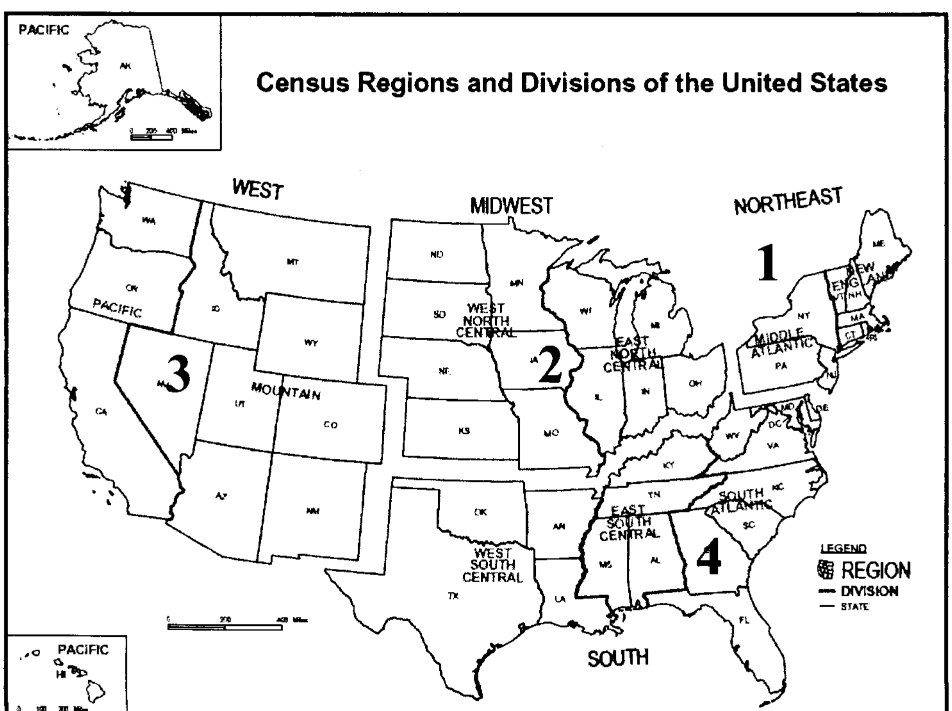


Figure 4.1. Census Regions and Division of the United States

Table 4.1. Frequencies of Locations of Responders

Regions	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1-North East	13	13.27	13	13.27
2-Midwest	23	23.47	36	36.73
3-West	22	22.45	58	59.18
4-South	40	40.82	98	100.00

The responders, with technical or management background, were owners, federal or state transportation agency managers, designers, consultants, engineers, or project managers. Type of organization that the responders worked for included both public and private sector organizations. Among the public sector organizations were state DOTs, toll authorities, and other public agencies. All responses pertaining to other public agencies came from those working for FHWA. Among the private sector organizations were A/E consultants, design firms, contractors and subcontractors, and others. Table 4.2 indicates the frequency of responses from public and private sectors.

Table 4.2. Frequencies of Types of Organization

Organization Type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Public Sector	33	33.67	33	33.67
Private Sector	65	66.33	98	100.00

Responders also provided answers related to use of risk assessment in highway construction projects. Regarding the use of risk assessment in projects, about 51% of the responders used it in some projects and 36% of the responders used in all their projects (see Table 4.3). While 30% of the responders had less than 10 years of experience, 70% of the responders had more than 10 years of experience, which was quiet promising and gave credence to the data obtained from responses to the survey regarding risks in highway construction projects. Appendix C provides detailed frequency tables related to the experience in use of risk assessment. However, the responses regarding experience did not have additional information regarding the tools and techniques used for risk assessment, and whether use of risk assessment had been effective and successful. Some of these insights were better obtained from analysis of responses in Parts II and III of the survey, which are discussed later.

Table 4.3. Frequencies of Use of Risk Assessment in Chosen Projects

Using risk assessment	Frequency	Percent	Cumulative Frequency	Cumulative Percent
None	13	13.27	13	13.27
Some	50	51.02	63	64.29
All	35	35.71	98	100.00

Majority of the responders considered that risk management played an important role in cost and time performance of highway construction projects. In fact, about 80% of the responders considered risk management as important, very important, or extremely important for good performance of highway construction projects (see Table 4.4), which is certainly an important recognition of the fact that risk management can lead to project success.

Table 4.4. Importance of Risk Management in Highway Project Performance

Importance of risk management	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Not Important	5	5.10	5	5.10
Fairly Important	15	15.31	20	20.41
Important	18	18.37	38	38.78
Very Important	49	50.00	87	88.78
Extremely Important	11	11.22	98	100.00

4.2.2. Survey – Part II

There were 17 questions in Part II of the survey, and the responder could choose to respond for up to three different projects. Different and separate responses to Parts II and III of the survey were important for each of the chosen project. Part II was about specific characteristics of the chosen projects and is explained more in this section. Part III of the survey was about providing ratings for relative importance, cost impact, and schedule impact for 31 risk drivers, which has been discussed in next section and Chapter 5.

Frequency tables were developed for project location and project type. Table 4.5 presents the frequency of project locations across the census delineated four regions in the U.S., as was discussed earlier. Most of the projects for which responses were received from the survey were from south (Region 4). The five different project types were: new road construction or expansion of existing road (PT-1), rehabilitation or reconstruction of

Table 4.5. Frequencies of Location of Projects

Regions	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1-North East	12	12.24	12	12.24
2-Midwast	23	23.47	35	35.71
3-West	21	21.43	56	57.14
4-South	42	42.86	98	100.00

existing road (PT-2), bridge or tunnel project (PT-3), intelligent transportation systems (ITS) project (PT-4), and complex project (PT-5), which could be a combination of the previous four types of project. These types of project provide information regarding the context of the projects and the risk considerations vary with these varying project types and contexts. Table 4.6 provides the frequency table for different project types in the projects reported in survey responses. The number of responses related to ITS project (PT-4) was very low and also the nature of this type of project is very different from other types. As a result, responses related to ITS project (PT-4) were not used for analysis in this study.

Table 4.6. Frequencies of Project Types

Project type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Road, New Construction/Expansion (PT-1)	33	33.67	33	33.67
Road, Rehabilitation/Reconstruction (PT-2)	19	19.39	52	53.06
Bridge/Tunnel (PT-3)	21	21.43	73	74.49
Complex Project (PT-5)	25	25.51	98	100.00

Information was also collected regarding the highway type, which was categorized as urban or rural. Table 4.7 shows how many of projects in the responses received were in urban and rural areas. Most of the projects were in urban areas. The context, constraints and risks are different in urban and rural areas. Since over 60 percent of the projects were in urban areas much of the understanding developed in this study would be more applicable to urban projects.

Table 4.7. Frequencies of Highway Types

Highway type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Rural	35	36.46	35	36.46
Urban	61	63.54	96	100.00

The projects reported in the survey responses used different project delivery methods. Among different project delivery methods were design-bid-build (DBB), design-build (DB), and others. Other types of project delivery methods included public-private partnerships (PPP), A+B, design sequencing, and modified design-build. Majority of the projects in the survey responses (about 67%) used DBB project delivery method (see Table 4.8).

Table 4.8. Frequencies of Project Delivery Methods

Delivery method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
DBB	65	67.01	65	67.01
DB	23	23.71	88	90.72
Other	9	9.28	97	100.00

The projects reported in the survey responses used different procurement methods. Among the different procurement methods were low bid, alternative bids/design, multi-parameter bidding, best value, and other. Majority of the projects were either procured as low bid (65%) or best value (27%) as shown in Table 4.9.

Table 4.9. Frequencies of Procurement Methods

Procurement Method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Low Bid	63	64.95	63	64.95
Alternative Bid	2	2.06	65	67.01
Multi-Parameter Bidding	3	3.09	68	70.10
Best-value	26	26.80	94	96.91
Other	3	3.09	97	100.00

The projects reported in the survey responses used different payment methods. Among the different payment methods were lump sum, unit price, and other. Majority of the projects were paid as unit price (65%) or lump sum (32%) as shown in Table 4.10.

Table 4.10. Frequencies of Payment Methods

Payment method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Lump Sum	31	32.29	31	32.29
Unit Price	62	64.58	93	96.88
Other	3	3.13	96	100.00

The reported projects in the survey responses were also categorized by total planned cost (TPC) at the time contract was awarded. The TPC of projects were categorized in the following five categories:

1) Category 1 -- Less than 5 million dollars

2) Category 2 -- Between 5 million and less than 20 million dollars

3) Category 3 -- Between 20 million and less than 50 million dollars

4) Category 4 -- Between 50 million and 100 million dollars

5) Category 5 -- Over 100 million dollars

The reported projects in survey responses were well presented in the five categories, with Category 1 having the least (see Table 4.11).

Table 4.11. Frequencies of Total Planned Costs of Projects

Total planned cost (in Millions of Dollars)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
< 5	8	8.42	8	8.42
5-<20	20	21.05	28	29.47
20-<50	25	26.32	53	55.79
50-100	17	17.89	70	73.68
> 100	25	26.32	95	100.00

The information regarding official project start year was also collected and collated. The start years of the projects reported in survey responses were classified in three categories:

1) Category 1 --All projects which started before year 2000.

2) Category 2 --Projects which started between 2000 and 2004

3) Category 3 --Projects which have started between 2005 and 2009

Majority (about 70%) of the reported projects in survey responses started after 2004 (see Table 4.12). Hence, the data and related results pertain to the practice that is current.

Table 4.12. Frequencies of Project Start Years

Project start year	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2005-2009	67	70.53	67	70.53
2000-2004	20	21.05	87	91.58
Before 2000	8	8.42	95	100.00

The reported projects in the survey responses were also categorized by total planned duration (TPD) or schedule at the time contract was awarded. Based on TPD, the projects were categorized in the following five categories:

1) Category 1 -- Less than 6 months,

2) Category 2 -- Between 6 and less than18 months

3) Category 3 -- Between 18 and less than 36 months

4) Category 4 -- Between 36 and 48 months

5) Category 5 -- More than 48 months

Most of the reported projects in the survey responses (44%) had total planned duration (TPD) between 18 and 36 months as shown in Table 4.13.

Table 4.13. Frequencies of Total Planned Durations (TPDs) of Projects

Total planned duration (TPD) (in months)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<6	5	5.21	5	5.21
6-<18	19	19.79	24	25.00
18-<36	42	43.75	66	68.75
36-48	19	19.79	85	88.54
>48	11	11.46	96	100.00

The percentage of owner's contingency has been described in some previous studies as the program contingency used by the planning offices of DOTs. The owner contingency percentages in the projects reported in the survey responses ranged from zero to 25% as shown in Table 4.14. However, for majority of the reported projects in the survey responses, the owner contingency percentage was either 5 or 10%.

Table 4.14. Frequencies of Owner's Contingency Percentages

Contingency percentage	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0-<5%	20	28.99	20	28.99
5-<10%	23	33.33	43	62.32
10-25%	26	37.68	69	100.00

It was also interesting to collate the responses regarding what was covered by owner's contingency. The owner's contingency covered cost changes. The reasons for cost changes or the work activities (or bid items) that were covered by owner's contingency in the projects reported in the survey responses were the following:

1) Additional work and unknowns;

2) Bid item overruns;

3) Contract changes for environmental cleanup;

4) Claims and change orders;

5) Unforeseen environmental mitigation, right-of-way cost increases;

6) Asphalt cement and fuel adjustments;

7) Owner directed changes;

8) Utility relocation;

9) Undefined damages discovered during reconstruction (because of issuing/ incomplete data of road/bridges and state of the art condition, etc);

10) Changes site conditions, additional deterioration of highways/bridges during final design; and

11) Inspection, engineering costs.

Contractor contingency percentages used in the projects reported in survey responses are shown in Table 4.15. However, majority of contractor contingency percentages reported were either 5% or 10%, with 5% used most often. Similar assignment for contingency percentage was observed for owner contingency also, as discussed before. This shows a common trend or practice in assigning contingency percentage. Moreover, often contingency percentages are assigned as predetermined percentage based on experience from previous projects.

Table 4.15. Frequencies of Contractor's Contingency Percentages

Contingency percentage	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0-<5%	28	48.28	28	48.28
5-<10%	17	29.31	45	77.59
10-25%	13	22.41	58	100.00

Contractor's contingency is used for cost changes the contractors face. It was also very insightful to collate information about the activities that involved these cost changes. The reasons for cost changes or the work activities (or bid items) that were covered by contractor's contingency in the projects reported in the survey responses were the following:

1) Escalation, weather-hurricanes, minor owner-directed changes;

2) Quantity variations, permit delay, and design delay;

3) Proprietary information;

4) Materials cost increases, fuel increases, unforeseen environmental mitigation, and acts of nature;

5) All potential risks that are not mitigated by the owner;

6) Design growth, quantity growth, labor availability, and labor cost;

7) Equipment availability, schedule risk, liquidated damages, differing site conditions, force majeure issues, funding availability, difficult owner and owner's representative;

8) Predicted damages;

9) Unforeseen circumstances;

10) The added value for the extended pavement design life;

11) Material/fuel cost increase;

12) Change orders;

13) Workers compensations;

14) Utilities, material escalation, environmental, scheduling complexities; and

15) Minor overruns

One of the highway project performance measures of interest in this study was the percentage of total cost growth (CG) that the chosen project encountered. The cost growth percentages were categorized in 11 categories. There were five categories with negative CG, one category with no or zero CG, and five categories with positive CG (see Table 4.16). Most (42%) of the reported projects in the survey responses had a CG between 0% and 6%. It was also interesting to note that about 34% of the reported projects in the survey responses were constructed on or under budget or had zero or negative CG. Chapter 6 discusses several issues related to cost growth in highway construction projects.

Another highway project performance measure of interest in this study was the percentage of total schedule growth (SG) that the chosen project encountered. The schedule growth percentages were categorized in 11 categories. There were five categories

Table 4.16. Frequencies of Cost Growth (CG) Percentages

Total cost growth percentage	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-14%	4	4.82	4	4.82
-14-<-10%	6	7.23	10	12.05
-10-< -6%	1	1.20	11	13.25
-6-< -3%	5	6.02	16	19.28
-3 -< 0%	6	7.23	22	26.51
0%	6	7.23	28	33.73
>0- < 3%	16	19.28	44	53.01
3 -< 6%	19	22.89	63	75.90
6 -< 10%	5	6.02	68	81.93
10-14%	7	8.43	75	90.36
>14%	8	9.64	83	100.00

with negative SG, one category with no or zero SG, and five categories with positive SG. The frequency table for schedule growth percentages is shown in Table 4.17. Most (41%) of the reported projects in the survey responses had a SG between 0% and 6%. This was in a way a similar trend as was observed for CG percentages. However, it was not clear if there was direct correlation between SG and CG just by looking at the similarity in the two trends. This particular issue is discussed later in this chapter. It was also interesting to note that about 51% of the reported projects in the survey responses were constructed on or under schedule or had zero or negative SG. Chapter 6 discusses several issues related to total schedule growth in highway construction projects.

Table 4.17. Frequencies of Schedule Growth (SG) Percentages

Total schedule growth percentage	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-14%	5	5.95	5	5.95
-14-<-10%	3	3.57	8	9.52
-10-< -6%	2	2.38	10	11.90
-6-< -3%	3	3.57	13	15.48
-3 -< 0%	8	9.52	21	25.00
0%	22	26.19	43	51.19
>0- < 3%	14	16.67	57	67.86
3 -< 6%	12	14.29	69	82.14
6 -< 10%	4	4.76	73	86.90
10-14%	6	7.14	79	94.05
>14%	5	5.95	84	100.00

It was also important to understand the role and involvement of the responders in the chosen project they reported for. The roles in the projects reported in the survey responses are summarized in Table 4.18. The roles were varied and at different levels. Thus, the responses represent variety of perceptions rather than just one perspective.

Information on whether the project team had used risk assessment and analysis in the chosen project was also of interest. Majority (about 62%) of responders indicated that

Table 4.18. Roles of Responders in the Projects Reported

1	Project Manager & Designer	24	Responsible for the Highway Design and Coordination of all Design Efforts.
2	Corridor Mobility Coordinator	25	Construction Manager
3	Oversight	26	Project Manager - TN DOT
4	DB cost consultant	27	Prime contractor to Wisconsin DOT
5	Estimator	28	Senior Manager
6	Project Director	29	Vice president operations
7	Construction administration from a Central Office perspective / change orders	30	Executive PM for General Engineering Consultant
8	State oversight	31	Project principal
9	Advisor	32	Construction cost oversight and analysis
10	Designer on Design-Build Team	33	Construction technical advisor
11	Geotechnical designer	34	Design manager
12	Resident Engineer	35	Highway designer
13	Contract oversight	36	Construction Manager
14	Constructor	37	Owners Programs Management
15	Contract package development	38	VP provided oversight of Project Management team
16	Right of way acquisition and utility relocation	39	Estimating and construction management
17	Managed the Estimate and Proposal	40	Executive
18	Assist in the review of claims at the agency level.	41	Design-Build Coordination Manager
19	Contract Administration	42	VP operations
20	Project Manager	43	Sub contractor
21	Division Manager	44	Project Administrator - CEI
22	Designer of record	45	Residing Engineer
23	Lead Estimator	46	Senior CM/Claims Support

risk assessment and analysis was used in the projects for which they provided the response (see Table 4.19). This is a good trend. In addition, the responses for rating of risks are based on knowledge and experience of people, who used some form of risk assessment and analysis and were directly, involved in highway construction projects. This helps give credence to the perceptions of responders and the quality of data used and analyzed in this study.

Table 4.19. Use of Risk Assessment in Project

Using risk assessment	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes	53	62.35	53	62.35
No	32	37.65	85	100.00

4.2.3. Survey – Part III

The third part of the survey was regarding providing rating for relative importance (RI), cost impact (CI), and schedule impact (SI) for 31 risk drivers (R1 to R31, refer to Table 3.1 in Chapter 3). The responders had the flexibility to add additional risk drivers and provide rating information related to those risks. However, the responders were asked to provide ratings for RI, CI, and SI for a risk driver, only if the risk had been encountered in the chosen project. If these risks were not encountered, the responders were asked to leave it blank and provide no response for ratings. Only two additional risk drivers, R32 and R33, were identified by the responders. All frequency tables for all reported risks are listed in Appendix (C). Since the two additional risk drivers identified had very low number of responses and low rating, they were not analyzed in this study. Risk rating and ranking issues are discussed in more detail in Chapter 5.

4.3. Analyzing Dependency Correlations

The purpose of this section is to highlight the numerous dependency correlations associated with the use of risk assessment (RA), project characteristics, and risk rating data for 31 risk drivers. As was mentioned in Chapter 3, Chi-square, LR Chi-Square, and Fisher exact tests were used to evaluate the correlation dependency between different variables using the in SAS statistical software. The first seven of the 26 initial hypotheses are discussed here to identify some dependency correlations and what are the implications and interpretations of those correlations. The null hypotheses were mostly about no dependency correlations between variables. Fisher exact test was particularly important when the frequency in the cell was very low. Also, alpha (α) value of 0.05 was used typically in all tests. In some tests, alpha (α) value of 0.10 was used for the purpose of highlighting the observed dependency correlation at this level.

The correlation dependency analyses were carried out with three different focuses in mind. The three focused areas of interest were use of risk assessment, project performance measures such as cost growth (CG) and schedule growth (SG), and project contingency. In the first focus, the importance of risk assessment (RA) and its use at the program and project level was of particular interest. It was also important to investigate to what extent different project parties had used RA in the chosen projects. In addition, there was a research need to determine if there was any variation in dependency correlations for different projects and their related characteristics and the use of RA. The correlations related to first focus is discussed in this chapter.

The second focus was on project performance measures such as cost growth (CG) and schedule growth (SG) percentages. Here again, there was a research interest to see if the dependency correlations varied with different types and attributes of project and by different types and attributes of responders. These dependency correlations were used to understand the impact of different construction risks on effectiveness of project construction management. The dependency correlations and related issues for the second focus is detailed, discussed, and documented in Chapter 6.

The third focus was on contingency percentage amount ($C_{owner.}$%/ $C_{cont.}$%), which are assigned by the owner and contractor. The dependency correlations between contingency percentages and rating values for RI, CI, and SI for 31 risk drivers were explored as part of this focus area. These correlations and related hypothesis tests and regression analyses are detailed, discussed, and documented in Chapter 7. The purpose of these tests and analyses was to gain insights on the impact of project characteristics and related risk rating values for RI, CI, and SI for 31 risk drivers on the assignment of contingency amounts and percentages.

4.3.1. Types of Organization and the Use of Risk Assessment in Projects and Program

Types of organization were categorized as public and private sector organizations. Hypothesis 1, identified in Chapter 3 and listed below, is tested to evaluate if the use of risk assessment is different or same in public and private sectors.

Hypothesis 1: Type of organization and the use of risk assessment in highway construction projects.

H_0: There is no dependency correlation between type of organization and the use of risk assessment in highway construction projects.

H_a: There is dependency correlation between type of organization and the use of risk assessment in highway construction projects.

Both chi-square statistics (see Table 4.20) have p-values less than (<) 0.05, which lead to rejection of the null hypothesis. Hence, there is dependency correlation between type of organization and the use of risk assessment (RA) in the chosen projects reported in the survey responses. It appears private sector organizations have been using RA more than public sector. About 46% of private organizations have used RA in all their projects reported in the survey, whereas only 15% of public organizations have done the same. Earlier, it was mentioned that about 50% of total responders had used RA in some projects and 35% in all their projects (see Table 4.3). This leads to conclusion the use of RA as a program strategy is more prevalent and has more commitment among private sector organizations than public sector organizations. This might be due to the reality that private sector is more closely involved with construction activities. However, it is important to emphasize that use of RA as program strategy is also quite important for public sector agencies as there is a need for more accountability regarding how efficiently tax payers money are being used in highway construction projects.

A related dependency correlation of interest was the perception of the two types of organization regarding the importance of risk management for performance of highway construction project. The test statistics indicate that there is not enough evidence to reject the alternative hypothesis and that there is a dependency correlation between organization type and the perception regarding the importance of risk management (see Table 4.21). About 86% of responders from private sector organizations and 67% of responders from public sector organizations believed that risk management was important, very important, or extremely important for performance of highway construction project. It is clear that both sectors consider risk management as important and in all likelihood there will be increased use of risk assessment and analysis in decades to come.

Table 4.20. Type of Organization and the Use of Risk Assessment

Type of organization	Use risk analysis in the project			
Frequency Row Pct Col Pct	None	Some	All	Total
Public Sect.	9 27.27 69.23	19 57.58 38.00	5 15.15 14.29	33
Private Sect.	4 6.15 30.77	31 47.69 62.00	30 46.15 85.71	65
Total	13	50	35	98

Statistic	DF	Value	Probability
Chi-Square	2	13.6686	0.0011
Likelihood Ratio Chi-Square	2	14.0509	0.0009

Table 4.21. Types of Organization and the Importance of Risk Management

Type of organization	Risk management importance			
Frequency Row Pct Col Pct	Not &Fairly Important	Important	Very &Extremely Important	Total
Public Sector	11 33.33 55.00	10 30.30 55.56	12 36.36 20.00	33
Private Sector	9 13.85 45.00	8 12.31 44.44	48 73.85 80.00	65
Total	20	18	60	98

Statistic	DF	Value	Probability
Chi-Square	2	12.9545	0.0015
Likelihood Ratio Chi-Square	2	12.9093	0.0016

4.3.2. Types of Organization and the Use of Risk Assessment in Specific Project

The testing of Hypothesis 2 (mentioned in Chapter 3 and listed below) is more focused on the use of RA in the chosen project reported in survey responses. Thus reflecting on whether it is being used at project level or simply considered at program level. It tests whether the program strategy has been implemented at project level by public and private sectors.

Hypothesis 2: Type of organization and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between type of organization and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between type of organization and the use of risk assessment in the chosen highway construction project.

As shown in Table 4.22 there is dependency correlation between organization type and the use of RA in the chosen project, and there is not enough evidence to reject the alternative hypothesis. About 73% of private sector organizations have used RA in the chosen projects, whereas only about 41% of public sector organizations have done the same. This leads to the interpretation that at both program and project levels risk assessment is used more within private sector organizations than the public sector organizations. This could be explained by highlighting that private sector organizations are more closely and integrally involved with various construction activities of highway projects than public sector organizations are.

Table 4.22. Types of Organization and the Use of Risk Assessment in Project

Type of organization	Risk analysis has been used in the project		
Frequency **Row Pct** **Col Pct**	**Yes**	**No**	**Total**
Public Sect.	12 41.38 22.64	17 58.62 53.13	29
Private Sect.	41 73.21 77.36	15 26.79 46.88	56
Total	53	32	85
Statistic	**DF**	**Value**	**Probability**
Chi-Square	1	8.2487	0.0041
Likelihood Ratio Chi-Square	1	8.1716	0.0043

4.3.3. Project Delivery Methods and the Use of Risk Assessment in Project

As mentioned earlier, the responses were obtained for three types of project delivery methods: design bid build (DBB), design build (DB), and other. However, the analysis was carried out only for DBB and DB project delivery methods. The testing of Hypothesis 3 (mentioned in Chapter 3 and listed below) investigates the significant correlation between the project delivery methods and the use of RA in the chosen projects.

Hypothesis 3: Project delivery method and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between project delivery method and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between project delivery method and the use of risk assessment in the chosen highway construction project.

Test statistics shown in Table 4.23 indicates dependency correlation and there is not enough evidence to reject the alternative hypothesis. About 85% of the projects using DB project delivery method used RA, whereas only 53% of the projects using DBB project delivery method used RA. This indicates that the use of RA is more prevalent, significant and important in projects using DB project delivery method, and could impact the cost and schedule of these projects more significantly than the projects using DBB project delivery method. Fisher's exact test was used here because of low cell counts in certain cells. Fisher exact test also indicated low probability value and provided basis for rejection of the null hypothesis at alpha (α) value of 0.05, which further supports the conclusions from Chi-square test.

4.3.4. Total Planned Project Costs (TPCs) and Use of Risk Assessment in Project

Total planned cost (TPC) of a project describes the size of the project. The testing of Hypothesis 4 was carried out to examine the perception that only large projects should use risk assessment (RA).

Hypothesis 4: Total planned project cost and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between total planned project cost and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total planned project cost and the use of risk assessment in the chosen highway construction project.

Table 4.23. Project Delivery Methods and the Use of Risk Assessment in Project

Using risk assessment	Project Delivery Method			
Frequency Row Pct Col Pct	**DBB**	**DB**	**other**	**Total**
Yes	31 58.49 53.45	17 32.08 85.00	5 9.43 83.33	53
No	27 87.10 46.55	3 9.68 15.00	1 3.23 16.67	31
Total	58	20	6	84

Statistic	DF	Value	Probability
Chi-Square	2	7.4947	0.0236
Likelihood Ratio Chi-Square	2	8.1750	0.0168

Fisher's Exact Test	
Table Probability (P)	0.0019
Pr <= P	0.0177

There is dependency correlation between TPC and the use of RA at alpha (α) value of 0.05 (see Table 4.24). There is not enough evidence to reject the alternative hypothesis. About 77% of responders used RA in projects over 50 million. RA was used in about 61% of medium size projects. Hence, it appears large highway construction projects are more likely to use risk assessment. Large highway construction projects not only have more risks, but the impact of risks is potentially high also. Thus, risk assessment helps control

Table 4.24. Total Planned Cost (TPC) and the Use of Risk Assessment in Project

Using risk assessment	Total planned project cost (TPC)			
Frequency Row Pct Col Pct	< 20 m	20-<50	>=50 m	Total
Yes	11 21.15 42.31	14 26.92 60.87	27 51.92 77.14	52
No	15 46.88 57.69	9 28.13 39.13	8 25.00 22.86	32
Total	26	23	35	84

Statistic	DF	Value	Probability
Chi-Square	2	7.6907	0.0214
Likelihood Ratio Chi-Square	2	7.7978	0.0203

and manages projects better as the project size and scope increases. However, the statistics is indicating RA is quite important for projects with both large and medium TPC.

4.3.5. Total Planned Durations (TPDs) and the Use of Risk Assessment in Project

If the project is subjected to tight schedule, it is very important to conduct RA to deal with and understand any uncertain events or unreasonable duration estimates, which might delay project completion. Also, a shorter duration project may have more likelihood of having schedule growth if unforeseen events take place. The larger duration projects could use floats effectively to manage delays resulting from unforeseen events. Hypothesis 5 (mentioned in Chapter 3 and listed here) was tested to tests these rational for the use of RA based on TPD.

Hypothesis 5: Total planned duration and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between total planned duration and the use of risk assessment in the chosen highway project.

H_a: There is dependency correlation between total planned duration and the use of risk assessment in the chosen highway project.

The results shown in Table 4.25 indicate there is no statistical evidence to accept the alternative hypothesis and that there is dependency correlation between total planned project duration (TPD) and the use of RA in the chosen project. Of the reported projects in survey responses that had total planned duration of 36 months or more, about 36% had conducted RA and 22% had not conducted RA. Also, the projects with long planned duration (more than 18 months) are most likely use RA as construction management tool to enhance cost and schedule performance of highway construction projects. However, based on statistical correlation, the TPD does not seem to impact project team's decision to use risk assessment or not.

4.3.6. Cost Impact Rating (CI) and the Use of Risk Assessment in Project

Cost impact (CI) ratings of risk drivers, reflecting impact on cost growth (CG), had three levels: low, moderate, and high. Hypothesis 6 was tested with the interest of seeing if there were any correlations between ratings of CI for any of the 31 different risk drivers and the use of RA in the chosen project. In other words, there was research interest to explore if rating of CI for a risk driver influenced the use of RA in a project, or if the use of

RA influenced the rating of CI.

Table 4.25. Total Planned Duration (TPD) and the Use of Risk Assessment in Project

Use of risk assessment	**Total planned duration (TPD)**					
Frequency **Row Pct** **Col Pct**	**<6 months**	**6-18**	**18-<36**	**36-48**	**>48 months**	**Total**
Yes	3 5.66 60.00	7 13.21 46.67	24 45.28 61.54	14 26.42 77.78	5 9.43 62.50	53
No	2 6.25 40.00	8 25.00 53.33	15 46.88 38.46	4 12.50 22.22	3 9.38 37.50	32
Total	5	15	39	18	8	85

Statistic	**DF**	**Value**	**Probability**
Chi-Square	4	3.4196	0.4902
Likelihood Ratio Chi-Square	4	3.5107	0.4763

Hypothesis 6: Rating for Cost Impact (CI) and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between rating of CI and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between rating of CI and the use of risk assessment in the chosen highway construction project.

There was not enough evidence to reject the alternative hypothesis. The statistical dependency correlations were found and identified for risk drivers R3, R10, R12, R17, R21, R29, and R30. These dependency correlations are explained further in the following discussions using several tables.

There was dependency correlation between cost impact of risk driver R3, changes to unforeseen site environmental requirements, and the use of RA (see Table 4.26). Based on both the Chi-square tests and Fisher's exact test, there is not enough statistical evidence to reject the alternative hypothesis at alpha (α) value of 0.10. In 46% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R3 (CI-3) was low. On the other hand for 50% of the projects reported in survey responses where RA was not used, the rating of CI-3 was high. Also, for 31% of the projects reported in the survey responses where RA was not used, the rating of CI-3 was low. This might be interpreted to mean that in projects where RA was not used, the rating of the CI-3 and impact on CG was high.

There was dependency correlation between cost impact of risk driver R10, high number of utilities in the site, and the use of RA at alpha (α) value of 0.10 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.27). In 68% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R10 (CI-10) was low. On the other hand for 33% of the projects reported in survey responses where RA was not used, the rating of cost impact of risk driver R10 (CI-10) was high. Also, for 44% of the projects reported in survey responses where RA was not used, the rating of CI-10 was low. This might be interpreted to mean that when the projects did use RA, rating of CI-10 and impact on CG was low. However, when the projects did not use RA, there was no clear pattern of impact on CG due to risk driver R10.

Table 4.26. CI-3 and the Use of Risk Assessment in Project

Using risk assessment		**CI-3**		
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	12 46.15 70.59	10 38.46 76.92	4 15.38 33.33	26
No	5 31.25 29.41	3 18.75 23.08	8 50.00 66.67	16
Total	17	13	12	42

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	5.9407	0.0513
Likelihood Ratio Chi-Square	2	5.9016	0.0523

Fisher's Exact Test	
Table Probability (P)	0.0053
Pr <= P	0.0582

There was dependency correlation between cost impact of risk driver R12, poor engineering practice within the state, and the use of RA at alpha (α) value of 0.05 based on Chi-square and LR Chi-Square tests (see Table 4.28). In 85% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R12 (CI-12) was low. Rating of CI-12 was also low for 63% of the projects reported in survey responses where RA was not used. However, for 31% of the projects reported in survey responses where RA was not used, the rating of CI-12 was high. This means that rating of CI-12 was not impacted by the use of RA for the project and cost impact of risk driver R12 was consistently rated low.

Table 4.27. CI-10 and the Use of Risk Assessment in Project

Using risk assessment	CI-10			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	15 68.18 65.22	6 27.27 60.00	1 4.55 14.29	22
No	8 44.44 34.78	4 22.22 40.00	6 33.33 85.71	18
Total	23	10	7	40

Statistic	DF	Value	Probability
Chi-Square	2	5.7595	0.0561
Likelihood Ratio Chi-Square	2	6.1291	0.0467

Fisher's Exact Test	
Table Probability (P)	0.0064
Pr <= P	0.0654

There was dependency correlation between cost impact of risk driver R17, inadequate constructability reviews, and the use of RA at alpha (α) value of 0.05 based on Chi-square and LR Chi-Square tests (see Table 4.29). In 71% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R17 (CI-17) was low. For 31% of the projects reported in survey responses where RA was not used, the rating of CI-17 was also low. However, for 25% of the projects where RA was not used, the rating of CI-17 was high. This might be interpreted to mean that when the projects did use RA, rating of CI-17 and impact on CG was low. However, when the projects did not use RA, there was no clear pattern for the rating of CI-17 and impact on CG.

Table 4.28. CI-12 and the Use of Risk Assessment in Project

Using risk assessment	CI-12			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	17 85.00 62.96	3 15.00 75.00	0 0.00 0.00	20
No	10 62.50 37.04	1 6.25 25.00	5 31.25 100.00	16
Total	27	4	5	36

Statistic	DF	Value	Probability
Chi-Square	2	7.4625	0.0240
Likelihood Ratio Chi-Square	2	9.3683	0.0092

Fisher's Exact Test	
Table Probability (P)	0.0046
Pr <= P	0.0173

There was dependency correlation between cost impact of risk driver R21, unforeseen hazard conditions, and the use of RA at alpha (α) value of 0.10 based on Chi-square and LR Chi-Square tests (see Table 4.30). In 68% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R21 (CI-21) was low. The rating of CI-21 was also low for 38% of the projects reported in survey responses when RA was not used. However, for 25% of the projects reported in survey responses where RA was not used, the rating of CI-21 was high. This might be interpreted to mean that when the projects did use RA, rating of the CI-21 and impact on CG was low.

However, when the projects did not use RA, there was no clear pattern for the rating of CI-21 and impact on CG.

Table 4.29. CI-17 and the Use of Risk Assessment in Project

Using risk assessment	**CI-17**			
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	15 71.43 75.00	5 23.81 41.67	1 4.76 20.00	21
No	5 31.25 25.00	7 43.75 58.33	4 25.00 80.00	16
Total	20	12	5	37

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	6.5778	0.0373
Likelihood Ratio Chi-Square	2	6.8171	0.0331

Fisher's Exact Test	
Table Probability (P)	0.0048
Pr <= P	0.0362

There was dependency correlation between cost impact of risk driver R29, inexperienced project manager, and the use of RA at alpha (α) value of 0.05 based on Chi-square and LR Chi-Square tests (see Table 4.31). In 87% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R29 (CI-29) was low. Similarly, for 44% of the projects reported in survey responses where RA was not used the rating of CI-29 was low. However, for 25% of the projects reported in survey responses where RA was not used the rating of CI-29 was high. This might be interpreted to mean that when the projects did use RA, rating of CI-29 and impact on CG was low. However, when the projects did not use RA, there was no clear pattern for the rating of CI-29 and the impact on CG.

Table 4.30. CI-21 and the Use of Risk Assessment in Project

Using risk assessment	**CI-21**			
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	13 68.42 68.42	5 26.32 55.56	1 5.26 14.29	19
No	6 37.50 31.58	4 25.00 44.44	6 37.50 85.71	16
Total	19	9	7	35

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	6.0488	0.0486
Likelihood Ratio Chi-Square	2	6.4570	0.0396

Fisher's Exact Test	
Table Probability (P)	0.0059
Pr <= P	0.0604

There was dependency correlation between cost impact of risk driver R30, inexperienced project manager, and the use of RA at alpha (α) value of 0.05 based on Chi-square and LR Chi-Square tests (see Table 4.32). In 90% of the projects reported in survey responses where RA was used, the rating for cost impact of risk driver R30 (CI-30) was low. Similarly, for 44% of the projects reported in survey responses where RA was not used the rating of CI-30 was low. However, for 38% of the projects reported in survey responses where RA was not used, the rating of CI-30 was high. This might be interpreted to mean that when the projects did use RA, rating of CI-30 and impact on CG was low. However, when the projects did not use RA, there was no clear pattern for the rating of CI-30 or the impact on CG.

Table 4.31. CI-29 and the Use of Risk Assessment in Project

Using risk assessment	CI-29			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	20 86.96 74.07	3 13.04 37.50	0 0.00 0.00	23
No	7 43.75 25.93	5 31.25 62.50	4 25.00 100.00	16
Total	27	8	4	39

Statistic	DF	Value	Probability
Chi-Square	2	9.8192	0.0074
Likelihood Ratio Chi-Square	2	11.3141	0.0035

Fisher's Exact Test	
Table Probability (P)	0.0013
Pr <= P	0.0049

4.3.7. Schedule Impact Rating (SI) and the Use of Risk Assessment in Project

Schedule impact (SI) ratings of risk drivers, reflecting impact on schedule growth

(SG), had three levels: low, moderate, and high. There was research interest in knowing if rating of SI for a risk driver influenced the use of RA in a project, or if the use of RA influenced the rating of SI. Hypothesis 7, mentioned in Chapter 3 and listed here, was tested to determine if there were any correlations between ratings of SI for any of the 31 different risk drivers and the use of RA in the projects reported in the survey responses.

Table 4.32. CI-30 and the Use of Risk Assessment in Project

Using risk assessment	**CI-30**			
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	19 90.48 73.08	1 4.76 25.00	1 4.76 14.29	21
No	7 43.75 26.92	3 18.75 75.00	6 37.50 85.71	16
Total	26	4	7	37

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	9.6097	0.0082
Likelihood Ratio Chi-Square	2	10.0852	0.0065

Fisher's Exact Test	
Table Probability (P)	0.0014
Pr <= P	0.0049

Hypothesis 7: Rating for Schedule Impact (SI) and the use of risk assessment in the chosen highway construction project.

H_o: There is no dependency correlation between SI and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between SI and the use of risk assessment in the chosen highway construction project.

There is no significant evidence to reject the alternative hypothesis. The statistical dependency correlations have been identified for risk drivers R3, R10, R12, R15, R21, R29, and R30 (refer to Table 3.1 for details regarding these risk drivers) and are discussed in following discussions using several tables.

There was dependency correlation between schedule impact of risk driver R3, changes to unforeseen site environmental requirements, and the use of RA at alpha (α) value of 0.05 based on Chi-square and LR Chi-Square tests (see Table 4.33). In 46% of the projects reported in the survey responses where RA was used, the rating for schedule impact of risk driver R3 (SI-3) was low. On the other hand for 63% of the projects reported in survey responses where RA was not used, the rating of SI-3 was high. Also, for 38% of the projects reported in survey responses where RA was not used, the rating of SI-3 was low. This might be interpreted to mean that when the projects did use RA, rating of the SI-3 and impact on SG was low. However, when the projects did not use RA, rating of the SI-3 and impact on SG was high.

There was dependency correlation between schedule impact of risk driver R10, high number of utilities in the site, and the use of RA at alpha (α) value of 0.10 based on Chi-square and LR Chi-Square tests (see Table 4.34). In 62% of the projects reported in the survey responses where RA was used, the rating for schedule impact of risk driver R10 (SI-

10) was low. On the other hand for 45% of the projects reported in survey responses where RA was not used, the rating of SI-10 was high. Also, for 39% of the projects reported in survey responses where RA was not used, the rating of SI-10 was low. This might be interpreted to mean that when the projects did use RA, rating of the SI-10 and impact on

Table 4.33. SI -3 and the Use of Risk Assessment in Project

Using risk assessment	SI-3			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	12 46.15 66.67	7 26.92 100.00	7 26.92 41.18	26
No	6 37.50 33.33	0 0.00 0.00	10 62.50 58.82	16
Total	18	7	17	42

Statistic	DF	Value	Probability
Chi-Square	2	7.5781	0.0226
Likelihood Ratio Chi-Square	2	9.8711	0.0072

Fisher's Exact Test	
Table Probability (P)	0.0022
Pr <= P	0.0194

SG was low. However, when the projects did not use RA, there was no clear pattern for rating of the SI-10 or impact on SG.

There was dependency correlation between schedule impact of risk driver R12, poor engineering practice within the state, and the use of RA at alpha (α) value of 0.05 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.35). In 90% of the projects reported in the survey responses where RA was used, the rating for schedule

Table 4.34. SI-10 and the Use of Risk Assessment in Project

Using risk assessment	SI-10			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	13 61.90 65.00	6 28.57 66.67	2 9.52 20.00	21
No	7 38.89 35.00	3 16.67 33.33	8 44.44 80.00	18
Total	20	9	10	39

Statistic	DF	Value	Probability
Chi-Square	2	6.2060	0.0449
Likelihood Ratio Chi-Square	2	6.4713	0.0393

Fisher's Exact Test	
Table Probability (P)	0.0047
Pr <= P	0.0562

impact of risk driver R12 (SI-12) was low. Similarly, 45% of the projects reported in survey responses where RA was not used, the rating of SI-12 was low. Also, for 25% of the projects reported in survey responses where RA was not used, the rating of SI-12 was high. This means that in both projects where RA was used and in projects where RA was not used, there was consistency and the rating for SI-12 and impact on SG was low.

There was dependency correlation between schedule impact of risk driver R15, inexperienced professionals for this type of project, and the use of RA at alpha (α) value of 0.05 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.36). In 85% of the projects reported in the survey responses where RA was used, the rating for

Table 4.35. SI-12 and the Use of Risk Assessment in Project

Using risk assessment	SI-12			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	18 90.00 66.67	2 10.00 40.00	0 0.00 0.00	20
No	9 56.25 33.33	3 18.75 60.00	4 25.00 100.00	16
Total	27	5	4	36

Statistic	DF	Value	Probability
Chi-Square	2	6.8400	0.0327
Likelihood Ratio Chi-Square	2	8.3594	0.0153

Fisher's Exact Test	
Table Probability (P)	0.0064
Pr <= P	0.0237

schedule impact of risk driver R15 (SI-15) was low. Similarly, 50% of the projects reported in survey responses where RA was not used, the rating of SI-15 was low. Also, for 19% of the projects reported in survey responses where RA was not used, the rating of SI-15 was high. This means that in both projects where RA was used and in projects where RA was not used, there was consistency and the rating for SI-15 and impact on SG was low.

There was dependency correlation between schedule impact of risk driver R21, unforeseen hazard conditions, and the use of RA at alpha (α) value of 0.05 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.37). In 75% of the projects reported in the survey responses where RA was used, the rating for schedule impact of risk

Table 4.36. SI-15 and the Use of Risk Assessment in Project

Using risk assessment	SI-15			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	17 85.00 68.00	3 15.00 37.50	0 0.00 0.00	20
No	8 50.00 32.00	5 31.25 62.50	3 18.75 100.00	16
Total	25	8	3	36

Statistic	DF	Value	Probability
Chi-Square	2	6.3743	0.0413
Likelihood Ratio Chi-Square	2	7.5327	0.0231

Fisher's Exact Test	
Table Probability (P)	0.0083
Pr <= P	0.0316

driver R21 (SI-21) was low. However, 38% of the projects reported in survey responses where RA was not used, the rating of SI-21 was low. Also, for 38% of the projects reported in survey responses where RA was not used, the rating of SI-21 was high. This might be interpreted to mean that when the projects did use RA, rating of the SI-21 and impact on

SG was low. However, when the projects did not use RA, there was no clear pattern for rating of the SI-21 or impact on SG.

There was dependency correlation between schedule impact of risk driver R29, inexperienced project manager, and the use of RA at alpha (α) value of 0.05 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.38). In 87% of the projects

Table 4.37. SI-21 and the Use of Risk Assessment in Project

Using risk assessment	**SI-21**			
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	15 75.00 71.43	4 20.00 50.00	1 5.00 14.29	20
No	6 37.50 28.57	4 25.00 50.00	6 37.50 85.71	16
Total	21	8	7	36

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	7.0714	0.0291
Likelihood Ratio Chi-Square	2	7.5019	0.0235

Fisher's Exact Test	
Table Probability (P)	0.0036
Pr <= P	0.0321

reported in the survey responses where RA was used, the rating for schedule impact of risk driver R29 (SI-29) was low. Similarly, 44% of the projects reported in survey responses where RA was not used, the rating of SI-29 was low. Also, for 25% of the projects reported in survey responses where RA was interpreted to mean that when the projects did use RA, rating of the SI-29 and impact on SG was low. However, when the projects did not use RA, there was no clear pattern for rating of the SI-29 or impact on SG.

There was dependency correlation between schedule impact of risk driver R30, inadequate constructability reviews, and the use of RA at alpha (α) value of 0.05 based on Chi-square, LR Chi-Square, and Fisher's exact tests (see Table 4.39). In 90% of the not used, the rating of SI-29 was high. This might be

Table 4.38. SI-29 and the Use of Risk Assessment in Project

Using risk assessment	SI-29			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	20 86.96 74.07	3 13.04 37.50	0 0.00 0.00	23
No	7 43.75 25.93	5 31.25 62.50	4 25.00 100.00	16
Total	27	8	4	39

Statistic	DF	Value	Probability
Chi-Square	2	9.8192	0.0074
Likelihood Ratio Chi-Square	2	11.3141	0.0035

Fisher's Exact Test	
Table Probability (P)	0.0013
Pr <= P	0.0049

projects reported in the survey responses where RA was used, the rating for schedule impact of risk driver R30 (SI-30) was low. Similarly, 56% of the projects reported in survey responses where RA was not used, the rating of SI-30 was low. Also, for 31% of the projects reported in survey responses where RA was not used, the rating of SI-30 was high. This means that in both projects where RA was used and in projects where RA was not used, there was consistency and the rating for SI-30 and impact on SG was low.

Table 4.39. SI-30 and the Use of Risk Assessment in Project

Using risk assessment	**SI-30**			
Frequency **Row Pct** **Col Pct**	**1**	**2**	**3**	**Total**
Yes	19 90.48 67.86	1 4.76 33.33	1 4.76 16.67	21
No	9 56.25 32.14	2 12.50 66.67	5 31.25 83.33	16
Total	28	3	6	37

Statistic	**DF**	**Value**	**Probability**
Chi-Square	2	6.0054	0.0497
Likelihood Ratio Chi-Square	2	6.2246	0.0445

Fisher's Exact Test	
Table Probability (P)	0.0097
Pr <= P	0.0459

4.4. Summary

This chapter provided some analyses of the responses from survey. The analyses involved developing frequency tables and conducting hypothesis testing for seven hypotheses. The dependency correlations between ratings for RI, CI, and SI for 31 different risk drivers and the use of risk assessment in project provided some interesting insights.

The findings from different analyses performed in this chapter are summarized in this section.

Majority of responders (80%) indicated that risk assessment was important for highway construction projects. The use of risk assessment was more prevalent in private sector organizations than public sector organizations. Risk assessment has been used more often in design build projects than design bid build highway projects. The reason for this, from construction management point of view, is that the use of risk assessment potentially impacts cost and time performance much more significantly for design build projects than for the design bid build projects. Also, larger projects (with TPC over 20 million dollars) used risk assessment more often. However, the total planned duration (TPD) of project had statistically no significant impact on whether project team used risk assessment or not. In the majority of the projects reported in survey responses, the cost growth (CG) and schedule growth (SG) percentages were both between zero and 6%. About 66% of the reported projects had positive cost growth, and about 49% of the reported projects had positive schedule growth.

The dependency correlations between ratings of RI, CI, and SI for 31 different risk drivers and the use of risk assessment, based on the projects reported in the survey responses, provided several lessons. The use of risk assessment in highway construction projects lowered the rating of CI and SI of some critical risk drivers. Lack of use of risk assessment increased the rating of CI and SI of some critical risk drivers. The CI of risk drivers R3, R10, R12, R17, R21, R29, and R30 was rated as low in highway construction projects that used RA. In other words, the project team was able to mitigate impact of these risk drivers with development of plans to deal with the risks and their impact on cost growth. The SI of risk drivers R3, R10, R12, R15, R21, R29, and R30 was rated low in highway construction projects that used risk assessment. The development of appropriate plans can ably minimize the impact of these risk drivers on schedule growth. It should also be noted that when RA was not used in project, the cost impact of risk driver R3 was rated high. There also seems to be an agreement that the risk driver R12 does not impact CG. Similarly, there seems to be an agreement that the risk drivers R12, R15, and R30 do not impact SG. This analysis does not consider if there is any actual cost or schedule growth in the reported projects, because it is difficult to recognize which risk drivers have contributed to the project's cost or schedule growth. However, with other regression analyses some correlations of different risk drivers on cost and schedule growth have been studied and those analyses and related results have been discussed in Chapter 6. When the RA was not used in projects reported in survey responses, there was no significant evidence of recognizing the highest and lowest values of cost and schedule impact of these risks, which indicate that using risk assessment would be useful tool and technique to evaluate the cost and schedule impact of construction risks on project performance.

Finally, it must be recognized that use of risk assessment in the reported projects has improved construction management practices, which in turn led to the low ratings of CI and SI of certain risk drivers. The use of risk assessment lowered the rating of CI or SI of following risk drivers:

1) R3 (changes to unforeseen site environment requirements)

2) R10 (poor coordination among utility agencies, designers, and contractors)

3) R12 (poor engineering practice within the state)

4) R15 (inexperienced professionals for this type of project)

5) R17 (inadequate constructability reviews)

6) R21 (unforeseen hazard conditions)

7) R29 (inexperienced project manager)

Next chapter discusses the ranking of significant risks based on various statistical measures related to the ratings of RI, CI, and SI. The criticality of risks is identified by looking into all projects together, as well as for different types of project specifically.

CHAPTER 5. RISK RATING AND RANKING

The analyses, related discussions, and rankings of 31 risk drivers, mentioned in Chapter 3, are provided in this chapter. The ratings of RI, CI, and SI of the risk drivers have been used to identify the importance of risk drivers and the severity of their impact on cost and time performance of highway construction projects. As part of Step VIII, the rankings have been determined using various measures of central tendency of rating values of RI, CI, and SI. The rankings of risk drivers have been done for all projects as well as for different types of project.

5.1. Risk Rating

The encountered risk drivers were rated in terms of their relative importance (RI) first. The relative importance of a risk driver reflected the criticality of the occurrence of the risk and how severely it affected other risks. As mentioned before, the RI was rated at five levels:

1) Very low,
2) Low,
3) Moderate,
4) High, and
5) Very high.

The main purpose of relative importance rating is to recognize that there is interdependence among different risks and to take into consideration the impact of each rated risk on the rest of the encountered risks when rating for RI.

The risk drivers were also rated for their cost impact (CI) on project's cost growth (CG) and their schedule impact (SI) on project's schedule growth (SG), and these ratings were at three levels:

1) Low,

2) Medium, and

3) High.

However, no values or ranges of values were assigned to these qualitative levels. It is recognized that there could be variations in perceptions regarding these ratings for different types and sizes of projects. Appendix C provides several tables showing the rating frequencies for all 31 risk drivers.

5.2. Risk Ranking for All Projects

Several statistics related to ratings for RI, CI, and SI for all 31 different risk drivers were computed. Among the statistics computed were: mean, standard deviation, maximum, mode, and minimum values. Similar statistics are used in risk assessment practices, using simulation, to calculate the cumulative final time and cost for a project. These statistical measures were used in this study to rank the different risk drivers and to identify the most significant ones based on same measures. The purpose of defining most significant risk drivers is to identify which risk drivers should be the focus when planning highway construction projects. Risk assessment is ongoing process and involves analyzing previously completed projects, planning for future projects, and then managing and controlling projects from the start to the initial operation of highway construction project.

First the various measures were computed, considering all projects reported in the survey responses. After evaluating rating data for all risk drivers for all reported projects, mean and mode values were considered to be the appropriate measures to rank the significant risks in this study. The ranking was first done based on mean values in descending order. For the risk driver to be considered to be significant based on importance, the rating of its RI had to round to at least 3 (average value in the RI rating scale). Thereafter the mode values of these ranked risk drivers were checked and the risk drivers were further second ordered based on mode values in descending order. If the rating of CI and SI of a risk driver was rounded to at least 2 (average value in the CI and SI rating scale), then that risk driver was considered significant from the standpoint of its impact on cost growth and schedule growth. When the mean values were lower than average values, mode values were used in defining the most significant risk drivers. But it was also important reflect on lower values of mean for some guidance and insight into the criticality of risks. Total number of observations used for ranking purposes (based on ratings of RI, CI, or SI) was around 40 to 45. Using these observations, mean, mode, standard deviation, maximum, and minimum values were calculated. Table 5.1 lists the most significant risk drivers according to their relative importance, cost impact, and schedule impact.

The ranking of risk drivers for all types of projects is somewhat different depending on whether it was ranked based on RI, CI, or SI. However, some risk drivers were ranked high based on all these criteria. The rankings provide some useful insights that can be valuable for highway construction project planning and management and in consideration of risks.

Table 5.1. Significant Risk Drivers for All Projects

RI	Mean	STDEV	MAX	MODE	MIN
R3	3.140	1.320	5	3	1
R25	3.100	1.429	5	3	1
R20	3.026	1.367	5	3	1
R16	2.929	1.351	5	4	1
CI					
R2	1.978	0.812	3	2	1
R26	1.949	0.793	3	2	1
R3	1.907	0.840	3	1	1
R20	1.897	0.821	3	1	1
SI					
R3	2.000	0.926	3	3	1
R25	1.925	0.829	3	1	1
R2	1.911	0.848	3	1	1
R20	1.897	0.821	3	1	1

The most critical risk driver is R3 (changes to unforeseen site environment requirements), which includes but is not limited to unrealistic erosion control liability, equipment site requires extra environmental protection, traffic and lighting risk, permitting and restrictions to work flow, and environment and site design consistency. This risk driver ranks first based on both RI and SI, which implies that it has great impact on many other risks performance and on project's schedule growth.

Risk driver R25 (constraints in construction work window) comes second with regard to its relative importance to other risks, and also based on impact on SG. This risk driver includes potential construction work constraints if archeological sites are discovered during construction, set time frame, permits require specific sequences, and narrow workday window. Risk driver R20 (unforeseen and/ or different geotechnical conditions) comes third with regard to its relative importance on other risks. It also has impact on cost and schedule performance of highway construction project.

Risk driver R16 (design errors and omissions) comes fourth in its relative importance on other risks with mean value close to 3, and it has been considered as critical, with top risk drivers, because it also has a mode value of 4, which is higher than any other risks in the ranked list. R16 includes construction staging and plan design errors, poor foundation design, some design details, inaccurate quantities, and DB coordination. This risk driver has significant impact on other risks in general. However, and does not have significant ranking with regards to its impact on CG or SG because it comes tenth in the ranking list based on rating of CI and is even lower in the ranking list based on SI.

Risk driver R2 (changes by owner's request) is ranked first based on rating of CI and third based on rating of SI. Risk driver R2 includes unexpected external stakeholders involvement, extra road/ bridge capacity request, adding wetland mitigation, forcing contractors to work at night, and any other extra work. This risk driver has potential to impact both CG and SG. However, it was ranked seventh based on its relative importance and impact on other risks.

Risk driver R26 (material availability and price inflation) is ranked second based on rating of CI. This risk driver includes prices of steel, fuel, asphalt, and concrete prices, and escalation clauses. It has significant impact on project's CG when considering all types of projects in the ranking. Both this risk driver and risk driver R2 have larger mode values of rating of CI, and hence should be considered significant risks in terms of their impact on

CG.

In analyzing all projects and ranking risk drivers based rating for RI or importance to other risks, the most significant risk drivers were R3, R25, R20, and R16. The most significant risk drivers based on rating of CI were R2 and R26. When ranked based on rating of SI, R3 was found to be the most significant risk driver. It must be noted that these ranked risk drivers might be considered for some responses as part of other risks. It is also important to recognize that the ranking for specific project type may be different from the ranking developed based on consideration of all types of projects, which is discussed in next section.

5.3. Risk Ranking for Different Types of Projects

As was mentioned before, the reported projects in survey responses were categorized into five types as follows:

1) PT-1: new road construction or expansion for existing one,

2) PT-2: road rehabilitation or reconstruction of existing one,

3) PT-3: bridge or tunnel project,

4) PT-4; ITS project, and

5) PT-5: Complex project, which would be combination of the other four types.

It was also noted before that because of availability of few responses and differing nature of this type of project, PT4-ITS projects were not analyzed in this study. Of the 98 reported projects in survey responses, only 48 had responses on rating of RI, CI, and SI of risk drivers. Ranking risk drivers according to type of project revealed some meaningful and interesting insights, which were different than the risk ranking of all projects together provided.

5.3.1. New or Expansion Projects (PT-1)

In this type of project, risk driver R8 (high number of utilities in the site) was the most significant risk drivers in terms of its relative importance or impact on other risks. This risk was more significant in PT-1 than in PT-2. It should be noted that risk driver R20 was still significant in this type of project as it was when all projects were considered. The other risk drivers with mean rating values for RI of 3 or more were also ranked (see Table 5.2). But for risk drivers R8 and R20 the mode values were 4, so they were recognized as the most significant risks having impact on other risk drivers. Risk drivers R10 (poor coordination among utility agencies, designer, and contractors) and R19 (poor preliminary soil information and investigations) were also found significant based on rating for RI and are somewhat similar in nature and context to risk drivers R8 and R20. Other risk drivers considered significant based on rating of RI were R3, R2, R1, R4, R5, and R16.

The risk drivers R8 and R20 were also significant based on rating of CI and SI, and hence would have perceptible impact on CG and SG. It can be interpreted that for this type of project the underground conditions are the most significant factor for project performance and success. Risk driver R5 (land acquisition delay) was ranked third in terms of rating of SI, with potential to impact SG. Risk driver R5 includes delay in obtaining or any difficulty issues regarding access, relocation, and condemnations. It is interesting to note that risk driver R2 was ranked high for PT-1 projects also based on rating for CI and

SI, indicating potential for significant impact on CG and SG as was observed when ranking was done based on all projects.

Table 5.2. Significant Risk Drivers for New or Expansion Projects (PT-1)

	PT-1				
RI	Mean	STDEV	MAX	MODE	MIN
R8	3.273	1.555	5	4	1
R20	3.250	1.138	5	4	1
R3	3.167	1.193	5	3	1
R10	3.083	1.379	5	3	1
R19	3.083	0.996	4	4	1
R1	3.000	1.348	5	4	1
R2	3.000	1.080	5	2	2
R4	3.000	1.758	5	1	1
R5	3.000	1.706	5	1	1
R16	3.000	1.549	5	1	1
CI					
R8	2.182	0.982	3	3	1
R20	2.167	0.835	3	3	1
R2	2.154	0.689	3	2	1
R19	2.000	0.739	3	2	1
R5	1.917	0.996	3	1	1
SI					
R20	2.250	0.866	3	3	1
R8	2.091	1.044	3	3	1
R5	2.083	0.996	3	3	1
R2	2.077	0.760	3	2	1
R19	1.917	0.669	3	2	1

5.3.2. Rehabilitation or Reconstruction Projects (PT-2)

In this type of project risk driver R25 (constraints in construction work window) was the most significant risk driver in terms of its RI and impact on other risks. The ranking of risk drivers for this type of project based on rating for RI, CI, and SI is presented in Table 5.3. This ranking was, for most part, consistent with the ranking obtained based on all projects analysis. Risk driver R26 (material availability and price inflation) was ranked second based on rating of RI ranking. This risk driver has significant impact on other risks because of the fact that lack of availability of materials contribute significantly to breakdown of project's activities in this type of project. Risk driver R9 (inaccuracy of existing utility locations and survey data) was ranked third based on rating of RI. Risk driver R9 includes situations where data does not exist or is not complete and when poor initial utility data exist. It must be noted that this risk was not significant in PT-1, but it is significant in PT-2 because this type of project deals more with improvement of existing roads. Similarly, risk driver R28 (maintenance of traffic, staging, and auxiliary lanes) was found to significantly impact other risk drivers in PT-2, but it was not significant in PT-1. This is again due to the fact traffic has to be maintained when we are improving existing roads, but not when we are building new roads or expanding existing roads with full closure. Among other significant risk drivers for this type of project, which were also found significant when all projects were considered, were R3 and R20.

The cost and schedule impact of significant risk drivers in PT-2 are slightly different than that for PT-1. R25, ranked most significant based on rating of RI, was also ranked highest based on rating CI and SI. Risk drivers R26, R1, R2, and R3 were ranked as significant based on rating of CI and impact on CG. The risk drivers R2 and R3 were also ranked significant based on rating of SI and impact on SG. This emphasizes the importance of defining project scope well and the site and environmental analyses in minimizing the impact of these risk drivers on CG and SG. In terms of rating of SI and impact on SG, R7 (poor involvement of utility companies in planning stage) was significant, and it was also among the significant risk drivers which have significant RI rating. Risk driver R7 includes lack of involvement during procurement, multiple reviews by utilities, inaccurate as built drawings, and difficulty of involvement during planning in DB projects.

Table 5.3. Significant Risk Drivers for Rehabilitation or Reconstruction Projects (PT-2)

RI	PT-2				
	Mean	STDEV	MAX	MODE	MIN
R25	3.778	1.481	5	5	1
R26	3.778	1.302	5	4	1
R9	3.333	1.871	5	5	1
R28	3.300	1.252	5	3	1
R20	3.222	1.922	5	5	1
R3	3.182	1.328	5	4	1
R2	3.091	1.578	5	2	1
R7	3.000	1.658	5	1	1
CI					
R25	2.111	0.928	3	3	1
R26	2.111	0.782	3	2	1
R3	2.091	0.831	3	3	1
R1	2.000	1.000	3	3	1
R2	2.000	0.894	3	3	1
SI					
R25	2.333	0.866	3	3	1
R3	2.182	0.874	3	3	1
R2	2.091	0.944	3	3	1
R7	2.000	1.000	3	3	1
R9	2.000	1.000	3	3	1

5.3.3. Bridge or Tunnel Projects (PT-3)

In this type of project the relative importance of significant risk drivers is less than the average 3 value (see Table 5.4). There was distinct difference in ranking when compared to that obtained for PT-1 and PT-2. Risk driver R16 (design errors and omissions) was found to be the most significant risk driver based on RI and impact on other risks. This is because adequacy and accuracy of design of structures and foundation drawings are critical in project construction progress and performance in PT-3. There were some similarities between rankings as well. Risk driver R20 was found significant based on rating of RI and impact on other risks, as it was found in project types PT-1 and PT-2. Risk driver R19 was also found significant based on rating of RI, as it was found in project type PT-1. Risk drivers R2 and R3, which were found significant in other project types, were also found significant for this project type based on RI and impact on other risks.

The most significant risk driver found based on rating of CI and SI and impact on CG and SG for this type of project was R27 (subcontractors errors and delays). This risk driver includes subcontractor's schedule conflicts and incomplete process management tools and actions with contractors. This risk driver was not found significant in PT-1 and PT-2 based on rating of CI and SI. Based on rating of SI and impact on SG, risk driver R25 was found significant for this type of project and project type PT-2.

5.3.4. Complex Projects (PT-5)

The most significant risk driver based on rating of RI and impact on other risks is R24 (delay of permits) in this type of project (see Table 5.5). This risk driver is not significant in previous projects' types. It must be noted that because of the complexity of

Table 5.4. Significant Risk Drivers for Bridge or Tunnel Projects (PT-3)

RI	**PT-3**				
	Mean	STDEV	MAX	MODE	MIN
R16	2.583	1.240	5	2	1
R20	2.500	1.243	4	1	1
R2	2.462	1.050	5	2	1
R19	2.455	1.036	4	3	1
R3	2.417	0.996	4	2	1
CI					
R27	1.583	0.669	3	1	1
R2	1.538	0.776	3	1	1
R16	1.500	0.674	3	1	1
R20	1.500	0.674	3	1	1
R21	1.500	0.850	3	1	1
SI					
R25	1.667	0.651	3	2	1
R27	1.667	0.651	3	2	1
R2	1.615	0.870	3	1	1
R3	1.500	0.905	3	1	1
R20	1.500	0.674	3	1	1

this type of project, delay of permits might affect the whole project as well as different activities and stages. The risk driver ranked second based on rating of RI and impact on other risks was Risk driver R1 (project purpose is poorly defined), which was also significant in project type PT-1. The risks drivers R3 and R25 were also found significant based on rating RI for this type of project and also in previous project types. Risk driver R30 (safety issues) was also found significant based on rating of RI and impact on other risks for this type of project, but it was not so in previous types of project. Risk driver R30 includes safety officer and plan requirements, traffic closures, and safety hazard problems. Risk drivers R3 and R24, were considered significant based on rating of CI and SI and impact on SG and CG for this type of project, and for PT-2.

Table 5.5. Significant Risk Drivers for Complex Projects (PT-5)

RI	**PT-5**				
	Mean	STDEV	MAX	MODE	MIN
R24	4.429	0.976	5	5	3
R1	4.143	1.215	5	5	2
R3	4.125	1.458	5	5	1
R25	4.125	0.991	5	5	3
R30	4.000	1.673	5	5	1
CI					
R3	2.625	0.518	3	3	2
R26	2.571	0.535	3	3	2
R24	2.429	0.787	3	3	1
R2	2.375	0.744	3	3	1
R25	2.375	0.744	3	3	1
SI					
R3	2.750	0.463	3	3	2
R24	2.714	0.488	3	3	2
R10	2.500	0.756	3	3	1
R25	2.500	0.756	3	3	1
R5	2.429	0.787	3	3	1

5.4. Summary

The ranking of risk drivers was carried out using mean and mode values of rating of RI, CI, and SI for 31 risk drivers in the projects reported in survey responses. There were some interesting differences in rankings based on relative importance (RI), cost impact

(CI), and schedule impact (SI), and also across different types of project. Table 5.6 summarizes the rankings and illustrates the differences. There were some risk drivers that ranked high among all types of project, and there were some risk drivers that were significant for only particular type(s) of project.

Some significant risk drivers that consistently ranked high based on rating of RI, CI, or SI were those that were related to project scope. The risk drivers related to project's scope include R1 (poor definition of project purpose), R2 (changes by owner's request), and R3 (changes to unforeseen site environment requirements). The latter two were particularly important and significant. In project construction management category, the risk driver that was common and significant was R25 (a constraint in construction work window). In A/E services category, the most significant risk driver was R20 (unforeseen and/or different geotechnical conditions).

The ranking of risk drivers based on RI and impact on other risks is in some ways similar to ranking based on rating of CI and SI and impact on CG and SG. However, there are some differences in ranking among these different bases and across different types of project. Risk driver R8 (high numbers of utilities in the site) risk driver is more significant based on relative importance in new road construction and expansion projects (PT-1) than other types of project. Risk driver R25 (a constraint in construction work window) is more significant based on relative importance in road rehabilitation and reconstruction projects (PT-2) than other types of project. Risk driver R16 (design errors and omissions) is more significant based on relative importance in bridge and tunnel projects (PT-3) than other types of project. Risk driver R24 (delay of permits) is more significant based in relative importance in complex projects (PT-5) than other types of project.

Table 5.6. Summary of Significant Risk Drivers for Different Types of Projects

	RI		
PT-1	**PT-2**	**PT-3**	**PT-5**
R8	R25	R16	R24
R20	R26	R20	R1
R3	R9	R2	R3
R10	R28	R19	R25
R19	R20	R3	R30
	CI		
R8	R25	R27	R3
R20	R26	R2	R26
R2	R3	R16	R24
R19	R1	R20	R2
R5	R2	R21	R25
	SI		
R20	R25	R25	R3
R8	R3	R27	R24
R5	R2	R2	R10
R2	R7	R3	R25
R19	R9	R20	R5

In new road construction and expansion projects (PT-1), risk drivers R8 (high number of utilities in the site), R20 (unforeseen and different geotechnical conditions), and R5 (land acquisition delay) are the most significant in terms of impact on CG and SG. The project professional planner should focus on assessing these risk drivers and set construction management plans for them as this type of project mostly constructed for new developed and urban regions, which mostly have large number of utilities in the site.

In road rehabilitation and reconstruction projects (PT-2), risk drivers R25 (constraints in construction work window) and R26 (material availability and price inflation) are the most significant in terms of impact on CG. The risk drivers impacting SG most in PT-2 projects are R25 (constraints in construction window), R7 (poor involvement of utility companies in planning stage), and R9 (inaccuracy of existing utility locations and survey data). This type of project is different from PT-1 in its scope of work and is more involved with existing roads and changing their conditions and capacities. They also require maintenance of traffic flow throughout the duration and geometric length of the project. The other factor of material prices shows that this type of projects use asphalt and/or concrete in large amounts compared to other non-expensive materials in total cost estimates.

In bridge and tunnel projects (PT-3) the risk driver that has significant impact on SG is R25 (constraints in construction work window), as was the case in project type PT-2. However, R25 does not have as significant an impact on CG in this type of project as it did in project type PT-2. This is due to the fact that the geometric length of project in PT-3 is less than that in PT-2. Risk driver R27 (subcontractors errors and delays) has more significant impact on CG and SG in this type of project compared to other types of project. This might be because of the fact that this type of project has more superstructure components, which need very skilled subcontractors specialized in this area of construction profession.

In complex projects (PT-5) the risk driver R3 (changes to unforeseen site environmental requirements) has the most significant impact on SG and CG. Even though this risk driver is really significant in all projects' types, but its impact is felt the most in PT-5 because of the complexity of this type of project. Risk driver R24 (delay of permits) also impacts CG and SG significantly in this type of project.

As has been analyzed and discussed in this chapter, the type of project is playing a significant role in identifying the significant risk drivers which impact cost and time performance of highway construction project. The responses for rating of RI, CI, and SI, were based on perceptions of key highway construction professionals. The rating of CI and SI of a risk driver is supposed to be reflection of the impact of the risk driver on CG and SG in a project. The responses on cost growth and schedule growth percentages in project reported in survey were also obtained. However, the rating of CI and SI does not necessarily correspond with SG and CG percentages. Hence, a correlation of ratings of RI, CI, SI for 31 risk drivers with CG and SG percentages was carried out, which is discussed in next chapter.

The main objective for this chapter was to highlight and focus on the most significant risk drivers as it impacts other risks (e.g. RI), cost growth (e.g. CI), and schedule growth (e.g. SI). These identifications can help deal with the uncertainty of whether the risk has an impact or not in any potential future project in more informed way. Historical data from completed projects, as has been collected from risk ratings in this survey questionnaire, can be used to develop guidelines and probability distributions for future project's planning and risk assessment.

CHAPTER 6. IMPACT ON PROJECT PERFORMANCE MEASURES

Project performance has been discussed in many previous studies, which were reviewed in literature review. Project performance has many dimensions related to cost, time, quality, scope, safety, owner and customers' satisfaction, which can be used as basic measures for assessing effectiveness and success of any project. The two major performance measures which have been used widely are cost and schedule growth. In this chapter the different project parameters have been evaluated in terms of their impact on cost and schedule growth of project. Cost growth (CG) measures how much the project total cost changes (either increase or decrease), and schedule growth (SG) measures how much the project total duration changes (either increase or decrease). Both these measures (CG and SG) have been used as dependent variables in the models that were developed and tested in Steps VIII, IX and X.

Construction cost represents about 80% of total project cost. In this study total planned cost (TPC) was considered to be the total construction cost and cost growth (CG) has been used interchangeably as construction cost growth percentage. However, in design build projects, the design efforts are included in the total planned project cost and it was challenging to separate the design cost portion from the construction portion in total planned cost in DB projects. This particular aspect was considered when total planned cost was taken into account in the analyses in this study. A note regarding this was also provided in the survey and the responders were asked to report only the total construction cost. Similar caution and concern related to schedule growth (SG) was also provided in the survey. The responders were asked to provide total planned project duration for DB projects to be that which focused on construction effort only. In following sections some project parameters have been evaluated and dependency correlations have been tested between these project parameters and CG or SG.

6.1. Cost Growth

When risk assessment (RA) was done, it was important to consider other parameters of project characteristics in measuring project cost growth performance. Cost growth mathematical model, as explained in Chapters 2 and 3, is as follows:

$$CG=\frac{(FC-TPC)}{TPC} \times 100 \qquad 6.1$$

CG = Cost Growth %

TPC = Total Planned Construction Cost

FC = Final Total Construction Cost

There were 11 categories or levels for cost growth percentages, which included five levels of cost growth with negative percentages (for projects that were completed under budget), a zero level (for projects completed on budget), and five other levels of cost growth with positive percentages (for projects that were completed over budget). The frequencies of these levels in the projects reported in the survey responses are shown in Table 6.1.

Testing of CG at 11 categorical levels with respect to TPC was not found significant due to small frequency values and high number of levels. CG categories were therefore collapsed into five levels as shown in Table 6.2. However, no significant

Table 6.1. Frequencies of Different Cost Growth Levels

Cost growth (CG)	CG level	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-14%	1	4	4.82	4	4.82
-14-<-10%	2	6	7.23	10	12.05
-10-<-6%	3	1	1.20	11	13.25
-6-<-3%	4	5	6.02	16	19.28
-3-<0%	5	6	7.23	22	26.51
0%	6	6	7.23	28	33.73
>0-<3%	7	16	19.28	44	53.01
3 -<6%	8	19	22.89	63	75.90
6 -<10%	9	5	6.02	68	81.93
10-14%	10	7	8.43	75	90.36
>14%	11	8	9.64	83	100.00

Table 6.2. Frequency Table for Five Cost Growth Levels

Cost growth	CG level	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-6%	1	11	13.25	11	13.25
-6%-<0%	2	11	13.25	22	26.51
0%	3	6	7.23	28	33.73
>0%-<+6%	4	35	42.17	63	75.90
>+6%	5	20	24.10	83	100.00

analysis could be done at these levels either. Finally, two levels were used in this study. Some meaningful results were obtained when only two levels of CG were used. The two levels of CG were considered for logistic modeling and other dependency correlation analyses. The frequency table for the two levels of CG is shown in Table 6.3. From this table it is evident that majority of projects reported in survey responses (about 66%) had positive cost growth.

Table 6.3. Frequency Table for Two Cost Growth Levels

Cost growth	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<=0	28	33.73	28	33.73
>0	55	66.27	83	100.00

In the following section analysis of other project characteristics and related dependency correlations with cost growth are discussed to develop an understanding of the impact of project characteristics or parameters on CG.

6.2. Cost Growth Dependency Correlations

There were no significant dependency correlations found between CG and organization type and projects' locations (based on the four census delineated regions). However, the frequency tables shown in Tables 6.4 and Table 6.5 provide some insights. Most of the projects reported by public sector (about 72%) resulted in CG. On the other hand, projects reported by private sector resulted in both positive and negative CG. Region 1 (north east region) performed better than other regions with regard to CG as project performance measure. This is indicative of the good quality of construction management practices in the north east region.

Hypotheses 14 and 15 were tested to explore the impact of CG on owner's as well as contractor's contingency. There was no significant dependency correlation found between CG and either owner's or contractor's contingency.

Table 6.4. Type of Organization and Cost Growth

Type of organization	Cost growth (CG)		
Frequency Row Pct Col Pct	<=0	>0	Total
Public Sector	8 27.59 28.57	21 72.41 38.18	29
Private Sector	20 37.04 71.43	34 62.96 61.82	54
Total	28	55	83

Table 6.5. Project Location and Cost Growth

Cost growth	Project location (region)				
Frequency Row Pct Col Pct	1	2	3	4	Total
<=0	6 21.43 60.00	5 17.86 26.32	4 14.29 22.22	13 46.43 36.11	28
>0	4 7.27 40.00	14 25.45 73.68	14 25.45 77.78	23 41.82 63.89	55
Total	10	19	18	36	83

6.2.1. Cost Growth and Project Type

The analysis in chapter 5 indicated the risk drivers that impacted CG significantly, based on the rating of CI. It is believed that different types of project experience different cost growth. Hypothesis 8 was tested to understand this.

Hypothesis 8: Total cost growth and project type for highway construction projects.

H_0: There is no dependency correlation between total cost growth and project type for highway construction projects.

H_a: There is dependency correlation between total cost growth and project type for highway construction projects.

The results of chi-square tests (shown in Table 6.6) indicate significant dependency correlation between CG and type of project at alpha (α) value of 0.10. It seems there is not much correlation shown by project type PT-1. However, other types of project do show that they have more projects with CG. This is particularly true for project type PT-5 (complex projects), for which 89% of the reported projects have encountered CG. Since, the dependency correlations were found at two levels of CG, there was interest in testing the correlations with higher levels of CG to get better insight.

The frequency analyses for type of project and its correlation with the detailed categorical levels of cost growth is shown in Table 6.7. This provides a better insight about CG in project type PT-1. It is evident that reported projects of type PT-1 encountered CG at all CG levels, however some of the reported projects were also completed under budget. The projects reported as type PT-5, on the other hand, encountered CG between 0 to 6%, which indicates that it is hard to find complex projects which can be completed under budget. As was evidenced and indicated before (from Table 6.6) the probability of CG was about 89% for complex projects.

Table 6.6. Project Type and Cost Growth at Two Levels

Project type (PT)	**Cost growth**		
Frequency **Row Pct** **Col Pct**	**<=0**	**>0**	**Total**
PT-1	14 48.28 50.00	15 51.72 27.27	29
PT-2	5 31.25 17.86	11 68.75 20.00	16
PT-3	7 36.84 25.00	12 63.16 21.82	19
PT-5	2 10.53 7.14	17 89.47 30.91	19
Total	28	55	83

Statistic	**DF**	**Value**	**Probability**
Chi-Square	3	7.4473	0.0589
Likelihood Ratio Chi-Square	3	8.2796	0.0406

Whether this discrepancy between PT-1 and PT-5 in terms of CG was due to project delivery method was not clear and needed to be explored further. Hence, a correlation between type of project and project delivery method was also investigated using frequency correlation shown in Table 6.8. It seems both PT-1 and PT-5 have similar frequency distributions between DBB and DB project delivery methods. Hence, the argument that since PT-1 had both positive and negative CG because of project delivery methods, which may have contributed to better performance with respect to CG in 48% of reported PT-1 projects, impact of project delivery method is not considered significant. Interestingly, even though PT-5 projects used DB, they still encountered CG.

Table 6.7. Project type and Cost Growth at Eleven Levels

Project type (PT)	**Cost growth (CG)**											
Frequency Row Pct Col Pct	**<- 14%**	**-14-<- 10%**	**-10-<- 6%**	**-6-<- 3%**	**-3 -< 0%**	**0%**	**>0- < 3%**	**3 -< 6%**	**6 -< 10%**	**10- 14%**	**>14%**	**Total**
CG level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
	2	5	0	3	1	3	5	2	2	4	2	29
PT-1	6.90	17.24	0.00	10.34	3.45	10.34	17.24	6.90	6.90	13.79	6.90	
	50.00	83.33	0.00	60.00	16.67	50.00	31.25	10.53	40.00	57.14	25.00	
	1	0	1	1	2	0	3	5	0	1	2	16
PT-2	6.25	0.00	6.25	6.25	12.50	0.00	18.75	31.25	0.00	6.25	12.50	
	25.00	0.00	100.00	20.00	33.33	0.00	18.75	26.32	0.00	14.29	25.00	
	1	1	0	1	1	3	2	6	1	0	3	19
PT-3	5.26	5.26	0.00	5.26	5.26	15.79	10.53	31.58	5.26	0.00	15.79	
	25.00	16.67	0.00	20.00	16.67	50.00	12.50	31.58	20.00	0.00	37.50	
	0	0	0	0	2	0	6	6	2	2	1	19
PT-5	0.00	0.00	0.00	0.00	10.53	0.00	31.58	31.58	10.53	10.53	5.26	
	0.00	0.00	0.00	0.00	33.33	0.00	37.50	31.58	40.00	28.57	12.50	
Total	4	6	1	5	6	6	16	19	5	7	8	83

Another possible reason for the difference in cost performance between PT-1 projects and PT-5 project could be attributed to the project size or total planned cost. As a result, the correlation was tested between project type and total planned cost. The results of this test are shown in Table 6.9. No significant evidence of statistical correlation was found. However, the frequency percentages of both PT-1 projects and PT-5 projects have

Table 6.8. Project Type and Project Delivery Method

Project type	**Project delivery method**			
Frequency **Row Pct** **Col Pct**	**DBB**	**DB**	**other**	**Total**
PT-1	21 65.63 32.31	8 25.00 34.78	3 9.38 33.33	32
PT-2	12 63.16 18.46	3 15.79 13.04	4 21.05 44.44	19
PT-3	17 80.95 26.15	3 14.29 13.04	1 4.76 11.11	21
PT-5	15 60.00 23.08	9 36.00 39.13	1 4.00 11.11	25
Total	65	23	9	97

shown that both types of project have some large projects and some small projects. It should also be noted that there were more smaller-size projects in project type PT-1 than was found in project type PT-5. This might lead to the conclusion that the smaller projects have performed better in project type PT-1. However there was no statistical evidence to support this assertion.

6.2.2. Cost Growth and Project Delivery Method

There was interest in understanding if there was correlation between CG and

Table 6.9. Project Type and Planned Project Cost

Project type (PT) Frequency Row Pct Col Pct	Planned project cost (TPC) < 5	5-<20	20-<50	50-100	> 100	Total
PT-1	4 12.12 50.00	10 30.30 50.00	7 21.21 28.00	4 12.12 23.53	8 24.24 32.00	33
PT-2	2 10.53 25.00	4 21.05 20.00	8 42.11 32.00	1 5.26 5.88	4 21.05 16.00	19
PT-3	2 10.53 25.00	3 15.79 15.00	6 31.58 24.00	5 26.32 29.41	3 15.79 12.00	19
PT-5	0 0.00 0.00	3 12.50 15.00	4 16.67 16.00	7 29.17 41.18	10 41.67 40.00	24
Total	8	20	25	17	25	95

project delivery method. Hypothesis 9 was tested for developing this understanding.

Hypothesis 9: Total cost growth and project delivery method for highway construction projects.

H_0: There is no dependency correlation between total cost growth and project delivery method for highway construction projects.

H_a: There is dependency correlation between total cost growth and project delivery method for highway construction projects.

The test did not show any significant correlation. The frequency table shown in Table 6.10 indicates that in both project delivery methods most of the projects reported a cost growth (CG). To understand the correlation better, testing and analysis was done using more detailed CG levels. Table 6.11 presents the result of this testing. It is interesting to note that most of the reported projects that used either DB or DBB project delivery method encountered CG.

Table 6.10. Project Delivery Method and Cost Growth at Two-Levels

Project delivery method	**Cost growth**		
Frequency Row Pct Col Pct	**<=0**	**>0**	**Total**
DBB	19 33.33 67.86	38 66.67 70.37	57
DB	6 31.58 21.43	13 68.42 24.07	19
other	3 50.00 10.71	3 50.00 5.56	6
Total	28	54	82

6.2.3. Cost Growth and Total Planned Project Cost

There was also interest to explore if there was any correlation between cost growth and total planned project cost, which was the intent of testing Hypothesis 10.

Hypothesis 10: Total cost growth and total planned cost for highway construction projects.

H_o: There is no dependency correlation between total cost growth and total planned cost for highway construction projects.

H_a: There is dependency correlation between total cost growth and total planned cost for highway construction projects.

Table 6.11. Project Delivery Method and Cost Growth at Eleven Levels

Project delivery method	**Cost growth**											
Frequency Row Pct Col Pct	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
	4	4	0	4	4	3	9	14	3	5	7	57
DBB	7.02	7.02	0.00	7.02	7.02	5.26	15.79	24.56	5.26	8.77	12.28	
	100.00	66.67	0.00	80.00	66.67	50.00	56.25	73.68	75.00	71.43	87.50	
	0	2	1	0	1	2	7	4	1	1	0	19
DB	0.00	10.53	5.26	0.00	5.26	10.53	36.84	21.05	5.26	5.26	0.00	
	0.00	33.33	100.00	0.00	16.67	33.33	43.75	21.05	25.00	14.29	0.00	
	0	0	0	1	1	1	0	1	0	1	1	6
other	0.00	0.00	0.00	16.67	16.67	16.67	0.00	16.67	0.00	16.67	16.67	
	0.00	0.00	0.00	20.00	16.67	16.67	0.00	5.26	0.00	14.29	12.50	
Total	4	6	1	5	6	6	16	19	4	7	8	82

Testing the correlation between CG and total planned cost (TPC) revealed that there was statistical dependency correlation at alpha (α) at value of 0.05 (see Table 6.12). About 83% of reported projects, with TPC larger than 50 million dollars, encountered CG. It was also interesting to note that the medium size projects, with TPC between 20 and 50 million dollars, performed better than larger projects with respect to CG.

Table 6.12. Total Planned Project Cost and Cost Growth at Two Levels

Cost growth (CG)	Total planned cost (TPC)			
Frequency Row Pct Col Pct	<20 m	20-50 m	>50 m	Total
<=0	10 35.71 40.00	12 42.86 54.55	6 21.43 17.14	28
>0	15 27.78 60.00	10 18.52 45.45	29 53.70 82.86	54
Total	25	22	35	82

Statistic	DF	Value	Probability
Chi-Square	2	8.9522	0.0114
Likelihood Ratio Chi-Square	2	9.2511	0.0098

6.2.4. Cost Growth and Total Planned Project Duration

There was also interest in testing correlation between CG and total planned duration (TPD) and it was done by testing hypothesis 11.

Hypothesis 11: Total cost growth and total planned duration for highway construction projects.

H_o: There is no dependency correlation between total cost growth and total planned duration for highway construction project.

H_a: There is dependency correlation between total cost growth and total planned duration for highway construction project.

When testing the dependency correlation between CG and TPD, no statistical evidence was found to reject the null hypothesis.

6.2.5. Cost Growth and the Use of Risk Assessment

One of the key interests was to test if the use of risk assessment (RA) impacted cost growth. This was the intent of testing Hypothesis 12.

Hypothesis 12: Total cost growth and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and the use of risk assessment in the chosen highway construction project.

There was statistical evidence to reject the null hypothesis at alpha (α) value of 0.10, which means that there was dependency correlation between CG and the use of RA in the chosen project (see Table 6.13). About 37 % of projects, where RA was used, completed on or under budget compared to about 63% of similar projects that encountered CG. Also, about 71% of projects, where RA was not used, encountered CG. This implies better project cost performance was realized when RA was used. However, it is also important to highlight that using RA did not eliminate CG in most reported projects.

Table 6.13. Use of Risk Assessment and Cost Growth at Two Levels

Using risk assessment	Cost growth		
Frequency Row Pct Col Pct	<=0	>0	Total
Yes	19 37.25 67.86	32 62.75 59.26	51
No	9 29.03 32.14	22 70.97 40.74	31
Total	28	54	82
Statistic	DF	Value	Probability
Chi-Square	1	2.7998	0.0943
Likelihood Ratio Chi-Square	1	2.8180	0.0932

6.2.6. Cost Growth and Schedule Growth

Increased duration has tendency to increase cost. It was important to understand the dependency correlation between CG and SG. Hypothesis13 was tested with that intent.

Hypothesis 13: Total cost growth and total schedule growth in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and schedule growth in the chosen highway construction project.

H_a: There is dependency correlation between total cost growth and schedule growth in the chosen highway construction project.

The results related to testing of Hypothesis 13 are presented in Table 6.14. There was statistical evidence to reject the null hypothesis with alpha (α) value of = 0.05, and therefore there was dependency correlation between CG and SG. It must be noted that most of the projects reported in survey responses that encountered SG, also encountered CG.

Table 6.14. Schedule Growth and Cost Growth at Two Levels

Cost growth	**Schedule growth**		
Frequency **Row Pct** **Col Pct**	**<=0**	**>0**	**Total**
<=0	26 92.86 61.90	2 7.14 5.00	28
>0	16 29.63 38.10	38 70.37 95.00	54
Total	42	40	82
Statistic	**DF**	**Value**	**Probability**
Chi-Square	1	29.5032	<.0001
Likelihood Ratio Chi-Square	1	33.5866	<.0001

6.2.7. Cost Growth and Risk Ratings

The explanation of the dependency correlations between ratings for RI, CI, and SI of 31 risk drivers and CG was also important interest in this study. Hypothesis 16 was tested for that purpose.

Hypothesis 16: Total cost growth and ratings for relative importance (RI), cost impact (CI), and schedule impact (SI) for risks in the chosen highway construction project.

H_0: There is no dependency correlation between total cost growth and ratings for RI, CI, and/or SI for any of the 31 risks in highway construction projects.

H_a: There is dependency correlation between total cost growth and ratings for RI, CI, and/or SI for some of the 31 risks in highway construction projects.

The testing indicated that there was no dependency correlation between any ratings of relative importance (RI) or schedule impact (SI) of all 31 risk drivers and CG. However, there was dependency correlation between cost impact of risk driver R9 (inaccuracy of existing utility locations and survey data) and CG at alpha (α) value of 0.05 based on Chi square, LR Chi Square, and Fisher exact tests, and are shown in Table 6.15. The null hypothesis was rejected at alpha (α) value of 0.05, which means that there is dependency correlation between rating of cost impact of risk driver R9 and CG. Most of the projects reported in survey responses had the rating for CI-9 as low or medium. But, all these projects encountered CG.

It was of research interest to explore if the use of risk assessment impacted or influenced the results. From Table 6.16 one can see that there are many projects, where RA was used, and had rating of CI-9 as low. This might have different interpretations. The professionals for these projects planned for R9 and therefore the perception about CI-9 was low, or R9 was not driving the CG in these projects. Moreover, it is hard to quantify or define the impact of R9 on CG, and project construction management practices in these projects may not be able to effectively track the link between R9 and CG.

Table 6.15. CI-9 and Cost Growth at Two Levels

Cost growth	CI-9			
Frequency Row Pct Col Pct	1	2	3	Total
<=0	7 46.67 36.84	2 13.33 18.18	6 40.00 85.71	15
>0	12 54.55 63.16	9 40.91 81.82	1 4.55 14.29	22
Total	19	11	7	37

Statistic	DF	Value	Probability
Chi-Square	2	8.3151	0.0156
Likelihood Ratio Chi-Square	2	8.7797	0.0124

Fisher's Exact Test	
Table Probability (P)	0.0021
Pr <= P	0.0141

Table 6.16. CI-9 and Use of Risk Assessment

Using risk assessment	CI-9			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	14 66.67 70.00	5 23.81 45.45	2 9.52 33.33	21
No	6 37.50 30.00	6 37.50 54.55	4 25.00 66.67	16
Total	20	11	6	37

There was also dependency correlation found between cost impact of risk driver R14 (surveys late and/or surveys in error) and CG at alpha(α) value of 0.05 based on Chi square, LR Chi Square, and Fisher exact tests (see Tables 6.17). Despite low rating for CI-14, the projects encountered CG. Similar argument can be made for this anomaly as was used for explaining the impact of risk driver R9. It is important to highlight that 83% of projects reported projects where CI-14 was rated high, CG was encountered. The impact of use of risk assessment in rating of CI-14 and CG was also of interest.

Table 6.18 shows there are many projects where RA was used and CI-14 was rated as low. This might have different interpretations. The professionals in these projects had planned for R14, the perception about the impact of R14 was considered low, or R14 was not driving the CG in these projects. In addition, it is hard to quantify or define the impact of R14 on CG, and project construction management practices in these projects were not effective to track the link between R14 and CG.

6.3. Schedule Growth

Schedule growth (SG) as used in this research is as follows:

$$SG = \frac{(FD - TPD)}{TPD} \text{ X } 100 \qquad 6.2$$

SG = Cost Growth %

TPD = Total Planned Construction Duration

FD = Final Duration

Table 6.17. CI-14 and Cost Growth at Two Levels

Cost growth	CI-14			
Frequency Row Pct Col Pct	1	2	3	Total
<=0	6 42.86 27.27	7 50.00 87.50	1 7.14 16.67	14
>0	16 72.73 72.73	1 4.55 12.50	5 22.73 83.33	22
Total	22	8	6	36

Statistic	DF	Value	Probability
Chi-Square	2	10.4504	0.0054
Likelihood Ratio Chi-Square	2	10.8969	0.0043

Fisher's Exact Test	
Table Probability (P)	9.434E-04
Pr <= P	0.0073

Table 6.18. CI-14 and Use of Risk Assessment

Using risk assessment	CI-14			
Frequency Row Pct Col Pct	1	2	3	Total
Yes	14 70.00 60.87	3 15.00 37.50	3 15.00 60.00	20
No	9 56.25 39.13	5 31.25 62.50	2 12.50 40.00	16
Total	23	8	5	36

When analyzing schedule growth at two levels (see Table 6.19), it was found that there was approximately the same number of projects with zero or less than zero growth as there were with positive schedule growth. As a result, no clear trend was observed with regard to SG performance measure. Nonetheless, it was clearer with regard to CG as performance measure.

Table 6.19. Frequency Table of Schedule Growth at Two Levels

Total Schedule Growth (SG)				
Schedule growth	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
<=0	43	51.19	43	51.19
>0	41	48.81	84	100.00

6.4. Schedule Growth Dependency Correlations

There was also interest in exploring if project type or total planned cost effected schedule growth. Hypotheses 17 and 19, shown here and in Chapter 3, were tested to explore an explanation for this. The results did not indicate any significant dependency correlation in either of the two tests.

Hypothesis 17: Total schedule growth and project type for highway construction projects.
H_0: There is no dependency correlation between total schedule growth and project type for highway construction projects.

H_a: There is dependency correlation between total schedule growth and project type for highway construction projects.

Hypothesis 19: Total schedule growth and total planned cost for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and total planned cost for highway construction projects.

H_a: There is dependency correlation between total schedule growth and total planned cost for highway construction projects.

6.4.1. Schedule Growth and Total Planned Project Duration

There was a research interest to understand if there was any impact of total planned duration on schedule growth. Hypothesis 20 was tested to explore dependency correlation between total planned duration and schedule growth.

Hypothesis 20: Total schedule growth and total planned duration for highway construction projects.

H_0: There is no dependency correlation between total schedule growth and total planned duration for highway construction project.

H_a: There is dependency correlation between total schedule growth and total planned duration for highway construction project.

The test did not show any statistical evidence to reject the null hypothesis, which means that there was no dependency correlation found. In other words, total schedule growth was not dependent on total planned project duration.

6.4.2. Schedule Growth and the Use of Risk Assessment

Use of risk assessment has potential to reduce schedule growth, by allowing one to prepare for anticipated risks. Hypothesis 21 was tested to understand the correlation between use of risk assessment and schedule growth.

Hypothesis 21: Total schedule growth and the use of risk assessment in the chosen highway construction project.

H_0: There is no dependency correlation between total schedule growth and the use of risk assessment in the chosen highway construction project.

H_a: There is dependency correlation between total schedule growth and the use of risk assessment in the chosen highway construction project.

Table 6.20 shows that the null hypothesis must be rejected at alpha (α) value of 0.05 and that there was dependency correlation between using RA and SG (when SG was considered at five levels). Projects, where RA was used, performed better than others. However there were 31% of the reported projects, where RA was used, but still encountered SG between 0% and 6%. About 29% of the projects, where RA was not used, encountered SG of over 6%. Table 6.21 shows that the null hypothesis must be rejected at alpha (α) value of 0.10 and there is dependency correlation between using RA and SG (when SG was considered at two levels).

Table 6.20. Use of Risk Assessment and Schedule Growth at Five Levels

Using risk assessment	Schedule growth					
Frequency Row Pct Col Pct	<-6%	-6%-<0%	0%	>0%-<+6%	>+6%	Total
Yes	2 3.85 20.00	8 15.38 80.00	20 38.46 90.91	16 30.77 61.54	6 11.54 40.00	52
No	8 25.81 80.00	2 6.45 20.00	2 6.45 9.09	10 32.26 38.46	9 29.03 60.00	31
Total	10	10	22	26	15	83

Statistic	DF	Value	Probability
Chi-Square	4	19.8707	0.0005
Likelihood Ratio Chi-Square	4	21.4341	0.0003

Fisher's Exact Test	
Table Probability (P)	2.090E-07
Pr <= P	3.176E-04

6.4.3. Schedule Growth and Project Delivery Method

Hypothesis 18 was tested to explore if there was any correlation between schedule growth and project delivery method.

Hypothesis 18: Total schedule growth and project delivery method for highway construction projects.

H_o: There is no dependency correlation between total schedule growth and project delivery method for highway construction projects.

H_a: There is dependency correlation between total schedule growth and project delivery method for highway construction projects.

Table 6.21. Use of Risks Assessment and the Schedule Growth at Two Levels

Using risk assessment	**Schedule growth**		
Frequency **Row Pct** **Col Pct**	**<=0**	**>0**	**Total**
Yes	30 57.69 71.43	22 42.31 53.66	52
No	12 38.71 28.57	19 61.29 46.34	31
Total	42	41	83

Statistic	**DF**	**Value**	**Probability**
Chi-Square	1	2.7998	0.0943
Likelihood Ratio Chi-Square	1	2.8180	0.0932

The testing of Hypothesis 18 did not show any statistical evidence to reject the null hypothesis, which means that there is no dependency correlation. Table 6.22 shows the correlation frequency between project delivery method and SG (with SG at eleven different levels). The results offer few interpretations. Projects with DB project delivery method performed better with respect to SG compared to projects with DBB project delivery method. For the projects using DB project deliver method about of 42% of projects were completed on time and 21% of projects were completed under budget. No clear trend was observed for projects with DBB project delivery method with regard to SG.

Table 6.22. Project Delivery Method and Schedule Growth at Eleven Levels

Project Delivery Method	**Schedule growth**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
DBB	5 8.62 100.00	2 3.45 66.67	1 1.72 50.00	2 3.45 66.67	4 6.90 50.00	12 20.69 54.55	11 18.97 78.57	9 15.52 75.00	2 3.45 66.67	6 10.34 100.00	4 6.90 80.00	58
DB	0 0.00 0.00	0 0.00 0.00	1 5.26 50.00	1 5.26 33.33	2 10.53 25.00	8 42.11 36.36	3 15.79 21.43	3 15.79 25.00	1 5.26 33.33	0 0.00 0.00	0 0.00 0.00	19
other	0 0.00 0.00	1 16.67 33.33	0 0.00 0.00	0 0.00 0.00	2 33.33 25.00	2 33.33 9.09	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	0 0.00 0.00	1 16.67 20.00	6
Total	5	3	2	3	8	22	14	12	3	6	5	83

There was also interest in understanding if SG or anticipation of SG impacted the owner's or the contractor's contingency. Hypotheses 22 and 23 were evaluated to test the dependency correlation between SG and owner's and contractor's contingency. No significant dependency correlation was found in either test. Hypothesis 24 was evaluated to test the dependency correlation between SG and any of the risks ratings. No significant dependency correlation was found in any case.

6.5. Summary

In this chapter project performance measures were evaluated and dependency correlations between CG or SG and other project characteristics were explored and analyzed. Key findings and their implications are summarized here.

Most of reported projects encountered CG. About 72% of projects reported by public sector responders encountered CG, which was higher than what was found in projects reported by private sector. Cost growth was encountered even though risk assessment was used in most of the projects reported by public and private sectors. As high as 89% of reported complex projects encountered CG, which was the highest percentage observed for any type of projects, regardless of what project delivery method was used. New roads and expansion projects (PT-1 projects) performed better than other types of project with regard to CG.

Project delivery method did not appreciably affect CG performance of projects. About 68% of projects with DB project delivery method and 67% of projects with DBB project delivery method encountered CG. Cost growth was encountered more in large projects (with TPC greater than 50 million dollars) than in small projects (with TPC under 50 million dollars). This suggests that there is dependency correlation between project's size and CG. However, the total duration of project (TPD) did not have significant impact on CG. About 71% of projects, where RA was not used, encountered CG. Only 63% of projects, where RA was used, encountered CG. This means that the probability of encountering positive CG was lower when RA was used.

There is dependency correlation between SG and CG; whenever the project encountered SG, it also encountered CG. There is dependency correlation between CG and cost impact of risk drivers R9 (inaccuracy of existing utility locations and survey data) and R14 (surveys late and/or surveys in error). It was interesting to note that in most of the projects where RA was used cost impact of risk drivers were rated as low, despite the fact that the probability of these projects to encounter CG was higher than those that had high rating of cost impact of these risks. This perhaps is an indication that construction management and risk assessment practices lead professionals to underestimate the rating of CI-9 and CI-14 and their significance in impacting CG performance. Highway construction professionals' perceptions of cost impact of these risk drivers were different from the actual cost growth related probability in these projects. Professional perception regarding risks seems to be playing an important role in evaluating the risks.

The statistical analysis of ratings for RI, SI, and CI of other 29 risk drivers did not show any significant dependency correlation with CG. Similarly there was no statistical dependency correlation between SG and project parameters or ratings of risk drivers. However, there was statistical dependency correlation between SG and the use of RA. Projects where RA was used performed better than others with regards to SG. It must also be noted that there were 31% of projects where RA was used, but SG in the range of 0% to +6% was encountered. Also, 29% of the projects, where RA was not used, encountered SG of over 6%. Projects with DB project delivery method performed better with respect to SG compared to the projects with DBB project delivery method. About of 42% of DB projects were completed on time and 21% of projects were completed under budget.

Finally, it has been shown that testing the correlation between the ratings of RI, CI, and SI of risk drivers and CG was challenging. Only risk drivers R9 and R14 showed any correlation. It was interesting to note that the lower the rating for CI-9 and CI-14 the higher was the chance for cost growth. Nevertheless, the probability of CG was high for high ratings for cost impact of risk driver R14. Moreover, the probability of CG was higher at low rating than other levels for both risk drivers R9 and R14. This might indicate that the responders were either not able to rate the cost impact of these risk drivers effectively or they underestimated the significance of these risk drivers. Furthermore, it should be noted that most of the responders rated these risks as low impact on cost and schedule even though there was dependency correlation between cost impact of these risks and CG. Hence, their low ratings might be considered to mean refer that as the risks has already been controlled and accounted for in the completed reported projects and evaluated with respect to the allocated contingency, the impact of risks was perceived to be low.

The cost and schedule impact of these risk drivers were not evaluated clearly with respect to cost and schedule growth performance measures of projects due to potential unfamiliarity of responders with this kind of qualitative risk assessment and the difficulty to trace the impact level to specific CG percentage. It is also possible that most of these risk drivers are systemic or programmatic risk drivers rather than project specific. Nonetheless, the correlation findings emphasize the importance of risk drivers R9 and R14 in future planning for highway transportation projects. The lower rating levels of theses risk drivers could also be attributed to the use of higher contingency amounts to manage these risks in completed projects. This particular aspect is explored and discussed in next chapter. In next chapter the owner and contractor contingency percentages have been explained and evaluated with respect to other project's characteristics and ratings of RI, CI, and SI of 31 different risk drivers.

CHAPTER 7. CONTINGENCY

One of the strategies to reasonably estimate the project construction costs is to assign contingencies to different project cost components or to the total project base cost to account for project uncertainty and risk. Estimators have tried to estimate the adequate amount or percent of project contingencies so that cost growth can be avoided and the unused contingency at project completion can be minimized.

In the literature review (Chapter 2) different contingency definitions were explained. The main focus in this study was the contingency, used as part of budget or construction cost estimate, whether this contingency was allocated by the owner or by the contractor, and calculated as percentage of total construction cost. In some reported projects the contingency percentage was provided for both the owner's and contractor's contingency, whereas the others had only owner's contingency or contractor's contingency. There were differences in the contingency percentages reported by public and private sector organization (see Appendix C).

The reported percentages of contingencies were tested with ratings for RI, CI, and SI of 31 risk drivers. The main objective was to explore and identify the impact of the rating of the encountered risk drivers on contingency estimates. In this study a parametric method has been used to serve as a planning tool in assessing contingency for highway construction projects. Linear stepwise regression tests were used to identify the risk drivers that significantly influence the contingency percentages.

The responders had provided actual values for contingency percentages used in the reported projects. As it was discussed and highlighted in Chapter 4 the majority of responses for contingency percentages were either 5% or 10%. Hence, to carry out hypothesis testing two levels of contingency values were used. Level one was for contingency values of 5 percent or less and level two was for contingency values greater than 5 percent. Hypotheses 25 and 26 (see Chapter 3) were conducted using these two levels of contingency and the ratings of RI, CI, and SI for all 31 risk drivers. However, no dependency correlations were established for between any ratings for 31 risk drivers and owner's or contractor's contingency. Since actual values of contingency percentages were available, stepwise regression analysis was also performed and are discussed in following sections.

7.1. Owner's Contingency

In an effort to determine the risk drivers that influence the contingency amount, stepwise regression modeling was used. The ratings of RI, CI, and SI for all risk drivers were used as independent variables in the model. These rating values were tested against the dependent or response variable, y, which represented the reported contingency percentage by owner or contractor. SAS® software was used to determine the most important independent variables.

7.1.1. Owner's Contingency and Relative Importance of Risks (RI)

Out of total 97 reported projects in the survey, there were 29 projects with valid and complete ratings with regard to owner's contingency. Hence, only those 29 projects were used in the tests and analyses. The number of projects that were relevant when using RI and SI as independent variable was 29 and 26, respectively. The owner's contingency percentage was modeled using ratings of relative importance for all 31 risk drivers and the functional form of the model was as shown below. Stepwise regression was used for this purpose.

$$C_{owner.}\,\% = f(RI_1, RI_2, \ldots, RIi) \qquad 7.1$$

The final prediction model developed using ratings of RI for all risk drivers is shown in Figure 7.1.

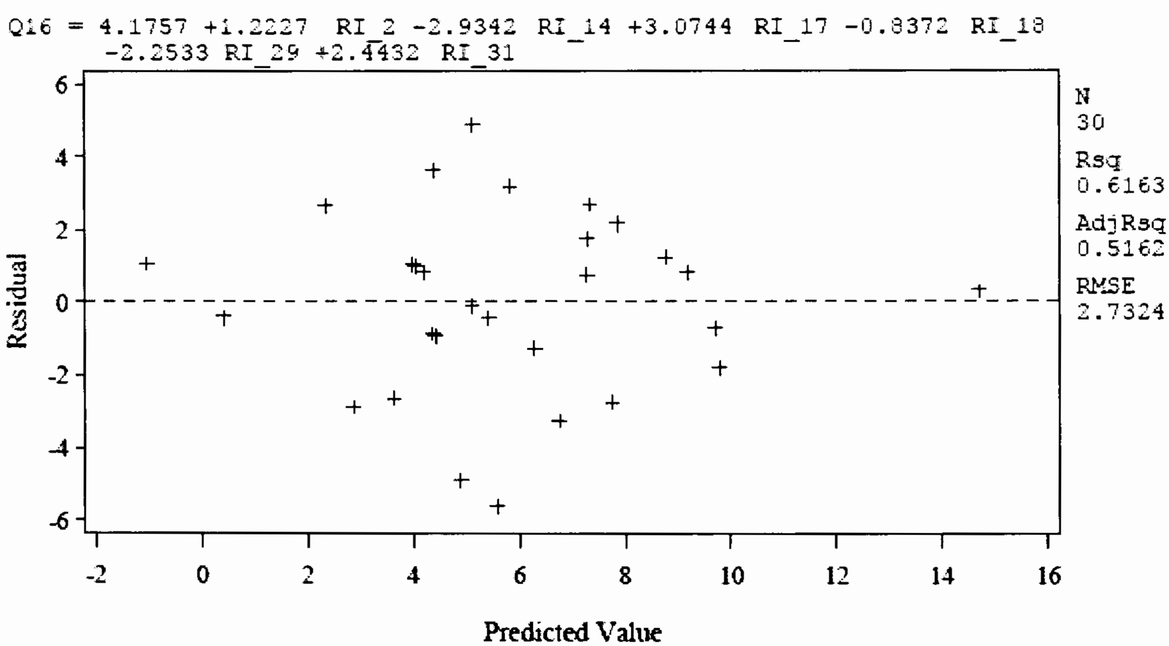


Figure 7.1. Linear Regression Model for Owner's Contingency

The most significant risk drivers influencing owner's contingency are shown in

Table 7.1. Since Adjusted R-Square was about 0.5 for this model, the model is useful in explaining about 50% of the total sample variation in contingency values. There were 29 projects with valid and complete rating data. As a result, only 29 projects were analyzed for this purpose. If the parameter estimate has positive sign, it suggests that the corresponding risk driver tends to increase the contingency percentage used by owners.

Table 7.1. Stepwise Regression of Owner's Contingency with Relative Importance Ratings

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	6	275.82443	45.97074	6.16	0.0006
Error	23	171.71723	7.46597		
Corrected Total	29	447.54167			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	4.17565	1.52192	56.20212	7.53	0.0116
RI-2	1.22271	0.40169	69.17651	9.27	0.0058
RI-14	-2.93425	0.66218	146.59935	19.64	0.0002
RI-17	3.07445	0.70543	141.80985	18.99	0.0002
RI-18	-0.83720	0.54058	17.90726	2.40	0.1351
RI-29	-2.25332	0.70589	76.07795	10.19	0.0041
RI-31	2.44320	0.85352	61.17470	8.19	0.0088

If the parameter sign is negative, it suggests that those risk drivers tend to lower the owner's contingency. There were 6 risk drivers that were found in the final model to influence the owner's contingency amount. The reasons why these risk drivers might influence owner's contingency are discussed next.

Risk driver R17 (inadequate constructability reviews) was found to be one of the most significant risk drivers influencing contingency amount used by owners. The higher the RI rating of risk driver R17, the higher the owner's contingency amount used. This risk driver is crucial in project planning phase where constructability reviews are essential part of construction management practice. So if the owners believe that constructability reviews have not been done adequately or might not be within the acceptable level, they use higher contingency percentage to prepare for any unknowns or uncertainty associated with cost and schedule impact of construction activities.

Risk driver R14 (surveys late and/ or surveys in error), ended up with having a negative parameter estimate, which seems erroneous at first. The negative estimate suggests that the lower the rating of relative importance for R14, the higher the reported owner's contingency. In Chapter 6, it was pointed out that most of the responders, who used RA in their projects, were considering the impact of this risk to be low even though the projects encountered CG. There could be two explanations for this. First, risk driver R14 may not be considered important if contingency amount is at a certain level. Second, the owners rated the relative importance of R14 low if they had increased contingency amount and considered that increase to have already addressed the impact of R14 and the impact of R14 on other risk drivers.

Risk driver R29 (inexperienced project manager) also had negative parameter estimate. A lower rating of RI for R29 seemed to suggest a high owner's contingency percentage. An explanation for this could be that owners have allocated higher contingency amount to take into account the lack of experience of project manager. Having addressed that concern in this manner, the owners did not consider this risk driver to be as important, so they rated it low. It should also be noted that there was no dependency correlation found between rating of RI for R29 and CG.

The rating of risk driver R2 (changes by owner's request) also impacted owner's contingency amount. If the owner anticipated more requests for changes, the owner rated CI as high and the owner's contingency amount assigned to the project was higher. Similarly, if the owner anticipated fewer requests for changes, the owner rated CI as low and assigned a lower amount for owner's contingency to the project.

There was a concern that some of these parameter estimates were negative because of multi-collinearity. Hence, multi-collinearity detection test was conducted and Variance Inflation Factors (VIF) was calculated. The results did not show the existence of multi-collinearity. The next section discusses the stepwise regression analysis of relationship between owner's contingency and cost impact of all 31 risk drivers.

7.1.2. Owner's Contingency and Cost Impact of Risks (CI)

A stepwise linear regression analysis of relating owner's contingency percentage to cost impact ratings also did not produce any meaningful model or results.

7.1.3. Owner's Contingency and Schedule Impact of Risks (SI)

Following functional form was used to conduct linear stepwise regression analysis of relationship between owner's contingency and schedule impact ratings.

$$C_{owner.}\% = f(SI_1, SI_2, \dots, SI_i) \qquad 7.2$$

The model developed from the analysis is shown in Figure 7.2. Ratings of SI of four risk drivers were found to influence the choice of owner's contingency amount (see Table 7.2).

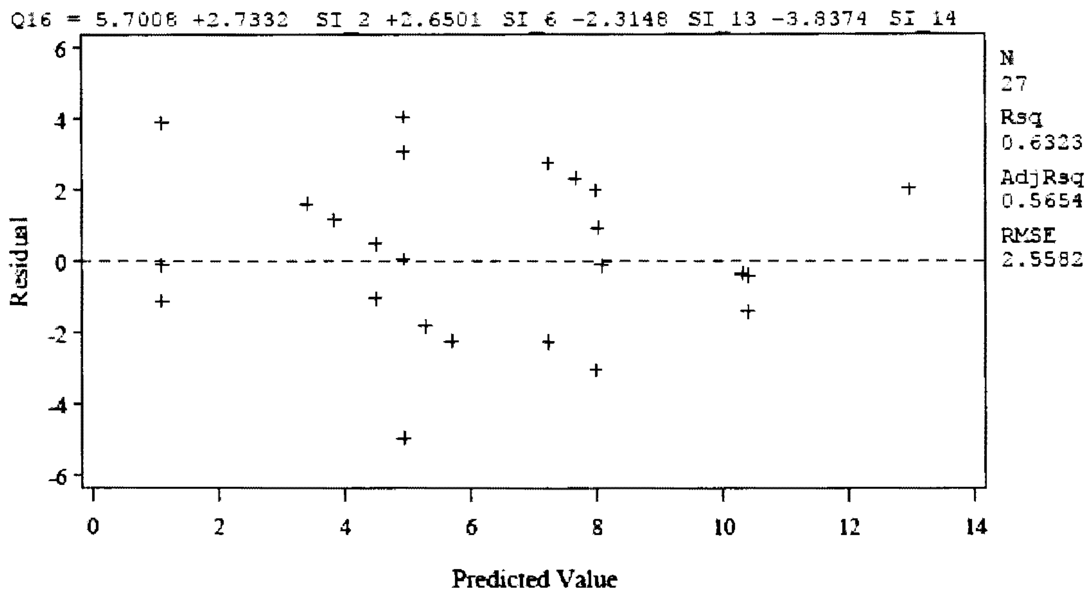


Figure 7.2. Stepwise Regression of Owner's Contingency with Schedule Impact Ratings

The rating of SI of risk driver R2 (changes by owner's request) impacted owner's contingency amount. If the owner anticipated more requests for changes, the owner rated SI as high and the owner's contingency amount assigned to the project was higher. The reverse is true also. If fewer changes were anticipated, then SI was rated as low and the owner's contingency percentage assigned to the project was low.

The SI of risk driver R14 (surveys late and/ or surveys in error), showed a negative parameter estimate for its schedule impact on owner's contingency. This can be explained using the argument that the responders may have rated its schedule impact as low because they might have considered that their contingency amount would cover the cost and delay of existing of this risk.

Table 7.2. Stepwise Regression of Owner's Contingency with Schedule Impact Ratings

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	4	247.54482	61.88620	9.46	0.0001
Error	22	143.97370	6.54426		
Corrected Total	26	391.51852			
Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**	**F Value**	**Pr > F**
Intercept	5.70079	1.51469	92.70086	14.17	0.0011
SI-2	2.73317	0.75913	84.83197	12.96	0.0016
SI-6	2.65012	0.90242	56.43821	8.62	0.0076
SI-13	-2.31484	0.87313	45.99869	7.03	0.0146
SI-14	-3.83735	0.85031	133.28257	20.37	0.0002

7.2. Contractor's Contingency

The same test procedures, which have been used with owner's contingency, has been used with contractor's contingency. Out of total 97 reported projects in the survey, there were 27 projects with valid and complete ratings. Hence only those 27 projects were used in the tests and analyses. The number of projects that were relevant when using RI, CI, and SI as independent variable was 23, 20, and 19, respectively.

7.2.1. Contractor's Contingency and Relative Importance of Risks (RI)

The contractor's contingency percentage was analyzed using the following functional form and ratings for relative importance.

$$C_{cont.}\ \% = f(RI_1, RI_2, \ldots, RI_i) \qquad 7.3$$

The predicting model developed using the contractor's contingency and the ratings of RI is shown in Figure 7.3 and the related results are provided in Table 7.3.

The rating of RI of risk drivers R2 (changes by owner's request) and R22 (inaccurate structures design) were found to be significant in predicting contractor's contingency and had positive impact. The contractors are more concerned about contingency amount if the design documents of delivered structures, provided by owner, are not appropriate or having some engineering flaws, which would in turn affect other risk

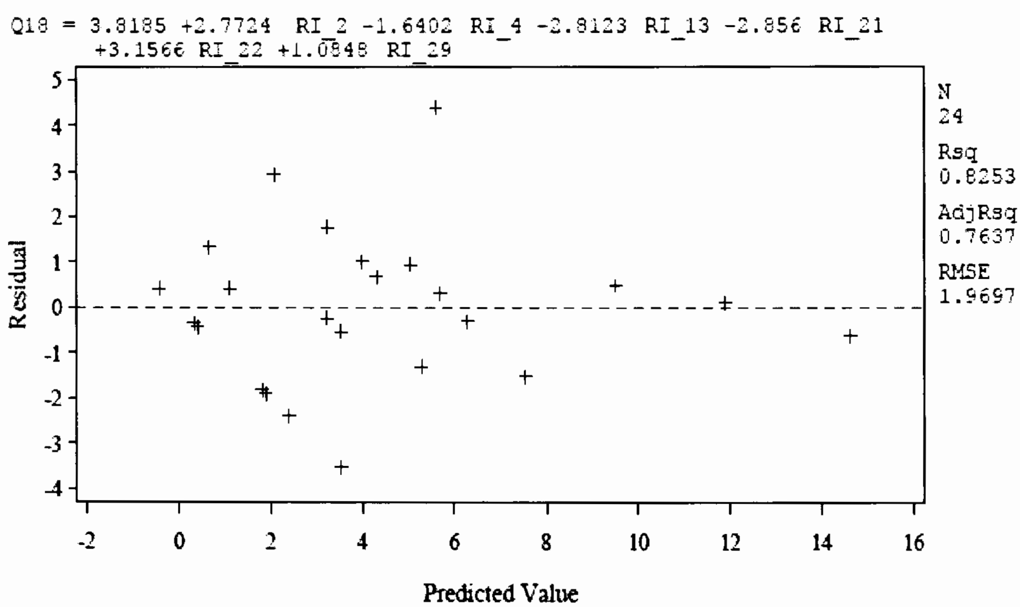


Figure 7.3. Stepwise Regression of Contractor's Contingency with RI Ratings of Risks

Table 7.3. Stepwise Regression of Contractor's Contingency with RI Ratings of Risks

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	6	311.67174	51.94529	13.39	<.0001
Error	17	65.95566	3.87974		
Corrected Total	23	377.62740			

Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**	**F Value**	**Pr > F**
Intercept	3.81848	1.02582	53.75786	13.86	0.0017
RI-2	2.77240	0.36969	218.19705	56.24	<.0001
RI-4	-1.64015	0.77841	17.22462	4.44	0.0503
RI-13	-2.81227	0.66762	68.84313	17.74	0.0006
RI-21	-2.85599	0.46463	146.58636	37.78	<.0001
RI-22	3.15662	0.93574	44.15115	11.38	0.0036
RI-29	1.08480	0.43899	23.69135	6.11	0.0243

drivers. The contractor also seems to increase contingency when rating of RI for risk driver R29 is high. The negative parameter estimates of risk drivers R4, R13, and R21 may suggest that the RI ratings of these risks by themselves do not affect contractor's contingency. However, having addressed these risks it could impact other risks positively and help reduce contingency amount needed.

7.2.2. Contractor's Contingency and Cost Impact of Risks (CI)

The contingency percentage was regressed against CI of 31 risk drivers using the following functional form.

$C_{cont.}\ \% = f(CI_1, CI_2, \ldots, CIi)$ 7.4

The prediction model that was developed is presented in Figure 7.4, and the results have been explained in Table 7.4. Cost impact of R22 (CI-22) and R9 (CI-9) were found to be the most significant independent variables in the model. R22 (inaccurate structures design) was found to impact the contractor's contingency, as did the rating of RI of R22. R9 (inaccuracy of existing utility locations and survey data) seems to negatively impact contractor's contingency. It was discussed in Chapter 6 that responders had rated low when cost growth was encountered and had rated low or high when cost growth was not encountered. It is also important to point out that the reported projects, which have high cost impact of this risk, did not encounter CG.

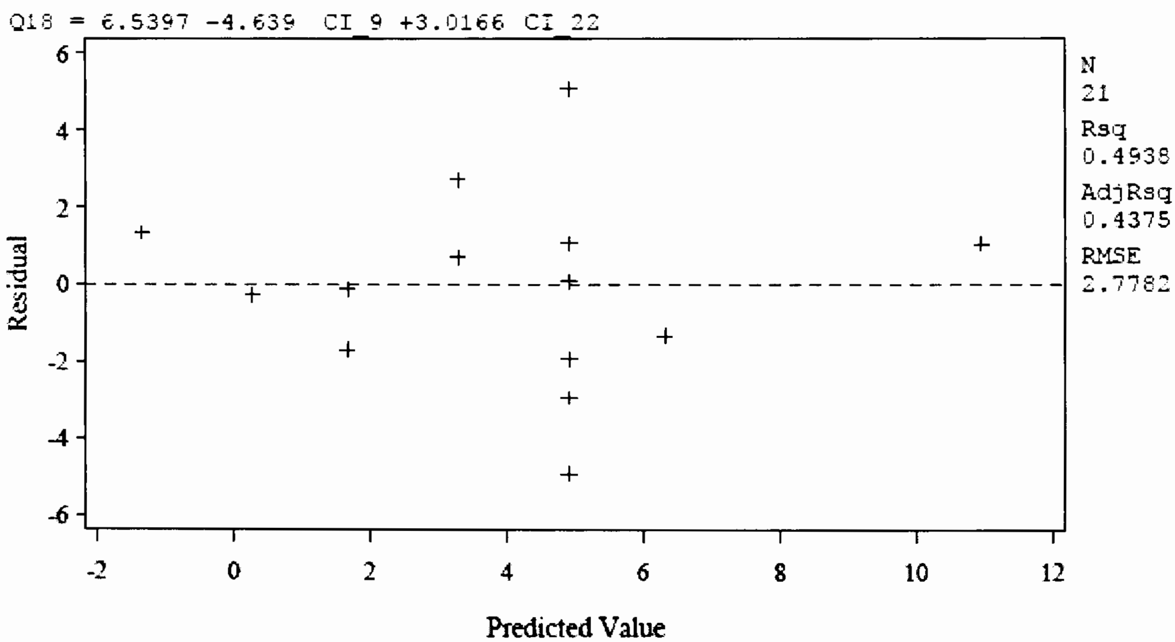


Figure 7.4. Stepwise Regression of Contractor's Contingency with CI Ratings of Risks

Table 7.4. Stepwise Regression of Contractor's Contingency with CI Ratings of Risks

Analysis of Variance						
Source		**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model		2	135.50412	67.75206	8.78	0.0022
Error		18	138.93160	7.71842		
Corrected Total		20	274.43571			
Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**		**F Value**	**Pr > F**
Intercept	6.53969	1.49170	148.34732		19.22	0.0004
CI-9	-4.63899	1.10726	135.47957		17.55	0.0006
CI-22	3.01661	1.02900	66.33359		8.59	0.0089

7.2.3. Contractor's Contingency and Schedule Impact of Risks (SI)

The impact of ratings of SI for 31 different risk drivers on contractor's contingency was analyzed using the following functional form and was tested using linear stepwise regression analysis.

$$C_{cont.}\ \% = f(SI_1, SI_2, \dots, SI_i) \qquad 7.5$$

The model developed has been presented in Figure 7.5 and the results have been explained in Table 7.5.

Contractor's contingency amount is positively impacted by the rating of SI for risk drivers R2 (changes by owner's request) and R7 (poor involvement of utility companies in planning stage). The rating of SI for risk drivers R6 (inadequate plan reviews by designers and contractors) and R28 (maintenance of traffic/ staging/ auxiliary lanes) had negative impact on predicting contractor's contingency percentage.

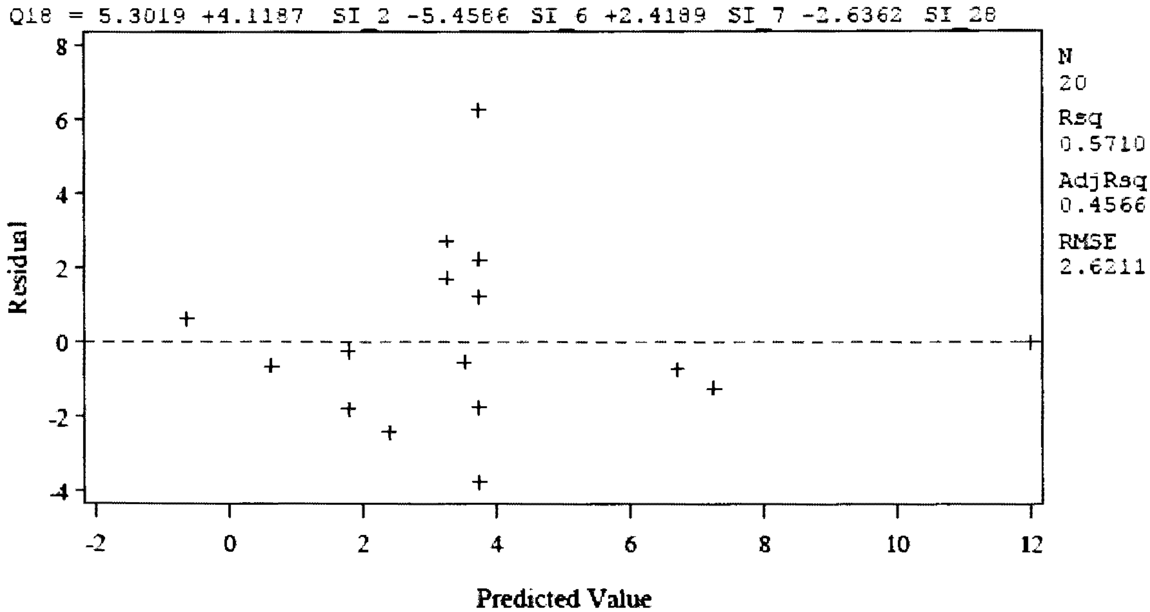


Figure 7.5. Stepwise Regression of Contractor's Contingency with SI Ratings of Risks

Table 7.5 Stepwise Regression of Contractor's Contingency with SI Ratings of Risks

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	4	137.17398	34.29349	4.99	0.0093
Error	15	103.05340	6.87023		
Corrected Total	19	240.22738			
Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**	**F Value**	**Pr > F**
Intercept	5.30193	1.53656	81.79713	11.91	0.0036
SI-2	4.11867	1.16703	85.57038	12.46	0.0030
SI-6	-5.45856	1.52692	87.80001	12.78	0.0028
SI-7	2.41889	1.41588	20.05166	2.92	0.1082
SI-28	-2.63624	1.11946	38.10017	5.55	0.0326

7.3. Summary

No dependency correlation were found between the contingency percentage and the ratings for any of the 31 risk drivers when carried out at two contingency levels (less than or equal to 5% and greater than 5%). Risk driver R17 (inadequate constructability reviews) was found to be the most critical risk drivers based on relative importance that positively influenced owner's contingency. Risk driver R2 (changes by owner's request) was found to be the most critical risk driver based on relative importance and schedule that impacted positively both the owner's contingency and contractor's contingency. Risk driver R22 (inaccurate structures design), based on relative importance rating and cost impact, was found to be the most significant risk driver influencing contractor's contingency amount.

It was interesting to find that R9 was rated low for high cost growth and high contingency percentages, and rated high for low or no cost growth and low contingency value. This could be explained in two ways. The rating for R9 is underestimated or the risk is thought to be mitigated when high contingency amount is determined and assigned to the project. It appeared that 5 percent was appropriate for both owner's and contractor's contingency.

The models developed and discussed in this chapter could assist in addressing risks in highway construction projects by looking at the rating of RI, CI, and SI of risk drivers and judging on the contingency percentage to use. However, the models cannot be generalized and used without understanding the boundaries within which to use them.

Finally, for better decision making process in predicting construction contingency amount from contractor's perspective, all the three type of models (one for RI, CI, and SI) can be used whenever the reported risk drivers have the probability of occurrence in construction phase. By calculating the three values, the project planner can then choose the highest value for contingency to be conservative in determining the construction cost estimate. The chosen value could be the predetermined contingency value from these developed models. Using this method in planning phase, where project definition is not completely identified and the detailed work break down structure has not been developed, appropriate contingency range estimates can be developed.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATION

The research conducted in this dissertation emphasized the importance of consideration of risks in highway construction projects. The research also identified numerous challenges in getting appropriate and adequate data. The study provided many insights, based on numerous analyses, which can be beneficial for highway construction projects.

8.1. Conclusions

Cost and time overruns are the greatest risks that impact highway construction projects and influence their performance. Using risk assessment has been recognized as an important tool to improve performance of highway construction projects in the U.S., particularly large projects with total planned cost (TPC) greater than 50 million dollars. It was also found that use of risk assessment is more prevalent in projects with duration greater than 36 months than in projects with lower duration. In addition, it was found that the use of risk assessment in projects tends to lower the rating of cost impact (CI) and schedule impact (SI) of most encountered risks.

Project performance measures that were used in this study were cost growth (CG) and schedule growth (SG). Data challenges related to completeness and accuracy allowed only 48 projects for analysis. By studying risk drivers that impact cost and schedule growth, the study identified the critical construction risks in highway construction projects in the United States. Using the mean values of the ratings of relative importance (RI), cost impact (CI), and schedule impact (SI) of 31 risk drivers, the study prioritized the most significant risk drivers for different types of project. Risk drivers R1 (project purpose poorly defined), R2 (changes by owner's request), and R3 (changes to unforeseen site environmental requirements) were found to significantly impact all types of projects. Interestingly, all these risk drivers are related to the scope of the project. However, there were also some uniqueness and difference found in different types of project with regard to other significant risks based on their relative importance. Relative importance (RI) of a risk indentifies how significantly it impacts other risks in highway construction project. Risk driver R8 (high number of utilities in the site) more significantly impacted other risks in new road construction and expansion projects (PT-1) than in any other type of project. Risk driver R25 (constraints in the construction work window) was found to more significantly impact other risks in road rehabilitation and reconstruction projects (PT-2) than in any other type of project. Risk driver R16 (design errors and omissions) was found to more significantly impact other risks in bridge and tunnel projects (PT-3) than in any other type of project. Risk driver R24 (delay of permits) was found to more significantly impact other risks in complex projects (PT-5) than in any other type of project.

Risk drivers R8 (high number of utilities in the site), R20 (unforeseen and different geotechnical conditions), R19 (poor preliminary soil information and investigations), and R5 (land acquisition delay) were found to be the most significant risk drivers that impacted cost growth and schedule growth in new road construction and expansion projects (PT-1). Hence, the highway construction project professionals should focus on assessing and setting construction management plans for these identified risk drivers for new road construction or expansions projects. This is especially true for most of the highway construction projects in newly developed and urban regions, where large number of utilities are located and found in the vicinity of the project site.

Risk drivers R25 (constraints in construction work window) and R26 (material availability and price inflation) are the most significant risk drivers that impacted cost growth (CG) in road rehabilitation and reconstruction projects (PT-2). Risk drivers R25 (constraints in construction work window), R7 (poor involvement of utility companies in planning stage), and R9 (inaccuracy of existing utility locations and survey data) significantly impacted schedule growth (SG) in road rehabilitation and reconstruction projects (PT-2). It must be emphasized that PT-2 projects are different from PT-1 projects in their scope of work, and are more involved with existing roads and changing their capacities. In addition, PT-2 projects have to maintain traffic operations throughout the duration and geometric length of the project. Moreover, in PT-2 projects cost related to use of asphalt is much larger proportion of the total project costs and is greatly impacted the price fluctuation of oil.

Risk driver 25 (constraints in construction work window) has significant impact on schedule growth (SG) in bridge and tunnel projects (PT-3), but no significant impact on cost growth (CG). This was somewhat different than what was found for project type PT-2. One of the reasons for this difference could be because the extent of geometric length is less in PT-3 compared to that in PT-2. Risk driver R27 (subcontractors errors and delays) more significantly impacted on cost growth (CG) and schedule growth (SG) in project type PT-3 than in any other type of project. This could be attributed to the fact that PT-3 projects have more superstructure components, which need very skilled subcontractors specialized in this area of the construction profession.

For complex projects (PT-5), risk driver R3 (changes to unforeseen site environmental requirements) was found to most significantly impact cost growth and schedule growth. As a matter of fact, risk driver R3 was significant in all types of project, but its impact was most pronounced in PT-5 projects because of the complexity of the projects. Impact of risk driver R24 (delay of permits) was also most pronounced in PT-5 projects.

The study also analyzed the correlation between project characteristics and the cost or schedule growth in project. Project characteristics data obtained from the survey were both qualitative and quantitative in nature. The analyses were also done using the ratings of RI, CI, and SI of 31 risk drivers. These analyses provided several insights. Most of the projects encountered cost growth (CG) more than the schedule growth (SG). Project delivery method (design-build versus design-bid-build) impacted and improved schedule growth (SG), but had no appreciable difference in impact on cost growth (CG). This was not found in previous research studies. It was also found that probability of cost growth was more in large projects (with total planned cost (TPC) greater than 50 million dollars) than smaller projects (with TPC less than 5 million dollars). The use of risk assessment approach in projects improved schedule growth better than it did the cost growth.

It was quite challenging to correlate project cost growth with ratings of RI, CI, and SI of 31 different risk drivers. There were variabilities in the ratings reported by the responders. The reasons for these variabilities could be because (a) the responders were not totally familiar with rating of the risks, (b) some responders found it difficult to relate their perceptions about degree of impact of any risk on project's cost and schedule performance without correlating these risks with certain construction activities, and (c) most of the risk drivers were more systemic or programmatic in nature than being project specific. It was also important to find from some responses that some of the risks were mitigated by use of higher contingency.

One anomaly was found when assessing the dependency correlations between CG and ratings of RI, CI, and SI for 31 risk drivers. Risk drivers R9 (inaccuracy of existing utility locations and survey data) and R14 (surveys late and/ or surveys in error) impacted cost growth in counter-intuitive manner. Most of the projects reported in survey responses where the ratings of impacts for these two risk drivers were low, the projects had encountered cost growth (CG) and also had higher contingency percentages assigned.

Three different models were developed using step wise regression for predicting owner's contingency as well as contractor's contingency percentages. Analyses of impact of rating of risk drivers on the assignment of owner's and contractor's contingency percentages in projects revealed some interesting findings. Risk driver R2 (changes by owner's request) was found to influence the assignment of both the owner's contingency and contractor's contingency. Both owners and contractors use higher contingency percentage when it is anticipated that there will be more requests for changes in project scope by owners during the life of the project. It is important to minimize the probability of these requests for changes from the owners. A well-defined project scope with minimal need for request of changes by owners must be the main goal for project planners in project planning phase. Risk driver R17 (inadequate constructability reviews) was found to impact assignment of only owner's contingency. The rating of relative importance of risk driver R22 (inaccurate structures design) plays an importance role in assignment of contractor's contingency.

Majority of professionals who responded to the survey and the projects that were reported in survey responses seemed to have conducted or used risks assessment and allocated appropriate and adequate contingency amount to deal with the potential and encountered risks. However, there were several correlations of cost growth and schedule growth that could not be established using the data obtained from the responses to the survey. This indicates the importance of studying and planning not only for project-specific risk drivers, but also for other systemic and programmatic risk drivers. It is always much more challenging to trace the cost and schedule impact of the systemic and programmatic risks.

Highway construction project type, which describes project context and was categorized in five types in this study, is playing big role in identifying the significant construction risks. Every project type has different set of construction risk drivers that impact cost and schedule performance objectives. The study has identified these risk drivers, which should be considered for more in-depth analysis in future project constructability reviews in the planning phase and be updated through project development phases.

8.2. Significance of the Study

The study was a comprehensive evaluation of 31 risk drivers considered most significant for highway construction projects, particularly with regard to their impact on cost and schedule performance of projects. Investigating the correlation between project characteristics (based on qualitative and quantitative data) and the ratings of RI, CI, and SI of significant construction risk drivers was the critical part in this study, and has been studied in this manner for the first time.

There has been no significant study done for understanding the impact of risk drivers (using rating data) on project performance measures, particularly related to cost and schedule. This study highlighted the impact of highway construction professionals' perception regarding project risks on project performance for completed projects. It was clear that professional experience and perception regarding risks also plays an important role in planning for contingencies and in allocation and assignment of contingency percentages by owners as well as contractors. It was also highlighted how this assignment of contingency percentage is same and different between owners and contractors. It was interesting to find that the professionals rate impact of risk drivers low when risk assessment is used. Hence, it is important to emphasize that the time frame for risk assessment process has an impact on which risks are how significant at the time of assessment. The significant findings regarding the studied risk drivers should be considered in any future planning of highway construction projects.

8.3. Recommendations

Construction companies should focus on using historical data, similar to the ones collected from the survey and used in this research, from completed projects. Such data compilations can provide more clarity and additional insights regarding dependency correlations, which in turn can be helpful in developing reliable predictive models. In addition, additional analyses with additional data can be used to develop additional guidelines and even probability distributions for improved planning and more effective use of risk assessment for project-specific risk drivers in future projects. Furthermore, project planners should consider and assess systemic and programmatic risk drivers and include them in a holistic risk assessment approach.

Another important observation from this research was that there is still lot of room for improvement in assessing risks more effectively and to comply with the project management standards relevant and adopted for present day and future. None of the responders provided any formal risk register document regarding the project they reported on as part of survey responses. For private sector projects it might be considered confidential, but for the public sector projects this should be available to the public, if there is such a document. Risk registers contain very important and relevant information, which can be very useful in analyses and development of models.

There is need for increased use of the quantitative risk assessment techniques in highway construction industry. There is a need to develop more reasonable estimates for probabilities and ranges for values of input variables related to cost and schedule performance measures of highway construction projects. Improved values for input variables can enable project planners and professionals to develop better estimates at higher confidence levels for outputs such as cost, time, and contingency, throughout the project development cycle. In addition, it can also enable development of better estimates of total cost and time probability distribution curves. Probabilistic simulation analysis can be enhanced with such models, results, and findings.

New emphases should be considered and placed in the differentiation of risk drivers as programmatic and project-specific, in quantifiable manner so impact of both types of risks can be traced to specific construction activities and be aggregated for project as a whole. This would be more effective in precisely identifying the cost and schedule impact of risk drivers on project performance. Last, but not the least, there is also an important need and challenge to educate and train highway construction professionals and students in risk management and assessment techniques.

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APPENDIX A. STUDY ABBREVIATIONS

BC	Base Cost	
BD	Base Duration	
$C_{cont.}$ %	Contractor's Contingency	
CG	Cost Growth	
CI-*i*	Cost Impact of Risk (*i*)	and *i*= 1, 2, 3…, 31
C_{owner}%	Owner's Contingency	
DB	Design-Build	
DBB	Design-Bid-Build	
FC	Final Cost	
FD	Final Duration	
LS	Lump Sum	
PDM	Project Delivery Method	
PM	Payment Method	
PT	Project's Type	
PT-1	New Road Construction/Expansion Project	
PT-2	Road Rehabilitation/Reconstruction Project	
PT-3	Bridge/Tunnel Project	
PT-4	ITS-Intelligent Traffic Systems Project	
PT-5	Complex Project-Combination of some of all types	
R*i*	Risk or Risk driver (*i*)	and *i*= 1, 2, 3…, 31

RI-*i*	Relative Importance of Risk (*i*) and *i*= 1, 2, 3…, 31
SG	Total Schedule Growth/ Schedule Growth
SI-*i*	Schedule Impact of Risk (*i*) and *i*= 1, 2, 3…, 31
TPC	Total Planned Project Cost
TPD	Total Planned Project Duration
UP	Unit Price

APPENDIX B. THE SURVEY FORM

Modeling Impact of Risk on Highway Projects

The purpose of this survey is to collect risk and other data related to highway projects for a research study, which will be used to improve our understanding and model impact of risks on highway projects. This survey is intended to be directed to individual, who is involved in highway projects, whether as technical professional, contractor, consultant, owner, or project company representatives, from private and public sectors.

The survey consists of two sections. The first section includes general questions about the responder and the organization which he/she belongs to. The second section seeks responses regarding importance and impact of construction risk drivers in completed highway projects the responder was involved in.

This survey is voluntarily effort by the responders. However, the responses from responder are critical to complete and make this study meaningful, and therefore are greatly appreciated. The survey should take about 20 minutes to complete. If you have any questions or concern you might contact Mohamed Diab @mohamed.diab@ndsu.edu

Part-I

General Questions:

1. Responder job title:

2. Organization location; State:

3. What type of organization do you work for?

- State Department DOT
- Public agency
- A/E Consultant
- Contractor/subcontractor
- Toll Authority
- Design Firm
- Design-builder
- Other

4. Do you use risk analysis for all your projects?

- None
- Some projects
- All projects

5. How many years of experience do you have in risk analysis and assessment? Years

6. Please Rate how much important do you believe that risk management is playing a role in highway project cost/time performance

- Not important
- Fairly important
- Important
- Very Important
- Extremely important

Part-II

Please answer the following questions for the chosen projects: Please choose up to three different completed highway projects you have been involved in and answer the following section for each project as it has been listed as follows:

Project #1

7. Project location (State):

8. Project type:

- Road, New construction/expansion
- Road, Rehabilitation/reconstruction/
- Bridge/Tunnel
- ITS
- Complex project, combination of the above

9. Highway type:

- Rural
- Urban

10. Project delivery method:

- Design Bid Build
- Design-Build
- Other (specify)

11. The procurement method which has been used in this project is

- Low bid
- Alternative bids/design
- Multi-parameter bidding
- Best-value
- Other (specify)

12. Payment method is

- Lump sum
- Unit price
- Other (specify)

13. The total <u>planned</u> project cost at contract award is

- < 5 Millions
- 5 - < 20 Millions
- 20 - < 50 Millions
- 50 - 100 Millions
- >100 Millions

14. The official project start year:

15. The average total contract <u>planned</u> project duration is

- < 6 months
- 6 - 18 months
- 18 - < 36 months
- 36 - 48 months
- > 48 months

16. The owner total project contingency amount is %

17. The owner contingency covers the following

18. The contractor total project contingency amount is ______ %

19. The contractor contingency covers the following

20. The average total cost growth% [=((final construction cost-planned cost)/ planned cost)*100] in this project is

- < -14%
- -14 - < -10%
- -10 - < -6%
- -6 - < -3%
- -3 - < 0%
- 0%
- >0 - < 3%
- 3 - < 6%
- 6 - < 10%
- 10 - 14%
- > 14%

21. The average total schedule growth% [=((total time-total as planned)/total as planned)*100] in this project is

- < -14%
- -14 - < -10%
- -10 - < -6%
- -6 - < -3%
- -3 - < 0%
- 0%
- >0 - < 3%
- 3 - < 6%
- 6 - < 10%
- 10 - 14%
- > 14%

22. The responder's role in this project is

23. Was risk analysis and assessment used in this project?

- Yes
- No

Part-III

Listed below are project construction risk drivers in highway projects in the U.S. and they have been identified at the end of construction planning phase. Please identify the encountered risk in your project, rate and assess the relative importance, and rate the impact of risk drivers on cost growth and schedule growth for each of the risk drivers listed, according to your experience in these types of projects. You may also write-in additional risk drivers, if not already in the list and provide responses for those risks also.

1. **Describe the encountered risk—please provide any details which will clarify the nature of risk.**
2. **Relative importance**; measures how the evaluated risk is critical to the occurrence and severity of other risks and the project objectives; cost and time
    1) Very low
    2) Low
    3) Moderate
    4) High
    5) Very High
3. **Risk impact on Cost growth%** [=((final construction cost-planned cost)/ planned cost)*100]
    1) Low
    2) medium
    3) high
4. **Risk impact on Schedule growth%** [=((total time-total as planned)/total as planned)*100]
    1) low
    2) medium
    3) high

24. Construction Phase Risk Drivers:

	Describe the encountered risk	Relative importance					Risk impact on Cost growth%			Risk impact on Schedule growth%		
		Very Low	Low	Moderate	High	Very High	Low	Medium	High	Low	Medium	High
I. Project scope:												
Project purpose is poorly defined												
Changes by owner's request												
Changes to unforeseen site environment requirements												
II. Right of Way:												
Right of Way analysis in error												
Land acquisition delay												
III. Utility conflicts:												
Inadequate plan reviews by designers and contractors/ design errors												
Poor involvement of utility companies in planning stage												
High number of utilities in the site												
Inaccuracy of existing utility locations and survey data												
Poor coordination among utility agencies, designers, and contractors												
Increased utility relocation costs												
Poor engineering practice within the state												
Utility damages by contractors/subcontractors faults in construction												
IV. A/E services:												
Surveys late and/or surveys in error												

Inexperienced professionals for this type of project

Design errors and omissions

Inadequate Constructability reviews

Delay in QA/QC services

Poor preliminary soil information and investigations

Unforeseen and/or different geotechnical conditions

Unforeseen hazard conditions

Inaccurate structures design

Poor communication with owner and contractor

V. Project construction management:

Delay of permits

Constraints in construction work window

Material availability and price inflation

Subcontractors errors and delays

Maintenance of traffic/staging/auxiliary lanes

Inexperienced project manager

Safety issues

Warranty issues

Other

Other

Please add your comments:

APPENDIX C. DETAILED DESCRIPTIVE FREQUENCY TABLES

Table C.1. Frequency Table of Location of Organization of Survey Responders

Organization Location	Frequency	Percent	Cumulative Frequency	Cumulative Percent
ALASKA	1	1.02	1	1.02
ARIZONA	3	3.06	4	4.08
CALIFORNIA	5	5.10	9	9.18
COLORADO	1	1.02	10	10.20
CONNECTICUT	2	2.04	12	12.24
FLORIDA	6	6.12	18	18.37
GEORGIA	4	4.08	22	22.45
ILLINOIS	4	4.08	26	26.53
MARYLAND	8	8.16	34	34.69
MINNESOTA	9	9.18	43	43.88
NEBRASKA	1	1.02	44	44.90
NEW MEXICO	2	2.04	46	46.94
NEW YORK	6	6.12	52	53.06
NORTH CAROLINA	1	1.02	53	54.08
NORTH DAKOTA	1	1.02	54	55.10
OHIO	1	1.02	55	56.12
OKLAHOMA	1	1.02	56	57.14
OREGON	6	6.12	62	63.27
PENNSYLVANIA	5	5.10	67	68.37
TENNESSEE	1	1.02	68	69.39
TEXAS	5	5.10	73	74.49
UTAH	4	4.08	77	78.57
VIRGINIA	10	10.20	87	88.78
WEST VIRGINIA	4	4.08	91	92.86
WISCONSIN	7	7.14	98	100.00

Table C.2. Frequency Table of Types of Organization of Survey Responders

Organization type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
State department DOT	19	19.39	19	19.39
Toll authority	1	1.02	20	20.41
Public agency	4	4.08	24	24.49
Design firm	3	3.06	27	27.55
A/E consultant	29	29.59	56	57.14
Contractor/ subcontractor	33	33.67	89	90.82
other	9	9.18	98	100.00

Table C.3. Frequency Table of the Use of Risk Assessment

Using risk assessment	Frequency	Percent	Cumulative Frequency	Cumulative Percent
None	13	13.27	13	13.27
Some	50	51.02	63	64.29
All	35	35.71	98	100.00

Table C.4. Frequency Table on Importance of Risk Management for Project Performance

Importance of risk management	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Not Important	5	5.10	5	5.10
Fairly Important	15	15.31	20	20.41
Important	18	18.37	38	38.78
Very Important	49	50.00	87	88.78
Extremely Important	11	11.22	98	100.00

Table C.5. Frequency Table of Experience of Organization of Survey Responders

Number of years of experience	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	8	8.70	8	8.70
1.5	1	1.09	9	9.78
2	4	4.35	13	14.13
3	2	2.17	15	16.30
4	2	2.17	17	18.48
5	9	9.78	26	28.26
7	1	1.09	27	29.35
10	13	14.13	40	43.48
13	1	1.09	41	44.57
14	1	1.09	42	45.65
15	9	9.78	51	55.43
19	3	3.26	54	58.70
20	9	9.78	63	68.48
24	3	3.26	66	71.74
25	12	13.04	78	84.78
30	4	4.35	82	89.13
32	1	1.09	83	90.22
35	3	3.26	86	93.48
36	3	3.26	89	96.74
40	1	1.09	90	97.83
45	1	1.09	91	98.91
50	1	1.09	92	100.00

Table C.6. Frequency Table of Location of Survey Responders

Project Location	Frequency	Percent	Cumulative Frequency	Cumulative Percent
ALASKA	1	1.02	1	1.02
ARIZONA	3	3.06	4	4.08
CALIFORNIA	4	4.08	8	8.16
COLORADO	1	1.02	9	9.18
DELAWARE	1	1.02	10	10.20
DISTRICT OF COLUMBIA	2	2.04	12	12.24
FLORIDA	9	9.18	21	21.43
GEORGIA	2	2.04	23	23.47
ILLINOIS	4	4.08	27	27.55
LOUISIANA	1	1.02	28	28.57
MARYLAND	8	8.16	36	36.73
MINNESOTA	8	8.16	44	44.90
MISSOURI	1	1.02	45	45.92
NEBRASKA	1	1.02	46	46.94
NEW MEXICO	2	2.04	48	48.98
NEW YORK	6	6.12	54	55.10
NORTH CAROLINA	1	1.02	55	56.12
OHIO	1	1.02	56	57.14
OKLAHOMA	1	1.02	57	58.16
OREGON	6	6.12	63	64.29
PENNSYLVANIA	5	5.10	68	69.39
SOUTH CAROLINA	2	2.04	70	71.43
SOUTH DAKOTA	1	1.02	71	72.45
TENNESSEE	1	1.02	72	73.47
TEXAS	3	3.06	75	76.53
UTAH	4	4.08	79	80.61
VIRGINIA	8	8.16	87	88.78
WEST VIRGINIA	4	4.08	91	92.86
WISCONSIN	7	7.14	98	100.00

Table C.7. Frequency Table of Regional Location of Survey Responders

Regions	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1-North East	12	12.24	12	12.24
2-Midwest	23	23.47	35	35.71
3-West	21	21.43	56	57.14
4-South	42	42.86	98	100.00

Table C.8. Frequency Table of Project Types in Responses

Project type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
(PT-1)	33	33.67	33	33.67
(PT-2)	19	19.39	52	53.06
(PT-3)	21	21.43	73	74.49
(PT-5)	25	25.51	98	100.00

Table C.9. Highway Type Frequency

Highway type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Rural	35	36.46	35	36.46
Urban	61	63.54	96	100.00

Table C.10. Frequencies of Different Project Delivery Methods

Delivery method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
DBB	65	67.01	65	67.01
DB	23	23.71	88	90.72
Other	9	9.28	97	100.00

Table C.11. Frequencies of Different Procurement Methods

Procurement Method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Low Bid	63	64.95	63	64.95
Alt bid	2	2.06	65	67.01
Multi	3	3.09	68	70.10
Best-value	26	26.80	94	96.91
Other	3	3.09	97	100.00

Table C.12. Frequencies of Different Payment Methods

Payment method	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Lump Sum	31	32.29	31	32.29
Unit Price	62	64.58	93	96.88
Other	3	3.13	96	100.00

Table C.13. Frequencies of Different Total Project Planned Cost Ranges

Total planned cost	Frequency	Percent	Cumulative Frequency	Cumulative Percent
< 5	8	8.42	8	8.42
5-<20	20	21.05	28	29.47
20-<50	25	26.32	53	55.79
50-100	17	17.89	70	73.68
> 100	25	26.32	95	100.00

Table C.14. Frequencies of Different Project Start Year

Project Start Year	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1972	1	1.05	1	1.05
1978	1	1.05	2	2.11
1984	1	1.05	3	3.16
1986	1	1.05	4	4.21
1991	1	1.05	5	5.26
1997	1	1.05	6	6.32
1998	1	1.05	7	7.37
1999	1	1.05	8	8.42
2000	3	3.16	11	11.58
2001	2	2.11	13	13.68
2002	2	2.11	15	15.79
2003	4	4.21	19	20.00
2004	9	9.47	28	29.47
2005	10	10.53	38	40.00
2006	15	15.79	53	55.79
2007	13	13.68	66	69.47
2008	21	22.11	87	91.58
2009	8	8.42	95	100.00

Table C.15. Frequencies of Different Project Planned Duration Ranges

Total planned duration (TPD)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<6 months	5	5.21	5	5.21
6-<18	19	19.79	24	25.00
18-<36	42	43.75	66	68.75
36-48	19	19.79	85	88.54
>48 months	11	11.46	96	100.00

Table C.16. Frequencies of Different Owner's Contingency Percentages

Owner's Contingency %	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	10	14.49	10	14.49
1	3	4.35	13	18.84
2	1	1.45	14	20.29
3.5	5	7.25	19	27.54
4	1	1.45	20	28.99
5	15	21.74	35	50.72
7	1	1.45	36	52.17
8	3	4.35	39	56.52
9	4	5.80	43	62.32
10	16	23.19	59	85.51
12	1	1.45	60	86.96
15	6	8.70	66	95.65
20	3	4.35	69	100.00

Table C.17. Frequencies of Different Contractor's Contingency Percentages

Contractor's Contingency %	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	17	29.31	17	29.31
0.5	1	1.72	18	31.03
1	1	1.72	19	32.76
1.55	1	1.72	20	34.48
2	3	5.17	23	39.66
3	4	6.90	27	46.55
4	1	1.72	28	48.28
5	11	18.97	39	67.24
6	5	8.62	44	75.86
8	1	1.72	45	77.59
10	7	12.07	52	89.66
12	3	5.17	55	94.83
14	1	1.72	56	96.55
15	1	1.72	57	98.28
25	1	1.72	58	100.00

Table C.18. Frequencies of Different Cost Growth Levels

Total cost growth percentage	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-14%	4	4.82	4	4.82
-14-<-10%	6	7.23	10	12.05
-10-< -6%	1	1.20	11	13.25
-6-< -3%	5	6.02	16	19.28
-3 -< 0%	6	7.23	22	26.51
0%	6	7.23	28	33.73
>0- < 3%	16	19.28	44	53.01
3 -< 6%	19	22.89	63	75.90
6 -< 10%	5	6.02	68	81.93
10-14%	7	8.43	75	90.36
>14%	8	9.64	83	100.00

Table C.19. Frequencies of Different Schedule Growth Levels

Schedule Growth	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<-14%	5	5.95	5	5.95
-14-<-10%	3	3.57	8	9.52
-10-< -6%	2	2.38	10	11.90
-6-< -3%	3	3.57	13	15.48
-3 -< 0%	8	9.52	21	25.00
0%	22	26.19	43	51.19
>0- < 3%	14	16.67	57	67.86
3 -< 6%	12	14.29	69	82.14
6 -< 10%	4	4.76	73	86.90
10-14%	6	7.14	79	94.05
>14%	5	5.95	84	100.00

Table C.20. Frequencies on Use of Risk Assessment

Using risk assessment	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Yes	53	62.35	53	62.35
No	32	37.65	85	100.00

Table C.21. Relative Importance Ratings Frequency

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-1				
1	12	28.57	12	28.57
2	5	11.90	17	40.48
3	8	19.05	25	59.52
4	9	21.43	34	80.95
5	8	19.05	42	100.00
RI-2				
1	5	11.11	5	11.11
2	16	35.56	21	46.67
3	11	24.44	32	71.11
4	7	15.56	39	86.67
5	6	13.33	45	100.00
RI-3				
1	6	13.95	6	13.95
2	8	18.60	14	32.56
3	11	25.58	25	58.14
4	10	23.26	35	81.40
5	8	18.60	43	100.00
RI-4				
1	16	41.03	16	41.03
2	7	17.95	23	58.97
3	4	10.26	27	69.23
4	5	12.82	32	82.05
5	7	17.95	39	100.00
RI-5				
1	16	41.03	16	41.03
2	5	12.82	21	53.85
3	3	7.69	24	61.54
4	8	20.51	32	82.05
5	7	17.95	39	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-6				
1	11	27.50	11	27.50
2	8	20.00	19	47.50
3	9	22.50	28	70.00
4	5	12.50	33	82.50
5	7	17.50	40	100.00
RI-7				
1	9	23.08	9	23.08
2	8	20.51	17	43.59
3	10	25.64	27	69.23
4	6	15.38	33	84.62
5	6	15.38	39	100.00
RI-8				
1	9	23.08	9	23.08
2	8	20.51	17	43.59
3	8	20.51	25	64.10
4	5	12.82	30	76.92
5	9	23.08	39	100.00
RI-9				
1	8	21.05	8	21.05
2	9	23.68	17	44.74
3	11	28.95	28	73.68
4	3	7.89	31	81.58
5	7	18.42	38	100.00
RI-10				
1	9	21.95	9	21.95
2	10	24.39	19	46.34
3	8	19.51	27	65.85
4	7	17.07	34	82.93
5	7	17.07	41	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-11				
1	14	36.84	14	36.84
2	11	28.95	25	65.79
3	6	15.79	31	81.58
4	1	2.63	32	84.21
5	6	15.79	38	100.00
RI-12				
1	12	32.43	12	32.43
2	12	32.43	24	64.86
3	6	16.22	30	81.08
4	4	10.81	34	91.89
5	3	8.11	37	100.00
RI-13				
1	14	36.84	14	36.84
2	14	36.84	28	73.68
3	5	13.16	33	86.84
4	2	5.26	35	92.11
5	3	7.89	38	100.00
RI-14				
1	12	32.43	12	32.43
2	6	16.22	18	48.65
3	10	27.03	28	75.68
4	7	18.92	35	94.59
5	2	5.41	37	100.00
RI-15				
1	11	29.73	11	29.73
2	8	21.62	19	51.35
3	9	24.32	28	75.68
4	5	13.51	33	89.19
5	4	10.81	37	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-16				
1	8	19.05	8	19.05
2	9	21.43	17	40.48
3	9	21.43	26	61.90
4	10	23.81	36	85.71
5	6	14.29	42	100.00
RI-17				
1	6	15.79	6	15.79
2	14	36.84	20	52.63
3	8	21.05	28	73.68
4	5	13.16	33	86.84
5	5	13.16	38	100.00
RI-18				
1	7	18.42	7	18.42
2	14	36.84	21	55.26
3	8	21.05	29	76.32
4	7	18.42	36	94.74
5	2	5.26	38	100.00
RI-19				
1	8	20.51	8	20.51
2	5	12.82	13	33.33
3	15	38.46	28	71.79
4	9	23.08	37	94.87
5	2	5.13	39	100.00
RI-20				
1	8	20.51	8	20.51
2	5	12.82	13	33.33
3	10	25.64	23	58.97
4	10	25.64	33	84.62
5	6	15.38	39	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-21				
1	9	24.32	9	24.32
2	11	29.73	20	54.05
3	9	24.32	29	78.38
4	2	5.41	31	83.78
5	6	16.22	37	100.00
RI-22				
1	14	37.84	14	37.84
2	7	18.92	21	56.76
3	7	18.92	28	75.68
4	6	16.22	34	91.89
5	3	8.11	37	100.00
RI-23				
1	11	28.95	11	28.95
2	10	26.32	21	55.26
3	7	18.42	28	73.68
4	6	15.79	34	89.47
5	4	10.53	38	100.00
RI-24				
1	15	38.46	15	38.46
2	6	15.38	21	53.85
3	4	10.26	25	64.10
4	5	12.82	30	76.92
5	9	23.08	39	100.00
RI-25				
1	6	15.00	6	15.00
2	9	22.50	15	37.50
3	11	27.50	26	65.00
4	3	7.50	29	72.50
5	11	27.50	40	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-26				
1	8	20.51	8	20.51
2	5	12.82	13	33.33
3	17	43.59	30	76.92
4	4	10.26	34	87.18
5	5	12.82	39	100.00
RI-27				
1	11	28.21	11	28.21
2	7	17.95	18	46.15
3	16	41.03	34	87.18
5	5	12.82	39	100.00
RI-28				
1	8	20.00	8	20.00
2	13	32.50	21	52.50
3	8	20.00	29	72.50
4	3	7.50	32	80.00
5	8	20.00	40	100.00
RI-29				
1	13	32.50	13	32.50
2	12	30.00	25	62.50
3	10	25.00	35	87.50
4	1	2.50	36	90.00
5	4	10.00	40	100.00
RI-30				
1	13	34.21	13	34.21
2	8	21.05	21	55.26
3	8	21.05	29	76.32
4	2	5.26	31	81.58
5	7	18.42	38	100.00

Table C.21 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
RI-31				
1	15	38.46	15	38.46
2	16	41.03	31	79.49
3	5	12.82	36	92.31
4	2	5.13	38	97.44
5	1	2.56	39	100.00

Table C.22. Cost Impact Ratings Frequency

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
CI-1				
1	22	52.38	22	52.38
2	6	14.29	28	66.67
3	14	33.33	42	100.00
CI-2				
1	15	33.33	15	33.33
2	16	35.56	31	68.89
3	14	31.11	45	100.00
CI-3				
1	17	39.53	17	39.53
2	13	30.23	30	69.77
3	13	30.23	43	100.00
CI-4				
1	25	64.10	25	64.10
2	3	7.69	28	71.79
3	11	28.21	39	100.00
CI-5				
1	24	61.54	24	61.54
2	5	12.82	29	74.36
3	10	25.64	39	100.00
CI-6				
1	23	57.50	23	57.50
2	9	22.50	32	80.00
3	8	20.00	40	100.00
CI-7				
1	21	53.85	21	53.85
2	12	30.77	33	84.62
3	6	15.38	39	100.00
CI-8				
1	21	53.85	21	53.85
2	8	20.51	29	74.36
3	10	25.64	39	100.00

Table C.22 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
CI-9				
1	20	52.63	20	52.63
2	11	28.95	31	81.58
3	7	18.42	38	100.00
CI-10				
1	23	56.10	23	56.10
2	10	24.39	33	80.49
3	8	19.51	41	100.00
CI-11				
1	24	63.16	24	63.16
2	9	23.68	33	86.84
3	5	13.16	38	100.00
CI-12				
1	27	72.97	27	72.97
2	4	10.81	31	83.78
3	6	16.22	37	100.00
CI-13				
1	26	68.42	26	68.42
2	6	15.79	32	84.21
3	6	15.79	38	100.00
CI-14				
1	23	62.16	23	62.16
2	8	21.62	31	83.78
3	6	16.22	37	100.00
CI-15				
1	23	62.16	23	62.16
2	10	27.03	33	89.19
3	4	10.81	37	100.00
CI-16				
1	21	50.00	21	50.00
2	10	23.81	31	73.81
3	11	26.19	42	100.00

Table C.22 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
CI-17				
1	20	52.63	20	52.63
2	12	31.58	32	84.21
3	6	15.79	38	100.00
CI-18				
1	23	62.16	23	62.16
2	13	35.14	36	97.30
3	1	2.70	37	100.00
CI-19				
1	16	41.03	16	41.03
2	14	35.90	30	76.92
3	9	23.08	39	100.00
CI-20				
1	15	38.46	15	38.46
2	13	33.33	28	71.79
3	11	28.21	39	100.00
CI-21				
1	19	52.78	19	52.78
2	9	25.00	28	77.78
3	8	22.22	36	100.00
CI-22				
1	23	62.16	23	62.16
2	8	21.62	31	83.78
3	6	16.22	37	100.00
CI-23				
1	25	65.79	25	65.79
2	10	26.32	35	92.11
3	3	7.89	38	100.00
CI-24				
1	25	64.10	25	64.10
2	6	15.38	31	79.49
3	8	20.51	39	100.00

Table C.22 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
CI-25				
1	18	45.00	18	45.00
2	11	27.50	29	72.50
3	11	27.50	40	100.00
CI-26				
1	13	33.33	13	33.33
2	15	38.46	28	71.79
3	11	28.21	39	100.00
CI-27				
1	23	58.97	23	58.97
2	12	30.77	35	89.74
3	4	10.26	39	100.00
CI-28				
1	23	57.50	23	57.50
2	13	32.50	36	90.00
3	4	10.00	40	100.00
CI-29				
1	27	67.50	27	67.50
2	8	20.00	35	87.50
3	5	12.50	40	100.00
CI-30				
1	26	68.42	26	68.42
2	5	13.16	31	81.58
3	7	18.42	38	100.00
CI-31				
1	30	78.95	30	78.95
2	5	13.16	35	92.11
3	3	7.89	38	100.00

Table C.23. Schedule Impact Ratings Frequency

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
SI-1				
1	22	53.66	22	53.66
2	8	19.51	30	73.17
3	11	26.83	41	100.00
SI-2				
1	18	40.00	18	40.00
2	13	28.89	31	68.89
3	14	31.11	45	100.00
SI-3				
1	18	41.86	18	41.86
2	7	16.28	25	58.14
3	18	41.86	43	100.00
SI-4				
1	22	57.89	22	57.89
2	4	10.53	26	68.42
3	12	31.58	38	100.00
SI-5				
1	22	56.41	22	56.41
2	4	10.26	26	66.67
3	13	33.33	39	100.00
SI-6				
1	21	52.50	21	52.50
2	8	20.00	29	72.50
3	11	27.50	40	100.00
SI-7				
1	21	53.85	21	53.85
2	6	15.38	27	69.23
3	12	30.77	39	100.00
SI-8				
1	21	53.85	21	53.85
2	5	12.82	26	66.67
3	13	33.33	39	100.00

Table C.23 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
SI-9				
1	19	50.00	19	50.00
2	9	23.68	28	73.68
3	10	26.32	38	100.00
SI-10				
1	20	50.00	20	50.00
2	9	22.50	29	72.50
3	11	27.50	40	100.00
SI-11				
1	28	73.68	28	73.68
2	7	18.42	35	92.11
3	3	7.89	38	100.00
SI-12				
1	27	72.97	27	72.97
2	5	13.51	32	86.49
3	5	13.51	37	100.00
SI-13				
1	29	76.32	29	76.32
2	4	10.53	33	86.84
3	5	13.16	38	100.00
SI-14				
1	22	59.46	22	59.46
2	10	27.03	32	86.49
3	5	13.51	37	100.00
SI-15				
1	25	67.57	25	67.57
2	8	21.62	33	89.19
3	4	10.81	37	100.00
SI-16				
1	23	54.76	23	54.76
2	10	23.81	33	78.57
3	9	21.43	42	100.00

Table C.23 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
SI-17				
1	20	52.63	20	52.63
2	9	23.68	29	76.32
3	9	23.68	38	100.00
SI-18				
1	23	62.16	23	62.16
2	13	35.14	36	97.30
3	1	2.70	37	100.00
SI-19				
1	15	38.46	15	38.46
2	15	38.46	30	76.92
3	9	23.08	39	100.00
SI-20				
1	15	38.46	15	38.46
2	13	33.33	28	71.79
3	11	28.21	39	100.00
SI-21				
1	21	56.76	21	56.76
2	8	21.62	29	78.38
3	8	21.62	37	100.00
SI-22				
1	22	59.46	22	59.46
2	8	21.62	30	81.08
3	7	18.92	37	100.00
SI-23				
1	24	63.16	24	63.16
2	11	28.95	35	92.11
3	3	7.89	38	100.00
SI-24				
1	22	56.41	22	56.41
2	4	10.26	26	66.67
3	13	33.33	39	100.00

Table C.23 *continued*

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
SI-25				
1	15	37.50	15	37.50
2	13	32.50	28	70.00
3	12	30.00	40	100.00
SI-26				
1	21	53.85	21	53.85
2	11	28.21	32	82.05
3	7	17.95	39	100.00
SI-27				
1	20	51.28	20	51.28
2	14	35.90	34	87.18
3	5	12.82	39	100.00
SI-28				
1	27	67.50	27	67.50
2	9	22.50	36	90.00
3	4	10.00	40	100.00
SI-29				
1	27	67.50	27	67.50
2	8	20.00	35	87.50
3	5	12.50	40	100.00
SI-30				
1	28	73.68	28	73.68
2	4	10.53	32	84.21
3	6	15.79	38	100.00
SI-31				
1	34	87.18	34	87.18
2	5	12.82	39	100.00

APPENDIX D. DETAILED RISK RATINGS

Table D.1. Relative Importance Ratings for All Projects

	All Projects			*RI*	
	Mean	STDEV	MAX	MODE	MIN
R3	3.140	1.320	5	3	1
R25	3.100	1.429	5	3	1
R20	3.026	1.367	5	3	1
R16	2.929	1.351	5	4	1
R8	2.923	1.494	5	1	1
R1	2.905	1.511	5	1	1
R2	2.844	1.224	5	2	1
R10	2.829	1.412	5	2	1
R26	2.821	1.254	5	3	1
R7	2.795	1.380	5	3	1
R19	2.795	1.174	5	3	1
R9	2.789	1.379	5	3	1
R28	2.750	1.410	5	2	1
R6	2.725	1.450	5	1	1
R17	2.711	1.271	5	2	1
R24	2.667	1.644	5	1	1
R5	2.615	1.616	5	1	1
R21	2.595	1.363	5	2	1
R18	2.553	1.155	5	2	1
R15	2.541	1.346	5	1	1
R23	2.526	1.350	5	1	1
R30	2.526	1.484	5	1	1
R27	2.513	1.275	5	3	1
R4	2.487	1.571	5	1	1
R14	2.486	1.283	5	1	1
R22	2.378	1.361	5	1	1
R11	2.316	1.416	5	1	1
R12	2.297	1.266	5	1	1
R29	2.275	1.240	5	1	1
R13	2.105	1.203	5	1	1
R31	1.923	0.984	5	2	1

Table D.2. Cost Impact Ratings for All Projects

	All Projects			***CI***	
	Mean	STDEV	MAX	MODE	MIN
R2	1.978	0.812	3	2	1
R26	1.949	0.793	3	2	1
R3	1.907	0.840	3	1	1
R20	1.897	0.821	3	1	1
R25	1.825	0.844	3	1	1
R19	1.821	0.790	3	1	1
R1	1.810	0.917	3	1	1
R16	1.762	0.850	3	1	1
R8	1.718	0.857	3	1	1
R21	1.694	0.822	3	1	1
R9	1.658	0.781	3	1	1
R7	1.650	0.770	3	1	1
R4	1.641	0.903	3	1	1
R5	1.641	0.873	3	1	1
R10	1.634	0.799	3	1	1
R17	1.632	0.751	3	1	1
R6	1.625	0.807	3	1	1
R24	1.564	0.821	3	1	1
R14	1.541	0.767	3	1	1
R22	1.541	0.767	3	1	1
R28	1.525	0.679	3	1	1
R27	1.513	0.683	3	1	1
R11	1.500	0.726	3	1	1
R30	1.500	0.797	3	1	1
R15	1.486	0.692	3	1	1
R13	1.474	0.762	3	1	1
R29	1.450	0.714	3	1	1
R12	1.432	0.765	3	1	1
R23	1.421	0.642	3	1	1
R18	1.405	0.551	3	1	1
R31	1.289	0.611	3	1	1

Table D.3. Schedule Impact Ratings for All projects

	All Projects			*SI*	
	Mean	STDEV	MAX	MODE	MIN
R3	2.000	0.926	3	3	1
R25	1.925	0.829	3	1	1
R2	1.911	0.848	3	1	1
R20	1.897	0.821	3	1	1
R19	1.846	0.779	3	2	1
R8	1.795	0.923	3	1	1
R10	1.775	0.862	3	1	1
R5	1.769	0.931	3	1	1
R7	1.769	0.902	3	1	1
R24	1.769	0.931	3	1	1
R9	1.763	0.852	3	1	1
R6	1.750	0.870	3	1	1
R4	1.737	0.921	3	1	1
R1	1.732	0.867	3	1	1
R17	1.711	0.835	3	1	1
R16	1.667	0.816	3	1	1
R21	1.649	0.824	3	1	1
R26	1.641	0.778	3	1	1
R27	1.615	0.711	3	1	1
R22	1.595	0.798	3	1	1
R14	1.541	0.730	3	1	1
R29	1.450	0.714	3	1	1
R23	1.447	0.645	3	1	1
R15	1.432	0.689	3	1	1
R28	1.425	0.675	3	1	1
R30	1.421	0.758	3	1	1
R12	1.405	0.725	3	1	1
R18	1.405	0.551	3	1	1
R13	1.368	0.714	3	1	1
R11	1.342	0.627	3	1	1
R31	1.128	0.339	2	1	1

Table D.4. Relative Importance Ratings for New or Expansion Projects (PT-1)

	PT-1			***RI***	
	Mean	STDEV	MAX	MODE	MIN
R8	3.273	1.555	5	4	1
R20	3.250	1.138	5	4	1
R3	3.167	1.193	5	3	1
R10	3.083	1.379	5	3	1
R19	3.083	0.996	4	4	1
R1	3.000	1.348	5	4	1
R2	3.000	1.080	5	2	2
R4	3.000	1.758	5	1	1
R5	3.000	1.706	5	1	1
R16	3.000	1.549	5	1	1
R6	2.909	1.578	5	1	1
R7	2.909	1.446	5	2	1
R11	2.909	1.640	5	1	1
R22	2.909	1.375	5	4	1
R27	2.909	1.578	5	3	1
R17	2.818	1.250	5	2	1
R9	2.727	1.191	5	3	1
R14	2.636	1.206	4	3	1
R15	2.636	1.362	5	1	1
R18	2.636	1.206	4	2	1
R25	2.636	1.362	5	2	1
R26	2.636	1.502	5	1	1
R23	2.545	1.508	5	2	1
R13	2.455	1.036	4	2	1
R21	2.455	1.128	5	3	1
R28	2.364	1.286	5	2	1
R24	2.273	1.489	5	1	1
R12	2.200	1.398	5	1	1
R30	2.182	1.168	5	2	1
R29	2.091	1.221	5	1	1
R31	2.000	1.000	4	1	1

Table D.5. Cost Impact Ratings for New or Expansion Projects (PT-1)

	PT-1			***CI***	
	Mean	STDEV	MAX	MODE	MIN
R8	2.182	0.982	3	3	1
R20	2.167	0.835	3	3	1
R2	2.154	0.689	3	2	1
R19	2.000	0.739	3	2	1
R5	1.917	0.996	3	1	1
R11	1.909	0.944	3	1	1
R26	1.909	0.944	3	1	1
R4	1.833	1.030	3	1	1
R6	1.818	0.874	3	1	1
R7	1.818	0.751	3	2	1
R1	1.750	0.866	3	1	1
R3	1.750	0.754	3	1	1
R9	1.727	0.905	3	1	1
R16	1.727	0.905	3	1	1
R17	1.727	0.786	3	1	1
R27	1.727	0.905	3	1	1
R21	1.636	0.809	3	1	1
R22	1.636	0.809	3	1	1
R23	1.636	0.809	3	1	1
R10	1.583	0.793	3	1	1
R13	1.545	0.820	3	1	1
R14	1.545	0.820	3	1	1
R25	1.545	0.820	3	1	1
R28	1.545	0.688	3	1	1
R12	1.500	0.850	3	1	1
R15	1.455	0.688	3	1	1
R29	1.455	0.820	3	1	1
R30	1.273	0.647	3	1	1
R31	1.273	0.467	2	1	1
R18	1.182	0.405	2	1	1
R24	1.182	0.405	2	1	1

Table D.6. Schedule Impact Ratings for New or Expansion Projects (PT-1)

	PT-1			***SI***	
	Mean	STDEV	MAX	MODE	MIN
R20	2.250	0.866	3	3	1
R8	2.091	1.044	3	3	1
R5	2.083	0.996	3	3	1
R2	2.077	0.760	3	2	1
R19	1.917	0.669	3	2	1
R1	1.909	0.831	3	1	1
R3	1.833	0.937	3	1	1
R4	1.833	0.937	3	1	1
R10	1.833	0.835	3	1	1
R6	1.818	0.874	3	1	1
R9	1.818	0.874	3	1	1
R7	1.727	0.905	3	1	1
R17	1.727	0.786	3	1	1
R27	1.727	0.905	3	1	1
R16	1.636	0.809	3	1	1
R21	1.636	0.809	3	1	1
R22	1.636	0.809	3	1	1
R23	1.636	0.809	3	1	1
R26	1.636	0.924	3	1	1
R12	1.500	0.850	3	1	1
R11	1.455	0.820	3	1	1
R13	1.455	0.688	3	1	1
R24	1.455	0.820	3	1	1
R25	1.455	0.688	3	1	1
R28	1.455	0.688	3	1	1
R29	1.455	0.820	3	1	1
R14	1.364	0.674	3	1	1
R15	1.364	0.674	3	1	1
R18	1.273	0.467	2	1	1
R30	1.273	0.647	3	1	1
R31	1.182	0.405	2	1	1

Table D.7. RI Ratings for Rehabilitation or Reconstruction Projects (PT-2)

	PT-2			***RI***	
	Mean	STDEV	MAX	MODE	MIN
R25	3.778	1.481	5	5	1
R26	3.778	1.302	5	4	1
R9	3.333	1.871	5	5	1
R28	3.300	1.252	5	3	1
R20	3.222	1.922	5	5	1
R3	3.182	1.328	5	4	1
R2	3.091	1.578	5	2	1
R7	3.000	1.658	5	1	1
R1	2.909	1.640	5	1	1
R6	2.900	1.792	5	1	1
R17	2.889	1.453	5	4	1
R8	2.778	1.856	5	1	1
R12	2.778	1.641	5	1	1
R21	2.778	1.787	5	5	1
R10	2.667	1.500	5	1	1
R16	2.667	1.500	5	1	1
R19	2.667	1.803	5	1	1
R29	2.667	1.732	5	1	1
R4	2.444	1.810	5	1	1
R15	2.444	1.509	5	1	1
R30	2.444	1.509	5	1	1
R14	2.333	1.581	5	1	1
R18	2.333	1.414	5	2	1
R23	2.333	1.581	5	1	1
R27	2.333	1.323	5	3	1
R5	2.250	1.753	5	1	1
R22	2.222	1.856	5	1	1
R24	2.222	1.641	5	1	1
R11	2.111	1.764	5	1	1
R13	2.111	1.764	5	1	1
R31	2.111	1.537	5	1	1

Table D.8. Cost Impact Ratings for Rehabilitation or Reconstruction Projects (PT-2)

	PT-2			CI	
	Mean	STDEV	MAX	MODE	MIN
R25	2.111	0.928	3	3	1
R26	2.111	0.782	3	2	1
R3	2.091	0.831	3	3	1
R1	2.000	1.000	3	3	1
R2	2.000	0.894	3	3	1
R16	1.889	1.054	3	1	1
R19	1.889	0.928	3	1	1
R21	1.889	0.928	3	1	1
R4	1.778	0.972	3	1	1
R7	1.778	0.833	3	1	1
R9	1.778	0.833	3	1	1
R12	1.778	0.972	3	1	1
R15	1.778	0.833	3	1	1
R20	1.778	0.833	3	1	1
R10	1.667	0.866	3	1	1
R17	1.667	0.866	3	1	1
R22	1.667	1.000	3	1	1
R28	1.600	0.699	3	1	1
R8	1.556	0.882	3	1	1
R13	1.556	0.882	3	1	1
R14	1.556	0.726	3	1	1
R29	1.556	0.882	3	1	1
R5	1.500	0.926	3	1	1
R6	1.500	0.850	3	1	1
R18	1.500	0.535	2	2	1
R24	1.444	0.726	3	1	1
R30	1.444	0.726	3	1	1
R11	1.333	0.500	2	1	1
R31	1.333	0.707	3	1	1
R23	1.222	0.441	2	1	1
R27	1.222	0.441	2	1	1

Table D.9. Schedule Impact Ratings for Rehabilitation or Reconstruction Projects (PT-2)

	PT-2			***SI***	
	Mean	STDEV	MAX	MODE	MIN
R25	2.333	0.866	3	3	1
R3	2.182	0.874	3	3	1
R2	2.091	0.944	3	3	1
R7	2.000	1.000	3	3	1
R9	2.000	1.000	3	3	1
R6	1.900	0.994	3	1	1
R4	1.889	1.054	3	1	1
R19	1.889	0.928	3	1	1
R1	1.818	0.982	3	1	1
R8	1.778	0.972	3	1	1
R12	1.778	0.972	3	1	1
R17	1.778	0.972	3	1	1
R20	1.778	0.833	3	1	1
R21	1.778	0.972	3	1	1
R24	1.778	0.972	3	1	1
R10	1.667	0.866	3	1	1
R13	1.667	1.000	3	1	1
R15	1.667	0.866	3	1	1
R16	1.667	1.000	3	1	1
R22	1.667	1.000	3	1	1
R26	1.667	0.707	3	2	1
R14	1.556	0.726	3	1	1
R29	1.556	0.882	3	1	1
R5	1.500	0.926	3	1	1
R30	1.444	0.726	3	1	1
R28	1.400	0.699	3	1	1
R18	1.375	0.518	2	1	1
R11	1.333	0.500	2	1	1
R27	1.333	0.500	2	1	1
R23	1.222	0.441	2	1	1
R31	1.111	0.333	2	1	1

Table D.10. RI Ratings for Bridge or Tunnel Projects (PT-3)

	PT-3			*RI*	
	Mean	STDEV	MAX	MODE	MIN
R16	2.583	1.240	5	2	1
R20	2.500	1.243	4	1	1
R2	2.462	1.050	5	2	1
R19	2.455	1.036	4	3	1
R3	2.417	0.996	4	2	1
R15	2.364	1.206	5	2	1
R21	2.364	1.286	5	2	1
R17	2.333	1.155	5	2	1
R24	2.333	1.557	5	1	1
R25	2.333	1.155	5	2	1
R27	2.333	1.231	5	3	1
R18	2.273	1.104	5	2	1
R26	2.250	0.965	3	3	1
R23	2.182	1.250	5	1	1
R8	2.167	0.937	4	2	1
R28	2.167	1.115	5	2	1
R29	2.167	1.193	5	2	1
R30	2.167	1.337	5	1	1
R6	2.154	0.987	4	1	1
R14	2.091	1.044	4	1	1
R1	2.083	1.311	5	1	1
R9	2.000	0.739	3	2	1
R10	2.000	0.853	4	2	1
R22	2.000	1.000	4	1	1
R5	1.917	0.996	4	1	1
R7	1.917	0.793	3	2	1
R11	1.833	0.577	3	2	1
R4	1.750	0.866	4	2	1
R12	1.667	0.492	2	2	1
R13	1.667	0.492	2	2	1
R31	1.667	0.492	2	2	1

Table D.11. Cost Impact Ratings for Bridge or Tunnel Projects (PT-3)

	PT-3			***CI***	
	Mean	STDEV	MAX	MODE	MIN
R27	1.583	0.669	3	1	1
R2	1.538	0.776	3	1	1
R16	1.500	0.674	3	1	1
R20	1.500	0.674	3	1	1
R21	1.500	0.850	3	1	1
R24	1.500	0.905	3	1	1
R25	1.500	0.674	3	1	1
R26	1.500	0.522	2	1	1
R19	1.455	0.688	3	1	1
R1	1.417	0.793	3	1	1
R3	1.417	0.793	3	1	1
R17	1.417	0.669	3	1	1
R29	1.417	0.669	3	1	1
R30	1.417	0.793	3	1	1
R15	1.364	0.674	3	1	1
R22	1.364	0.674	3	1	1
R23	1.364	0.674	3	1	1
R5	1.333	0.651	3	1	1
R9	1.333	0.492	2	1	1
R28	1.333	0.651	3	1	1
R6	1.308	0.480	2	1	1
R18	1.273	0.647	3	1	1
R8	1.250	0.452	2	1	1
R10	1.250	0.622	3	1	1
R14	1.182	0.405	2	1	1
R4	1.167	0.577	3	1	1
R13	1.167	0.389	2	1	1
R7	1.083	0.289	2	1	1
R11	1.083	0.289	2	1	1
R12	1.000	0.000	1	1	1
R31	1.000	0.000	1	1	1

Table D.12. Schedule Impact Ratings for Bridge or Tunnel Projects (PT-3)

	PT-3			*SI*	
	Mean	STDEV	MAX	MODE	MIN
R25	1.667	0.651	3	2	1
R27	1.667	0.651	3	2	1
R2	1.615	0.870	3	1	1
R3	1.500	0.905	3	1	1
R20	1.500	0.674	3	1	1
R24	1.500	0.905	3	1	1
R19	1.455	0.688	3	1	1
R21	1.455	0.820	3	1	1
R22	1.455	0.820	3	1	1
R16	1.417	0.669	3	1	1
R23	1.364	0.674	3	1	1
R17	1.333	0.651	3	1	1
R26	1.333	0.492	2	1	1
R29	1.333	0.651	3	1	1
R30	1.333	0.778	3	1	1
R6	1.308	0.480	2	1	1
R10	1.273	0.647	3	1	1
R14	1.273	0.467	2	1	1
R15	1.273	0.647	3	1	1
R18	1.273	0.647	3	1	1
R1	1.250	0.622	3	1	1
R5	1.250	0.622	3	1	1
R7	1.250	0.622	3	1	1
R9	1.250	0.452	2	1	1
R28	1.250	0.622	3	1	1
R4	1.182	0.603	3	1	1
R8	1.167	0.389	2	1	1
R11	1.083	0.289	2	1	1
R12	1.000	0.000	1	1	1
R13	1.000	0.000	1	1	1
R31	1.000	0.000	1	1	1

Table D.13. Relative Importance Ratings for Complex Projects (PT-5)

	PT-5			***RI***	
	Mean	STDEV	MAX	MODE	MIN
R24	4.429	0.976	5	5	3
R1	4.143	1.215	5	5	2
R3	4.125	1.458	5	5	1
R25	4.125	0.991	5	5	3
R30	4.000	1.673	5	5	1
R10	3.875	1.458	5	5	1
R7	3.857	0.900	5	3	3
R8	3.857	1.215	5	5	2
R9	3.667	1.211	5	3	2
R5	3.571	1.813	5	5	1
R28	3.571	1.813	5	5	1
R16	3.500	1.080	5	3	2
R6	3.333	1.366	5	2	2
R20	3.333	1.033	5	3	2
R23	3.286	0.756	4	4	2
R14	3.167	1.329	5	3	1
R18	3.143	0.690	4	3	2
R4	3.000	1.673	5	4	1
R12	3.000	1.095	4	3	1
R17	3.000	1.414	5	3	1
R19	3.000	0.577	4	3	2
R21	3.000	1.414	5	3	1
R2	2.875	1.246	5	3	1
R26	2.857	0.378	3	3	2
R15	2.833	1.602	5	3	1
R11	2.500	1.517	5	1	1
R27	2.429	0.787	3	3	1
R13	2.333	1.506	5	2	1
R22	2.333	1.033	3	3	1
R29	2.250	0.707	3	2	1
R31	2.000	0.816	3	2	1

Table D.14. Cost Impact Ratings for Complex Projects (PT-5)

	PT-5			*CI*	
	Mean	STDEV	MAX	MODE	MIN
R3	2.625	0.518	3	3	2
R26	2.571	0.535	3	3	2
R24	2.429	0.787	3	3	1
R2	2.375	0.744	3	3	1
R25	2.375	0.744	3	3	1
R20	2.333	0.816	3	3	1
R1	2.286	0.951	3	3	1
R10	2.250	0.707	3	2	1
R6	2.167	0.983	3	3	1
R14	2.167	0.983	3	3	1
R30	2.167	0.983	3	3	1
R7	2.125	0.835	3	2	1
R4	2.000	0.894	3	2	1
R8	2.000	0.816	3	2	1
R9	2.000	0.894	3	3	1
R16	2.000	0.816	3	2	1
R19	2.000	0.816	3	2	1
R5	1.857	0.900	3	1	1
R18	1.857	0.378	2	2	1
R11	1.833	0.753	3	2	1
R13	1.833	0.983	3	1	1
R17	1.833	0.753	3	2	1
R21	1.833	0.753	3	2	1
R28	1.714	0.756	3	1	1
R31	1.714	0.951	3	1	1
R12	1.667	0.816	3	1	1
R22	1.500	0.548	2	2	1
R23	1.429	0.535	2	1	1
R27	1.429	0.535	2	1	1
R29	1.375	0.518	2	1	1
R15	1.333	0.516	2	1	1

Table D.15. Schedule Impact Ratings for Complex Projects (PT-5)

	PT-5			*SI*	
	Mean	STDEV	MAX	MODE	MIN
R3	2.750	0.463	3	3	2
R24	2.714	0.488	3	3	2
R10	2.500	0.756	3	3	1
R25	2.500	0.756	3	3	1
R5	2.429	0.787	3	3	1
R7	2.429	0.787	3	3	1
R8	2.429	0.787	3	3	1
R4	2.333	0.816	3	3	1
R6	2.333	1.033	3	3	1
R9	2.333	0.816	3	3	1
R14	2.333	0.816	3	3	1
R17	2.333	0.816	3	3	1
R19	2.286	0.756	3	3	1
R20	2.167	0.753	3	2	1
R1	2.143	0.900	3	3	1
R26	2.143	0.900	3	3	1
R16	2.000	0.816	3	2	1
R2	1.875	0.835	3	1	1
R18	1.857	0.378	2	2	1
R21	1.833	0.753	3	2	1
R30	1.833	0.983	3	1	1
R27	1.714	0.756	3	1	1
R28	1.714	0.756	3	1	1
R11	1.667	0.816	3	1	1
R22	1.667	0.516	2	2	1
R23	1.571	0.535	2	2	1
R12	1.500	0.548	2	2	1
R13	1.500	0.837	3	1	1
R15	1.500	0.548	2	2	1
R29	1.500	0.535	2	1	1
R31	1.286	0.488	2	1	1