# A RISK-BASED MODEL TO SELECT DELIVERY METHODS FOR HIGHWAY DESIGN AND CONSTRUCTION PROJECTS

by

DAI (DANIEL) TRAN

B.S., Civil Engineering, National University of Civil Engineering, 2003

M.S., Civil Engineering/Structural Eng., Georgia Institute of Technology, 2009

M.S., Applied Mathematics/Probability and Statistics, University of Colorado, 2013

A dissertation submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirement for the degree of

Doctor of Philosophy

Department of Civil, Environmental, and Architectural Engineering

*2013*

This dissertation entitled:
A risk-based Model to Select Delivery Methods for Highway Design and Construction Projects
written by Dai (Daniel) Tran
has been approved for the Department of Civil, Environmental, and Architectural Engineering

______________________________________
Professor Keith Molenaar

______________________________________
Professor Stuart Anderson

______________________________________
Professor James Diekmann

______________________________________
Assistant Professor Matthew Hallowell

______________________________________
Assistant Professor Mehmet Ozbek

Date____________________

The final copy of this dissertation has been examined by the signatories, and we
Find that both the content and the form meet acceptable presentation standards
Of scholarly work in the above mentioned discipline.

Tran, Dai (Daniel) (Ph.D., Civil Engineering)

A Risk-based Model to Select Delivery Methods for Highway Design and Construction Projects

Dissertation directed by Professor Keith Molenaar

Project delivery methods and contracting strategies allocate risk for design and construction between contractual parties. Selecting an appropriate delivery method is a critical to the success of highways and other infrastructure projects. The selection is often made early in the project development process. At the time of the decision, the owner and stakeholders often have little information and projects lack details to make accurate judgments about final project costs. Researcher and practitioners have striven to develop tools and techniques to support the project delivery decision, but most are qualitative approaches. In the last decade, transportation agencies have successfully applied cost and schedule risk analyses on their major projects, but they make project delivery decisions independently from these risk analyses. This dissertation capitalizes on the opportunity to apply quantitative risk analysis techniques to the highway project delivery selection process. This dissertation employs content analysis, survey research, univariate and multivariate analysis, and cross-impact analysis techniques to develop a risk-based model to quantitatively make informed delivery decisions. The dissertation follows a three-journal paper format. The first paper focuses on investigating the impact of risk on design-build (DB) Delivery. The DB method was selected as the main research setting for this paper because its risk allocation mechanism tends to be more complex than the traditional design-bid-build (DBB) or alternative construction manager/general contractor (CMGC) delivery method. The second paper advances understanding of how risk impacts the three fundamental delivery methods commonly used in highways: DBB, DB, and CMGC. Building upon these results, the third paper develops a risk-

based model to quantify the impact of risk and delivery methods on project cost. It provides for an understanding of the optimal delivery method for an individual highway design and construction project. The dissertation contributes to theory by introducing a new approach to selecting project delivery methods. This dissertation also addresses a practical need to increase understanding of how risks impact project delivery selection in the highway design and construction industry.

To my family and friends

**ACKNOWLEDGMENTS**

I thank the faculty of the Department of Civil, Environmental and Architectural Engineering at the University of Colorado for providing me with research and teaching opportunities, sharing with me invaluable graduate school experience, and preparing the foundation for my future path. I would like to thank special individuals for their intellectual and emotional support and guidance with this dissertation and in my career development.

My advisor, Dr. Keith Molenaar, is an exceptional role model. He is the ideal advisor and a great friend to me. His passion, patience, understanding, insight, and support have been invaluable through my entire time at the University of Colorado. He supported me with teaching and research assistantships, provided guidance on every corner of my doctoral journey, and has instilled in me confidence and determination. He showed me what it means to be a professional engineer and exceptional researcher. I am truly grateful to him for advising and inspiring me to pursue the path which I am on today.

I am thankful to each of my doctoral committee members who provided profound insight into this dissertation and inspired me through their passion, intelligence, and academic integrity. I am particularly grateful to Dr. James Diekmann for spending hours with me to discuss the research problem and providing me with invaluable recommendations and guidance. His knowledge, professionalism, personality, and supportive nature are the inspiration to my career. I am privileged to be able to work with Dr. Matthew Hallowell. He is intelligent, patient, kind, and caring. He gave needed advice on improving my speaking and writing skills and always had time for me. I feel that he will be a close colleague and friend. I am grateful to Dr. Stuart Anderson for providing me with extremely useful comments and suggestions on this dissertation. I also appreciate his insightful advice on my career development. I was greatly impressed by his flying from Texas to Colorado for my defense. I would like to thank Dr. Mehmet Ozbek for his useful guidance on several aspects of this research and flexibility in schedule. Finally, I wish to thank Dr. Amy Javernick-Will and Dr. Paul Goodrum for sharing with me their invaluable graduate school experience.

I would like to acknowledge and express my deep sense of gratitude toward the National Cooperative Highway Research Program and the Transportation Pooled-Fund Program for supporting me through graduate school.

I wish to thank the participants and organizations who took their precious time and energy to contribute to this research. I am indebted to a number of people in the Federal Highway Administration and state Departments of Transportation. In particular, I would like to thank Mr. Craig Actis, Mr. Peter Clogston, Ms. Latoya Johnson, Mr. Benjamin Acimovic, Mr. Mike McGregor, Mr. Kostas Svarnas, and Ms. Vilma Croft. I also would like to extend my gratitude to all the individuals not specifically listed who contributed to this research. Without their contributions, this research would not have been possible.

I thank my friends. Without their support and encouragement, I could not have accomplished my goals. There are too many to name. So, I thank you all for the help; I valued our friendship.

Most importantly, I am deeply grateful to my parents, grandparents, aunts, uncles, sister, brother, in-laws, and relatives for their unconditional love and confidence in me. Specially, I am always indebted to my wife, Oanh, for her sacrifice and patience and providing me endless support to pursue my dreams.

**TABLE OF CONTENTS**

Abstract ........ iv

Acknowledgments ........ vii

Table of Contents ........ ix

List of Tables ........ xiii

List of Figures ........ xiv

CHAPTER 1: INTRODUCTION ........ 1

Observed Problem ........ 2

Dissertation Format ........ 8

Research Questions and Methodology Overview ........ 8

References ........ 10

CHAPTER 2: THE IMPACT OF RISK ON DESIGN-BUILD SELECTION FOR HIGHWAY DESIGN AND CONSTRUCTION PROJECTS ........ 14

Abstract ........ 15

Introduction ........ 16

Literature Reviews and Point of Departure ........ 17

Research Methodology ........ 19

Questionnaire ........ 20

Data Collection Process ........ 20

Data analysis ........ 21

Results ........ 24

Discussion ........ 25

Comparison of Public Owner and Designer/Contractor Risk Preferences ........ 39

Summary and Conclusions ........................................................................................41

Acknowledgements.....................................................................................................44

Appendix: Abridged Risk Factors in Survey Questionnaires ......................................................44

References ...............................................................................................................47

CHAPTER 3: A MULTIVARIATE ANALYSIS OF PROJECT DELIVERY SELECTION RISK FACTORS FOR TRANSPORTATION DESIGN AND CONSTRUCTION....................51

Abstract.....................................................................................................................52

Introduction...............................................................................................................53

Background...............................................................................................................55

Research Method ......................................................................................................57

Identifying risk factors that affect project delivery methods .......................................................58

Data Collection ........................................................................................................59

Data Analysis ...........................................................................................................60

Results ......................................................................................................................62

Discussion ................................................................................................................66

Limitations and Future Research ..............................................................................75

Conclusions ..............................................................................................................76

Appendix: Survey Questionnaires ............................................................................79

References ................................................................................................................84

CHAPTER 4: A RISK-BASED PROJECT DELIVERY SELECTION MODEL FOR HIGHWAY DESIGN AND CONSTRUCTION............................................................87

Abstract.....................................................................................................................88

Introduction...............................................................................................................89

Literature Review....................................................................................................90
Risk-based Project Delivery Selection Model ..........................................................92
Input Level ..............................................................................................................93
Delivery Risk Factors ..........................................................................................93
Cross-Impact Analysis Input ...............................................................................98
Processing Level ....................................................................................................103
Cross-Impact Analysis Processing ....................................................................103
Monte Carlo Simulation and Computer Programming ......................................104
Model Verification and Validation.....................................................................106
Output Level ..........................................................................................................107
Project Information.............................................................................................108
Probabilistic Cost Risk Analysis Results ..........................................................108
Risk-based Project Delivery Selection Model Input ..........................................109
Discussion of Model Results ..............................................................................110
Limitations and Future Research ...........................................................................113
Conclusions............................................................................................................115
Acknowledgements................................................................................................117
Appendix: Delivery Risk Factors for Risk-based Model .......................................118
References .............................................................................................................120

CHAPTER 5: CONCLUSION ...............................................................................123
Summary and Conclusion......................................................................................124
Contributions..........................................................................................................127
Contributions to Theory ....................................................................................127
Contributions to Practice ...................................................................................130

Limitations and Suggestions for Future Research ........................................................ 132

Anticipated Impact of the Research ........................................................................ 143

References ............................................................................................................. 145

INTEGRATED REFERECNES ................................................................................ 147

APPENDIX I: Definitions of Delivery Risk Factors .................................................... 155

APPENDIX II: Survey Questionnaires ........................................................................ 158

APPENDIX III: Project Case Studies ......................................................................... 173

APPENDIX IV: Model Programming – C++ Code ...................................................... 192

## LIST OF TABLES

CHAPTER 1

Table 1. Available Project Delivery Method Selection Approaches ..............................................3

CHAPTER 2

Table 1. Results of Data Collection Process.......................................................................22

Table 2. Delivery Selection Risk Factors for DB Projects ..........................................................25

Table 3. Risk Preference Comparison between Public Owners and Design-builders ..................40

CHAPTER 3

Table 1. Critical Risk Factors for the DBB Delivery Method ......................................................63

Table 2. Critical Risk Factors for the CMGC Delivery Method...................................................64

Table 3. Critical Risk Factors for the DB Delivery Method........................................................65

Table 4. Critical Risk Factors for Project Delivery Decisions......................................................66

CHAPTER 4

Table 1. Critical Risk Factors for Project Delivery Decisions......................................................94

Table 2. Example of Initial Probability of Risk Variable for Risk-based Model ..........................96

Table 3. Examples of Initial Estimate of Project Outcome for Risk-based Model........................97

Table 4. Example of Cross-Impact Matrix for DB Delivery ......................................................103

Table 5. Delivery Expected Costs for DB, DBB, and CMGC....................................................110

## LIST OF FIGURES

CHAPTER 1

Figure 1. Project Development Phases (Adapted from Minnesota DOT) ......................................7

Figure 2. Research Questions and Methodology Overview ..........................................................9

CHAPTER 4

Fig. 1. Overview of Risk-based Model ..........................................................................................92

Fig. 2. Derivation of Initial Probability from Cost Cumulative Distribution ...............................97

Fig. 3. Factor Loadings and Percentage of Explained Variance ....................................................99

Fig. 4. Model Interaction for DB Delivery ..................................................................................101

Fig. 5. Approximate Cost Distributions of DB, DBB, and CMGC ............................................111

Fig. 6. Sensitivity Analysis Results of DB Selection ..................................................................112

CHAPTER 5

Fig. 1. Research Questions, Results and Contributions ..............................................................126

Fig. 2a. Approximate Cost Distributions for DB, DBB, and CMGC
for Rt. 295 and 42/ I-76 Project, New Jersey ................................................................134

Fig. 2b. Approximate Cost Distributions for DB, DBB, and CMGC
for Lake Bridges Project Kentucky ................................................................................134

Fig. 2c. Approximate Cost Distributions for DB, DBB, and CMGC
for I-395 Reconstruction Project, Florida ........................................................................134

Fig. 3a. Tornado Diagram for DBB Selection for Rt. 295 and 42/ I-76 Project, New Jersey .....135

Fig. 3b. Tornado Diagram for DBB Selection for Lake Bridges Project, Kentucky ...................136

Fig. 3c. Tornado Diagram for DB Selection for I-395 Reconstruction Project, Florida .............136

Fig. 4. Sensitivity Analysis Results for Initial Project Outcomes ...............................................138

# CHAPTER 1

# INTRODUCTION

## OBSERVED PROBLEM

Billions of dollars have annually been spent on highway design and construction projects. The American Society of Civil Engineers (ASCE) Report Card 2013 has recently indicated that there is "a significant backlog of overdue maintenance across our infrastructure systems." An estimated $170 billion is needed annually to upgrade road and highway conditions and performance. One in nine of the nation's bridges is rated as structurally deficient, and $8 billion is spent annually on the construction and maintenance of bridges. The demand to deliver highway projects in less time, at a high level of quality, and limited budgets has driven state departments of transportation (DOTs) across the country to adopt innovations in project delivery methods, procurement procedures, and payment provisions. Currently, state DOTs can employ a variety of alternative contracting systems to allocate risk and responsibility among all parties involved in the project. The Federal Highway Administration's (FHWA) Every Day Counts 1 (EDC-1) initiative notes that DBB highway projects can take up to 13 years to deliver and the separation of design and construction processes is a barrier and a potential for claims and disputes (http://www.fhwa.dot.gov/everydaycounts/projects/methods/). The current FHWA EDC-2 initiative also supports and promotes the national use of alternative delivery methods to delivery projects more quickly, improve constructability, enhance early cost certainty and contractor innovation, and control cost growth.

The growing use of alternative delivery methods has led researchers and practitioners to seek decision support for choosing an appropriate delivery method. As a result, selection techniques have been developed that range from simple approaches, such as flowcharts (Goldon, 1994), to complex frameworks, such as multi-attribute utility/value theory (Oyetunji and Anderson, 2006), and analytical hierarchical process/value engineering/multi-criteria multi-screening (Alhazmi and McCaffer, 2000; Mahli and Alreshaid, 2005). Table 1 summarizes the typical research efforts on project delivery selection in the construction industry.

**Table 1. Available Project Delivery Method Selection Approaches**

| Approaches | Typical Reference |
|---|---|
| Evaluation of Individual delivery method | Yate (1995); Songer and Molenaar (1996); Bear et al. (2001); Lam et al. (2008); Gransberg et al. (2006); Migliaccio et al. (2009) |
| Comparison of alternative delivery methods | Konchar and Sanvido (1998); CII (1997); Molenaar et al. (1999); Debella and Ries (2006); Ibbs et al. (2003); Rojas and Kell (2008); Hale et al. (2009); NCHRP (2006); Shrestha et al. (2007) |
| Flowchart | Gordon (1994) |
| Multi-attribute utility/value theory | Molenaar and Songer (1998); Miller et al. (2000); CII (2003); Oyetunji and Anderson (2006); Mahdi and Alreshaid (2005); Skitmore and Marsden (1988); Love et al. (1998) |
| Analytical hierarchical process (AHP) | Al Khalil (2002); Alhazmi and McCaffer (2000) |
| Fuzzy logic model | Ng et al. (2002); Chan (2007) |
| Knowledge-based decision support | Kumaraswamy and Dissanayaka (2001) |
| Case-based/ qualitative assessment | Luu et al. (2003; 2006); Warne (2005); Touran et al. (2011) |

Through an extensive literature review, the author observed that limited research employs risk-based approaches to the selection of project delivery methods. Although transportation agencies have successfully applied probabilistic cost and schedule risk analyses on their major projects over the last two decades, they often conduct the probabilistic risk analysis independently with project delivery selection. Consequently, there is a lack of understanding of how risk affects the project delivery selection process. This dissertation addresses this knowledge gap.

## The Role of Risk Management in Project Delivery Selection Process

Although many project delivery methods are available, a study by the Construction Industry Institute (CII 1997) specified that there are only three fundamental project delivery methods: design-bid-build (DBB), design-build (DB), and construction manager/general contractor (CMGC). This specification is supported by the *NCHRP Synthesis of Highway Practice 402* (Gransberg and Shane, 2010) and the EDC initiative. Touran *et al*. (2011) claimed that the difference between project delivery methods lies in the fact that the contracts among the owner, the designer, and the builder are formed and the technical relationship among parties within those contracts.

Every project delivery method has certain opportunities and obstacles, and the risks and risk allocation associated with each delivery method vary. The FHWA (2006) presented four fundamental principles of rigorous risk allocation: (1) allocate risks to the party best able to manage them; (2) allocate risks in alignment with project goals; (3) share risk when appropriate to accomplish project goals; and (4) ultimately seek to allocate risks to promote team alignment with customer-oriented performance goals.

### *DBB Risk Allocation Mechanism*

The risk allocation in DBB is clearly understood by the transportation design and construction community. The majority of design risk is borne by the transportation agency and the construction risk is borne by the contractor. The assumption that complete design and specifications are accurate and adequate is a major risk in the DBB delivery method. In fact, even if a project conforms to plans and specifications, it may not perform as the owner expects (Rubin and Wordes, 1998). Under DBB projects, the owner owns the details of the design and is responsible for any errors or omissions in the drawings and specifications, and the contractor assumes the risk of completing construction in compliance with the contract documents. The contractor also assumes the risks related to scheduling, coordinating, and administering work conducted by subcontractors and suppliers. In addition, the contractor is responsible for inflation and interest rate fluctuations if escalation clauses are not included in the contract. The potential for an adversarial relationship between the designer and the contractor may cause project delays and cost overruns.

### *CMGC Risk Allocation Mechanism*

Under the CMGC delivery method, transportation agencies select construction managers based their qualifications to (1) assist the project team implement preconstruction services (e.g., cost estimating and constructability reviews) and (2) perform construction work after prices have been agreed upon. Construction managers are paid a fee for construction management services until a guaranteed maximum price (GMP) agreement for construction is reached, at which point the construction managers assume the risk for the final cost and time of construction. According to Gransberg and Shane (2010), the major advantages of the CMGC delivery method include enhanced constructability, real-time construction pricing capability, implementation speed, the ability to implement new and innovative technologies, and the ability to create an environment with rich collaboration. However, in CMGC projects, the owner must manage two contracts and is ultimately responsible for design risks while the construction manager is responsible for scheduling, quality control, and estimating construction costs.

### *DB Risk Allocation Mechanism*

Risk in the DB delivery method often stems from the scope of work, statutory or regulatory restrictions, and environmental issues. Under DB projects, the design-builder is solely responsible for all design and construction issues. However, Ghavamifar and Touran (2009) showed that simply choosing DB to transfer risks to the contractor is problematic because risks affect the price proposal. To reduce risks in DB projects, the owner needs to understand the scope of work and to use performance criteria to communicate project goals at the time of contracting.

## Project Delivery Selection Process vs. Project Development Process

The highway project development process typically includes the four overlapped phases: (1) planning, (2) programing (scoping), (3) design phase including preliminary and final design, and (4) letting.  Figure 1 presents graphically these phases a long with the 20 year plan before construction. The years *10 to 20* of the 20 year plan are related to planning phase. The objective of the planning phase is to identify purpose and need, requirement studies, environmental issues, right-of-way requirements, schematic development, and public involvement. The year *5 to 10* of the 20 year plan is considered as the *scoping phase* or programing phase. During the scoping phase, analyses are carried out on environmental impacts, alternative selections, right-of-way impact, design criteria and parameters, project economic feasibility, public hearings, and funding authorization. The year *0 to 4* is known as the State Transportation Improvement Program (STIP). Any project with a completed scoping phase and an approved scoping report can be programmed into the STIP. The STIP basically initiates the design phase of the project in which the designs and plans of the project are developed and completed for letting.

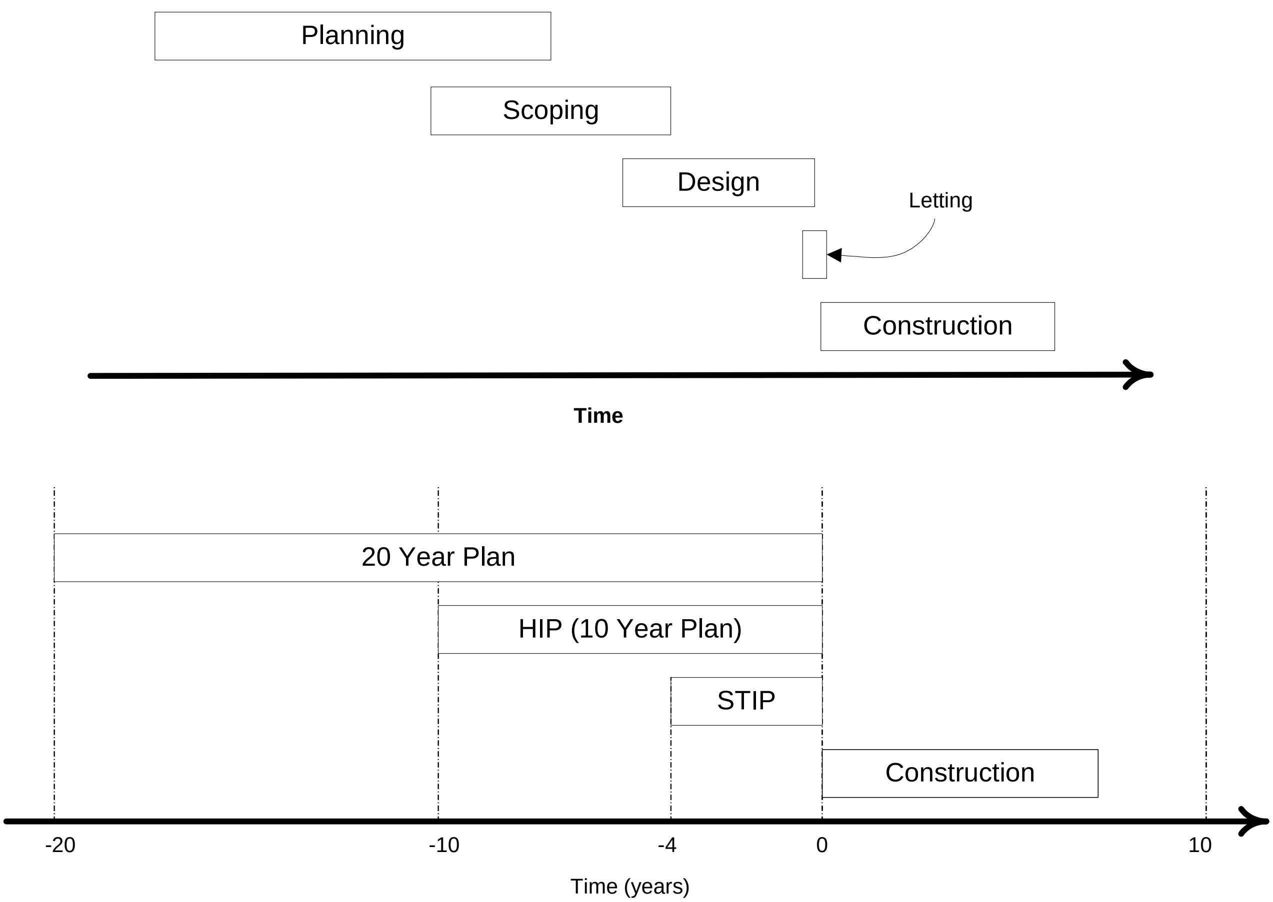


**Fig. 1. Project Development Phases (Adapted from Minnesota DOT)**

To maximize the project performance, the authors believe that the project delivery decision should be made in the scoping phase or shortly thereafter.

## DISSERTATION FORMAT

The research problems, questions, methods, and results presented in this dissertation follow the three-journal-paper format. Each of the subsequent chapters (Chapters 2, 3, and 4) are independent papers that have been published or submitted to peer-reviewed academic journals. While the papers are independent, each builds directly upon the findings from the previous paper. It should be noted that because of the independent nature of these papers, it should be expected some degree of overlap between papers (e.g., research motivation, data collection and methodology). A summary of theoretical and practical contributions of the research and suggestions for future research are presented in the concluding chapter. References used in each of three papers are combined in the integrated reference. Four appendices are included at the end of the dissertation to reinforce the data collection, data analysis, and findings from three papers. Appendix I provides definitions of all 39 delivery risk factors. Appendix II presents the survey questionnaire in detail. Appendix III summarizes the results of project case studies used to test the risk-based delivery selection model. Appendix IV offers the C++ code for computational structure of the risk-based model.

## RESEARCH QUESTIONS AND METHODOLOGY OVERVIEW

To explain the point of departure previously presented, this research aimed to answer the following research question:

> **How do risk factors influence the project delivery selection process in highway design and construction projects?**

Specifically, to address the practical and theoretical aspects from this overarching research question, the research explores six sub-questions that build upon one another shown in Figure 2.

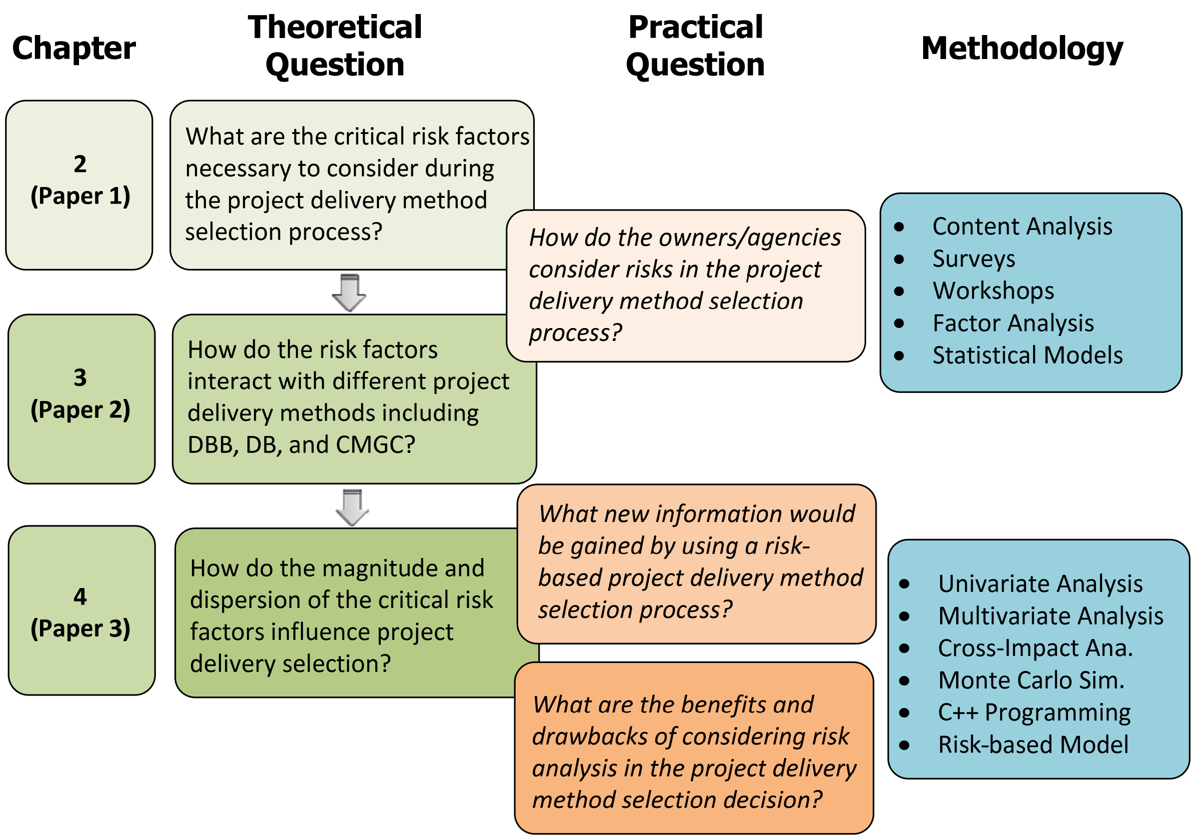


**Fig. 2. Research Questions and Methodology Overview**

To address which risk factors need to consider in the project delivery selection process, the first paper (Chapter 2) investigates the relationship between risk and uncertainty and DB delivery selection. The authors selected DB as the main research setting for this paper because the DB risk allocation mechanisms tend to be more complex than that of DBB and CMGC delivery methods. This paper has been published by the *Journal of Management in Engineering*. Building upon the findings from the first paper, the second paper (Chapter 3) investigates the interactions between risk and three fundamental delivery methods used in highways: DBB, DB, and CMGC. Chapter 3 also analyzes how risks propagate from project conditions to project outcomes associated with DBB, DB, and CMGC delivery methods. The research methodology used in Chapters 2 and 3 primarily includes content analysis, surveys, workshops, factor analysis, and statistical model. Finally, integrating the findings from Chapters 2 and 3, Chapter 4 (paper 3) develops a risk-based model to quantify how risks impact the project delivery selection process. The risk-based model is constructed by combining the results of univariate and multivariate statistical analyses (Chapters 2 and 3) with a cross-impact analysis and Monte Carlo simulation for individual projects.

**REFERENCES**

Alhazmi, T., and McCaffer, R. (2000). “Project procurement system selection model.” *Journal of Construction Engineering and Management*, 126(3), 176–184.

Al Khalil, M. I. (2002). “Selecting the appropriate project delivery method using AHP.” *International Journal of Project Management*, 20(6), 469-474.

Associated General Contractors (2004). *Project delivery systems for construction*, Associated General Contractors of America, Arlington, VA.

Beard, J. L., Loulakis, M. C., Wundram, E. C. (2001). *Design-Build: Planning Through Development*, McGraw-Hill, New York, NY.

Chan, C. T. W. (2007). “Fuzzy procurement selection model for construction projects.” *Construction Management and Economics*, 25(6), 311-618.

Construction Industry Institute (CII 1997) “Project Delivery Systems: CM at Risk, Design-Build, Design- Bid-Build,” *Research Summary RS 133*, Austin, Texas.

Construction Industry Institute (2003). *Owner’s Tool for Project Delivery and Contract Strategy Selection User’s Guide*, Research Summary IR165-2.

*Construction Project Management Handbook (2006) Federal* Transit Administration, Washington D.C.3–7.

Debella, D. C., and Ries, R. (2006). “Construction delivery systems: A comparative analysis of their performance within school districts.” *Journal of construction engineering and management*, 132, 1131.

FHWA (2006a). "Guide to Risk Assessment and Allocation for Highway Construction Management", *Federal Highway Administration, U.S. Department of Transportation, American Association of State Highway Transportation Officials, and the National Cooperative Highway Research Program,* Washington, DC.

FHWA (2006b). Design-Build Effectiveness Study, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

Ghavamifar, K., and Ali Touran, F. (2009). "Owner's risks versus control in transit projects." *Journal of Management in Engineering*, 25(4), 230-233.

Gordon, C. M. (1994). "Choosing appropriate construction contracting method." *Journal of Construction Engineering and Management*, 120(1), 196–210.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for design-build projects: a primer for owners, engineers, and contractors*. American Society of Civil Engineers. Reston, VA.

Gransberg, D., and Shane, J. (2010). "NCHRP Synthesis of Highway Practice 402: Construction Manager-at-Risk Project Delivery for Highway Programs." *Transportation Research Board of the National Academies, Washington, DC*.

Hale, D. R., Shrestha, P. P., Gibson Jr, G. E., Migliaccio, G. C., and others. (2009). "Empirical comparison of design/build and design/bid/build project delivery methods." *Journal of Construction Engineering and Management*, 135, 579.

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). "Project delivery systems and project change: Quantitative analysis." *Journal of Construction Engineering and Management*, 129(4), 382-387.

Konchar, M., and Sanvido, V. (1998). "Comparison of US project delivery systems." *Journal of Construction Engineering and Management*, 124(6), 435-444.

Kumaraswamy, M. and Dissanayaka, S. (2001). "Developing a decision support system for building project procurement." *Building and Environment*, 36(3), 337-349.

Lam, E. W. M., Chan, A. P. C., Chan, D. W. M., and others. (2008). "Determinants of successful design-build projects." *Journal of Construction Engineering and management*, 134, 333.

Love, P. E. D., Skitmore, M. and Earl, G. (1998). "Selecting a suitable procurement method for a building project." *Construction Management and Economics,* 16(2), 221-233.

Luu, D. T., Ng, S. T. and Chen, S. E. (2003). "A case-based procurement advisory system for construction." *Advances in Engineering Software*, 34, 429-438.

Luu, D. T., Ng, S. T., Chen, S. E. and Jefferies, M. (2006). "A Strategy for evaluating a fuzzy case-based construction procurement selection system." *Advances in Engineering Software*, 37, 159-171.

Mahdi, I. M., and Alreshaid, K. (2005). “Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP).” *International Journal of Project Management*, 23(7), 564–572.

Migliaccio, G., Gibson, G., O’Connor, J., and others. (2009). “Procurement of Design-Build Services: Two-Phase Selection for Highway Projects.” *Journal of Management in Engineering*, 25, 29.

Molenaar, K.R, Gransberg, D., Scott, S., Downs, D., Ellis, R. (2008). “NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide.” *Transportation Research Board of the National Academies, Washington, DC*.

Molenaar, K. R. and Songer, A. D. (1998). “Model for public sector design-build project selection”, *Journal of Construction Engineering and Management*, 124(6), 467-479.

Molenaar, K. R., Songer, A. D., and Barash, M. (1999). “Public-sector design/build evolution and performance.” *Journal of Management in Engineering*, 15(2), 54-62.

Ng, S. T., Luu, D. T., Chen, S. E. and Lam K. C. (2002). “Fuzzy membership functions of procurement selection criteria.” *Construction Management and Economics*, 20, 285–296

Oyetunji, A. A., Anderson, S. D., and others. (2006). “Relative effectiveness of project delivery and contract strategies.” *Journal of Construction Engineering and Management*, 132(1), 3-13.

Parsons, Touran, A., and Golder Assoc. (2004). “Risk Analysis Methodologies and Procedures,” *Federal Transit Administration*.

Rojas, E. M., and Kell, I. (2008). “Comparative analysis of project delivery systems cost performance in Pacific Northwest public schools.” *Journal of Construction Engineering and Management*, 134, 387.

Rubin, R., and Wordes, D. (1998). “Risky business.” *Journal of Management in Engineering*, 14(6), 36–43.

Shrestha, P. P., Migliaccio, G. C., O’Connor, J. T., and Gibson, G. E. (2007). “Benchmarking of Large Design-Build Highway Projects: One-to-One Comparison and Comparison with Design-Bid-Build Projects.” *Transportation Research Record: Journal of the Transportation Research Board*, 1994(-1), 17–25.

Skitmore, R. M. and Marsden, D. E. (1988). “Which procurement system? Towards a universal procurement selection technique.” *Construction Management and Economics*, 6, 71-89.

Songer, A. D., and Molenaar, K. R. (1996). “Selecting design-build: public and private sector owner attitudes.” *Journal of Management in Engineering*, 12(6), 47–53.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). “Selection of Project Delivery Method in Transit: Drivers and Objectives.” *Journal of Management in*

*Engineering*, 27(1), 21–27.

Warne, T. R. _2005_. *Design build contracting for highway projects: A performance assessment*, Tom Warne & Associates, LLC.

Yates, J. (1995). “Use of design/build in E/C industry.” *Journal of Management in Engineering*, 11(6), 33–38.

# CHAPTER 2

# THE IMPACT OF RISK ON DESIGN-BUILD SELECTION FOR HIGHWAY DESIGN AND CONSTRUCTION PROJECTS

**ABSTRACT**

The design-build (DB) project delivery method continues to grow as a viable alternative delivery method for highway projects. The primary reason for selecting DB delivery is to take advantage of the time savings inherent in the process. However, because of low levels of design at the time of contract awards, DB contracts often carry more risks and uncertainties than other contracts, which makes the decision to select DB delivery complex. Applying risk analysis strategies and tools to the delivery selection process will help decision makers evaluate and select the DB delivery method consistently and defensibly. This paper examines 39 generic risk factors related to the DB delivery selection process. These risks were identified through previous research and risk analysis workshops on transportation projects worth more than $10 billion. To explore how these risks impact DB delivery selection, a questionnaire was developed to collect data from a national cross-section of professionals with an average of 25 years of experience related to risk and project delivery methods in the transportation industry. An exploratory factor analysis was used to investigate the relationship between DB delivery selection and the 39 generic risk factors. The results indicate that seven delivery selection risk factors have the most influence on DB delivery selection: (1) scope risk; (2) third-party and complexity risk; (3) construction risk; (4) utility and right-of-way (ROW) risk; (5) level of design and contract risk; (6) management risk; and (7) regulation and railroad risk. This study compares risk preferences of public owners and design-builders for choosing DB delivery. Understanding these risk factors will help professionals not only select DB for appropriate projects but also allocate risks more properly in DB contracts.

**KEYWORDS:** Design-build; Risk management; Decision making; Procurement; Highways.

## INTRODUCTION

Although the use of design-build project delivery (DB) now comprises more than 40% of the non-residential construction sector (DBIA 2011), the Federal Highway Administration (FHWA) and state departments of transportation (DOT) have only used DB sparingly. The highway design and construction sector first investigated DB in 1988 when the Transportation Research Board (TRB) established a task force to study innovative contract processes (FHWA 2006a). At that time, the FHWA regulations did not allow the use of DB on federally funded highway projects. In 1994, the FHWA allowed DB under its Special Experimental Projects (SEP) No. 14 program, and SEP 14 showed benefits of DB in terms of schedule and cost. As a result, the 1998 Transportation Equity Act for the 21st Century (TEA-21) allowed the use of DB on select federally funded projects and required the FHWA to develop regulations for DB project delivery use (TEA-21, Public Law, Title1, Subtitle C, Sec. 107). In 2002, the FHWA published its Design-Build Contracting Final Rule, and the DB project delivery method was moved from experimental status to mainstream use on federally funded projects (FHWA 2002). Since then, changes to state project delivery legislation have followed.

Project delivery methods, by definition, allocate risk for design and construction. Researchers (FHWA 2006a; Gransberg et al. 2006; Molenaar and Gransberg 2001) have documented that the advantage of using DB is to transfer two primary risks: design liability for errors and omissions in plans and disputes between designers/owners and contractors from the traditional design-bid-build (DBB) delivery method to the design-builder. However, design liability and disputes are only two of many risks that DOTs must consider when deciding to use DB. Transferring other risks, whether intentionally or unintentionally, can result in higher initial prices or lower design-builder competition. This paper, which is part of a more comprehensive risk-based study to select project delivery, explores our understanding of the impact of risk on the choice of DB for highway projects. Based on the results of rigorous risk identification and a comprehensive national survey, we aimed to: (1) identify the delivery selection risk factors that owners and design-builders must consider when selecting DB for highway projects; (2) categorize the generic risk factors using exploratory factor analysis; (3) discuss how the findings can help highway agencies make better project delivery decisions; and (4) compare risk perspectives of public owners and design-builders regarding DB selection.

## LITERATURE REVIEW AND POINT OF DEPARTURE

Owners have several project delivery methods to choose from. Currently, the three fundamental project delivery methods in use by the highway industry are DBB, DB, and construction manager/general contractor (CMGC). Each project has its own characteristics and requirements. No single delivery method is the most suitable for any type of project (Touran et al. 2011; Ibb et al. 2003; Gordon 1994). The paper focuses DB, which has experienced rapid growth in the highway sector. After a review of the legislative codes and statutes of all states, Ghavamifar and Touran (2008) pointed out that 13 state DOTs did not have the authority to use DB. However, according to a report from the Design-Build Institute of America (DBIA 2012), only six state DOTs did not have the authority to use DB as of 2012. Although use of DB is increasing across state DOTs and it is used on large projects, its practice comprises only a fraction of most DOTs' design and construction programs by number. DB is still relatively new to the majority of DOT staff, and many DOTs are still developing an institutional culture appropriate for the new approach (Migliaccio et al. 2009; Molenaar and Gransberg 2001). In fact, fewer than half of all DOTs have used DB on more than 10 highway projects (DBIA 2012; FHWA 2009). This indicates that state DOTs need assistance in understanding when to select DB.

The growing use of alternative delivery methods has led researchers and practitioners to seek decision support for choosing appropriate delivery methods. As a result, an array of research approaches has been developed to assist these decision makers. These approaches can be divided into two distinct groups. The first group results from research based on comparisons of performance measurements of alternative delivery methods (e.g., Songer and Molenaar 1996; Konchar and Sanvido 1998; Gransberg et al. 2006; Hale et al. 2009; Shrestha et al. 2012). The second group of approaches stems from research that focuses on proposing frameworks for decision makers to use to select an appropriate delivery method given a set of relevant criteria. This group ranges from simple approaches, such as flowcharts (Goldon 1994), to complex frameworks, such as multi-attribute utility/value theory (e.g., Miller et al. 2000; Oyetunji and Anderson 2006) and analytical hierarchical process/value engineering (e.g., Alhazmi and McCaffer 2000; Mahli and Alreshaid 2005; Touran et al. 2011).

Selecting appropriate methods is a complex decision process. These decisions should be made in the project scoping phase and certainly before the final design phase begins. However, the scoping stage involves a definition of purpose and need, but lacks detailed site investigation or engineering design details. Further, highway design and construction projects are often fraught with risk and uncertainty at this stage (Molenaar et al. 2010) so selecting the most appropriate project delivery method can be critical for project success. Selecting DB is even more critical because of the complex risk allocation mechanism in DB contracts. The scope of this study is limited to the process of selecting DB for highway projects.

A review of the literature indicated that no published work has investigated the interaction between the characteristics of risk and DB delivery selection. Our point of departure for this study is how risk influences DB selection. The paper seeks to add to the current body of knowledge about DB for highway design and construction by providing a comprehensive list of risk factors that DOTs should consider when selecting the DB delivery method. We expect that these findings will help transportation agencies make more informed project delivery decisions and will provide guidance on determining when to use the DB delivery method. Although the data for this study focuses on highway design and construction, the categories of risk may provide insight into other sectors of design and construction.

## RESEARCH METHODOLOGY

The research methodology involved the following steps: (1) developing a questionnaire to explore the relationship between documented cost and schedule risk factors and the selection of DB project delivery; (2) collecting data from a knowledgeable group of professionals; (3) analyzing the data using exploratory factor analysis; (4) discussing findings and providing recommendations for a risk-based approach to selecting DB delivery for highway projects; and (5) comparing the delivery selection risk perspectives of public owners and design-builders.

## QUESTIONNAIRE

A survey questionnaire was used to collect data for this study. The unit of analysis for the questionnaire was the individual respondent and the impact of risk factors on the DB selection process in his or her organization. The questionnaire was developed through an exhaustive literature review of project delivery selection frameworks and cost/schedule risk assessments for highway projects.

An initial list of approximately 200 risk factors for highway design and construction projects was compiled. These risk factors had been identified and developed during previous research and risk analysis workshops on more than $10 billion in transportation projects for the National Cooperative Highway Research Program (Roberds et al. 2010; Molenaar et al. 2008; FHWA 2006b) and the Washington DOT (Molenaar 2005). This comprehensive list of risk factors was analyzed to combine overlapping risks, and risks that did not relate to project delivery decisions were removed. We took a conservative approach in combining and removing these risks to be certain that no relevant risks were excluded. As a result, 39 generic risk factors that relate to the project delivery selection process were identified and used for the empirical survey questionnaire. A list of these 39 generic risk factors is provided in the Appendix. A web-based survey allowed for a random rotation of questions to eliminate any sequence bias.

## DATA COLLECTION PROCESS

The questionnaire was sent to a cross-section of public agencies and private sector designers and contractors. We chose a subset of national associations committees and specialty conference attendee lists to ensure that a knowledgeable group of professionals would respond to the questionnaire. The list of respondents was developed from the TRB Project Delivery Committee; TRB Construction Management Committee; American Association of State Highway and Transportation Officials (AASHTO) Joint Technical Committee on Design-Build; AASHTO Subcommittee on Construction; AASHTO Standing Committee on Planning; Colorado Department of Transportation's (CDOT) Innovative Contracting Advisory Committee; and participants of the Design-Build Institute of America's DB Transportation Conference.

A pilot questionnaire was sent to 50 respondents to test the appropriateness and clarity of the survey. The pilot test resulted in minor adjustments to the questionnaire. The revised questionnaire was then sent to 450 potential respondents from 52 state DOTs and a number of designers, contractors, subcontractors, professionals, and practitioners from the private sector. The questionnaire asked respondents to rate the impact of the 39 generic risk factors on the DB delivery selection process on an ordinal scale (0 = NA; 1 = Very Low Impact; 2 = Low Impact; 3 = Moderate Impact; 4 = High Impact; and 5 = Very High Impact). This scale was designed to mitigate the discontinuity effect of the data by including numbers corresponding to different thresholds (Knapp 1990). Respondents who did not have knowledge about a risk factor could select NA. We treated NA as a missing value and excluded it from the analysis. Respondents were also asked to provide explanations for their answers.

## DATA ANALYSIS

A total of 152 valid responses were received, for an overall response rate of approximately 34%. These responses were grouped into three categories, owner agencies; design/engineering/consultant firms; and contractors/subcontractors. It was decided that 15 respondents from the 152 responses who had fewer than 10 years of relevant professional experience were excluded from the analysis. The remaining 137 respondents had an average of 25 years of professional experience. Of the valid responses, 71 respondents (51.8%) were from public owner agencies; 35 respondents (25.5%) were from design, engineering, or consulting firms; and 31 respondents (22.7%) were contractors or subcontractors. Table 1 summarizes the results of the survey questionnaire.

**Table 1. Results of Data Collection Process**

| Organization | Qualified responses received | Proportion (%) |
|---|---|---|
| Public owners | 71 | 52 |
| Engineering/Design firms | 35 | 26 |
| General contractors/Subcontractors | 31 | 23 |
| Total | 137 | 100 |

The Statistical Package for Social Sciences (SPSS) version 19.0 was used to perform both descriptive and inferential analysis. The descriptive statistics convey overall quantities and measures of magnitude and dispersion. The inferential statistics provide a means of drawing conclusions for the overall population based on a smaller sample. To identify the risk factors that have a significant impact on DB delivery selection, exploratory factor analysis was employed. It is important to note that although factor analysis is designed for interval data, it can be used for scaled ordinal data (Kim and Mueller 1978).

Before performing factor analysis, all 39 generic risk factor variables were tested for potential outliers and normality. For univariate outlier testing, the standard score of all cases varied from -2.7 to +2.5, which is within an acceptable threshold (from -4.0 to +4.0) recommended by Hair et al. (2009) for sample sizes larger than 80. For multivariate outlier testing, the probability associated with Mahalanobis distance (Mahalanobis $D^2$) ranged from 0.0160 to 0.9835, which is above the acceptable threshold (0.001) recommended by Hair et al. (2009). Therefore, no outliers were found in the data set. The normality of all independent variables was tested with skewness and kurtosis tests. The skewness values of all 39 variables (generic risk factors) for all cases varied from -0.57 to +0.87. The kurtosis values for all variables ranged from -0.99 to +0.08. Because these values were within a range of -1.0 to +1.0 at a p-value > 0.05, all variables were reasonably considered normal distributed.

The Kaiser-Meyer-Olkin (KMO) value was 0.74, which is above the acceptable threshold of 0.6 recommended in the literature (Hair et al. 2009). Bartlett's test of sphericity provided an approximate chi-square statistic of 868.5 with 276 degrees of freedom. The associated significant levels were small at $p < 0.001$. These values indicate that this data set is suitable for factor analysis.

The primary objective of factor analysis is to describe and capture the relationships among many variables in terms of a few underlying factors that can be used to represent the entire sample. Factor analysis was conducted through the following steps.

1. Perform required tests to capture the correlation matrix for all factors and determine the appropriateness of the factor analysis including Bartlett's test of sphericity; the KMO test of overall measure of sampling adequacy (MSA); and anti-image correlation for partial correlations and for individual MSA.

2. Perform factor extraction to determine the numbers of factors retained. Based on the recommendations from Fabrigar et al. (1999) and Costello and Osborne (2005), maximum likelihood and multiple scree tests were employed for this study.
3. Perform factor rotation to simplify and clarify the data structure.
4. Interpret and label underlying (grouped) factors that reflect as accurately as possible the variables loading on that factor.

**RESULTS**

The factor analysis results indicated that only 23 of the 39 generic risk factors impact DB delivery selection and these 23 risks are grouped into seven DB risk factors. These seven factors accounted for 64.4% of the total variance in responses, which is above the 60.0% of variation that Hair et al. (2009) recommended for terminating the factor extraction process. Table 2 summarizes these seven DB risk factors and their components. The first three factors (Factor 1: Scope Risk with 20%, Factor 2: Third-party and Complexity Risk with 12%, and Factor 3: Construction Risk with11%) explained 43% of the variability in the decision. While factor analysis groups the variables (factor components) that have large loading for the same factors, it does not attach labels to the factors. Kim and Muler (1978) suggested that the substantive meaning of the factor label should typically be based on an examination of what the high loading variables measure. In this study, the seven DB risk factors were defined based on an examination of the loading distributions from 23 risks and how they were grouped together from the factor analysis. Table 2 shows that almost all factor loadings were greater than 0.5, and 15 of them were greater than 0.7. These factor loadings were reasonably consistent with the interpretation of the factors extracted.

**Table 2. Delivery Selection Risk Factors for DB Projects**

| Delivery Selection Risk Factors and their Components | Factor Loading | % of Variance | Cumulative % |
|---|---|---|---|
| **Factor 1: Scope Risk** | | 19.52 | 19.52 |
| Project definition | 0.822 | | |
| Scope definition | 0.781 | | |
| Staff experience/availability | 0.747 | | |
| Conformance with regulations/guidelines/documentation | 0.701 | | |
| Challenge in appropriate environmental documentation | 0.638 | | |
| **Factor 2: Third-party and Complexity Risk** | | 12.14 | 31.66 |
| Delays in completing utility agreements | 0.739 | | |
| Obtaining other agency approvals | 0.738 | | |
| Project complexity | 0.722 | | |
| Defined and non-defined hazardous waste | 0.711 | | |
| Legal challenges and changes in law | 0.662 | | |
| **Factor 3: Construction Risk** | | 10.61 | 42.27 |
| Geotechnical investigation | 0.771 | | |
| Work zone traffics control | 0.730 | | |
| Environmental impact | 0.663 | | |
| Construction QC/QA | 0.484 | | |
| **Factor 4: Utility and ROW Risk** | | 7.32 | 49.59 |
| Unexpected utility encounter | 0.844 | | |
| Delays in right-of-way (ROW) process | 0.626 | | |
| **Factor 5: Level of Design and Contract Risk** | | 5.53 | 55.12 |
| Design completion | 0.813 | | |
| Single or multiple contracts | 0.775 | | |
| Unclear contract documents | 0.408 | | |
| **Factor 6: Management Risk** | | 4.91 | 60.03 |
| Project and program management issues | 0.786 | | |
| Insurance | 0.719 | | |
| **Factor 7: Regulation and Railroad Risk** | | 4.34 | 64.37 |
| Intergovernmental agreements/regulation | 0.793 | | |
| Railroad agreements | 0.526 | | |

## DISCUSSION

This section discusses the seven DB risk factors in detail and provides possible explanations as to why these risk factors are particularly important to DB delivery selection, project cost, and the implications for schedule performance. This section also discusses why the groupings were discovered in the factor analysis.

**Factor 1: Scope Risk**

Scope risk accounted for nearly 20% of variance in the DB delivery decision (Table 2). Scope risk encompasses four components that had factor loadings greater than 0.7: project definition; scope definition; staff experience and availability; and conformance with regulations, guidelines, and documentation. This finding is consistent with the literature. Gransberg et al. (2006) showed that a well-defined project will minimize the amount of contingency in design-builder proposals and offer the owner a competitive price. Likewise, Ghavamifar and Touran (2009) posited that in the DB contract, the owner agency and contractor should clearly understand the scope of work and realize critical information related to uncertain conditions at the time of award. In DB projects, because agencies define project scope and requirements through requests for proposal (RFP) and procure both the final design and construction by evaluating technical proposals or price, vague scope definition is the most common reason behind budget and scheduling disputes in these projects (Gransberg et al. 2006).

Staff experience and availability directly impact an agency's ability to develop a solid scope definition for any delivery method, but this is particularly essential for DB where project success hinges on the accuracy and completeness of the RFP. Because DB is relatively new in many states, existing staff may need training to address their changing roles and responsibilities. Lack of staff experience is one of the main concerns for highway agencies when they are deciding whether to use DB for their projects. Gransberg et al. (2008) found that a major failing in DB RFPs is the lack of staff experience to define a solid scope, especially for design quality control /quality assurance (QC/QA) activities after the award. In the questionnaire response, one public owner described the lack of the staff experience for the DB delivery method as follows:

> It is critical to have experienced staff for the DB delivery method. The success of DB projects is tied to the abilities of the staff. The staff experience [and availability] can be a major problem for the DB method.

Because of the long history of prescriptive regulatory guidelines and documentation in highway projects, some regulations such as the use of performance criteria in DB can cause conflict within the project scope. In the words of one contractor, "design criteria, regulations, and relevant documentation have to be cleared up front or the design-builder will not know what to do." Conformance with regulations, guidelines, and documentation is a component that affects scope risk. Agencies should explicitly specify the appropriate documentation, regulation and guideline in the project scope definition to avoid risk.

**Factor 2: Third-party and Complexity Risk**

This DB risk factor includes five components that are primarily concerned with delays in utility agreements, agency approvals, project complexity, hazardous waste, and legal challenges (Table 2). Third-party and complexity risk accounted for 12% of variance in the DB selection. A utility agreement is usually developed and executed between the highway agency and the utility company with complete design plans and specifications. However, in DB projects, completing utility agreements and obtaining agency approvals often occur concurrently with construction activities. Under the DB delivery method, risks relating to design are often transferred from the highway agency to the design-builder. Thus, delays in completing utility agreements and obtaining agency approvals have an influence on highway DB project schedule and cost. One contractor described the impact of the utility work on the DB selection as follows:

> Under DB, [utility work] is a major concern due to the lack of time for the "planning" part of the process. It can be a high risk for [the design-builder]. If the utility companies do not get enough notice to design their relocations, order materials, or mobilize forces, this could cause delay to the contractor. Owners usually identify the utilities but put the entire burden on [the design-builder] to solve.

Project complexity is another main component of this DB risk factor. Highway project complexity is often characterized by seven project elements: roadway, ROW, traffic control, structures, utilities, environmental issues, and stakeholders (Anderson et al. 2007). The finding that project complexity greatly influences DB selection is consistent with the literature. O'Connor et al. (2006) found that one of the main concerns of transportation agencies about the DB delivery method is a lack of project control, especially for complex projects. This risk may hinder highway agencies from selecting the DB delivery method for their projects. One public owner explained that,

> on some projects, the DB delivery method should not be used due to complexity and unknown variables. Loss of direct control and oversight, challenges in management of the desired end [product], and performance have a big impact on the DB selection.

Risks caused by hazardous waste also influence DB selection. The National Environmental Policy Act/State Environmental Policy Act (NEPA/SEPA) process requires a definition of major project features (Wood et al. 2011). An environmental site assessment to identify potential hazardous waste is important during the project delivery method selection processes. Involvement with hazardous waste sites can lead to significant cleanup costs and project delays. In general, transportation agencies conduct the studies, prepare the documents, and apply for appropriate environmental clearances. This process is a challenge for both DB and DBB projects, but it is more critical for DB projects due to the transfer of design risk. Since 2003, FHWA's Design–Build Contracting Final Rule requires that the NEPA clearance process be completed before the final DB RFP is released (FHWA 2002). Wood et al. (2011) also suggested that highway agencies should include NEPA risk as part of the project delivery selection process. One public owner with extensive DB experience discussed the risks caused by hazardous waste:

> There is always uncertainty in hazardous waste in any delivery methods, but because of the loss direct control and oversight in DB projects, it could be a high risk if the burden of dealing with unknown hazardous material is on the design-builder. Unknown hazardous waste and material are usually a major point of contention due to greater risk allocation provisions to the design-builder.

Finally, risks caused by legal challenges and changes in law also impact DB selection. Although 44 states have authorized the use of DB in their projects by 2012 (DBIA 2012), every state has given a certain level of authority to the DOT. Some state DOTs can use DB in their projects without any limitations (e.g., Florida, Colorado, South Dakota). Other states require extra approvals from entities outside the DOT or put some limitations on the use of DB delivery method. For example, approval of the House and Senate transportation committees is required for using DB for highway projects in Louisiana DOT. Likewise, DB is used in a pilot program in Arkansas Delaware, Kansas, Minnesota, Washington, and West Virginia (DBIA 2012). Legal challenges and changes in law play an important role in the choice of DB for highway projects. One public owner explained the impact of legal challenges and changes in law on DB selection:

> DB delivery method is relatively new in the public transportation sector, a lot of contractors don't trust it (i.e., viewed as being too subjective) and unsophisticated owners don't know how to use it properly or don't realize they don't have the enabling legislation in their state. Changes in the law are more of a risk in longer term contracts, which is more frequently in DB projects.

**Factor 3: Construction Risk**

The construction risk factor encompasses the uncertainties and risks relating to geotechnical investigation, work zone traffic control, environmental impact, and construction QC/QA (Table 2). This risk factor accounted for nearly 11% of variance in the DB selection decision. A common issue in DB projects is the level of geotechnical investigation that owner agencies include in the RFP. The DB delivery method transfers some or all aspects of geotechnical risk from the owner agency to the design-builder. Kim et al. (2009) asserted that under DB projects the design-builder is responsible for all elements of design and construction, including risks from geotechnical investigation. Although insufficient geotechnical information may result in high contract prices because the design-builder must allocate a large contingency, an overly extensive geotechnical investigation may decrease the benefits of using DB and result in wasted resources. As a result, the level of geotechnical investigation is important for DB projects. However, DB selection does not always allow for thorough geotechnical investigations. One public owner explained that,

> under the DB project, time/schedule constraints can cause delays in getting appropriate data for design. Some information is included in the plans. It is up to the DB team to decide

> if they need more and how to address this in their bid. Not addressing it adequately can lead to additional costs for the DB team and reduced profits. [Geotechnical investigation] is crucial for DB projects.

Risks caused by traffic control during construction need to be considered in DB projects. The traffic control plan is often included by the design-builder in the technical proposal and evaluated as a part of the selection decision. Under the DB delivery method, if the traffic control plan is not reasonably included in the proposal, it may cause a major problem for the work zone and maintenance of traffic during construction. One contractor said that "the performance specifications are the key to reducing work-zone traffic control risk." A public owner also pointed out that "work-zone traffic control is a high risk if the design-builder is entirely responsible for traffic control and maintenance of traffic because the design-builder is often tempted to minimize this attention to reduce costs."

Environmental conditions and restrictions can have a considerable effect on the cost and schedule of DB projects. As discussed in third-party risk, Wood et al. (2011) introduced several NEPA-related risks that need to be considered in the project delivery selection process. In the DB delivery method, poorly defined environmental criteria can directly lead to project delays and cost overrun. Because the DB delivery method limits the agency's control in obtaining environmental permits when the design is incomplete, environmental commitments may be a challenge for the design-builder during construction. Furthermore, when the design deviates from the original plan, some permits must be reissued before the construction can be resumed. One public owner discussed the issue as follows:

> Environmental approvals often are in place before awarding the contract, but DB is responsible for any design related changes that may require a supplemental approval. This could be a big concern and delays can happen since design and construction are closely tied.

It should be noted that the environmental permit acquisition process typically takes significant time and effort. Because design is concurrent with construction in DB projects, obtaining environmental permits is a long-lead item that can affect the project from the preliminary design to construction phase. This may explain why the environmental risk components can occur in scope risk (e.g., environmental documentation), in third-party risk (e.g., hazardous waste), and in construction risk (e.g., environmental impact) (Table 2).

Finally, construction QC/QA is also a major concern for the DB delivery selection. Gransberg and Molenaar (2004) recommended that the agency must delineate both design and construction quality clearly in the RFP and this description needs to be very accurate in the working definition of quality for each feature of work. In some DB projects, risks caused by construction QC/QA can be significant. Higbee (2002) pointed out that design-builders may have opportunities to select and make payments to their QC/QA firms and may bring pressure to bear on the inspectors regarding the content, timing, and efficacy of the inspections. One public-owner discussed the impact of QC/QA risk on DB projects:

> QC/QA is a big risk in DB projects. [The design-builders] are responsible for QC and QA, but most of them do not get it. Time constraints may impact the ability to perform a proper

QA/QC. It is crucial to include specific criteria in the RFP for acceptable work and payment.

**Factor 4: Utility and ROW Risk**

The utility and ROW risk factor accounted for 7% of the variance in responses. Because ROW acquisition is a complex process that involves multiple uncertainties (Anderson et al. 2009), it is recommended that the state transportation agencies purchase ROW. Generally, government agencies have more power and control over the ROW acquisition process (Molenaar et al. 2008). However, under DB projects highway agencies can transfer part of or all this risk to the design-builder. In this case, the RFP must clearly and sufficiently define all aspects related to the ROW acquisition process. Delays in the ROW process can significantly impact project schedules and costs. One public owner stated that "you should not release the RFP if the ROW process is not complete or well defined." Another public owner with extensive DB experience discussed the ROW acquisition in DB projects.

> Right-of-way can be in flux. The best way to do DB is to acquire the land first, then let the design-builder within the footprint. Only the states have powers to condemn the property if needed. If the DB team is responsible for the ROW acquisition, it could be very high risk. We have challenges when [the design-builder] tries to buy ROW as part of the contract.

Utility relocation, the other component of this factor, is basically a two-step process. The first step is to identify existing utilities and the second is to remove or relocate the utilities. Similar to ROW acquisition, obtaining utility agreements is a potentially high-risk process that can impact project schedules and costs. In DB projects, the highway agency can choose to shift the responsibility for obtaining utility agreements to the design-builder, but these RFPs should include all provisions related to the utility work. The level of communication and coordination between the design-builder and utility companies is key to success. Generally, it is challenging for the design-builder to acquire utility agreements because highway agencies have traditional relationships with utility companies and will likely have more influence than the design-builder. One contractor described the impact of utility work on DB projects:

> Utility work may be under the design-builder risk and therefore it can be a huge issue. The performance specifications need to be clear about what is required and what the betterment is and how to resolve and issue with a third party who is not part of the DB contract with the design-builder. It is hard to negotiate with utility companies. The owner must consider utility impacts and if they can be appropriately mitigated under the DB delivery method.

**Factor 5: Level of Design and Contract Risk**

This risk factor accounted for nearly 6% of variance in the DB delivery selection and includes three components that primarily focus on level of design and contract issues. Although the design-builder is the single point of accountability for both design and construction, the agency must provide a sufficient design to the design-builder in the RFP. However, determining an appropriate level of design prior to contract award for DB projects is a challenging task. For example, if the agency provides too much initial design, it can greatly limit the chances of innovation from the design-builders. Typically, DB projects were awarded with less than 30% design completion (FHWA 2006a). In addition, to achieve a successful RFP for a DB project, the agency must clearly state the definition of design QC/QA activities. Gransberg et al. (2008) reported that only 8% of

RFPs mentioned design QC/QA. This low percentage of design QA/QC in RFP may be a major failing in DB projects. One public owner explained that

> the design should be advanced to the point where there is some information about soil conditions, ground water conditions, etc… so that reasoned assumptions can be made. Otherwise, there is risk of increased cost and delays. The design-builder will undoubtedly look to the owner for compensation.

Contract ambiguities also influence DB delivery selection because contracts are the vehicles for distributing risk to all parties involved in a DB project. Although contracts can take many forms, it is essential for DB project owners to have comprehensive strategies for developing strong and equitable contracts. In addition to the technical considerations in RFPs, owners need to include contract clauses that describe the relationships between the design-builder and the owner and that define the responsibilities of each during project execution. One participant discussed the influence of contract issues on the DB delivery selection:

> The performance specifications are very, very important, and too often they are written like a legal document rather than engineering terms. Any time there is ambiguous language in a contract, it poses a significant risk to the owner for claims or change orders that result. This is especially true in the case of DB since this would open up the door to cost negotiations that would normally be at the risk of the DB team.

It is important to note that the level of design is closely tied to the contract. Gransberg et al. (2006) found that the owner must be satisfied that the level of design included in the RFP will be sufficient to allow the design-builder to precisely develop a price without excessive contingencies to cover the potential cost of design decisions that must be made after DB contract award. This is consistent with the findings of this study in that risks caused by design completion and contract issues were congregated in the analysis.

**Factor 6: Management Risk**

The management risk factor, which includes two components, project and program management and insurance, accounted for 5% of the variance in responses. In the highway industry, a project is not built in isolation, but often is built concurrently with other projects in a program. As a result, resource conflicts in a multi-project environment can lead to project delays or cost overruns. Platje and Seidel (1993) showed that, because all project managers simultaneously use several pools of resources, at the program level resource allocation is a complex process related to conflicts of interest. Design-build projects and design-build programs require different approaches. At the program level, highway agencies should establish a set of policies and document templates that can be used for projects suitable for the DB delivery method. Molenaar et al. (2008) posited that DB programs require new procedures and attitudes that highway agencies should perceive the DB delivery method in terms of a program rather than simply a set of individual projects. However, these new requirements can be a major concern in highway agencies because they have worked with the traditional DBB method for so many years. One contractor described how the “lack of quick decisions are common problems with owners” and “conflicts in owner expectations can cause significant risk.” One public-owner also explained that

> DB requires a certain level of owner oversight especially for federally funded projects. Sometimes, owners may not be prepared for oversight of an aggressive schedule. A lot of

> things are typically happening in parallel. So, a good and experienced management is the key to success. More effort is required by all parties to develop the DB program.

Insurance is another issue in management that influences the DB delivery selection. Because design and construction are combined into single contracts in the DB delivery method, issues relating to bonding and insurance will affect relationships in DB teams. Design-builders are predominantly teams that combine contractors and subcontracted engineers. A main concern of contractors is protection from claims of errors and omissions pertaining to the design. Traditionally, design professionals provide errors and omissions insurance and contractors provide performance and payment bonds. Because contractors' general liability policies usually have little or no deductible while professional liability policies have large deductibles, these policies may have disparate impacts on the DB team (Friedlander 1998). To mitigate this issue, highway agencies must be clear in the RFP on bonding and insurance requirements for these parties. One contractor discussed the influence of insurance on the DB delivery method:

> The approach to insurance coverage in the DB delivery method may cause risk. [Insurance] can be high risk due to onerous or unobtainable insurance requirements set by owners or their attorney. Lack of knowledge to specify insurance requirements to the DB team is a primary concern.

**Factor 7: Regulation and Railroad Risk**

Regulation and railroad risk accounted for 4% of variance in responses for the DB delivery selection (Table 2). In DB projects, the levels of communication and coordination between the design-builder and local agencies and railroad companies vary based on the project. Typically, highway agencies have established processes for negotiation with local agencies and railroad companies. However, by the nature of DB projects, design-builders are responsible for the actual design and construction, so highway agencies may shift the risk of working with local agencies or railroad companies to the design-builders. This may cause a major risk for the design-builders because they are not in the best position for these negotiations. The design-builder is in a contractual relationship with highway agencies, not with these third parties. One contractor explained that "because the design-builders build in certain design assumptions that might be impacted by outside agencies and these agencies can present a large risk if they are not cooperative." To achieve success in DB highway projects, Molenaar et al. (2008) recommended that highway agencies should have extensive preliminary and on-going communication with outside entities and maintain a strong ownership role throughout the contract. This recommendation is consistent with the findings of this study. One public owner pointed out that

> because the DB delivery method is quite new to many states and local agencies, owners should obtain railroad agreements and other intergovernmental agreements prior to award. Strong leadership from the owner must occur during DB procurement to maintain the need to coordinate with governmental agencies – jurisdictions.

Another public owner said, "We have had one project which required the design-builder to interact with the railroad company. However, the railroad refused to work with the design-builder and our department had to intervene and broker a third-party agreement."

## COMPARISON OF PUBLIC OWNER AND DESIGNER/CONTRACTOR RISK PREFERENCES

The data allowed for a comparison of the risk preferences between public owners and design-builders in DB delivery selection. Knowing these differences will help with the delivery selection and risk allocation in the DB contract. The seven DB risk factors identified in the factor analysis (Table 2) were further examined by using the two-sample Hotelling's $T^2$ test. This test is the multivariate analogue of the familiar two-sample t-test in univariate statistics, but it is designed to compare the mean vectors of the two populations rather than two individual means.

Two research hypotheses were tested to compare the risk attitudes between public owners and design-builders toward DB selection:

Null hypothesis ($H_0$): There is no significant difference in the risk preference between public owners and design-builders regarding delivery selection risk factors in the DB delivery method decision.

Alternative hypothesis ($H_a$): There is a significant difference in the risk preference between public owners and design-builders regarding delivery selection risk factors in the DB delivery method decision.

The null hypothesis ($H_0$) is accepted unless there is sufficient statistical evidence for rejection. Hotelling's $T^2$ test is based on three assumptions: (1) the two populations are normally distributed, (2) the observations are independent, and (3) the two populations have the same covariance matrix. The first two assumptions were clearly satisfied because they were previously tested in the factor analysis. For the third assumption, Box's M test was used to test the homogeneity of variance-covariance matrices. The results of the Box's M test showed that the p-values of all seven factors are greater than 0.05 (Table 3). Thus, the third assumption for the Hotelling's $T^2$ test is satisfied.

**Table 3. Risk Preference Comparison between Public Owners and Design-builders**

| Delivery Selection Risk Factor | Box's M Test of Assumptions | | | Hotelling's $T^2$ Test | | |
|---|---|---|---|---|---|---|
| | Box's M | F-value | p-value | $T^2$ value | F-value | p-value |
| Factor 1: Scope Risk | 19.80 | 1.254 | 0.223 | 1.94 | 0.375 | 0.865 |
| Factor 2: Third-party and Complexity Risk | 16.18 | 1.026 | 0.423 | 8.45 | 1.628 | 0.159 |
| Factor 3: Construction Risk | 16.19 | 1.556 | 0.113 | 25.43 | 6.185 | 0.00* |
| Factor 4: Utility and ROW Risk | 1.14 | 0.372 | 0.773 | 3.83 | 1.899 | 0.155 |
| Factor 5: Level of Design and Contract Risk | 3.36 | 0.544 | 0.775 | 7.18 | 2.349 | 0.077 |
| Factor 6: Management Risk | 4.29 | 1.403 | 0.240 | 5.77 | 2.857 | 0.062 |
| Factor 7: Regulation and Railroad Risk | 0.92 | 0.302 | 0.824 | 3.48 | 1.723 | 0.183 |

** indicates that the p-value is less than 0.05*

In this study, the specification of the rejection region was chosen to be < 0.05. Therefore, if the probability (p-value) from Hotelling's $T^2$ test is less than 0.05, we reject the null hypothesis (and accept the alternative hypothesis). Alternatively, if the p-value is greater than 0.05, we will accept the null hypothesis.

Only construction risk (Factor 3) has a p-value less than $\alpha = 0.05$ (Table 3). This suggests that there is a statistical difference between the risk preference of the public owner and the design-builder with regard to construction risk. It is important to note that more construction risk is transferred from the agency to the design-builder in DB projects versus DBB. The agency delegates responsibilities for construction oversight to the design-builder, who is solely responsible for all construction risks. In addition, the contract is performance-based through RFP performance criteria rather than prescriptive-based through plans and specifications. There is no shared-risk option in the construction risk between the agency and the design-builder. Alternatively, as discussed in the factor analysis results, risks caused by project scope (Factor 1), third-party and project complexity (Factor 2), utility and ROW (Factor 4), level of design and contract risk (Factor 5), management risk (Factor 6), and regulation and railroad risk (Factor 7) are often shared between the owner agency and the design-builder. Thus, it is reasonable to observe that while the risk preference between the owner agency and the design-builder is different for construction risk, there is no statistical difference in the risk preferences of the public owner and the design-builder for other factors.

Appropriate risk allocation is a component of all successful contracts. It is even more important for DB contracts because many of the risks traditionally managed by the agency can, and do, become the responsibility of the design-builder. Because risk preference between the public owner and design-builders is not always the same, highway agencies must carefully consider risks associated with construction such as geotechnical investigations, work zone traffic control, environmental impact, and construction QA/QC in their DB projects. In addition, it is important to note that while DB delivery offers the opportunity to transfer other risks to the design-builder and that many public agencies have chosen to use the DB delivery method to better manage their risk (Gurry and Smith 1995), inappropriate risk allocation will result in higher costs to the agency (Molenaar et al. 2008).

## SUMMARY AND CONCLUSIONS

Seven DB risk factors were extracted by the factor analysis of the generic delivery risk factors identified from a synthesis of empirical studies and expert opinions. It should be noted that only

23 of the 39 generic risk factors constituted the seven DB risk factors. These seven DB risk factors (scope risk, third-party and complexity risk, construction risk, utility and ROW risk, level of design and contract risk, management risk, and regulation and railroad risk) established the basis for applying risk analysis strategies to DB highway projects. The findings of this study are consistent with the literature. Previous research has shown that scope risk has the greatest impact on DB project cost and schedule performance (Ghavamifar and Touran 2009; Granberg et al. 2008; Granberg et al. 2006) and that risks caused by third-party permits (Wood et al. 2011; Anderson et al. 2009; Migliaccio et al. 2009; Molenaar et al. 2008; Granberg et al. 2006) and construction risks (Kim et al. 2009; Gransberg and Molenaar 2004; and Higbee 2002) are major concerns for highway agencies in selecting the DB delivery method. These findings can be used as guidance for highway agencies when selecting the DB delivery method. Further, the results of this study may serve as a checklist for decision makers when deciding whether to use the DB delivery method.

In addition to the identification and classification of risk factors related to the DB delivery selection, this study investigated the difference in risk preference between public owners and design-builders toward the selection of the DB delivery method using the two-sample Hotelling's $T^2$ test. The results of this test indicate that risk preference between public owners and designers and contractors toward the selection of the DB delivery method is not significantly different in scope risk, third-party and complexity risk, utility and ROW risk, level of design and contract risk, management risk, or regulation and railroad risk but is statistically different in construction risk. This difference may be explained by the fact that under DB projects, construction risk is entirely transferred from the agency owner to the design-builder while the other DB risk factors are shared between these two parties.

This study endeavors to add to the body of knowledge within the project delivery methods and risk analysis and management. Because highway agencies should perform a risk assessment early in the project development process, the findings of this study not only provide guidance for agency owners to select DB for their projects, but also promote a better understanding of DOT risk management cultures and enhance collaboration among project participants. In addition, the seven DB risk factors discussed in this paper will assist agencies identify appropriate procurement procedures and contract payment provisions associated with the DB delivery method.

Although the research advances knowledge about the interaction between risk analysis and project delivery methods, this study has several limitations. The study had to rely on the participants' perceptions of risks and uncertainties based on their recollections of past projects. Although respondents with fewer than 10 years of professional experience were excluded from the analysis, perceptions of risk and its impact on the project delivery method may vary. Further, the study has not provided a framework that can quantitatively evaluate the DB delivery method selection. Case studies may address these limitations in future work and may also be used to expand the findings to develop an optimal risk-based framework for comparing the DB delivery method with other project delivery methods. The risk factors identified by this study will serve as the primary inputs for the risk-based framework to evaluate different delivery methods in terms of cost and schedule. It is expected that using the risk-based approach will help decision-makers evaluate each project delivery method consistently and defensibly. Finally, additional work should focus first on documenting the benefits, costs, and risks associated with different delivery methods and their compatible procurement procedures and contracting payment provisions then on validating the framework to realize the maximum benefits with regard to the project type, size, and complexity that are best suited for the DB delivery method.

## ACKNOWLEDGEMENTS

The writers would like to thank all the state transportation employees, general contractors, and engineering/design firms who contributed their expertise and time to the data collection for this research. Without their willingness to participate, this study would not have been possible.

## APPENDIX. ABRIDGED RISK FACTORS IN SURVEY QUESTIONNAIRES

The following is a list of 39 risk factors relative to the project delivery selection process. Respondents were asked to rate and explain the impact of the following risk factor on the selection of the design-build delivery method (0 = NA; 1 = Very Low Impact; 2 = Low Impact; 3 = Moderate Impact; 4 = High Impact; and 5 = Very High Impact):

1. Challenge to appropriate environmental documentation – uncertainty in appropriate environmental documentation (e.g., DCE vs. EA vs. EIS, NEPA) and all the related consequential events (e.g., change in design, scope, and construction costs)
2. Uncertainty in geotechnical investigation
3. Single or multiple contracts – the use of single vs. multiple contracts (e.g., difficulties in multiple contractor interfaces)
4. Challenge to project funding (e.g., funding delay, funding shortfall)
5. Uncertain annual inflation rate
6. Difficult conformance with regulations/guidelines/documentation
7. Design errors and omissions (e.g., errors in plans/specs/estimates)
8. Problems with material quality and availability

9. Project and program management issues (e.g., workload management, executive oversight)
10. Delays in right-of-way (ROW) – uncertainty in the time required for ROW plan development and approval process.
11. Problems with defined and non-defined hazardous waste
12. Issues related to constructability of designs
13. Challenge to delivery schedule – uncertainty in the overall project delivery schedule from scoping through design, construction, and opening to the public
14. Unexpected utility encounter
15. Insurance - uncertainty in the availability of insurance coverage
16. Challenge to staff experience and availability
17. Delays in completing utility agreements (e.g., delay due to disagreement over responsibility to move, over cost-sharing)
18. Problems with community relations
19. Challenge to work zone traffic control (e.g., problems with maintenance of traffic, issues related to proposed plans, detour)
20. Challenge to railroad agreements
21. Difficult obtaining other agency approvals
22. Uncertainty in material, labor, equipment costs beyond what is included in inflation rates
23. Third-party delay during construction (e.g., railroad conflict, utility conflicts, and work-window restrictions)
24. Problems with construction QC/QA
25. Uncertainty in scope definition

26. Unclear contract document – ambiguities in the contract documents
27. Problems with design exceptions –the need for design exceptions to federal/state/local regulations
28. Delays in in procuring critical materials, labor, and specialized equipment
29. Issues related to project definition
30. Challenges to environmental impact (uncertain wetland mitigation, meandering, connectivity)
31. Changes in design standards/criteria
32. Legal challenges and changes in law
33. Problems with Design QC/QA process
34. Design completion issues - uncertainty in the level of design completion at the time of the project delivery selection
35. Uncertainty in planned construction sequencing/staging/phasing
36. Challenge to intergovernmental agreement and regulation – uncertainty in coordinating with related government agencies and jurisdiction
37. Problems with construction market conditions (e.g., availability of contractor, pricing strategies of contractors)
38. Issues related to strikes/labor disputes (e.g., labor issues, contract negotiation)
39. Challenge to project complexity (e.g., the level of interaction between people, technical issues, and process)

## REFERENCES


Anderson, S., Molenaar, K. R., and Schexnayder, C. (2007). "NCHRP Report 574: Guidance for Cost Estimation and Management for Highway Projects during Planning, Programming, and Preconstruction." *National Cooperative Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Anderson, S. D., Molenaar, K. R., and Schexnayder, C. J. (2009). "NCHRP Report 625: Procedures Guide for Right-of-Way Cost Estimation and Cost Management." *National Cooperative Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Alhazmi, T., and McCaffer, R. (2000). "Project procurement system selection model." *Journal of Construction Engineering and Management*, 126(3), 176–184.

Costello, A. B., and Osborne, J. W. (2005). "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis." *Practical Assessment, Research & Evaluation*, 10(7), 1–9.

DBIA. (2011). Industry Research and Reports, http://www.dbia.org/pubs/research/rsmeans110606.htm (Accessed 09/09/2012)

DBIA. (2012). State Statute Report, http://www.dbia.org/NR/rdonlyres/27DEBA31-342B-4177-B6E0-AE8D9108D518/0/statestatuterpt120411.pdf (Accessed 09/10/2012)

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., and Strahan, E. J. (1999). "Evaluating the use of exploratory factor analysis in psychological research." *Psychological methods*, 4(3), 272–299.

FHWA. (2009). Current Design-Build Practices for Transportation Projects, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

FHWA. (2006a). Design-Build Effectiveness Study, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

FHWA. (2006b). Guide to Risk Assessment and Allocation for Highway Construction Management, *U.S. Department of Transportation, the National Cooperative Highway Research Program,* Washington, DC.

FHWA. (2002). Design-Build Contracting: Final Rule. *Federal Register,* 67(237).

Friedlander, M. C. (1998). "Design/build solutions." *Journal of Management in Engineering*, 14(6),59-64.

Ghavamifar, K., and Touran, A. (2009). "Owner's risks versus control in transit projects." *Journal of Management in Engineering*, 25(4), 230–233.

Ghavamifar, K., and Touran, A. (2008). "Alternative Project Delivery Systems: Applications and

Legal Limits in Transportation Projects." *Journal of Professional Issues in Engineering Education and Practice*, 134, 106.

Gordon, C. M. (1994). "Choosing appropriate construction contracting method." *Journal of construction engineering and management*, 120(1), 196–210.

Gransberg, D. D., K. R. Molenaar, and Datin, J. N. (2008). *NCHRP Synthesis 376: Quality Assurance in Design-Build Projects,* Transportation Research Board of the National Academies, Washington, D.C.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for Design-Build Projects: a Primer for Owners, Engineers, and Contractors*. American Society of Civil Engineers. Reston, VA.

Gransberg, D. D., and Molenaar, K. R. (2004). "Analysis of owner's design and construction quality management approaches in design/build projects." *Journal of Management in Engineering*, 20(4), 162–169.

Gurry, W. W., and Smith, R. J. (1995). "Allocation of Risk in Design/Build Project." *Proceedings of the 1995 Construction Congress*, San Diego, CA.

Hale, D. R., Shrestha, P. P., Gibson Jr, G. E., Migliaccio, G. C. (2009). "Empirical comparison of design/build and design/bid/build project delivery methods." *Journal of Construction Engineering and Management*, 135, 579.

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2009). *Multivariate Data Analysis*. Prentice Hall.

Higbee, J. B. (2002). "Geotechnical issues with large design-build highway projects." *Transportation Research Record: Journal of the Transportation Research Board*, 1808(1), 144–152.

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). "Project delivery systems and project change: Quantitative analysis." *Journal of Construction Engineering and Management*, 129(4), 382–387.

Kim, K. J., Kreider, C. A., and Valiquette, M. D. (2009). "North Carolina Department of Transportation's Practice and Experience with Design-Build Contracts." *Transportation Research Record: Journal of the Transportation Research Board*, 2116(-1), 47–52.

Kim, J. O., and Mueller, C. W. (1978). *Factor analysis: Statistical methods and practical issues*. Sage Publications, Inc.

Knapp, T. R. (1990). "Treating ordinal scales as interval scales: an attempt to resolve the controversy." *Nursing Research*, 39(2), 121–123.

Konchar, M., and Sanvido, V. (1998). "Comparison of US project delivery systems." *Journal of Construction Engineering and Management*, 124(6), 435–444.

Mahdi, I. M., and Alreshaid, K. (2005). "Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP)." *International Journal of Project Management*, 23(7), 564–572.

Migliaccio, G., Gibson, G., and O'Connor, J. (2009). "Procurement of Design-Build Services: Two-Phase Selection for Highway Projects." *Journal of Management in Engineering*, 25, 29.

Miller, J. B., Garvin, M. J., Ibbs, C. W., and Mahoney, S. E. (2000). "Toward a new paradigm: Simultaneous use of multiple project delivery methods." *Journal of Management in Engineering*, 16(3), 58–67.

Molenaar, K. R., Anderson S., and Schexnayder, C. (2010). "NCHRP Report 658: Guidebook on risk analysis tools and management practices to control transportation project costs." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R , Gransberg, D., Scott, S., Downs, D., and Ellis, R. (2008). "NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R. (2005). "Programmatic cost risk analysis for highway megaprojects." *Journal of Construction Engineering and Management*, 131(3), 343–353.

Molenaar, K. R., and Gransberg, D. D. (2001). "Design-builder selection for small highway projects." *Journal of Management in Engineering*, 17, 214.

O'Connor, J. T., Gibson, G. E., Jr., Migliaccio, G. C., and Shrestha, P. P. (2006). "Organizational structures and communications on the SH 130 project." *Center for Transportation Research*, Univ. of Texas at Austin, Austin, Tex.

Oyetunji, A. A., and Anderson, S. D. (2006). "Relative effectiveness of project delivery and contract strategies." *Journal of Construction Engineering and Management*, 132(1), 3–13.

Platje, A., and Seidel, H. (1993). "Breakthrough in Multiproject Management: How to Escape the Vicious Circle of Planning and Control." *International Journal of Project Management*, 11(4), 209–213.

Roberds, B., McGrath, T., Molenaar, K.R., Loulakis, M., and Ferragut, T. (2010). "NCHRP-SHRP Project R-09: Guide for the Process of Managing Risk on Rapid Renewal Projects" *Strategic Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Shrestha, P. P., O'Connor, J. T., and Gibson Jr, G. E. (2012). "Performance Comparison of Large Design-Build and Design-Bid-Build Highway Projects." *Journal of Construction Engineering and Management*, 138, 1.

Songer, A. D., and Molenaar, K. R. (1996). "Selecting design-build: public and private sector owner attitudes." *Journal of Management in Engineering*, 12(6), 47–53.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). "Selection of Project Delivery Method in Transit: Drivers and Objectives." *Journal of Management in Engineering*, 27(1), 21–27.

Warne, T. R. (2005). *Design-build contracting for highway projects: A performance assessment*, Tom Warne & Associates, LLC.

Wood, H. P., Kassoff, H., McGrath, T., Malley, W. G., Rose, D. C., and Skinner, N. (2011). "NCHRP 20-24/Task 71: Guide for Managing NEPA-Related and Other Risks in Project Delivery." *Transportation Research Board of the National Academies, Washington, DC.*

# CHAPTER 3

## A MULTIVARIATE ANALYSIS OF PROJECT DELIVERY SELECTION RISK FACTORS FOR TRANSPORTATION DESIGN AND CONSTRUCTION

**ABSTRACT**

Selecting an appropriate delivery method for transportation projects can reduce time and cost, but because of risks and uncertainties, selection is a challenging task and a complex decision process. Although transportation agencies have been conducting formal cost and schedule risk analyses on major projects over the past decade, limited research has explored how risks affect the project delivery method selection process. This study reports on 39 risk factors related to the three primary United States (US) project delivery methods: design-bid-build (DBB); design-build (DB); and construction management/general contractor (CMGC). These risk factors were identified through an extensive literature review that included studies of more than $10 billion of transportation projects. Practitioners with an average of 25 years of professional experience related to risk and project delivery methods in the transportation industry were invited to participate in a survey to analyze the risks, and 137 valid responses were analyzed. Factor analysis that extracted critical risk factors for project delivery selection revealed that there were six critical factors for DBB, seven for DB, and six for CMGC. This paper identifies all of these factors and discusses construction risk, constructability and documentation risk, and scope risk in detail. Knowledge of these risk factors will allow researchers to better understand the impact of risk on the project delivery selection process. Transportation agencies can use these risk factors to make more effective and defensible project delivery decisions.

**KEYWORDS:** Project delivery methods; Highways; Risk analysis and management.

## INTRODUCTION

The selection of an appropriate project delivery method can have a major impact on the achievement of project goals and objectives. Researchers (e.g., Oyetunji and Anderson, 2006; Luu *et al*., 2003; Love *et al*., 1998) have shown that using a suitable project delivery method can increase the efficiency and the success rate of a construction project. In fact, Love *et al*. (2012) and Gordon (1994) pointed out that the selection of an appropriate procurement method could decrease the total project cost by an average of 5%. Rwelamila and Meyer (1999) indicated that applying an inappropriate project delivery method may impede a project's performance and even lead to project failure. As a result, over the past decade transportation agencies have sought an effective delivery method to maximize project performance.

In the United States (US), many state transportation agencies have recently adopted design-build (DB) and construction manager/general contract (CMGC) delivery methods as alternatives to the traditional design-bid-build (DBB) delivery method. Using alternative delivery methods stems from the needs to deliver projects more quickly, improve cost and schedule performance/contingency, take advantage of constructability and construction innovation, and reduce disputes and improve relationships among project stakeholders. According to a report from the Design-Build Institute of America (DBIA 2011), at least 44 transportation agencies had full authorization to use DB in their transportation projects, and 14 transportation agencies had full authorization to use the CMGC delivery method. In addition, the Federal Highway Administration (FHWA) initiated the Every Day Counts program in 2010 to accelerate technology and innovation deployment and to deliver timely transportation projects to the public. The Every Day Counts philosophy is that "the sooner we can deliver projects, the sooner the public can enjoy their benefits" (http://www.fhwa.dot.gov/everydaycounts/). This philosophy will require the use of alternative delivery methods and place unprecedented risk on both the agency that plans projects and the private sector that delivers them.

The growing use of alternative delivery methods has led researchers and practitioners to seek decision support for choosing an appropriate delivery method. As a result, selection techniques have been developed that range from simple approaches, such as flowcharts (Goldon, 1994), to complex frameworks, such as multi-attribute utility/value theory (Oyetunji and Anderson, 2006), and analytical hierarchical process/value engineering/multi-criteria multi-screening (Alhazmi and McCaffer, 2000; Mahli and Alreshaid, 2005). A review of the literature revealed that risk management plays a pivotal role in procurement options (Osipova and Eriksson, 2011) in the success of transportation projects (Creedy *et al*., 2010). However, limited research employs risk-based approaches to the selection of project delivery methods. Although transportation agencies have successfully applied cost and schedule risk analyses on their major projects over the last two decades, they most frequently perform risk analysis and project delivery selection independently. Consequently, there is a lack of understanding of how risk factors affect the project delivery selection process. This study addresses this knowledge gap.

This study aims to (1) identify important risk factors that affect the project delivery selection process in transportation projects; (2) categorize these factors through factor analysis into a smaller group associated with three delivery methods (DB, DBB, and CMGC); and (3) explore correlations between risk factors and the delivery methods. The research provides new insights into the delivery selection process for researchers and practitioners in the transportation industry. These results will assist transportation agencies in making risk-based project delivery decisions.

## BACKGROUND

A project delivery method is the process of designing and constructing a facility for an owner by defining all the contractual relationships, roles, and responsibilities of the entities involved in a project. According to Touran *et al*. (2011), *project delivery method* is defined as "the process by which a construction project is comprehensively designed and constructed for an owner including project scope definition, organization of designers, constructors and various consultants, sequencing of design and construction operations, execution of design and construction, and closeout and start-up" (p. 21).

Every project delivery method has certain opportunities and obstacles, and the risks and risk allocation associated with each delivery method vary. The FHWA (2006) presented four fundamental principles of rigorous risk allocation: (1) allocate risks to the party best able to manage them; (2) allocate risks in alignment with project goals; (3) share risk when appropriate to accomplish project goals; and (4) ultimately seek to allocate risks to promote team alignment with customer-oriented performance goals.

Although many project delivery methods are available, a study by the Construction Industry Institute specified that there are only three fundamental project delivery methods: DBB, DB, and CMGC (or CMR-Construction Manager at Risk) (CII 1997). This finding is supported by the *NCHRP Synthesis of Highway Practice 402* (Gransberg and Shane, 2010) and the EDC initiative.

Touran *et al*. (2011) claimed that the difference between project delivery methods lies in the fact that the contracts among the owner, the designer, and the builder are formed and the technical relationship among parties within those contracts.

The risk allocation in DBB is clearly understood by the transportation design and construction community. The majority of design risk is borne by the transportation agency and the construction risk is borne by the contractor. The assumption that complete design and specifications are accurate and adequate is a major risk in the DBB delivery method. In fact, even if a project conforms to plans and specifications, it may not perform as the owner expects (Rubin and Wordes, 1998). Under DBB projects, the owner owns the details of the design and is responsible for any errors or omissions in the drawings and specifications, and the contractor assumes the risk of completing construction in compliance with the contract documents. The contractor also assumes the risks related to scheduling, coordinating, and administering work conducted by subcontractors and suppliers. In addition, the contractor is responsible for inflation and interest rate fluctuations if escalation clauses are not included in the contract. The potential for an adversarial relationship between the designer and the contractor may cause project delays and cost overruns.

Under the CMGC delivery method, transportation agencies select construction managers based their qualifications to (1) assist the project team implement preconstruction services (e.g., cost estimating and constructability reviews) and (2) perform construction work after prices have been agreed upon. Construction managers are paid a fee for construction management services until a guaranteed maximum price (GMP) agreement for construction is reached, at which point the construction managers assume the risk for the final cost and time of construction. According to

Gransberg and Shane (2010), the major advantages of the CMGC delivery method include enhanced constructability, real-time construction pricing capability, implementation speed, the ability to implement new and innovative technologies, and the ability to create an environment with rich collaboration. However, in CMGC projects, the owner must manage two contracts and is ultimately responsible for design risks while the construction manager is responsible for scheduling, quality control, and estimating construction costs.

Risk in the DB delivery method often stems from the scope of work, statutory or regulatory restrictions, and environmental issues. Under DB projects, the design-builder is solely responsible for all design and construction issues. However, Ghavamifar and Touran (2009) showed that simply choosing DB to transfer risks to the contractor is problematic because risks affect the price proposal. To reduce risks in DB projects, the owner needs to understand the scope of work and to use performance criteria to communicate project goals at the time of contracting.

## RESEARCH METHOD

The primary objectives of this research were to identify and categorize risk factors that affect the project delivery selection process and to explore the interaction between characteristics of risk factors and different delivery methods for transportation design and construction projects. To accomplish these objectives, the research method involved the following steps: (1) perform a literature review; (2) collect data through survey questionnaires; (3) analyze the data using statistical multivariate analysis techniques; and (4) discuss findings and provide recommendations for applying a risk-based approach to selecting delivery methods for transportation projects.

## IDENTIFYING RISK FACTORS THAT AFFECT PROJECT DELIVERY METHODS

Design and construction activities involve risk and uncertainty, and researchers have considered risk factors in investigations of project delivery method selection processes. Gordon (1994) included risk aversion as a factor in his procurement method selection flowchart. Mahdi and Alreshaid (2005) included risk management and risk allocation as significant factors in their analytical hierarchy process (AHP) model. Oyetunji and Anderson (2006) included a financial risk factor and site conditions in their decision support tool. Recently, Touran *et al*., (2011) explicitly considered risk management and risk allocation as well as several implicit risk-related factors such as project complexity, schedule, and third-party agreements.

An extensive literature review was performed in the areas of project delivery methods, project delivery method selection frameworks, and risk assessment and management in transportation design and construction. The authors reviewed articles, reports, guidebooks, and other work published by the American Society of Civil Engineering (ASCE), Transportation Research Board (TRB), and others from 1990 to 2012. This review process placed an emphasis on previous research for the National Cooperative Highway Research Program (Roberds *et al*., 2010; Molenaar *et al*., 2008), the FHWA (2006), and the Washington Department of Transportation (Molenaar 2005) that developed quantitative risk analysis methods for transportation design and construction projects. The authors initially compiled a list of approximately 200 generic risk factors in transportation design and construction projects. The comprehensive list of risks was dissected to combine overlapping risks, and risks that did not relate to project delivery decisions were removed. The authors took a conservative approach to removing these risks to be certain that no relevant risks were excluded; as a result, 39 risk factors relative to the project delivery selection process were identified (see Appendix for complete list).

## DATA COLLECTION

To determine the impact of the 39 risk factors on the selection of a project delivery method, a survey questionnaire was considered appropriate because of the large population of organizations involved in transportation design and construction projects. The list of potential respondents was developed from the TRB Project Delivery Committee; TRB Construction Management Committee; AASHTO Joint Technical Committee on Design-Build; AASHTO Subcommittee on Construction; AASHTO Standing Committee on Planning; the Colorado Department of Transportation's Innovative Contracting Advisory Committee; and participants of the Design-Build Institute of America's Design-Build Transportation Conference. Ultimately, transportation professionals including representatives of 52 transportation agencies and a number of contractors, subcontractors, professionals, and practitioners from the private sector were asked to complete the survey.

The questionnaire requested information about the individual respondent's professional experience with risk and delivery methods in transportation projects. Respondents were asked to rate the impact of uncertainty of the 39 risk factors on each project delivery method based on an ordinal scale (0 = NA; 1 = Very Low Impact; 2 = Low Impact; 3 = Moderate Impact; 4 = High Impact; and 5 = Very High Impact). This scale was designed to mitigate the discontinuity effect of the data by including numbers corresponding to different thresholds. The survey questions were distributed in a random order to eliminate sequence bias. The respondents who did not have knowledge about a risk factor could select NA; the authors treated NA as a missing value and excluded it from the analysis. Respondents were asked to provide explanations for their rating. In addition, respondents had an opportunity to add other delivery risk factors to the questionnaire to ensure the inclusion risk factors not identified by the authors.

The pilot study questionnaire that was used to test the correspondence of the risk factors with the three project delivery methods resulted in minor adjustments to the questionnaire. The authors distributed the final questionnaire to 450 professionals who were given two weeks to complete the survey. A total of 152 valid responses were received, representing a response rate of 33.8%. Based on responses to questions about professional experience, the authors grouped the responses into three categories, owner agencies; design, engineering, or consulting firms; and contractors or subcontractors. To obtain reliable input, data from respondents with fewer than 10 years of professional experience was excluded from the analysis. As a result, 137 qualified responses were considered for the further analysis. Of these, 71 respondents (51.8%) were from public owner agencies representing 43 transportation agencies; 35 respondents (25.5%) were from design, engineering, or consulting firms; and 31 respondents (22.7%) were contractors or subcontractors. These 137 qualified respondents had an average of 25 years of professional experience in project delivery methods and risk analysis in the transportation industry.

**DATA ANALYSIS**

Based on the input from 137 experts, the authors employed exploratory factor analysis using the Statistical Package for Social Sciences (SPSS) version 19 to derive a reduced set of critical risk factors from 39 factors in the questionnaire. The exploratory factor analysis was an appropriate statistical technique for this study because it allows for identifying latent variables that underlie two or more of the measured variables. The rational is that the impact of risk on the project delivery method selection process cannot be adequately captured by only one measurement—there exist interrelationships among 39 risk factors in the questionnaire). In addition, Kim and Mueller (1978) noted that factor analysis is designed for interval data, but appropriate for scaled ordinal data. In general, factor analysis is conducted through a two-stage process: factor extraction and factor rotation. The objective of factor extraction is to determine number of factors retained, while the goal of factor rotation is to make the factors more interpretable. It is important to note that the authors rigorously analyzed the latent factors identified by SPSS to confirm that they that were composed of factors that are theoretically related to one another.

Before performing the factor analysis, all risk variables (factors) were tested for the fundamental factor analysis assumptions. The results indicated that there are no multivariate outliers in the data sets and that the values of skewness and kurtosis for all cases are within -1.0 to +1.0 at the p-value > 0.05; thus, all variables are considered to be normally distributed. The values of the Kaiser-Meyer-Olkin test of overall measure of sampling adequacy for the delivery methods are 0.701 for DBB, 0.689 for CMGC, and 0.741 for DB. These values are greater than 0.6, as recommended by Hair *et al*. (2009) and Kaiser (1958). Bartlett's test of sphericity provides an approximate chi-square of 687.83 and 190 degrees of freedom for DBB; 534.13 and 210 degrees of freedom for CMGC; and 868.5 and 276 degrees of freedom for DB. The associated significance levels are small at $p < 0.001$ for the three delivery methods. These values suggest that the population correlation matrix is not an identity matrix and that all data sets satisfy the factor analysis assumptions

There are several factor analysis extraction methods. Fabrigar *et al*. (1999) suggested that if data are relatively normally distributed, a maximum likelihood is the best option for factor extraction because "it allows for the computation of a wide range of indexes of the goodness of fit of the model and permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals". As described above the data sets are normally distributed, thus the authors used maximum likelihood extraction and scree plots to determine the number of factors derived in the data for each method.

**RESULTS**

The critical risk factors are named the following way: the abbreviation for the delivery method, the rank for that method, and the name of the factor. For example, the most critical factor for DB is DB-1: Scope Risk, while the second most critical factor for DBB is DBB-2: Schedule Risk. The results and the following discussion use this convention for referring to the critical risk factors and their components. Factor loadings, percent of variance explained, and cumulative percent of variance explained associated with the DBB, CMGC, and DB delivery methods are presented in Tables 1, 2, and 3, respectively.

For the DBB delivery method, the results from factor analysis and scree plots indicated that six risk factors were extracted, and altogether accounted for 63.2% of the total variance in responses, which is above the 60.0% of variation that Hair *et al*. (2009) recommended for terminating the factor extraction process. The top two ranked risk factors (DBB-1: Construction Risk with 18.4% and DBB-2: Schedule Risk with 15.2%) account for 33.6% of the variance (Table 1). All factor loadings were greater than 0.60, and 16 of them were greater than 0.70. Thus, these loadings were reasonably consistent with the interpretation of the factors extracted.

**Table 1. Critical Risk Factors for the DBB Delivery Method**

| Critical Risk Factors | Loading | % of Variance | Cumulative % |
|---|---|---|---|
| **DBB-1: Construction Risk** | | 18.38 | 18.38 |
| Geotechnical investigation | 0.77 | | |
| Environmental impact | 0.77 | | |
| Work zone traffic control | 0.75 | | |
| Construction QC/QA | 0.63 | | |
| **DBB-2: Schedule Risk** | | 15.19 | 33.56 |
| Construction sequencing/staging/phasing | 0.74 | | |
| Unexpected utility encounter | 0.72 | | |
| Unclear contract documents | 0.72 | | |
| Delivery schedule | 0.70 | | |
| **DBB-3: Third-party and Complexity Risk** | | 9.65 | 43.21 |
| Obtaining other agency approvals | 0.82 | | |
| Defined and non-defined hazardous waste | 0.73 | | |
| Project complexity | 0.71 | | |
| Delays in completing utility agreements | 0.70 | | |
| **DBB-4: Constructability Risk** | | 8.07 | 51.28 |
| Delays in procuring materials, labor, and equipment | 0.81 | | |
| Constructability of design | 0.80 | | |
| Significant increase in material, labor, equipment cost | 0.71 | | |
| **DBB-5: Market Risk** | | 6.31 | 57.59 |
| Construction market conditions | 0.75 | | |
| Annual inflation rates | 0.72 | | |
| **DBB-6: ROW Risk** | | 5.62 | **63.21** |
| Delays in right-of-way (ROW) process | 0.62 | | |

For the CMGC delivery method, 62.3% of the total variance was attributable to six risk factors, which is similar to the total variance (63.2%) for DBB. The top three ranked risk factors (CMGC-1: Constructability and Documentation with 19.6%; CMGC-2: Construction Risk with 14.2%; and CMGC-3: Complexity Risk with 9.8%) account for 43.6% of the variance (Table 2). All factor loadings were greater than 0.55; 18 of them were greater than 0.60, and nine were greater than 0.70. The loadings and the interpretation of factors extracted were reasonably consistent.

**Table 2. Critical Risk Factors for the CMGC Delivery Method**

| Critical Risk Factors | Loading | % of Variance | Cumulative % |
|---|---|---|---|
| **CMGC-1: Constructability and Documentation Risk** | | 19.63 | 19.63 |
| Conformance with regulations/guidelines/documentation | 0.74 | | |
| Significant increase in material, labor, equipment cost | 0.69 | | |
| Constructability of design | 0.66 | | |
| Delays in procuring critical materials, labor, and equipment | 0.65 | | |
| Challenge to appropriate environmental documentation | 0.65 | | |
| **CMGC-2: Construction Risk** | | 14.19 | 33.82 |
| Work zone traffic control | 0.81 | | |
| Geotechnical investigation | 0.77 | | |
| Construction QC/QA | 0.67 | | |
| Environmental impact | 0.58 | | |
| **CMGC-3: Complexity Risk** | | 9.77 | 43.59 |
| Project complexity | 0.77 | | |
| Obtaining other agency approvals | 0.69 | | |
| Design QC and QA | 0.64 | | |
| Defined and non-defined hazardous waste | 0.61 | | |
| **CMGC-4: Management Issues and Schedule Risk** | | 7.75 | 51.34 |
| Project and program management issues | 0.77 | | |
| Insurance | 0.71 | | |
| Delivery schedule | 0.71 | | |
| **CMGC-5: Third-party Risk** | | 6.02 | 57.35 |
| Railroad agreements | 0.72 | | |
| Delays in completing utility agreements | 0.55 | | |
| **CMGC-6: Regulation Risk and ROW** | | 4.97 | **62.32** |
| Intergovernmental agreements/ regulation | 0.85 | | |
| Delays in right-of-way (ROW) process | 0.61 | | |

For the DB delivery method, 64.4% of the total variance was attributable to seven risk factors. The top three ranked risk factors (DB-1: Scope Risk with 19.5%; DB-2: Third-party and Complexity Risk with 12.1%; and DB-3: Construction Risk with 10.6%) account for 43.3% of the variance (Table 3). Factor loadings of the two components (Construction QA/QC with 0.48 and Unclear contract documents with 0.41) were below 0.50, while 15 factor loadings were greater than 0.70. These factor loadings were reasonably consistent with the interpretation of the factors extracted.

**Table 3. Critical Risk Factors for the DB Delivery Method**

| Critical Risk Factors | Loading | % of Variance | Cumulative % |
|---|---|---|---|
| **DB-1: Scope Risk** | | 19.52 | 19.52 |
| Project definition | 0.82 | | |
| Scope definition | 0.78 | | |
| Staff experience/availability | 0.75 | | |
| Conformance with regulations/guidelines/documentation | 0.70 | | |
| Challenge to appropriate environmental documentation | 0.64 | | |
| **DB-2: Third-party and Complexity Risk** | | 12.14 | 31.66 |
| Delays in completing utility agreements | 0.74 | | |
| Obtaining other agency approvals | 0.74 | | |
| Project complexity | 0.72 | | |
| Defined and non-defined hazardous waste | 0.71 | | |
| Legal challenges and changes in law | 0.66 | | |
| **DB-3: Construction Risk** | | 10.61 | 42.27 |
| Geotechnical investigation | 0.77 | | |
| Work zone traffics control | 0.73 | | |
| Environmental impact | 0.66 | | |
| Construction QC/QA | 0.48 | | |
| **DB-4: Utility and ROW Risk** | | 7.32 | 49.59 |
| Unexpected utility encounter | 0.84 | | |
| Delays in right-of-way (ROW) process | 0.63 | | |
| **DB-5: Level of Design and Contract Issues** | | 5.53 | 55.12 |
| Design completion | 0.81 | | |
| Single or multiple contracts | 0.78 | | |
| Unclear contract documents | 0.41 | | |
| **DB-6: Management Issues** | | 4.91 | 60.03 |
| Project and program management issues | 0.79 | | |
| Insurance | 0.72 | | |
| **DB-7: Regulation Risk and Railroad** | | 4.34 | **64.37** |
| Intergovernmental agreements/regulation | 0.79 | | |
| Railroad agreements | 0.53 | | |

## DISCUSSION

Table 4 summarizes the risk factors considered to have the most impact on the project delivery selection process for transportation projects. The most critical risk factor is different from each method; construction risk was most critical for DBB, scope risk for DB, and constructability and documentation risk for CMGC. Specifically, Table 4 indicates that though construction risk is considered the most important factor in DBB projects, this factor ranked second in the CMGC and third in the DB delivery method. Likewise, scope risk is considered the most important factor in the DB delivery method, yet it did not rank in either the CMGC or DBB delivery methods. Finally, constructability and documentation risk is considered the most important factor in the CMGC delivery method, but it did not rank in the DB delivery method and ranked fourth in the DBB delivery method (constructability risk). The following sections discuss these three critical risk factors in detail, suggest reasons for the groupings that resulted from the factor analysis, and provide representative explanations for rankings given by survey respondents.

**Table 4. Critical Risk Factors for Project Delivery Decisions**

| Rank | DB | CMGC | DBB |
|---|---|---|---|
| 1 | Scope Risk | Constructability and Documentation Risk | Construction Risk |
| 2 | Third-party and Complexity Risk | Construction Risk | Schedule Risk |
| 3 | Construction Risk | Complexity Risk | Third-party and Complexity Risk |
| 4 | Utility and ROW Risk | Management Issues and Schedule Risk | Constructability Risk |
| 5 | Level of Design and Contract Issues | Third-party Risk | Market Risk |
| 6 | Management Issues | Regulation Risk and ROW | ROW Risk |
| 7 | Regulation Risk and Railroad | | |

**Construction Risk**

Construction risk is considered the most important factor in DBB projects, and ranked second in the CMGC and third in the DB delivery method. This critical factor encompassed four main components: geotechnical investigation, work zone traffic control, environmental impact, and construction quality control/quality assurance (QC/QA).

Traditionally, DBB projects require 100% design completion at the time of contractor award. This requirement often minimizes competitive innovation opportunities, reduces constructability analysis, increases the potential of change orders, and causes adversarial relationships among all parties involved. In the DBB delivery method, the contractor is not involved until construction begins. Thus, construction risks, those risks related to site conditions, construction QC/QA, traffic controls, and environmental impacts, have a large impact on project cost and/or project schedule. Under the pressure of the low-bid approach, contractors may be aggressive in estimating production or use marginal subcontractors who may have problems performing the work. In addition, changes to the work or unforeseen conditions often lead to disputes and litigation that can drive up costs. This finding is in agreement with the literature. Rubin and Wordes (1998) pointed out that the major risks of DBB projects occur in the construction phase because of the assumption that the complete design and specifications accurately and adequately describe the project. In the survey conducted for this study, one public owner with extensive experience with risk and project delivery methods described how construction risk could considerably affect the DBB project:

> Traffic control is provided in most designs. However the contractor's [sic] change the sequencing with approval. [It is] difficult to anticipate every possible problem in advance of a bid . . . A contractor has no flexibility to further investigate geotechnical conditions and construction QC/QA can suffer from the low-bid approach.

Construction risk ranked second among the six critical risk factors that affect CMGC delivery selection. Under CMGC projects, although transportation agencies hire construction managers during the design phase to assist with innovation and constructability, agencies still must manage two contracts: one with designers and one with contractors. If the construction manager suggests phased construction, the owner begins the project before the total price is established. However, early completion may not offer a sufficient trade-off for this risk. Additionally, the transportation agency is ultimately responsible for design errors and other design-related risks. One contractor discussed the influence of the construction risk on CMGC projects as follows:

> [The construction manager] can do more planning and preparation during pre-construction services to mitigate [work zone traffic control] . . . CMGC projects can reduce the owner's risk on environmental impact. However, costs and delays will likely reflect in the GMP bid.

Finally, construction risk ranked third among seven critical risk factors for the DB delivery selection method. While construction risk is important in DB, it is ranked slightly lower than in DBB or CMGC. The lower ranking might be explained by the fact that the DB delivery method inherently transfers the risk for design errors and omissions and construction QA/QC from the transportation agency to the design-builder. Responsibility for activities like surveying, spill prevention, and maintenance of traffic may shift entirely to the design-builder. This finding also was consistent with the literature. Molenaar *et al*. (2008) indicated that risk for all or a portion of construction can be allocated to the design-builder when appropriate. In addition, under DB projects, the agency often requires the DB contractor to establish a firm fixed-price as well as the delivery time on a project that has not yet achieved a complete design. Therefore, the level of construction quality is very important for DB projects. One participant from the design/engineering firm discussed the construction risk related to the three delivery methods:

> QA/QC can suffer from the low-bid approach and reliability on third-party inspections. DB has the advantage of providing a better understanding of the design elements prior to construction and has more incentive to provide quality to meet overall performance requirements. CMGC provides contractors the opportunity to clearly understand the design intent, but they are less equipped than the DB contractors in managing quality.

In summary, construction risk is considered to have a high impact on the project delivery method selection process. This risk has the greatest impact on the traditional DBB delivery method, but it is important for all three delivery methods.

**Scope Risk**

Scope risk ranked first in the DB delivery method but did not rank for either CMGC or DBB. This critical risk factor involved risks and uncertainties caused by the following four components: project definition; scope definition; staff experience and availability; and conformance with regulations, guidelines, and documentation. The factor loadings associated with these components are larger than 0.7 (Table 3). The high factor loadings indicate that these four components highly impact scope risk in DB projects. The finding is consistent with the literature. Gransberg *et al*. (2006) stated that scope risk is a major risk in DB projects and that a well-defined project will minimize the amount of contingency in design-builder proposals and offer the owner a competitive price. Likewise, Ghavamifar and Touran (2009) asserted that in a DB contract, the owner agency and contractor should clearly understand the scope of work and realize critical information related to uncertain conditions at the time of award. In the DB delivery method, agencies define the project scope and requirements through the RFP and procure both the final design and construction through an evaluation of technical proposals and/or price. Vague scope definition is a common reason for budget and scheduling disputes in DB projects (Gransberg *et al*., 2006). Many participants described the significant impact of scope definition on DB projects. A main theme of their explanations was the importance of developing a clear and well-defined scope:

> When using design-build, we need to have a very well defined scope prior to issuing the RFP. This method allows flexibility with the design. Any changes by the owner could be costly. Owners must know clearly the scope and project definition. A meeting must be held during the technical evaluations to make sure that the short-listed firms understand the scope.

Staff experience and availability directly impact an agency's ability to develop a solid scope definition in any delivery method, but this is particularly true with the DB method as project success hinges on the accuracy and completeness of the RFP. Further, since DB is still new to many states, existing staff may need to be trained to address their changing roles and responsibilities. Inexperienced or untrained staff may decrease conformance with regulations, guidelines, and documentation and cause concern for transportation agencies when selecting DB delivery methods. One public owner discussed staff issues relating to the use of the DB delivery method in his state:

> It is critical to have staff experienced in DB who can perform under pressure. The experienced DB staff is generally less available. This method is still a new process and as such there continues to be a learning curve for all those involved. With an overall lack of experienced professionals, there are more problems.

Finally, unlike the DB delivery method where scope risk was the top ranked risk factor, scope risk did not rank for either the CMGC or DBB delivery methods. Under DBB projects, the scope is well defined through 100% construction drawings and complete technical specifications. In addition, the DBB delivery method is widely used and historically supported with well-established legal and contractual precedents, and staff is familiar with the process. One participant discussed scope risk in DBB projects as follows:

> The premise with DBB is that the scope is nailed down before bidding. Very few scope changes have occurred after award of design-bid-build contracts. This is the most known and highly utilized process that has been used for many years, so there are more people familiar with the process.

Similarly, in CMGC projects, scope risk did not rank in the result of the factor analysis. This may explain by the fact that in the CMGC delivery method contractors are involved early in the design phase to help owner agencies anticipate unforeseen conditions and long lead items to ultimately avoid scope creep (Gransberg and Shane, 2010). Further, the construction manager is responsible for checking and approving the design estimate.. The common theme about the impact of scope risk on the CMGC delivery method was similar to that of the DBB delivery method quoted below:

> There should be very little uncertainty in the definition of scope under CMGC since all parties play a role in defining the scope. The owner's constant involvement in design through a later stage of development than DB makes it less of an issue for CMGC. Usually scope is clear by GMP negotiations.

In summary, developing a well-defined scope of work is critical to the DB delivery method, but scope risk is less often an issue for both DB and CMGC delivery methods due to the completion of plans and specifications prior to construction.

**Constructability and Documentation Risk**

Constructability and documentation risk ranked first in CMGC but ranked fourth for DBB and did not rank for DB. This critical risk factor involved the uncertainties and risks relating to five components: conformance with regulations, guidelines, and documentation; significant increase in material, labor, and equipment cost; constructability of design; delays in procuring critical materials, labor, and equipment; and challenges in environmental documentation (Table 2). According to Gransberg and Shane (2010), constructability in the CMGC delivery method is a review process to determine the available tools, techniques, and technology to permit a qualified contractor to build the project at the required level of quality with an accurate cost estimate. One benefit of CMGC is enhanced constructability. However, constructability may rank as the highest risk factor for CMGC because CMGC is often chosen on projects with a high complexity of construction. Alder (2007) indicated that the constructability review may increase design time if negotiations fail because of a lack of mutual respect between designers and contractors. Researchers also showed that the designer's perception that "we can do it" and the desire of transportation agency design engineers to continue to complete the design with in-house assets are the major obstacles to constructability in the use of the CMGC delivery method in the transportation industry (Gransberg and Shane 2010). Furthermore, inadequate construction expertise in design organization and the reluctance of transportation agencies to invest additional money and effort in early project stages are barriers to the constructability review in the CMGC delivery method. One public owner with extensive CMGC experience explained the risks caused by the partnership between designers and contractors for CMGC project:

> Constructability is a high risk and has a huge impact on a project if designers do not communicate closely with [the] contractor.

In contrast, the DB delivery method often shifts the constructability risk to the design-builder. The DB delivery method, by definition, requires designers and contractors work as a team to manage constructability. Therefore, constructability risk may not be as important a risk factor in DB projects. On the other hand, for the DBB delivery method, the owner is responsible for all design-related risks and the contractor has little input to the design. As a result, the risk caused by constructability issues in DBB projects often leads to construction risk. This may explain why constructability risk ranked fourth, but construction risk ranked first for DBB delivery.

In addition to constructability risk, documentation risk also had the greatest influence on the CMGC delivery selection. This finding can be explained by the fact that the CMGC delivery method has only gained traction over the last five years and transportation agency use of the CMGC delivery method is very limited. Gransberg and Shane (2010) found that only three transportation agencies had experience with the use of CMGC in their transportation projects. As a result, there is a lack of guidelines and documentation that transportation agencies can use to administer their CMGC projects.

The final establishment of a GMP is critical to the CMGC delivery method. Gransberg and Shane (2010) pointed out that understanding the logic behind the numbers is crucial to negotiating a fair and adjustable GMP. To effectively track and manage a GMP, a transportation agency must document all of the steps that describe exactly what each number in the GMP represents. The process of managing GMPs often requires an element of trust between owners, designers, and construction managers, but it is most demanding to maintain trust when changes are being negotiated (Gransberg and Shane, 2010). Thus, a thorough documentation process is essential to success. In fact, Alder (2007) indicated that most of the risk associated with the CMGC delivery method is due to an undefined and undocumented process. Further, lack of clear guidance and lack of success measures are two main barriers to using CMGC in transportation construction projects (Gransberg and Shane, 2010). One contractor discussed the impact of documentation risk on the CMGC delivery method:

> In this method, the owner can request that the updated standards be implemented at any time. This could have a significant impact. Regulations, guidelines, and related documents have to be established prior to the project actually starting or the CM [will not] even know what to base the fee on.

It should be noted that documentation risk did not rank for either the DBB or DB delivery methods. This can be explained by the fact that almost all transportation agencies have well-established regulation and documentation for the DBB delivery method. On the other hand, in the DB delivery method, documentation risk is part of the scope risk category. Table 3 shows that two components of document risk had the lowest loadings compared to other components in scope risk: conformance with regulations/guidelines/documentation with a loading of 0.70, and challenge in appropriate environmental documentation with a loading of 0.64. These lower loadings explain that the two components of document risk was less important than the other components that are composed of scope risk in DB projects. Further, due to the nature of the DB contract in which the designer and contractor form a single entity—design-builder, it is reasonable to perceive two components (conformance with regulations/guidelines/documentation and challenge in appropriate environmental documentation) to be part of the scope risk for the DB delivery method.

## LIMITATIONS AND FUTURE RESEARCH

The primary objective of this study was to identify critical risk factors that impact the selection of delivery methods for transportation design and construction projects. Although the data was rigorously collected analyzed, this research has several limitations. First, while respondents with fewer than 10 years of professional experience were excluded from the analysis, this study did not take into account the role of participant's risk-aversion. In general, risk-averse decision makers tend to overestimate possible losses and limit state probability. To address this limitation, the authors suggest including risk tolerance of the project manager, program manager, engineer, designer, contractor, and other stakeholder by integrating utility theory into the project delivery selection framework. Second, although this study collected data from numerous relevant experts in the transportation industry, including representatives from 43 state DOTs, designers, engineers, and contractors, there were limited personnel who have experience with CMGC in transportation projects. While the CMGC data satisfied the statistical assumptions for the factor analysis, more data on CMGC projects will reduce sampling errors, enhance the findings, and provide more accurate results.

Finally, future researchers should collect more data to develop a risk-based quantitative approach to assist transportation agencies in determining which delivery method is best suited for particular projects of varying type, size, and complexity. The authors suggest that future research should compare the differential costs and schedules associated with the different delivery methods based on delivery risk factors found from this study. Such a comparison could be useful for developing a sound and defensible approach to selecting an optimal delivery method for transportation projects.

## CONCLUSIONS

The selection of an appropriate delivery method has recently received considerable attention in the transportation industry. An array of techniques and decision-support guidelines has been developed, but limited studies focus on the impact of risk on the project delivery selection process. The results from this study show that there are a variety of risks involved in the project delivery selection process, and decision makers must have a clear understanding of how risks impact each delivery method to select the best suited delivery method for their projects. The study found that seven critical risk factors exist for DB, six for DBB, and six for CMGC. The three factors—construction risk, constructability and documentation risk, and scope risk have the greatest impact on the selection of DBB, CMGC, and DB. These findings were supported by the literature. For example, construction risk is a major threat for DBB projects (Rubin and Wordes, 1998). Similarly, Gransberg *et al*. (2006) showed that scope risk is a major concern and relates directly to the success of the use of the DB delivery method, and Alder (2007) found that most of the risk associated with the CMGC delivery method comes from documentation and constructability risks.

This study contributes to the body of knowledge within the project delivery methods and risk management by offering a comprehensive list of risk factors necessary to consider in the project delivery selection process on a spectrum of three fundamental methods: DBB, DB, and CMGC. It also supplements the findings from the literature on the relationship between risk and the delivery selection. For example, Gordon (1994) included risk aversion as a factor in his procurement method selection flowchart. Mahdi and Alreshaid (2005) considered risk management and risk allocation as significant factors in their analytical hierarchy process (AHP) model. Oyetunji and Anderson (2006) included a financial risk factor and site conditions in their decision support tool. Recently, Touran et al., (2011) explicitly considered risk management and risk allocation as well as several implicit risk-related factors such as project complexity, schedule, and third-party agreements. It should be noted that although these studies mentioned the importance of considering risk in project delivery and procurement selection, they fall short of providing a comprehensive list of delivery risk factors.

In practice, the critical delivery risk factors identified in this study help decision makers evaluate the interaction between risks and the project delivery selection process and recognize which risk more severely affects each delivery method. For example, if the scope of work for a project is vague, the owner should be aware that the DB delivery method may not be a suitable option. If it is chosen, design-builders must appropriately price contingencies to manage their risks. Further, these critical risk factors provide a foundation for developing a risk-based approach to selecting the optimal delivery method in transportation design and construction projects. It is expected that using risk-based approach will provide owners an informed decision to realize the maximum benefits with regard to the project type, size, and complexity that are best suited for each delivery method.

In addition, the findings of this study can help agencies document risks and benefits associated with projects delivered under DBB, DB, or CMGC methods. This documentation plays a central role in quantifying the cost, schedule, and quality corresponding to each delivery method. With this information, transportation agencies can make more effective and defensible project delivery selections.

Finally, the risk factors found from this study serve as generic risks for transportation design and construction projects. These generic risks can implement and enhance the probabilistic risk analysis and management that often occurs later in the project development process. The results of this study provide the impetus for conducting risk analysis at the very beginning of the project development projects and augment risk management culture in transportation industry. The traditional DBB project delivery process can promote a risk adverse culture. Low bidding, complete designs, and the use of prescriptive specifications, while effective, can inhibit contractor innovation and extend project delivery time. Thorough risk identification and appropriate risk allocation through alternative delivery methods can promote thoughtful risk taking that can result in more efficient project delivery decision.

## APPENDIX. SURVEY QUESTIONNAIRES

The following is a list of 39 risk factors relative to the project delivery selection process. Respondents were asked to rate and explain the impact of these risk factor on the project delivery selection process including DBB, DB, and CMGC (0 = NA; 1 = Very Low Impact; 2 = Low Impact; 3 = Moderate Impact; 4 = High Impact; and 5 = Very High Impact):

1. Please rate the impact of risk caused by *challenge to appropriate environmental documentation* (e.g., Distributed computing environment (DCE) vs. Environmental assessment (EA) vs. Environmental impact statement (EIS)) and all the related consequential events (e.g., change in design, scope, and construction costs) for each delivery method. Please give reasons for your choice.
2. Please rate the impact of risk caused by *geotechnical investigation* for each delivery method. Please give reasons for your choice.
3. Please rate the impact of risk caused by *the use of single vs. multiple contracts* (e.g., difficulties in multiple contractor interfaces) for each delivery method. Please give reasons for your choice.

4. Please rate the impact of risk caused by *challenge to project funding* (e.g., funding delay, funding shortfall) for each delivery method. Please give reasons for your choice.
5. Please rate the impact of risk caused by *the uncertain annual inflation rate* for each delivery method. Please give reasons for your choice.
6. Please rate the impact of risk caused by *difficulty in conformance with regulations/guidelines/documentation* for each delivery method. Please give reasons for your choice.
7. Please rate the impact of risk caused by *design errors and omissions* (e.g., errors in plans/specs/estimates) for each delivery method. Please give reasons for your choice.
8. Please rate the impact of risk caused by *challenge to material quality and availability* for each delivery method. Please give reasons for your choice.
9. Please rate the impact of risk caused by *project and program management issues* (e.g., workload management, executive oversight) for each delivery method. Please give reasons for your choice.
10. Please rate the impact of risk caused by *delays in right-of-way (ROW*) – uncertainty in the time required for ROW plan development and approval process for each delivery method. Please give reasons for your choice.
11. Please rate the impact of risk caused by *challenge to defined and non-defined hazardous waste* for each delivery method. Please give reasons for your choice.
12. Please rate the impact of risk caused by issues related to *constructability of designs* for each delivery method. Please give reasons for your choice.

13. Please rate the impact of risk caused by *challenge to delivery schedule* – uncertainty in the overall project delivery schedule from scoping through design, construction, and opening to the public for each delivery method. Please give reasons for your choice.

14. Please rate the impact of risk caused by *unexpected utility encounter* for each delivery method. Please give reasons for your choice.

15. Please rate the impact of risk caused by *insurance* - uncertainty in the availability of insurance coverage for each delivery method. Please give reasons for your choice.

16. Please rate the impact of risk caused by *challenge to staff experience and availability* for each delivery method. Please give reasons for your choice.

17. Please rate the impact of risk caused by *delays in completing utility agreements* (e.g., delay due to disagreement over responsibility to move, over cost-sharing) for each delivery method. Please give reasons for your choice.

18. Please rate the impact of risk caused by *challenge to community relations* for each delivery method. Please give reasons for your choice.

19. Please rate the impact of risk caused by *difficulty in work zone traffic control* (e.g., problems with maintenance of traffic, issues related to proposed plans, detour) for each delivery method. Please give reasons for your choice.

20. Please rate the impact of risk caused by *challenge to railroad agreements* for each delivery method. Please give reasons for your choice.

21. Please rate the impact of risk caused by difficulty in *obtaining other agency approvals* for each delivery method. Please give reasons for your choice.

22. Please rate the impact of risk caused by *uncertainty in material, labor, equipment costs* beyond what is included in inflation rates for each delivery method. Please give reasons for your choice.
23. Please rate the impact of risk caused by *third-party delay during construction* (e.g., railroad conflict, utility conflicts, and work-window restrictions) for each delivery method. Please give reasons for your choice.
24. Please rate the impact of risk caused by problems with *construction Quality Control/Quality Assurance (QC/QA)* for each delivery method. Please give reasons for your choice.
25. Please rate the impact of risk caused by uncertainty in *scope definition* for each delivery method. Please give reasons for your choice.
26. Please rate the impact of risk caused *by unclear contract document* – ambiguities in the contract documents for each delivery method. Please give reasons for your choice.
27. Please rate the impact of risk caused by problems with *design exceptions* –the need for design exceptions to federal/state/local regulations for each delivery method. Please give reasons for your choice.
28. Please rate the impact of risk caused by *delays in in procuring critical materials, labor, and specialized equipment* for each delivery method. Please give reasons for your choice.
29. Please rate the impact of risk caused by *unclear project definition* for each delivery method. Please give reasons for your choice.
30. Please rate the impact of risk caused by *challenges to environmental impact* (uncertain wetland mitigation, meandering, and connectivity) for each delivery method. Please give reasons for your choice.

31. Please rate the impact of risk caused by *changes in design standards/criteria* for each delivery method. Please give reasons for your choice.
32. Please rate the impact of risk caused by *legal challenges and changes in law* for each delivery method. Please give reasons for your choice.
33. Please rate the impact of risk caused by *problems with design Quality Control/Quality Assurance (QC/QA) process* for each delivery method. Please give reasons for your choice.
34. Please rate the impact of risk caused by *design completion issues* - uncertainty in the level of design completion at the time of the project delivery selection for each delivery method. Please give reasons for your choice.
35. Please rate the impact of risk caused by *uncertainty in planned construction sequencing/staging/phasing* for each delivery method. Please give reasons for your choice.
36. Please rate the impact of risk caused by *challenge to intergovernmental agreement and regulation* – uncertainty in coordinating with related government agencies and jurisdiction for each delivery method. Please give reasons for your choice.
37. Please rate the impact of risk caused by problems with *construction market conditions* (e.g., availability of contractor, pricing strategies of contractors) for each delivery method. Please give reasons for your choice.
38. Please rate the impact of risk caused by *strikes/labor disputes* (e.g., labor issues, contract negotiation) for each delivery method. Please give reasons for your choice.
39. Please rate the impact of risk caused by *challenge to project complexity* (e.g., the level of interaction between people, technical issues, and process) for each delivery method. Please give reasons for your choice.

## REFERENCES


Alder, R. (2007). "UDOT Construction Manager General Contract (CMGC) Annual Report," Engineering Services and Bridge Design Section, *Utah Department of Transportation Project Development Group*, Salt Lake City.

Alhazmi, T., and McCaffer, R. (2000). "Project procurement system selection model." *Journal of Construction Engineering and Management*, 126(3), 176–184.

Construction Industry Institute (CII). (1997). "Project delivery systems: CM at Risk, Design-Build, Design-Bid-Build," *Research Summary RS 133*, Austin, Texas.

Costello, A. B., and Osborne, J. W. (2005). "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis." *Practical Assessment, Research & Evaluation*, 10(7), 1–9.

Creedy, G. D., Skitmore, M., and Wong, J. K. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects." *Journal of Construction Engineering and Management*, 136(5), 528–537.

DBIA. (2011). State Statute Report, <http://www.dbia.org/NR/rdonlyres/27DEBA31-342B-4177-B6E0-AE8D9108D518/0/StateStatuteRpt101029.pdf> (October 3, 2011).

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., and Strahan, E. J. (1999). "Evaluating the use of exploratory factor analysis in psychological research." *Psychological methods*, 4(3), 272–299.

FHWA. (2006). *Guide to risk assessment and allocation for highway construction management*, Federal Highway Administration, Washington, DC.

Ghavamifar, K., and Ali Touran, F. (2009). "Owner's risks versus control in transit projects." *Journal of management in engineering*, 25(4), 230–233.

Gordon, C. M. (1994). "Choosing appropriate construction contracting method." *Journal of construction engineering and management*, 120(1), 196–210.

Gransberg, D., and Shane, J. (2010). *NCHRP synthesis of highway practice 402: Construction manager-at-risk project delivery for highway programs,* Transportation Research Board of the National Academies, Washington, DC.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for design-build projects: a primer for owners, engineers, and contractors*, American Society of Civil Engineers, Reston, VA.

Gransberg, D. D., and Molenaar, K. R. (2004). "Analysis of owner's design and construction quality management approaches in design-build projects," *ASCE Journal of Management in Engineering*, 20(4), 162–169.

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2009). *Multivariate Data Analysis*. Prentice Hall.

Kaiser, H. F. (1958). “The varimax criterion for analysis rotation in factor analysis.” *Psychometrika*, 23, 187–200.

Kim, J. O., and Mueller, C. W. (1978). *Factor analysis: Statistical methods and practical issues*. Sage Publications, Inc.

Love, P. E .D. Edwards, D. J., Irani, Z., and Sharif, A. (2012). Participatory action research approach to public sector procurement selection. *ASCE Journal of Construction Engineering and Management*, 138(3), 311–22.

Love, P. E. ., Skitmore, M., and Earl, G. (1998). “Selecting a suitable procurement method for a building project.” *Construction Management & Economics*, 16(2), 221–233.

Luu, D. T., Ng, S. T., and Chen, S. E. (2003). “Parameters governing the selection of procurement system–an empirical survey.” *Engineering, Construction and Architectural Management*, 10(3), 209–218.

Mahdi, I. M., and Alreshaid, K. (2005). “Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP).” *International Journal of Project Management*, 23(7), 564–572.

Molenaar, K. R., Gransberg, D., Scott, S., Downs, D., and Ellis, R. (2008). “NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide.” *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R. (2005). “Programmatic cost risk analysis for highway megaprojects.” *Journal of Construction Engineering and Management*, 131(3), 343–353.

Osipova, E., and Eriksson, P. E. (2011). “How procurement options influence risk management in construction projects.” *Construction Management and Economics*, 29(11), 1149–1158.

Oyetunji, A. A., and Anderson, S. D. (2006). “Relative effectiveness of project delivery and contract strategies.” *Journal of Construction Engineering and Management*, 132(1), 3–13.

Roberds, B., McGrath, T., Molenaar, K.R., Loulakis, M., and Ferragut, T. (2010). *NCHRP-SHRP Project R-09: Guide for the Process of Managing Risk on Rapid Renewal Projects*, Strategic Highway Research Program, Transportation Research Board of the National Academies, Washington, DC.

Rubin, R., and Wordes, D. (1998). “Risky business.” *Journal of Management in Engineering*, 14(6), 36–43.

Rwelamila, P. D., and Meyer, C. (1999). “Appropriate or default project procurement systems?” *Cost Engineering*, 41(9), 40–44.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). “Selection of Project Delivery Method in Transit: Drivers and Objectives.” *Journal of Management in Engineering*, 27(1), 21–27.

# CHAPTER 4

# A RISK-BASED PROJECT DELIVERY SELECTION MODEL FOR HIGHWAY DESIGN AND CONSTRUCTION

**ABSTRACT**

Project delivery methods allocate risk for design and construction between contractual parties. State departments of transportation (DOTs) using Federal funds currently employ three project delivery methods: design-bid-build (DBB); design-build (DB); and construction manager/general contractor (CMGC). Because a project delivery method decision is best made early in the project development process, it is a complex decision that is fraught with risk and uncertainty. This paper presents a risk-based modeling methodology to evaluate and quantify the potential differences in project cost due to the selection of a project delivery method. The risk-based model consists of: (1) input level—embedded data and project specifics; (2) processing level—computational structure and model interaction; and (3) output level—model results and applications. The input level contains the risks that are incorporated into the delivery decision and translates static cost and schedule uncertainty from project specifics to input variables (risk factors) and to decision variables (project outcomes). The processing level utilizes the multivariate analysis results and employs cross-impact analysis techniques and probabilistic inferences to capture uncertainties and interactions among the input and decision variables. The output level provides three approximate cost distributions associated with three project delivery methods (DB, DBB, and CMGC) as well as a sensitivity result (i.e., tornado diagrams) that describes which risk factors have the most significant impact on these costs. The model was successfully tested with four highway projects. The results of one project are presented for illustrative purposes. The risk-based model provides state DOTs with information to make informed delivery decisions. Researchers benefit from the methodology that combines multivariate analysis with cross-impact analysis and integrates the probabilistic risk-based cost estimating into the project delivery selection process.

**KEYWORDS:** Project delivery selection process; risk analysis and management; Cross-impact analysis; Monte Carlo simulation.

## INTRODUCTION

The demand to deliver highway projects in less time, at a high level of quality with limited budgets has driven state departments of transportation (DOTs) to adopt innovations in project delivery methods. State DOTs can employ a variety of innovative contracting systems to allocate risk between the DOT, designer and construction parties. The traditional design-bid-build (DBB) is the predominant delivery model. However, DBB has been criticized for its lengthy schedule, separation of the design and construction processes and latent adversarial relationships that it can cause (Ibbs et al. 2003, Touran el al. 2011, Love et al. 2012). As a result, state DOTs are using design-build (DB) and construction manager/general contractor (CMGC) more frequently to overcome these challenges. However, the choice of a delivery method is often made on an ad hoc basis with little quantitative insight on how the choice will impact final project risk allocation and resulting costs.

The selection of an appropriate delivery method is a complex decision process due primarily to risk and uncertainty at the time of the decision. The growing use of alternative delivery methods has led researchers and practitioners to search for structured approaches to choose project delivery methods. A plethora of delivery selection techniques have been developed to help public and private owners make a systematic and defensible decision. These techniques range from simple flowchart approaches (Goldon 1994, Tran et al. 2013) to more complex approaches, such as multi-attribute utility/value theory (Oyetunji and Anderson 2006), and analytical hierarchical process/value engineering/multi-criteria multi-screening (Alhazmi and McCaffer 2000; Mahli and

Alreshaid 2005). Nevertheless, limited research has employed quantitative risk-based approaches to the delivery selection process, which is surprising because project delivery methods are risk allocation vehicles at their core.

State DOTs have recently gained a more quantitative understanding of risk through the application of probabilistic risk-based cost estimating on major highway projects (Molenaar 2005). However, these estimates are often performed independently from the project delivery selection process. The separation of the probabilistic risk analysis and delivery decision process leads to a limited understanding of how risk affects the project delivery performance. The limitation may not only increase the chance of choosing an inappropriate delivery method but it may also impede the realization of the anticipated benefits associated with each method. To address this knowledge gap, this research introduces a risk-based model that integrates the probabilistic risk-based cost estimating into the project delivery selection process.

**LITERATURE REVIEW**

Highway design and construction projects are often large in scope with total project costs in the hundreds of millions of dollars. They are long in design and construction durations with project delivery processes that typically last more than 10 years. Research shows that the highway design and construction industry is fraught with risk and uncertainty (Flyvbjerg 2003; Molenaar et al. 2010). The selection of a project delivery method early in the project development process will increase the likelihood of project success. Given a variety of risks and uncertainties at the time of the project delivery selection, state DOTs need a decision support system that addresses the impact of risk on the project delivery decision. The American Association of State Highway

Transportation Officials (AASHTO 2008) provided state highway agencies with a four-step approach to selection DB projects by defining project goals, allocating risk, planning the evaluation, and writing the contract documents. However, it falls short of providing detailed selection guidance. Touran et al. (2011) developed a decision support system for selecting delivery methods in transit and airport projects. The framework includes 24 pertinent issues categorizing into factors in five groups: project-level, agency-level, public policy/regulatory, life cycle, and others. Although this framework considers improving risk allocation a critical element, it does not describe how risk influences the selection process. Recently, Tran et al. (2013) proposed a simple but practical flowchart approach to selecting an appropriate delivery method for highways. Although this flowchart placed an emphasis on the impact of risk on the project delivery selection process, it was constructed based on the qualitative risk assessment.

In 2002, the Washington State DOT began to employ probabilistic risk-based cost estimating through its Cost Estimating Validation Process (CEVP) (Molenaar 2005). The CEVP approach to cost estimating was viewed positively by the U.S. DOT and highway agencies across the nation. In 2004, the Federal Highway Administration (FHWA) created a policy that requires projects over $100 million in value to conduct probabilistic models at the planning/scoping stages (FHWA 2004). These milestones have resulted in a greater familiarity with the probabilistic risk-based cost estimating and a rich data source of identified and quantified project risks. The authors believe that the result of the probabilistic estimates can be used to make more informed project delivery method selections. The remainder of this paper presents a risk-based model that integrates the quantitative cost risk analysis with the project delivery decision to optimize the project delivery and contracting decision for highways.

## RISK-BASED PROJECT DELIVERY SELECTION MODEL

The primary objective of the risk-based model is to capture risk and uncertainty and explain how individual risk factors impact the highway delivery decision process. The model was designed for highway projects greater than $ 100 million and must be used in conjunction with probabilistic risk-based cost estimating. Figure 1 graphically illustrates the three-tiered architecture of the risk-based model: (1) input level—embedded data and project specifics; (2) processing level—computational structure and model interaction; and (3) output level—model results and applications.

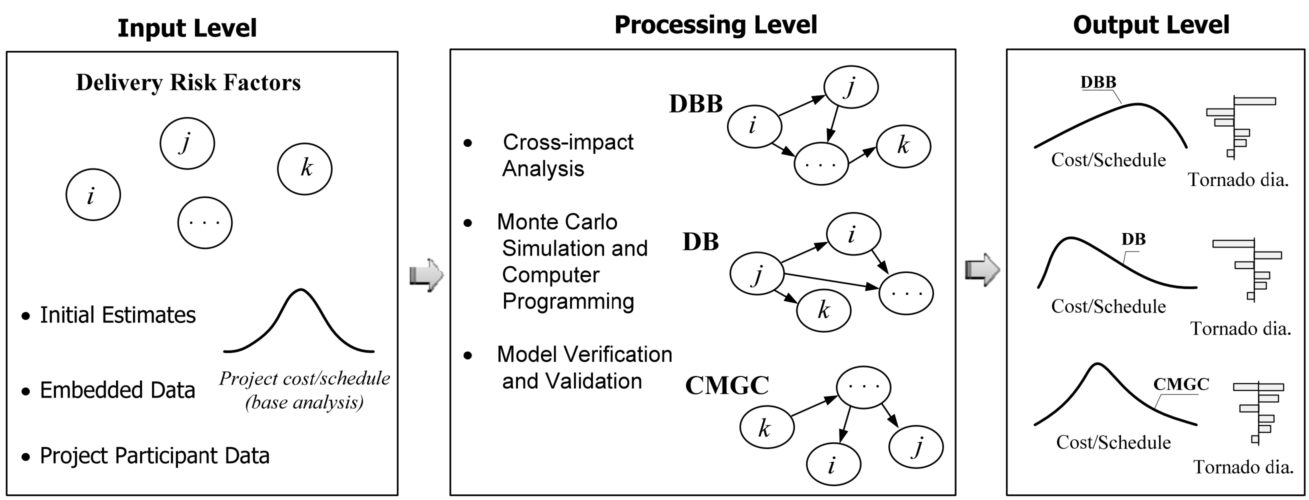


**Fig. 1. Overview of Risk-based Model**

The input level leverages embedded data from a factor analysis based upon data collected from 137 professionals from 43 state DOTs and a national sample of engineering firms and contractors. The participants had an average of 25 years of professional experience with risk and delivery methods. More than 50% of these experts have more than 30 years of experience; none have less than 10 years of professional experience. This level also collects data for project specific conditions. The processing level employs cross-impact analysis techniques, a Monte Carlo simulation, and computer programming to establish computational structure of the risk-based model. Finally, the output level provides three approximate cost distributions associated with three different delivery methods (DB, DBB, and CMGC) as well as a sensitivity result (i.e., tornado diagrams) that describes the risk factors that have the most significant impact on each delivery method. The sections that follow describe these three levels in detail. To elucidate the model application, the authors included examples of the model input resulted from an illustrative project case study in parallel with the model description. The detailed project information and model results were discussed in the output level.

## INPUT LEVEL

The risk-based delivery selection model requires multiple inputs to accurately simulate potential project costs. The primary inputs include: (1) estimates of initial probabilities for risks and project costs; (2) embedded data for the cross-impact analysis; and (3) project participant data for the cross-impact analysis. The identification and quantification of delivery risk factors forms the input framework for the initial probability framework. The cross-impact analysis of the delivery selection risks forms the framework for the remaining model inputs.

### Delivery Risk Factors

Delivery risk factors are the main input of the risk-based model. To capture the possible risks that impact a delivery decision, the authors reviewed literature and risks from probabilistic highway cost estimates. The literature consisted of articles, reports, guidebooks, and other work published by the American Society of Civil Engineering (ASCE), Transportation Research Board (TRB), and other journals from 1990 to 2012. The project data came from more than $10 billion in the Washington State and the FHWA probabilistic cost estimates previously described. The result was a list of approximately 200 generic risk factors found in transportation design and construction projects. The comprehensive list of risks was aggregated by the authors to combine overlapping risks and remove risks unrelated to project delivery decisions. Through the statistical analysis of data from a national survey questionnaire of 137 practitioners, the critical delivery risk factors corresponding to DBB, DB, and CMGC were determined (The detail of the analysis process can be found in Tran 2013). Table 1 summarizes these critical delivery risk factors in order of important with regard to each delivery method. . The list of all delivery risk factors and their definition is included in Appendix. This list provides the standard set of risks for the model, but decision makers can add or remove risk variables based on the specific characteristics of the project in question.

**Table 1. Critical Risk Factors for Project Delivery Decisions**

| Rank | DB | CMGC | DBB |
|---|---|---|---|
| 1 | Scope Risk | Constructability and Documentation Risk | Construction Risk |
| 2 | Third-party and Complexity Risk | Construction Risk | Schedule Risk |
| 3 | Construction Risk | Complexity Risk | Third-party and Complexity Risk |
| 4 | Utility and ROW Risk | Management and Schedule Risk | Constructability Risk |
| 5 | Level of Design and Contract Risk | Third-party Risk | Market Risk |
| 6 | Management Risk | Regulation Risk and ROW | ROW Risk |
| 7 | Regulation Risk and Railroad | | |

### *Estimating Initial Probabilities for Risks and Project Cost*

The model requires decision makers to evaluate the initial probabilities of these risk factors for the project in question. This process is best conducted through a workshop with key project personnel to leverage the collective knowledge of the project team in estimating these probabilities (e.g., FHWA representative, project/program manager, designer, engineer, utility representative, and the contractor). It is recommended that the decision makers should include the project personnel who participated in probabilistic risk-based cost estimating process. The initial probability of a risk variable, which is one of the main inputs for the risk-based model, is defined as the likelihood of each state of the variable occurring. Each risk variable is described in the model by a set of three mutually exclusive and collectively exhaustive events, which cover the full range of possible outcomes. Estimating initial probability assumes that the decision maker has some visual perception of risk variables and can produce subjective probabilities based on their expertise. For example, a decision maker is required to estimate the initial probability corresponding to geotechnical investigation risk for a project in question. The model uses three event states of high, medium, and low to describe this risk variable's condition. Based on the current state of the project, the decision maker judges that the probability of high risk in the geotechnical investigation is 0.3, medium is 0.6, and low is 0.1. The risk register from the probabilistic estimate supports the decision maker with this assessment. Table 2 presents an example of the initial probabilities of risk variables resulted from a project case study with Florida DOT. The detail of this project was presented in the output level.

**Table 2. Example of Initial Probability of Risk Variable for Risk-based Model**

| Risk ID | Risk Title | Variable's Status | | Initial Prob. | Notes |
|---|---|---|---|---|---|
| | | Status | Name | | |
| 1 | Risks caused by geotechnical investigation | 1 | Low | 0.1 | |
| | | 2 | Medium | 0.6 | |
| | | 3 | High | 0.3 | |
| 2 | Risks caused by environmental impacts | 1 | Low | 0.2 | |
| | | 2 | Medium | 0.5 | |
| | | 3 | High | 0.3 | |
| 3 | Risks caused by delays in right-of-way process | 1 | Low | 0.4 | |
| | | 2 | Medium | 0.4 | |
| | | 3 | High | 0.2 | |

Next, the model requires input of the values and initial probability of project outcomes (e.g., project cost and/or project schedule). These inputs should be directly taken from the cumulative probability distribution resulted from the probabilistic risk-based cost estimating. The project outcomes are described using five mutually exclusive and collectively exhaustive events (very low, low, average, high, and very high). The project cost values can be mapped into the cumulative probability distribution and the initial probabilities can be directly obtained by the definition of these cost values. Figure 2 shows an example with a probability that project cost is at the "average" state is 40%. Alternatively, the decision maker can specify the project cost values associated with five states by using a fitted procedure of the cumulative probability distribution (Clemen and Reilly 2004).

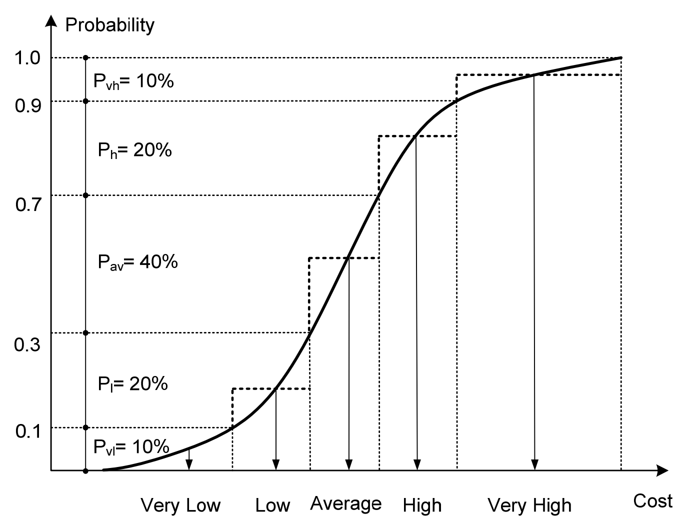


**Fig. 2. Derivation of Initial Probability from Cost Cumulative Distribution**

Table 3 shows an example of the five states of project outcomes associated with their values and initial probabilities. Based on the cost cumulative probability distribution, the decision makers can determine that there is 10% chance that project cost will be at the "very low" state; 20% at the "low" state; 40% at the "average" state; 10% at the "high" state; and 10% at the "very high" state.

Likewise, the cost values at these five states shown in Table 3 are easily determined from the cost cumulative probability distribution.

**Table 3. Example of Initial Estimate of Project Outcome for Risk-based Model**

| Project Outcome | States | Values ($ million) | Initial Prob. |
|---|---|---|---|
| Project Cost | Very Low | $ 632.2 | 10% |
| | Low | $ 723.8 | 20% |
| | Average | $ 792.4 | 40% |
| | High | $ 863.2 | 20% |
| | Very High | $ 978.1 | 10% |

### Cross-Impact Analysis Input

The computational structure for the risk-based model is derived from a cross-impact analysis. The main objective of the computational structure is to capture how the magnitude and dispersion of the risk factors impact project delivery selection. The cross-impact analysis technique is an analytical approach to determine the overall effect on the probability of a variable based on chains of impact from related variables (Honton et al. 1985; Alarcon 1992). This technique is suitable for this research because it is flexible and effective for predicting the outcome and combining scenarios of various alternatives, robust for assessing subjective probability, and relatively concise in its approach to evaluating expert judgments and defining outcome values.

There are a number of cross-impact analysis technique variations. This research utilizes "pattern" concepts developed by Alarcon and Ashley (1996) to capture the correlation between two variables. In the cross-impact relation pattern approach, the relationship between two variables is defined as: *SIG+:* Significantly in the same direction; *MOD+*: Moderately in the same direction; *SLI+:* Slightly in the same direction; *SIG-*: Significantly in the opposite direction; *MOD-* : Moderately in the opposite direction; *SLI* -: Slightly in the opposite direction; and *NO*: no impact. Application of the cross-impact relation pattern significantly reduces the cross-impact analysis knowledge acquisition when compared to a categorical BASIC approach developed by Honton et al. (1985). However, it still relies heavily on judgments of workshop participants. This reliance on decision makers' judgments can lead to inconsistencies when dealing with overwhelming amounts of uncertain information. Such is the case in highway project delivery selection due to the large number of variables. To overcome this burden, the authors introduced a new method that builds upon the multivariate analysis results to establish the cross-impact analysis relationship between variables.

### *Embedded Data Input for Cross-Impact Analysis*

The embedded data in the input level provides the strength of relationship between delivery risk factors though factor loadings and correlation coefficient matrices resulted from the factor analysis. The embedded data comes from the previously described survey of 137 professionals who accessed the impact of the embedded risks on the selection of a project delivery method (Tran 2013). Figure 3 summarizes the factor loadings of all delivery risk factors and the percentage of explained variance of all critical risk factors for all three delivery methods. The delivery risk factor and critical delivery risk factor are explained in detail in the previous study (Tran 2013). One can observe from Figure 3 that there exists an outlier associated with the delivery risk factor with loading smaller than 0.5. The low loading means that this delivery risk factor has little or no impact on the model. Based on the cross-impact relation pattern approach, it is reasonable to code the impact of this delivery factor as NO.

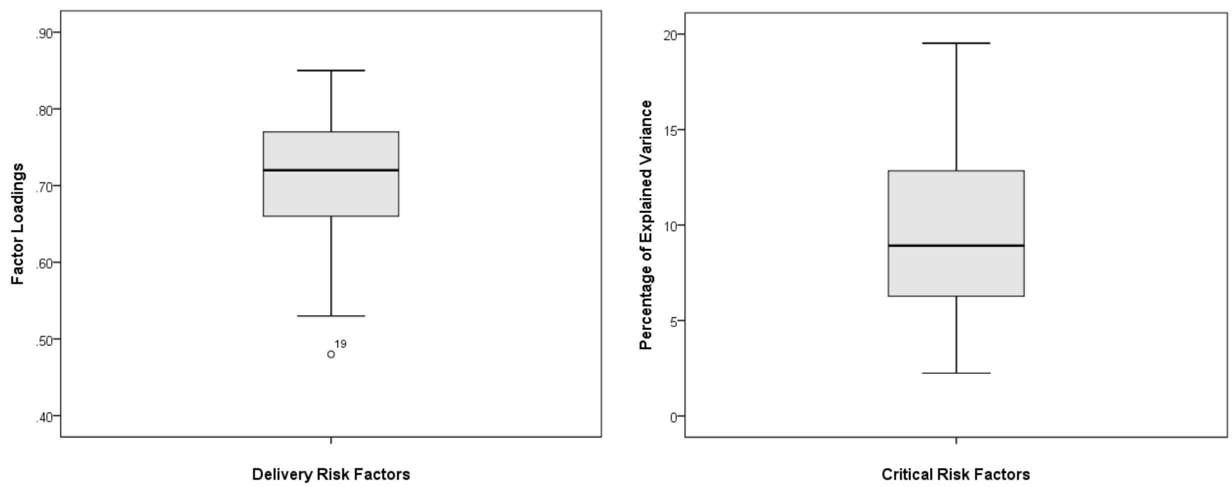


**Fig. 3. Factor Loadings and Percentage of Explained Variance**

To establish the cross-impact analysis relationship between variables, the authors generated three-level nominal versions of loading factors and the percentage of explained variance based on the data mining techniques (Witten and Frank 2005). The 33.33 percentile rank values of the loading factors and the percentage of explained variance for the three delivery methods are 0.647 and 6.7%. The 66.67 percentile rank values of the loading factors and the percentage of explained variance for the three delivery methods are 0.751 and 10.6%. As a result, loadings smaller than 0.65 is coded as SLI+; loadings between 0.65 and 0.75 is coded as MOD+; and loadings greater than 0.75 is coded as SIG+. Similarly, the percentage of explained variance of critical risk factors smaller than 6.7% is coded as SLI+; the percentage between 6.7% and 10.6% is coded as MOD+; and the percentage greater than 10.6% is coded as SIG+.

In addition, the strength of the relationship between two delivery risk factors can be identified based on the correlation coefficient matrices. Because all correlation coefficients are positive values, only four types of strength relationships (NO, SLI+, MOD+, and SIG+) are necessary to consider in the coding process. This result is consistent with the research setting in that risk each variable was defined as potentially adverse events that negatively impact project cost and schedule. The strength of the relationship between two delivery risk factors was assigned the following rule: If the correlation coefficient between two variables is smaller than 0.3, the strength of the relationship between these two variables is coded as NO; from 0.3 to 0.4 it is coded as SLI+; from 0.4 to 0.5 it is coded as MOD+; and greater than 0.5 it is coded as SIG+. Figure 4 graphically illustrates the interaction between delivery risk factors (ovals) and critical delivery risk factors (circles) based on the results from the multivariate analysis for DB delivery selection. It is important to note that the project characteristics and conditions (e.g., the project location, geography, or climate conditions) are taken into account in the model by changing the initial probability of each state of the delivery risk factors. For example, if a project is located in a historic site or wetland, the decision makers may set a high probability for risk caused by the environmental impact or geotechnical investigation.

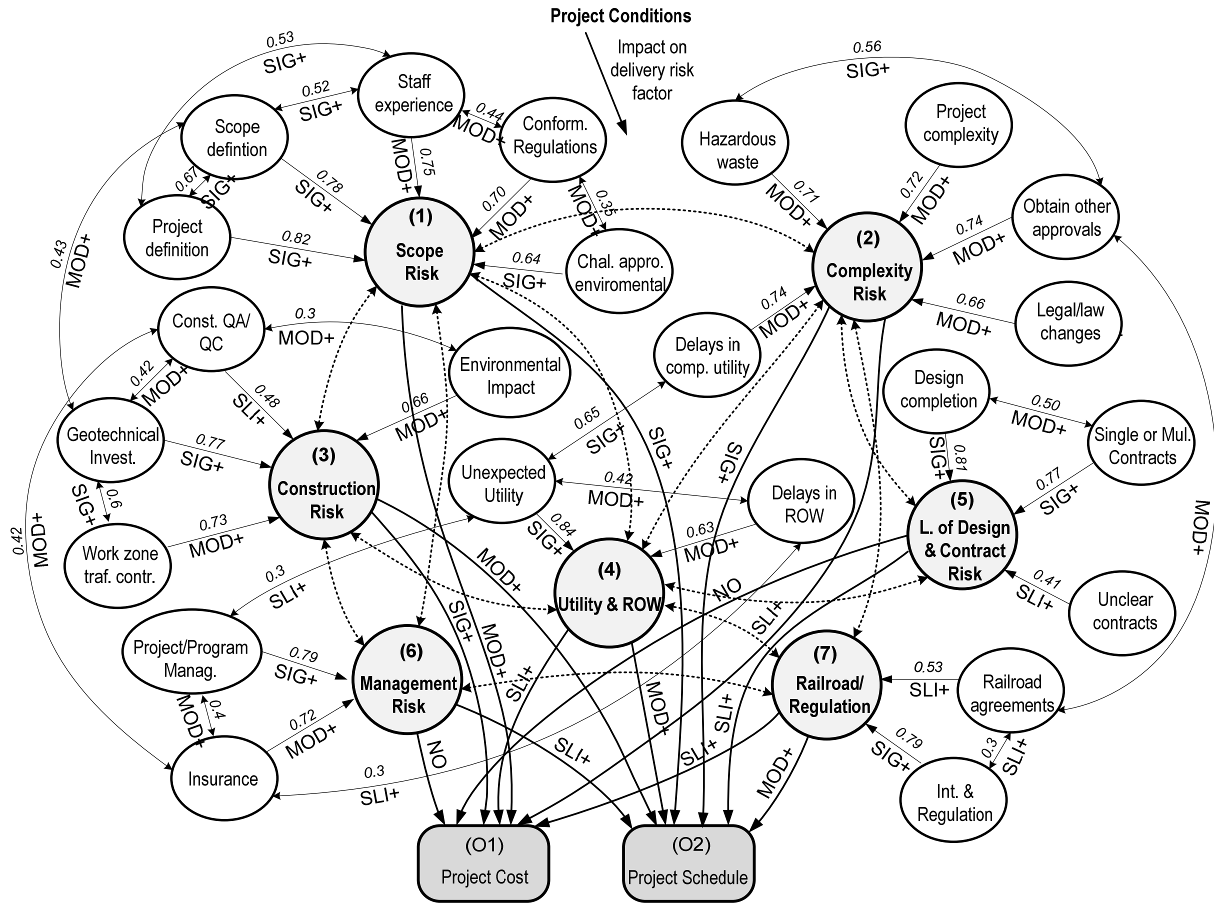


**Fig. 4. Model Interaction for DB Delivery**

In Figure 4, the rectangles with rounded corners represent the decision outcomes—project cost ($O_1$) and project schedule ($O_2$). The arrow from one node (risk variable) to another node represents the direction of relationship between these two risk variables. The numbers represent the loadings, percentage of explained variance, or correlation coefficients. For example, “Scope definition” has a significant impact (SIG+) on “Project definition” and “Staff experience” with correlation coefficients of 0.67 and 0.52 respectively; a moderate impact (MOD+) on “Geotechnical Investigation” with a correlation coefficient of 0.43; and a significant impact (SIG+) on the critical delivery risk factor “Scope Risk” with a loading of 0.78. Similar to DB, the model interaction for DBB and CMGC for the risk-based model were constructed in the same manner.

***Project Participant Data Input for Cross-Impact Analysis***

The final piece of data required for the risk-based delivery selection model is the input from the decision makers based on project conditions. The decision makers must evaluate the strength of the relationships between the critical delivery risk factors (the dotted curves shown in Figure 4) based on the characteristics and conditions of a considered project. They must also verify the quantitative assessments from multivariate analysis results to ensure that these assessments properly reflect the project conditions.

Table 4 illustrates the result of the workshop, which included seven experts participating in the project case study with Florida DOT, for the DB delivery method. To produce the assessments in this table, the decision makers were asked the question: “If the delivery risk factors shown in the columns were to occur, how would this affect the probability of delivery risk factors shown in the rows?” This process is repeated for DBB and CMGC delivery methods.

**Table 4. Example of Cross-Impact Matrix for DB Delivery**

| Critical Delivery Risk Factors | Scope Risk | Utility & ROW Risk | Construction Risk | Complexity Risk | Management Risk | Regulation Risk | Level of Design Risk |
|---|---|---|---|---|---|---|---|
| Scope Risk | NO | SLI+ | MOD+ | SLI+ | NO | SIG+ | NO |
| Utility & ROW Risk | SIG+ | NO | MOD+ | MOD+ | NO | NO | SLI+ |
| Construction Risk | SIG+ | SLI+ | NO | SIG+ | MOD+ | MOD+ | MOD+ |
| Complexity Risk | SIG+ | SLI+ | SLI+ | NO | NO | MOD+ | NO |
| Management Risk | SLI+ | SLI+ | SLI+ | MOD+ | NO | MOD+ | NO |
| Regulation Risk | MOD+ | SLI+ | SLI+ | MOD+ | SLI+ | NO | MOD+ |
| Level of Design Risk | MOD+ | SLI+ | SLI+ | SIG+ | SLI+ | SIG+ | NO |
| **Project Cost** | **MOD+** | **SLI+** | **SIG+** | **SLI+** | **SLI+** | **SLI+** | **SLI+** |

## PROCESSING LEVEL

The processing level uses a Monte Carlo simulation to model the input for the cross-impact analysis. This section describes the analytical process for the simulation to establish computational structure of the risk-based model. This section also discusses the model verification and validation.

### Cross-Impact Analysis Processing

After all assessments for the final model are determined and verified, the numerical values of the cross-impact matrix are used to calculate the impact and predict the risk propagation from project conditions to project outcomes. The cross-impact analysis process for the risk-based model is conducted based on the suggestion from Honton et al. (1985) and Alarcon and Ashley (1996). First, the odds of a risk event happening are calculated using Eq.(1). Next, each individual index value in the matrix is converted into a coefficient value (CV) based on Eqs.(2a) and (2b). The new odds are then updated by using Eqs. (3) and (4). Finally, the posterior probability of the risk event is calculated using Eq.(5).

$$Odds = \frac{priorP_{0i}}{1 - priorP_{0i}} \qquad \textit{Eq. (1)}$$

$$CV = |impact\_Index| + 1 \qquad \textit{If impact index >=0} \qquad \textit{Eq. (2a)}$$

$$CV = \frac{1}{|impact\_Index| + 1} \qquad \textit{If impact index < 0} \qquad \textit{Eq. (2b)}$$

$$new\_Odds = CV * Odds \qquad \textit{Eq. (3)}$$

$$new\_Odds = \frac{posteriorP_i}{1 - posteriorP_i} \qquad \textit{Eq. (4)}$$

$$posteriorP_i = \frac{priorP_{oi} * CV}{1 - priorP_{oi} + priorP_{oi} * CV} \qquad \textit{Eq. (5)}$$

**Monte Carlo Simulation and Computer Programming**

Using data collected from the input level and the cross-impact analysis processing, the risk-based model is simulated and experimentally modified to depict the risk propagation from project conditions to project outcomes. The modified process (sensitivity analysis) can be used to determine the degree of impact resulting from the proposed changes. The cross-impact analysis technique requires an intensive mathematical computation through a Monte Carlo simulation to compute the posterior probability of risk variables and outcome variables. A Monte Carlo simulation is a computerized tool for modeling a stochastic process based on a random input from certain statistical distributions (Clemen and Reilly 2004). The outputs of a Monte Carlo simulation result from running a large number of iterations used to measure their risk and uncertainty. In this research, a Monte Carlo simulation provides a vehicle to model the varied probability of delivery risk factors and capture probabilistic information regarding the propagation of risk and uncertainty from project conditions to project outcomes. The Monte Carlo simulation for the risk-based model includes the following steps:

*Step 1*: One risk event is randomly selected from the set of events of all delivery risk factors in the model.

*Step 2*: A random number between 0 and 1 is generated. If the random number is less than the probability of the event being selected, the event is said to occur. If the random number is greater than the event probability, the event does not occur.

*Step 3*: If the event occurs, the probabilities of the other events are adjusted based on Eqs. (1) to (5).

*Step 4*: Steps 1, 2, and 3 are repeated until all events of delivery risk variables in the mode have been tested for occurrence.

*Step 5*: Steps 1 through 4 are repeated a large number of times until the results tend to converge (i.e., increasing the simulation runs does not change the final result).

*Step 6*: The frequency of occurrence for each event of all runs determines the new probability for that event.

*Step 7*: The sensitivity analysis is performed to determine the degree of uncertainty of the decision variables. The model outcomes are tested by changing the initial probabilities of each delivery risk factor.

The following section discusses the model verification and validation process to confirm that the C++ programming of these seven steps is correct and the simulation model is appropriately constructed.

**Model Verification and Validation**

An important step of constructing the computerized model is to test and verify each module. Testing should ensure that the model was constructed correctly and the computer programming and implementation functions properly. Validation of the risk-based model included data validity, conceptual model validation, and computerized model verification. Additionally, the model was tested with one conceptual project and three actual projects with four separate highway agencies.

Sargent (2010) points out that the data validation process is critical to model integrity. In this research, as mentioned previously, the data used to build the risk-based model include 137 professionals with an average of 25 years of experience. More than 50% of these professionals have more than 30 years of experience. Respondents with less than 10 years of professional experience were removed from the data. The data collected from the professionals were rigorously analyzed using both univariate and multivariate statistical analysis techniques (Tran and Molenaar 2012; Tran and Molenaar 2013) to obtain appropriate and accurate data to construct the model.

Conceptual model validation confirmed that the model correctly represents the delivery selection process and that the model structure, mathematical relationships, and variable interactions are reasonable. To achieve this objective, the conceptual framework of the risk-based model was presented in detail with 20 professionals at four DOTs. The purpose of these discussions was to ensure that the model logic accurately depicts the project delivery selection process for highways. Additionally, the mathematical relationships and variable interactions in the risk-based model were confirmed using statistical results (i.e., factor analysis results and correlation coefficient matrices).

Computerized model verification was conducted to ensure that the computer programming and implementation are correct and accurate. In this research, the cross-impact analysis computer simulation and programming module in the risk-based model were simplified by including only three variables. The result from this simplification was then compared with the manual calculation and previous known results from literature. Consequently, the verification procedure confirmed that the results from the risk-based model were practically the same (less than 2% compared with the manual calculation and previous known results from literature). Further, an independent researcher verified the C++ programming code.

Finally, the risk-based model was tested with four highway projects. The results of the testing process indicated that the results from the risk-based model are consistent with the delivery decision made by these four state DOTs. The detailed results from one of these four testing projects are described in the following section for illustrative purposes.

**OUTPUT LEVEL**

The output level provides three approximate cost distributions associated for three project delivery methods (DB, DBB, and CMGC) as well as a sensitivity result (i.e., tornado diagrams) that describes which risk factors have the most significant impact on the cost of each delivery method. To illustrate the output level, this section presents the application of the risk-based model to the

Interstate 395 (I-395) Reconstruction project in Florida and then discusses the model output in detail.

## Project Information

The Florida DOT initiated a Project Development and Environment (PD&E) Study in 2004 to determine and document the feasibility of improving the geometric, operational and safety deficiencies of the I-395 corridor. The PD&E study was completed with the approval of the Record of Decision (ROD) from the FHWA in 2010. The Interstate 395 project involves the rebuilding of the I-395 corridor from its terminus at the west of the I-95/Midtown Interchange (I-95/State Road 836/I-395) to its corridor terminus at the West Channel Bridges of US 41/MacArthur Causeway, approximately 1.4 miles. I-395 is an interstate principal arterial and major east-west connector serving Miami Beach and the nearby ports. The project cost estimate at the 70% of confidence level is $835 million in year of expenditure. The anticipated completion date is October 2021. The major work on this project includes: (1) building new elevated ramps (one eastbound and one westbound) that will provide direct linkage between I-95 and I-395; (2) improving roadway design including updating the alignment and upgrading the roadway surface; (3) creating a visually appealing bridge; and (4) building vertically higher structures that will improve the visual quality of the bridge.

## Probabilistic Cost Risk Analysis Results

The probabilistic risk-based cost estimating process was conducted in 2012 by the review team including FHWA, Florida DOT, and engineering consultants. During the cost risk analysis process, the review team identified uncertainties and risks in the project such as base variability, inflation, market conditions, and risk events, which were modeled by the team to reflect the assessments of the subject matter experts. The result of probabilistic cost risk analysis specified that the project cost ranges from $632 million to $978 million at the 10% and 90% confidence intervals respectively. The average total project cost was estimated to approximately $ 792 million and the standard deviation was $ 124 million. The lowest and highest ends of the cost range are unlikely. The lowest end reflect the best case cost where few risks are realized and the highest end reflects a project cost where all significant risks identified during the review will be realized, including those with a relatively low likelihood.

**Risk-based Project Delivery Selection Model Input**

Seven experts from FHWA and Florida DOT were consulted to complete our risk-based project delivery selection model including the project manager, program manager, engineer, designer, utility manager, and an FHWA representative. Five of these seven experts participated previously in the probabilistic cost risk analysis and the other two were familiar with the project. This risk-based delivery workshop took approximately two and a half hours to complete. First, the participants reviewed the conceptual model, delivery risk factors, and the operation and function of the model to ensure that the model logic accurately described the delivery selection process for this project. Second, based on the probabilistic cost risk analysis data, the participants performed the initial estimate of the likelihood for 31 delivery risk factors. The participants were asked to determine the probabilities associated with three states (high, medium, and low) for each risk factor (see Table 2). The project risk register from the probabilistic cost risk analysis was a useful reference during this workshop. The result from this process is shown in Table 2 previously. The cumulative probability distribution of total project costs from the previously completed probabilistic cost risk estimate provided the five states (very low, low, average, high, and very high) and their probabilities for model input (see Figure 2 and Table 3). The result of this estimate is shown in Table 3. To complete the input, the participants reviewed the model interaction and determined the cross-impact matrix for the final model. Table 4 provides the result of the cross-impact matrix for DB delivery method (similar input was provided for DBB and CMGC).

**Discussion of Model Results**

The risk-based delivery selection model combined the cross-impact analysis technique and the Monte Carlo simulation to measure the total project cost with regard to three delivery methods: DBB, DB, and CMGC. The simulation was run for 10,000 iterations to reach convergence. Table 5 summarizes the expected cost for each delivery method.

**Table 5. Delivery Expected Costs for DB, DBB, and CMGC**

| Project | Project Cost Status | Initial est. based on stochastic cost reviews | | Expected cost values ($ millions) | | |
|---|---|---|---|---|---|---|
| | | Values ($ millions) | Prob. | DBB | DB | CMGC |
| I-395 Reconstruction Project in Florida | Very Low | $632.2 | 10% | $818.5 | $766.2 | $795.6 |
| | Low | $723.8 | 20% | | | |
| | Average | $792.4 | 40% | | | |
| | High | $863.2 | 20% | | | |
| | Very High | $978.1 | 10% | | | |

Table 5 indicates that DB is the delivery method with the lowest expected cost for the I-395 Reconstruction project. The expected cost value using DB delivery method is $766.2 million, which is less than the expected cost using CMGC ($795.6 million) or DBB ($818.5 million). Figure 5 illustrates three approximate cost distributions corresponding to DB, DBB, and CMGC resulting from the model simulation. One can observe that DB provides higher probabilities for completing the project at the lower end of the cost range and lower probabilities for completing the project at the higher end of the cost range when compared to DBB and CMGC. For example, Figure 5 shows that there is approximately a 25% chance that the total project cost is as low as $632.2 million when using DB versus a 19% chance for CMGC and a 15% for DBB at this same cost. Likewise, there is only approximately a 13% chance that the total project cost can be as high as $978 million when using DB versus a 17% chance for CMGC and a 23% chance for DBB at this same cost. In summary, the model quantitatively determines that DB is the best delivery method for this project.

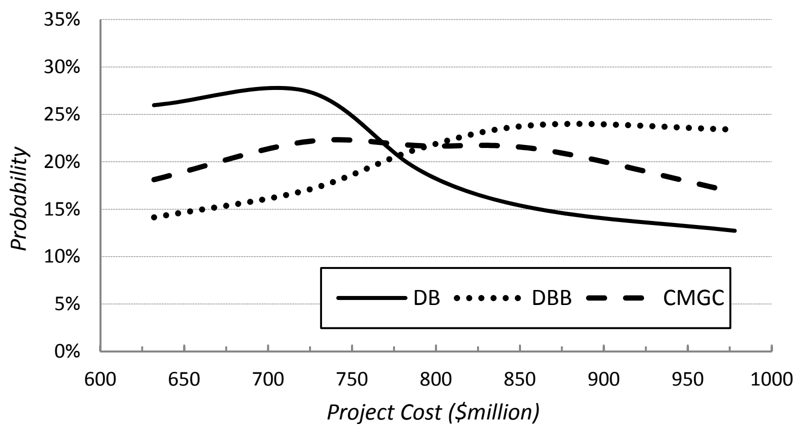


**Fig. 5. Approximate Cost Distributions of DB, DBB, and CMGC**

Because the approximate cost distributions associated with each delivery method are being driven by the unique project risks and cross impact analysis, the risk-based model can produce a sensitivity analysis in the form of a tornado diagram (Figure 6). The sensitivity analysis provides the user with a better understanding of the risks that are driving the cost distribution and also provides for a "what-if" analysis of the results. The owner agency can learn how and why specific risks will impact the selected delivery method. These results will allow the agency to determine a mitigation strategy to minimize the risks and maximize the project performance.

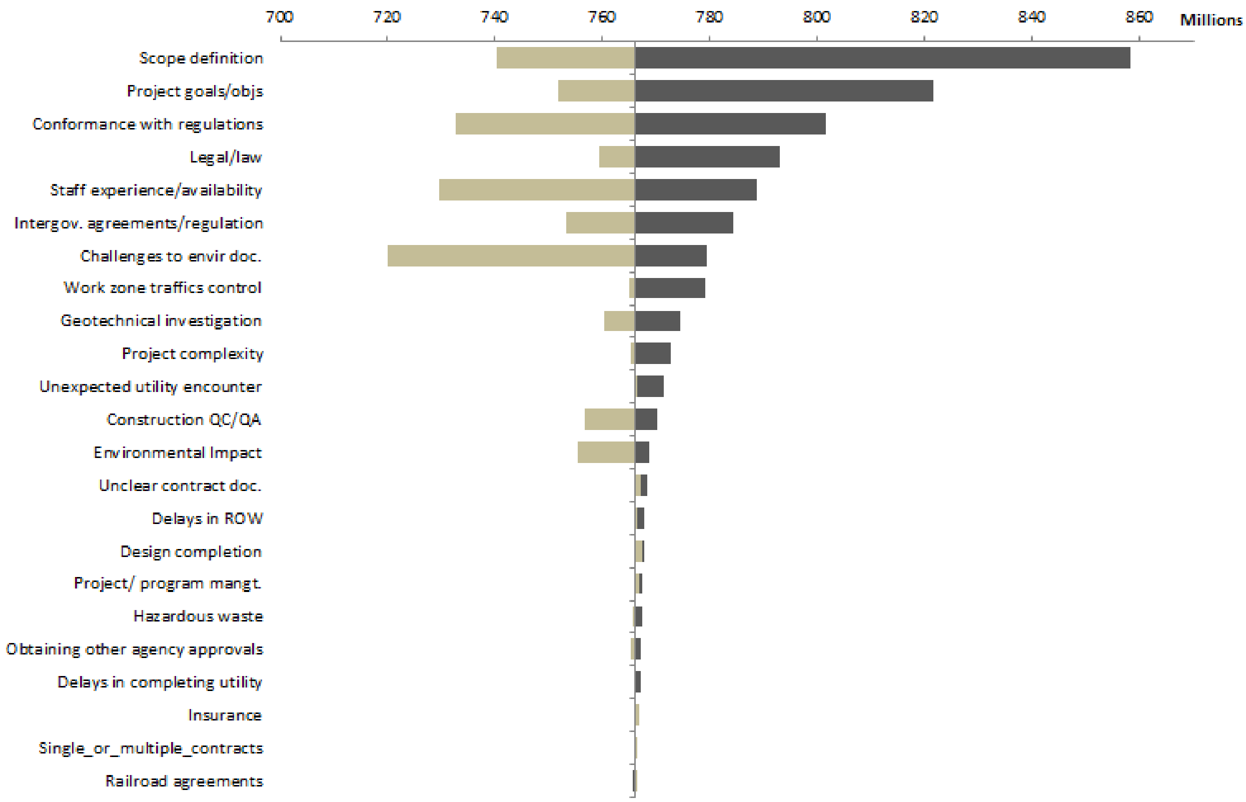


**Fig. 6. Sensitivity Analysis Results of DB Selection**

Figure 6 indicates that the risk caused by "scope definition," "project goals/objectives," and "conformance with regulation, design criteria, and guidelines" are the most significant impacts on the I-395 Reconstruction project for the DB selection (see Appendix for generic descriptions of these risk factors). A review of the results for the I-395 project by the project manager confirmed that these were the most significant risks. At the time of the cost estimate review, the design was in progress but had not reached 30% design plans and three types of signature bridges were being considered. Further, the project team considered adding $5.3 million for a recently discovered Florida Power Line distribution conflict and $36.3 million for the remaining right-of-way cost to the scope of the project. These facts reasonably explain why the scope risk, unclear definition of project goals and objectives, or the difficulty in conforming to guidelines, design criteria, and regulations are dominant for this DB highway project. However, the project team did not have a quantification of the impact of these risks before viewing the model. The sensitivity results also provide the delivery risk factors that have the least impact on project cost (Figure 6). As a result, the highway agency now knows which risks to focus on in project development (i.e., allocate more resources to mitigating) and which risks require less attention.

It is important to note that the risk-based model results depicted in Figures 5 and 6 provide pre-mitigated results. After Florida DOT invests in mitigating some of the most influential risks, they can revise the inputs, rerun the simulation and determine the effectiveness of their mitigation strategies. Although it is not likely in this case because DB is so clearly the most appropriate delivery method, post-mitigated model runs may change the best choice delivery model (e.g., CMGC or DB may become the best choice after risks are mitigated).

## LIMITATIONS AND FUTURE RESEARCH

While the risk-based delivery selection model presented in this paper provides a novel quantitative approach to selecting a highway project delivery method, it is important to recognize some limitations of the model and areas that future research can address. First, the risk-based model was constructed for large highway projects (project cost over $100 million) on which probabilistic risk-based cost estimating has been completed. In general, the probabilistic risk-based cost estimating is not required for projects of less than $25 million in value. For highway projects in the $25-100 million range, the model may not provide accurate results because the embedded data in the model that was generated for projects greater than $100 million. In addition, for small highway projects in which the probabilistic cost risk analysis results are not available or project team members are not familiar with the probabilistic risk analysis process, the data collection for the model input would also be a time-consuming process.

From a theoretical data modeling perspective, the model does not fully take the risk-aversion of the participants into account. The importance of risk-aversion in the decision-making process has been recognized in literature (e.g., Keeney and Raiffa 1976). Generally, risk-averse decision makers tend to overestimate possible losses and limit the state probabilities. Research shows that governments and their regulatory agencies often show risk-neutral attitudes in their decisions, but for the low probability and high consequence risk events, they tend to be risk-averse (Stewart at al. 2011). In the example in this research, the project manager, program manager, engineer, designer, utility manager, and other stakeholders likely had different risk tolerances. It would be beneficial to discover how the risk tolerances of each stakeholder impact the delivery decision. This avenue of research opens many interesting research topics such as integrating utility theory or cumulative prospect theory into the risk-based model.

The risk-based delivery selection model presented in this paper focuses on three fundamental delivery methods for highway projects: DBB, DB, and CMGC. The model does not consider the public-private partnership (PPP) method that is increasingly coming under consideration for infrastructure projects. One can discern that the financial and economic aspect is one of the main reasons to use PPP for infrastructure projects. To address this limitation, future work may need to consider additional risk factors and adjust the cross-impact matrix to include PPP in the model.

## CONCLUSIONS

The selection of an appropriate delivery method is critical to the success of a highway project. Research shows that there is no single delivery method that is appropriate for all projects, but there exists an optimal delivery method for each individual project (Gordon 1994, Love et al. 1998, Miller eta l. 2000, Ibbs et al. 2003, Gransberg et al. 2006, Touran et al. 2011, and Love at al. 2012, Tran et al. 2013). Researchers have been developing project delivery selection tools in an effort allocate risks properly and maximize project performance. An array of techniques and tools has been developed, but they have been limited in their ability quantifying cost, risk, and opportunities associated with each delivery method.

The risk-based delivery selection model presented in this paper provides a method to analyze of project cost, risk, and uncertainty corresponding to three fundamental delivery methods in highways to project. The results are concise and provide new insights for project management and other stakeholders. The results of the risk-based model help owner agencies make a sound decision on which method is the most suitable for their projects and how it is better than the other methods. The model's sensitivity analysis results convey the reasons why one delivery method is optimal. These sensitivity analysis results also offer insights into mitigation strategies which can assist owner agencies in optimizing a delivery method. The risk-base model also provides a vehicle to better understand and communicate the risks inherent in large highway projects. This process will promote a better understanding of DOT risk management and will enhance collaboration among project participants.

A significant byproduct of the risk-based model is the connection between the delivery selection model structure and the probabilistic risk analysis process for large highway projects. It has been shown that a probabilistic cost-risk analysis team can provide value engineering and constructability suggestions in addition to providing cost-risk analysis (Molenaar 2005). This study shows that these same team members can assist in project delivery selection. Building upon the probabilistic risk analysis process, the risk-based project delivery selection model workshop leverages the probabilistic cost-risk estimate simultaneously with the project delivery decision process. This combination will provide an effective, efficient, and transparent method to manage large highway projects.

This research endeavors to add to theoretical knowledge by introducing a new method that combines the cross-impact analysis technique with multivariate analysis results. Previous research has shown that the cross-impact analysis technique is a powerful tool to capture risk and uncertainty, but it is a time-consuming process (Gordon and Hayward 1968; Mitchell 1977; Alarcon and Ashley 1996; Han and Diekmann 2001). The integration of the multivariate analysis results with the cross-impact analysis not only significantly reduce the expert acquisition often required for the decision making process, but also provides more accurate judgments because they are based on statistical analysis rather than experts' opinion.

Finally, previous research also indicated that while the construction industry provides an excellent opportunity to develop and disseminate decision support systems. These systems often do not provide decision makers with a direct solution, but rather they assist decision makers to better understand problems and add value to reach the optimal decision (Hastak 1994; Bhargava et al.

1995; Molenaar and Songer 2001, and Bayraktar and Hastak 2009). The authors believe that the model presented in this paper advances the understanding of how risk impacts project delivery selection and why considering risk in the delivery selection process is essential for the success of highway design and construction projects.

**ACKNOWLEDGEMENTS**

The writers would like to acknowledge the help and support provided by the FHWA and the Florida DOT in the data collection for this research. Without their willingness to participate, this research would not have been possible. However, the findings and recommendations expressed in this paper are those of the writers alone and not necessarily the views or positions of the FHWA or the Florida DOT.

# APPENDIX: DELIVERY RISK FACTORS FOR RISK-BASED MODEL

| Risk | Risk Title | Description |
|---|---|---|
| 1 | Challenges to appropriate environmental documentation | The risk involves a change in environmental regulations, unforeseen formal National Environmental Policy Act (NEPA) consultation, an insufficient environmental study, or required environmental clearance. |
| 2 | Environmental impacts | Project may encroach into historic site, endangered species, wetland, coastal and scenic zone, wildlife, or the risk involves unexpected environmental constraints during planning and construction. |
| 3 | Uncertainty in geotechnical investigation | This risk may include unforeseen ground conditions, inappropriate design, contamination, ground water, settlement, chemically reactive ground, incomplete survey, and inadequate geotechnical investigation. |
| 4 | Work zone traffics control | The risk relates to unforeseen construction window because of problems with maintenance of traffic, unexpected plans and detours, and/or rainy season requirements. |
| 5 | Unexpected utility encounter | Required relocations of certain utilities are unknown; the risk relates to unforeseen conditions (e.g., seasonal requirements during utility relocation, utility company workload, financial condition or timeline). |
| 6 | Delays in completing utility agreements | The challenge in obtaining utility agreements is due to disagreement over responsibility to move, over cost-sharing or inadequate pool of qualified appraisers. |
| 7 | Delays in right-of-way (ROW) process | The delay of construction is due to the large number of parcels and businesses, acquisition of ROW required. |
| 8 | Delays in completing in railroad agreements | Because of the complex nature of the railroad involvement, obtaining railroad agreement may take longer time. |
| 9 | Third-party delay during construction | The risk involves a delay in the construction phase because of unforeseen third-party issues (e.g., railroad conflict, utility conflict, or work-window restrictions). |
| 10 | Difficulty in obtaining other agency approvals | The risk relates to new permits, new information required for permits, delays in agreements from Federal, State, or local agencies. |
| 11 | Defined and non-defined hazardous waste | The risk involves an incomplete analysis of hazardous waste site due to unexpected environmental constraints or unanticipated issues. |
| 12 | Project complexity | The risk relates to complex structures, unexpected ground conditions, environmental issues, unforeseen design and technical issues, and challenges in level of interaction between stakeholders |
| 13 | Scope definition | The risk of an incomplete scope definition leads to new or revised designs, added workload or time, rework and change orders (scope creep.) |
| 14 | Project goals/objectives | Project goals and objectives (schedule, cost, and deliverables) are not well-defined or understood. |
| 15 | Project funding | The risk of funding delay or shortfall may could significantly impact project goals and objectives. |
| 16 | Staff experience/availability | This risk relates mainly to the level of experience and availability of staff in application of various delivery methods. |
| 17 | Project and program management issues | The risk involves a lack of understanding of complex internal procedures or functional units not available or overloaded. |
| 18 | Constructability in design | The risk relates to unresolved constructability items, complex project features, and unforeseen construction windows. |
| 19 | Problems with material quality and availability | The lack of material availability and quality results in delays in schedule and increasing project cost. |

| | | |
|---|---|---|
| 20 | Delays in procuring critical materials, labor, and specialized equipment | The delay in procuring materials, labors, and equipment is due to unexpected constraints, unforeseen requirements, and complex structure. |
| 21 | Significant increase in material, labor, equipment cost | The risk involves market forces, unanticipated escalation in material, labor, and equipment costs. |
| 22 | Conformance with regulations/guidelines/design criteria | The risk relates to difficulties in conforming to guidelines, design criteria, and regulations (e.g., new or revised design standard, consultant design not up to department standards, and unforeseen design exceptions required) |
| 23 | Intergovernmental agreements and jurisdiction | The risk relates to intergovernmental agreement between the agency and other agencies (e.g., political factors, local community objections) |
| 24 | Legal challenges and changes in law | This risk involves a threat of lawsuits due to new permits or additional information required. |
| 25 | Community relationship issues | Unexpected issues with the community relationship cause a risk to project management and project delivery. |
| 26 | Unclear contract documents | The risk involves the ambiguities in the contract documents (e.g., incentive payment clauses, impact of long lead items, changes during construction). |
| 27 | Single or multiple contracts | This risk relates to difficulties in multiple contractor interfaces (e.g., lack of coordination/communication). |
| 28 | Insurance in contract | The risk relates to uncertainty in the availability of insurance coverage under which contractors accepts significant insurance risk from agencies. |
| 29 | Annual inflation rates | The risk involves a change in value due to deviation of the actual market consistent value and/or liabilities from the expected value due to inflation. |
| 30 | Construction market conditions | The risk relates to construction market changing (e.g., bid prices on similar work components on other projects varying considerably.) |
| 31 | Issues related to strikes/labor disputes | Strikes, disputes, or unforeseen labor issues directly result in project schedule delays and adding additional cost. |
| 32 | Delays in delivery schedule | The risk involves uncertainty in the overall project delivery schedule (pressure to deliver project on an accelerated schedule, underestimated support resources, or overly optimistic delivery schedule.) |
| 33 | Construction sequencing/staging/phasing | The risk relates to insufficient or limited construction or staging areas, unforeseen construction window, or rainy season requirements. |
| 34 | Construction QC/QA process | This risk relates to the impact project objectives due to continued evaluation and assessments of the activities of construction. |
| 35 | Design QC and QA | This risk involves the project objectives due to continued evaluation and assessments of the activities of development of plans, design and specifications, advertising and awarding of contract. |
| 36 | Design errors and omissions | The risk relates to errors in plans, specifications, and estimates in the design phase and causes negative outcomes to project cost and schedule. |
| 37 | Changes in design standards/criteria | The risk involves flexibility within the design criteria to achieve a balanced design (cost, safety, mobility, social and environmental impacts, and the needs of the project). |
| 38 | Design exceptions | The risk relates to considering design exceptions because of unforeseen encounter situations to obtain the appropriate design solution. |
| 39 | Design completion | This risk relates to inaccurate assumptions on technical issues, unforeseen design exception, incomplete quantity estimates at the level of design completion. |

## REFERENCES


Alarcon L. E (1992). "Project performance modeling: a methodology for evaluating project execution strategies," *PhD dissertation*, Dept. of Civil Engineering, University of California, Berkeley.

Alarcón, L. F., and Ashley, D. B. (1996). “Modeling project performance for decision making.” *Journal of Construction Engineering and Management*, 122(3), 265–273.

Alhazmi, T., and McCaffer, R. (2000). “Project procurement system selection model.” *Journal of Construction Engineering and Management*, 126(3), 176–184

Clemen, R. T. and Reilly, T. (2004). *Making hard decisions with Decision Tools Suite*, Druxbury Press, Pacific Grove, Calif.

AASHTO (2008) Design-Build Procurement Guide, *American Association of State Highway and Transportation Officials*, Washington, D.C.

Bayraktar, M. E., & Hastak, M. (2009). A decision support system for selecting the optimal contracting strategy in highway work zone projects. *Automation in Construction*, 18(6), 834-843.

Bhargava, H. K., King, A. S., and McQuay, D. S. (1995). “Decision Net: An architecture for modeling and decision support over the World Wide Web.” Proc., 3rd Int. Conf. on Decision Support System, International Society for Decision Support Systems, Austin, Tex., 499–506.

FHWA (2004). “Major Project Program Cost Estimating Guidance.” http://www.fhwa.dot.gov/ipd/project_delivery/tools_programs/cost_estimating/guidance.htm (accessed July 7, 2013)

Flyvbjerg, B., Holm, M., and Buhl, S. (2002). “Underestimating costs in public works projects: Error or lie?” J. Am. Plan. Assn., 68 (3), 279– 295.

Gordon, C. M. (1994). “Choosing appropriate construction contracting method.” *Journal of Construction Engineering and Management*, 120(1), 196–210.

Gordon, T., and Hayward, H. (1968). ‘‘Initial experiments with the cross impact method of forecasting.’’ *Futures*, Guilford, England, 1(2), 100– 116.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for Design-Build Projects: a Primer for Owners, Engineers, and Contractors*. American Society of Civil Engineers. Reston, VA

Han, S. H., and Diekmann, J. E. (2001). ‘‘Approaches for making riskbased Go/No-Go decision for international projects.’’ *J. Constr. Eng. Manage.,* 127(4), 300–308.

Hastak, M. (1994). “Decision support system for project cost control strategy and planning.” Ph.D.

thesis, Purdue Univ., West Lafayette, Ind.

Honton, E.J., Stacey, G.S. and Millet, S.M. (1985) *Future Scenarios: The BASICS Computational Method*, Battelle Technical, Columbus, OH

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). Project delivery systems and project change: Quantitative analysis. *Journal of Construction Engineering and Management*, 129 (4), 382-387.

Keeney, R. L., and Raiffa, H. (1976). "Decisions with multiple objectives. 1976." *John Wiley&Sons, New York.*

Love, P. E .D. Edwards, D. J., Irani, Z., and Sharif, A. (2012). Participatory action research approach to public sector procurement selection. *ASCE Journal of Construction Engineering and Management*, Vol.138, No.3, 2012, pp. 311–22

Love, P. E. ., Skitmore, M., and Earl, G. (1998). "Selecting a suitable procurement method for a building project." *Construction Management & Economics*, 16(2), 221–233.

Mahdi, I. M., and Alreshaid, K. (2005). "Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP)." *International Journal of Project Management*, 23(7), 564–572.

Miller, J. B., Garvin, M. J., Ibbs, C. W., and Mahoney, S. E. (2000). "Toward a new paradigm: Simultaneous use of multiple project delivery methods." *Journal of Management in Engineering*, 16(3), 58–67.

Mitchell (1977) Scenario Generation limitation and development in CIA, *Futures*, Guilford, England

Molenaar, K. R. (2005). "Programmatic cost risk analysis for highway megaprojects." *Journal of Construction Engineering and Management*, 131(3), 343–353.

Molenaar, K. R., and Songer, A. D. (2001). "Web-Based Decision Support Systems: Case Study inProject Delivery." *Journal of Computing in Civil Engineering*, 15(4), 259–267.

Molenaar, K. R., Anderson S., and Schexnayder, C (2010). *NCHRP Report 658: Guidebook on risk analysis tools and management practices to control transportation project costs*. Transportation Research Board of the National Academies, Washington, DC.

Oyetunji, A. A., Anderson, S. D., and others. (2006). "Relative effectiveness of project delivery and contract strategies." *Journal of Construction Engineering and Management*, 132(1), 3-13.

Sargent, R. G. (2012). "Verification and validation of simulation models." *Journal of Simulation*, 7(1), 12–24.

Stewart, M. G., Ellingwood, B. R., and Mueller, J. (2011). “Homeland security: a case study in risk aversion for public decision-making.” *International Journal of Risk Assessment and Management*, 15(5), 367–386.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011) Selection of Project Delivery Method in Transit: Drivers and Objectives. *Journal of Management in Engineering*, 27 (1) 21-27.

Tran, D. (2013). "A risk-based Model to Select Delivery Methods for Highway Design and Construction Projects" *PhD dissertation*, Dept. of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder.

Tran, D., and Molenaar, K. R. (2013). “The Impact of Risk on Design-Build Selection for Highway Design and Construction Projects.” *Accepted for the ASCE Journal of Management in Engineering.* doi:10.1061/(ASCE)ME.1943-5479.0000210.

Tran, D., Harper, C. M., Molenaar, K. R., Haddad, N. F., and Scholfield, M. M. (2013). “A Project Delivery Selection Matrix for Highway Design and Construction.” *Accepted for Publication in the Transportation Research Record, Journal of the Transportation Research Board.*

Tran, D. and Molenaar, K.R. (2012). “Critical Risk Factors in Project Delivery Method Selection for Highway Projects,” *ASCE Construction Research Congress, West Lafayette, IN,* May, 2012, 331–340.

Witten, I. H., and Frank, E. (2005). *Data Mining: Practical machine learning tools and techniques*. Morgan Kaufmann.

# CHAPTER 5

# CONCLUSION

## SUMMARY AND CONCLUSION

Selecting an appropriate delivery method is a critical to the success of highways and other infrastructure projects. The construction industry strives to select delivery methods that maximize project performance. Tools and techniques have been developed to help the industry make this selection, but most are qualitative approaches. This study provides a foundation to construct quantitative approaches to selecting the optimal project delivery method in highway design and construction projects.

This dissertation explores the impact of risk and uncertainty on highway project delivery method selection. The body of this dissertation includes three papers that present the research problem, methodologies, results, contributions, and applications. The first and second papers employ the content analysis, survey questionnaires, and factor analysis to identify the risk factors affecting the project delivery selection process. The first paper focuses on investigating the impact of risk on the individual delivery method (e.g., design-build). The authors selected DB as the main research setting for this paper because the DB risk allocation mechanism tends to be more complex than that of DBB and CMGC delivery methods. The findings from this paper indicate that seven delivery risk factors have the most influence on DB delivery selection: (1) scope risk; (2) third-party and complexity risk; (3) construction risk; (4) utility and right-of-way (ROW) risk; (5) level of design and contract risk; (6) management risk; and (7) regulation and railroad risk.

Building upon the findings from the first paper, the second paper advances the understanding of how risk impacts the three fundamental delivery methods commonly used in highways: DBB, DB, and CMGC. In addition to the seven critical delivery risk factors for DB, the paper identifies six factors for DBB, and six factors for CMGC. This paper also discusses the impact of these risk factors on the project delivery selection process in detail. The paper points out that the strength of impact of these risk factors is different for DBB, DB, and CMGC. For example, construction risk is considered the most important factor (ranked first) in DBB projects, but this factor ranked second in the CMGC and third in the DB delivery method. On the other hand, scope risk is considered the most important factor (ranked first) in the DB delivery method, yet it did not rank in either the CMGC or DBB delivery methods. The paper concludes that depending on which delivery method is used, risks are propagated in the different paths and interacts with each other differently.

The results from the second paper provide a foundation to construct a risk-based model presented in the third paper. The model utilizes the multivariate analysis results, cross-impact analysis technique, and Monte Carlo simulation to quantify the risk and uncertainty propagated from project conditions to project outcomes associated with each delivery method. One of the main advantages of the model is to integrate the probabilistic cost risk analysis into the delivery selection process. This integration process not only provides an opportunity to review risk and cost identified in probabilistic cost risk analysis, but also enhances the understanding and communication of risks involved in the project. The results of the model provide three approximate distributions with regard to project cost corresponding to DBB, DB, and CMGC selection. Through these distributions, decision makers can determine which delivery method is the most appropriate for their projects. In addition, the model provides the sensitivity analysis results in the form of a tornado diagram. These sensitivity analysis results can help the decision makers understand which individual risk factor has the greatest impact on the project cost or schedule for each delivery method. Further, the results of the model can help the decision makers develop mitigation strategies that can be used to manage projects more effectively. Figure 1 revisits the dissertation overview presented in Chapter 1 by adding results and contributions of each paper.

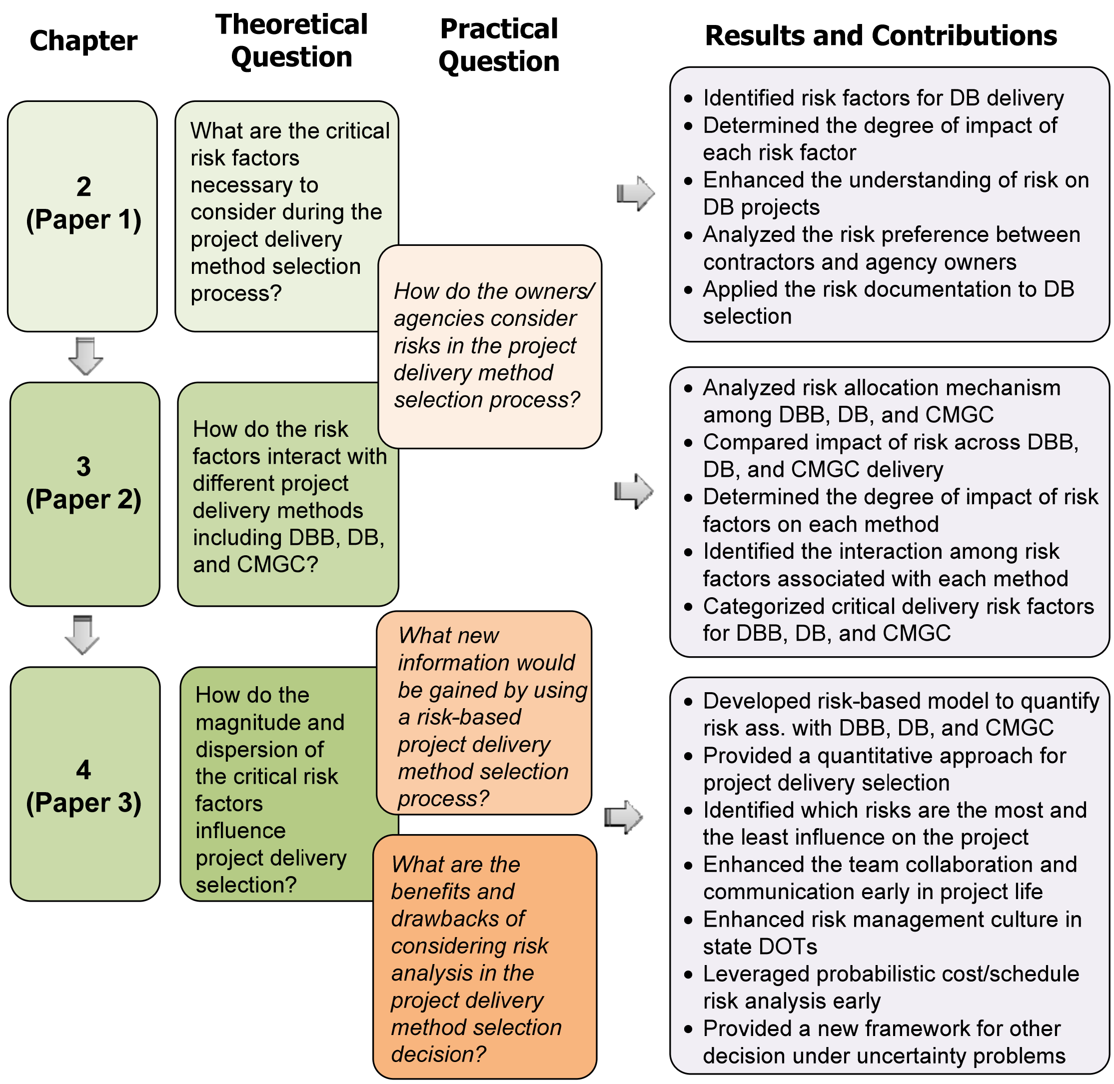


**Figure 1. Research Questions, Results and Contributions**

## CONTRIBUTIONS

To date there is no research applying probabilistic cost risk analysis to quantify and select project delivery methods in the construction industry. This research seeks to understand the interaction between the characteristics of critical risk factors and project delivery method decisions and then offer risk-based strategies to select the most suitable method with regard to project characteristics, goals, and objectives. This research offers three primary deliverables: (1) identifying the critical risk factors that affect the project delivery method selection process in highway design and construction projects; (2) offering an effective risk-based strategy for selecting an appropriate project delivery method in highway design and construction projects; and (3) providing a risk-based model which can be used for selecting an appropriate project delivery method. There are several contributions to both theory and practice in all chapters of the dissertation.

### Contributions to Theory

The dissertation provides a number of academic contributions. Overall, this dissertation offers a new approach, the risk-based model, to select a project delivery method in highways. A comprehensive literature review indicates that there are many frameworks for selecting an appropriate delivery method in the construction industry (Gordon 1994; Mahdi and Alreshaid 2005; Oyetunji and Anderson 2006; and Touran et al. 2011). However, there are no studies that attempt to employ quantitative risk analysis or comprehensively investigate the interaction between risk and the delivery selection process in their decision frameworks. Further, although the risk-based model was designed for highway projects, the logics and methodology can be used to determine the most suitable project delivery method in other areas such as building, water and wastewater, and transit projects.

Chapter 2 provides a fresh view on the use of risk to determine when DB is a suitable delivery method for highway projects. It also adds novel insights about which risks have the most influence on DB selection and how and why these risks are important. In addition, this chapter augments recent studies that have recognized the impact of risk on DB highway projects (Molenaar et al. 2008; FHWA 2006; Molenaar and Gransberg 2001). It enhances these studies by identifying, categorizing, and grouping the risk factors based on their significance of impact upon DB selection. Specifically, Chapter 2 categorizes seven delivery risk factors that have the most influence on the DB delivery selection. Through factor analysis, this chapter also includes the risk components associated with these seven delivery risk factors. These findings will help researchers focus on the most critical risks in DB project delivery selection. The findings from Chapter 2 lay the foundation for future work related to risk analysis and management on DB projects.

Chapter 3 provides a list of risk factors necessary to consider in the project delivery selection process on a spectrum of three fundamental methods: DBB, DB, and CMGC. Chapter 3 contributes to the construction engineering and management body of knowledge by offering a comprehensive list of risk factors that affect the delivery selection process. It also supplements the findings from the literature on the relationship between risk and the delivery selection. For example, Gordon (1994) included risk aversion as a factor in his procurement method selection flowchart. Mahdi and Alreshaid (2005) considered risk management and risk allocation as significant factors in their analytical hierarchy process (AHP) model. Oyetunji and Anderson (2006) included a financial risk factor and site conditions in their decision support tool. Recently, Touran et al., (2011) explicitly considered risk management and risk allocation as well as several implicit risk-related factors such as project complexity, schedule, and third-party agreements. It should be noted that although these studies mentioned the importance of considering risk in project delivery and procurement selection, they fall short of providing a comprehensive list of delivery risk factors as provided in Chapter 3.

In addition, Abowitz and Toole (2010) indicated that "A substantial portion of the papers using factor analysis that the second writer has reviewed over the past 5 years seemed to have used this technique inappropriately." Chapters 2 and 3 present a detailed procedure to conduct the factor analysis, including data examination, testing assumptions, and the interpretation process. This procedure provides some guidelines for construction engineering and management researchers to use factor analysis appropriately in their research.

Finally, Chapter 4 builds upon the results from Chapters 2 and 3 to develop a risk-based model to quantify the impact of risk on project cost and determine the optimal delivery method for a highway project. Chapter 4 offers several theoretical contributions to the construction engineering and management research. First, the risk-based model suggests a new method that combines the multivariate analysis results with the cross-impact technique to solve decision problems under uncertainty. To the author's knowledge, no research efforts have applied this method in the literature. Utilizing the multivariate analysis results improves the accuracy of the experts' judgments and reduces significant effort of knowledge acquisition required for the cross-impact analysis technique. Second, the risk-based model augments the probabilistic cost/schedule risk analysis by bringing multidisciplinary team members early in the project development process. Many previous studies have focused on developing a model for conducting the formal cost/schedule risk analysis (Diekmann 1983; Touran 1992; Molenaar 2005; Shane et al. 2009), but there is limited research, if any, that utilizes results from the probabilistic cost risk analysis to the delivery decision for highways. Next, the computer implementation and programming is a possible means for disseminating research results. Finally, the risk-based model suggests promising avenues of future research on risk analysis and project delivery methods in the construction industry.

### Contributions to Practice

The overall focus of this dissertation is to identify and analyze the risk factors that affect the project delivery selection process and then develop a risk-based model to help decision makers understand the impact of risks on their decisions. The research and findings from this dissertation contribute to practice in highway design and construction projects in several ways.

Chapters 2 and 3 identify and categorize a list of critical risk factors and their components affecting the project delivery selection process. These critical risk factors, seven for DB, six for CMGC, and six for DBB, provide guidance for practitioners selecting an appropriate project delivery in highway design and construction projects. They do not need to be applied to the simulation model in Chapter 4 to help practitioners with better project delivery selection. These critical risk factors will help practitioners recognize which risk more severely affects each delivery method. With a variety of risks or uncertainties involved in the project delivery method decision, it is important for highway agencies to have a clear understanding of the impact of risk on each delivery method. This understanding not only helps agencies select an appropriate delivery method, but also provides some guidance to choose suitable procurement procedures and payment provisions for their selected project delivery method. Further, the findings from Chapters 2 and 3 help highway agencies document risks and benefits associated with projects delivered under DBB, DB, or CMGC methods. This documentation can play a central role in quantifying the cost, schedule, and quality associated with each delivery method.

Finally, the risk factors found from Chapters 2 and 3 serve as generic risks for highway design and construction projects. These generic risks can implement and enhance the probabilistic risk analysis and risk management that often occurs later in the project development process.

Chapter 4 develops a risk-based model that provides a systematic and structured process for highway agencies to select an appropriate delivery method. The results of the risk-based model offer: (1) three approximate cost or schedule distributions associated with DBB, DB, and CMGC; and (2) sensitivity analyses results that identify which risk factors have the most influence on each delivery method. These results help decision makers effectively and defensibly select an optimal delivery method by comparing project performance (i.e., project cost) under each delivery method. The three approximate distributions corresponding to DBB, DB, and CMGC are a significant contribution to practitioners in that no quantitative approaches exist for state DOTs to evaluate project delivery methods for their highway projects.

Another benefit of the risk-based model is the sensitivity analysis result. This result provides decision makers the risk factors that have the greatest impact on each delivery method for their projects. The results of the sensitivity analysis may be more meaningful than the cost distributions – particularly when the distributions for the three delivery methods are similar in shape. The decision makers can use these results to propose mitigation strategies to reduce risks and increase opportunities based on the available resources for their projects. Further, the decision makers can also understand how magnitude and/or dispersion of a specific risk factor influence the project delivery selection process.

Finally, the risk-based model provides an excellent opportunity for the project team to discuss potential project risks early in the project development process. The team including the FHWA representatives, project/program managers, engineers, designers, third-party representatives, and contractors has a chance to review a probabilistic cost-risk estimate and voice their concerns about different delivery methods. Team members with different backgrounds and expertise will augment the understanding of the impact of risk on project performance throughout the project development process.

## LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Our current understanding of the fundamental relationship between risk and project delivery selection remains incomplete. Data to support the use of empirical research on the risk and project delivery selection is limited. Although the research presented in this dissertation provides novel insights into the delivery risk-based selection process, there are several limitations that warrant attention for future research, including:

1. Enhancing the model testing and implementation.
2. Including additional sensitivity analyses for model interaction and outcomes.
3. Expanding the model to more explicitly include schedule risks.
4. Improving the understanding of the impact of risk on CMGC projects.

5. Adding procurement procedures and payment provisions.
6. Including other performance measurements into the model.
7. Creating a new model for small highway projects.
8. Integrating public-private partnership project delivery methods into the model.
9. Developing an interactive and practical computer tool.
10. Expanding the model to other sectors in the construction industry.
11. Considering the role of risk-aversion in the model.
12. Applying the Bayesian network to enhance the accuracy of the model input.

The following paragraphs explain these limitations and suggestions for future research in more detail.

1. ***Enhancing the model testing and implementation.*** The risk-based model constructed in this research was tested with four highway projects. While the result of the testing process was consistent with the delivery decision from the state DOTs, additional testing could ensure the accuracy of the results and provide more insights into the effects of risk on project delivery.

   The results of two additional model tests are presented here to provide insights into the value of additional testing. Figure 1 presents the results of the risk-based model for three highway projects: the Rt. 295 and 42/ I-76 Project in New Jersey, Lake Bridges Project in Kentucky, and the I-35 Reconstruction Project in Florida. The cost-risk analyses for these projects were provided by the FHWA. The detailed data collection process for these projects is provided in Appendix III. (Note that the test results from the CDOT project are not included for publication since the risk-based estimate was not rigorous due to the conceptual scope of the project.)

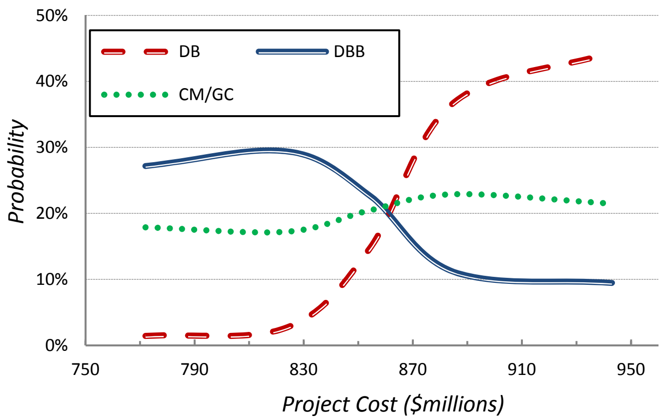


**Fig 2a. Rt. 295 and 42/ I-76 Project, New Jersey**

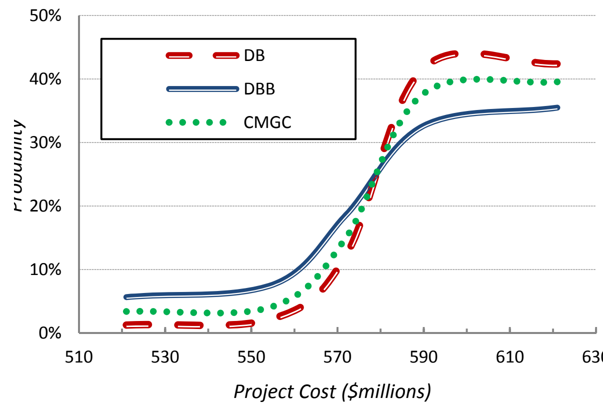


**Fig. 2b. Lake Bridges Project, Kentucky**

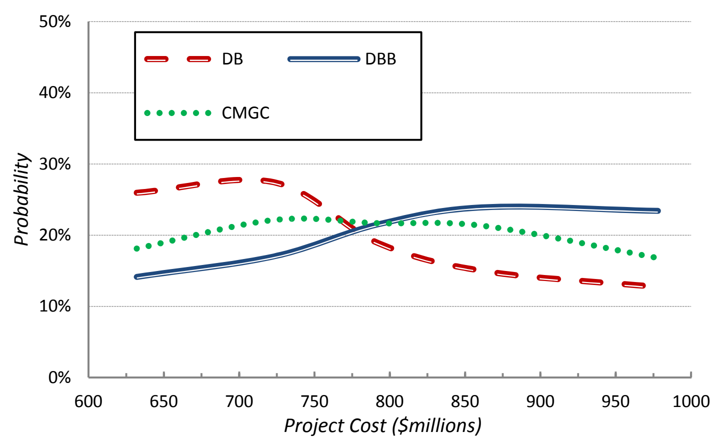


**Fig 2c. I-395 Reconstruction Project, Florida**

**Fig. 2. Approximate Cost Distributions for DB, DBB, and CMGC**

Based on the results in Figure 1, one can observe that DBB is the most suitable delivery method for the 295 and 42/ I-76 Project and the Lake Bridges Project (Figures 2a and 2b) and DB is the most suitable for the Rt. I-395 Reconstruction project (Figure 2c).

The other important result from the risk-based model is the "what-if" (sensitivity analysis) results. Figure 2 illustrates the sensitivity analysis results for Rt. 295 and 42/ I-76 Project

(Figure 3a), the Lake Bridges Project (Figure 3b), and the I-395 Reconstruction project (Figure 3c).

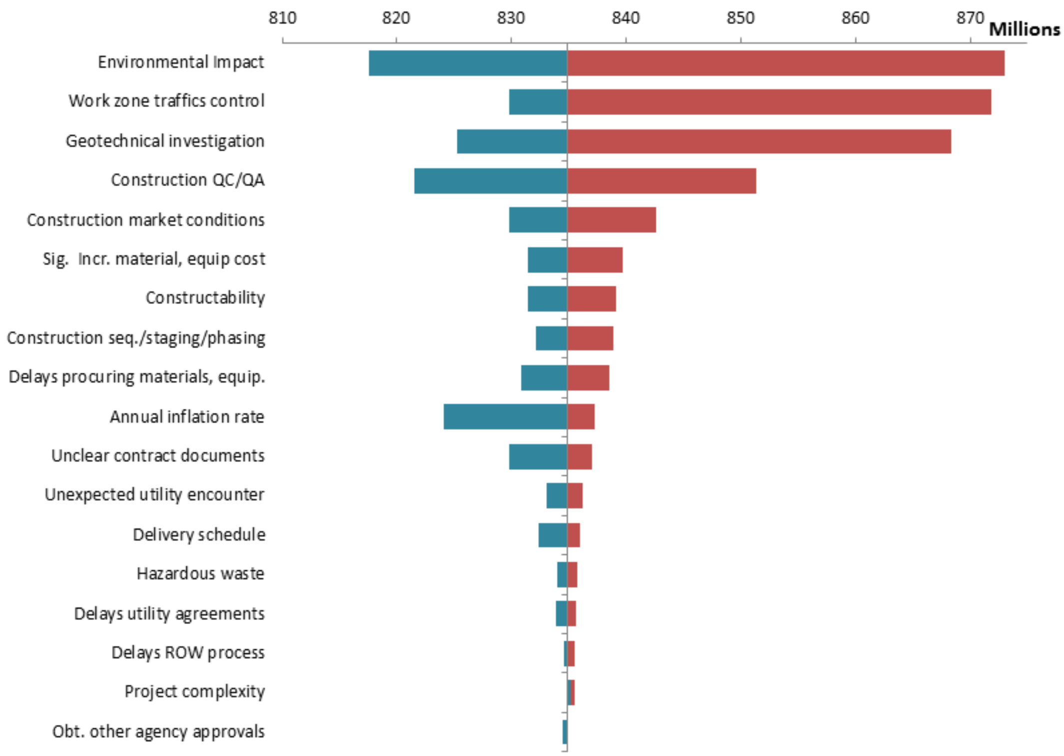


**Fig. 3a. Tornado Diagram for DBB Selection for Rt. 295 and 42/ I-76 Project, New Jersey**

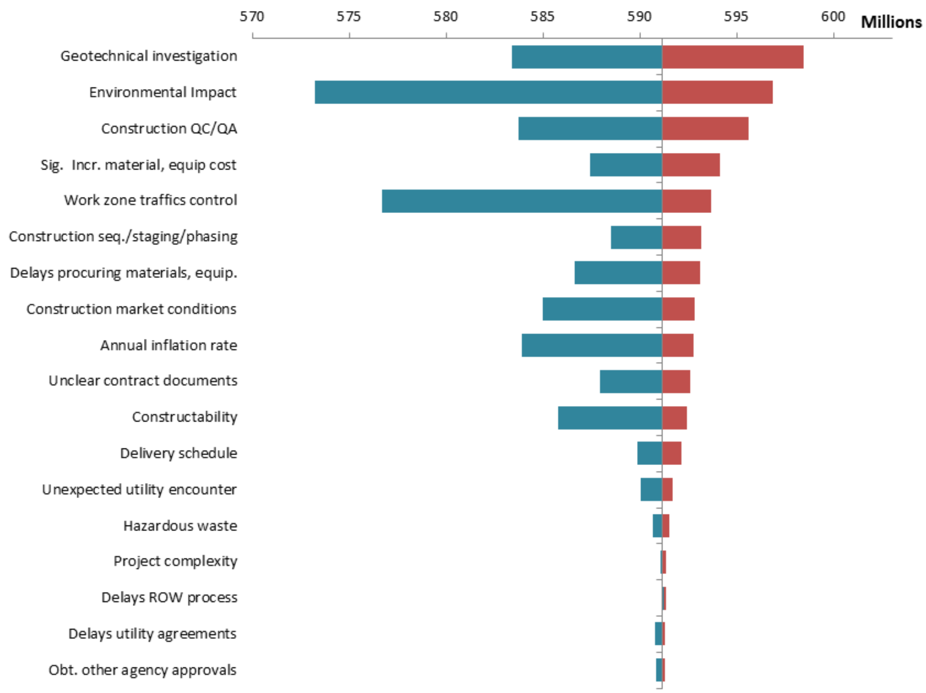


**Fig. 3b. Tornado Diagram for DBB Selection for Lake Bridges Project, Kentucky**

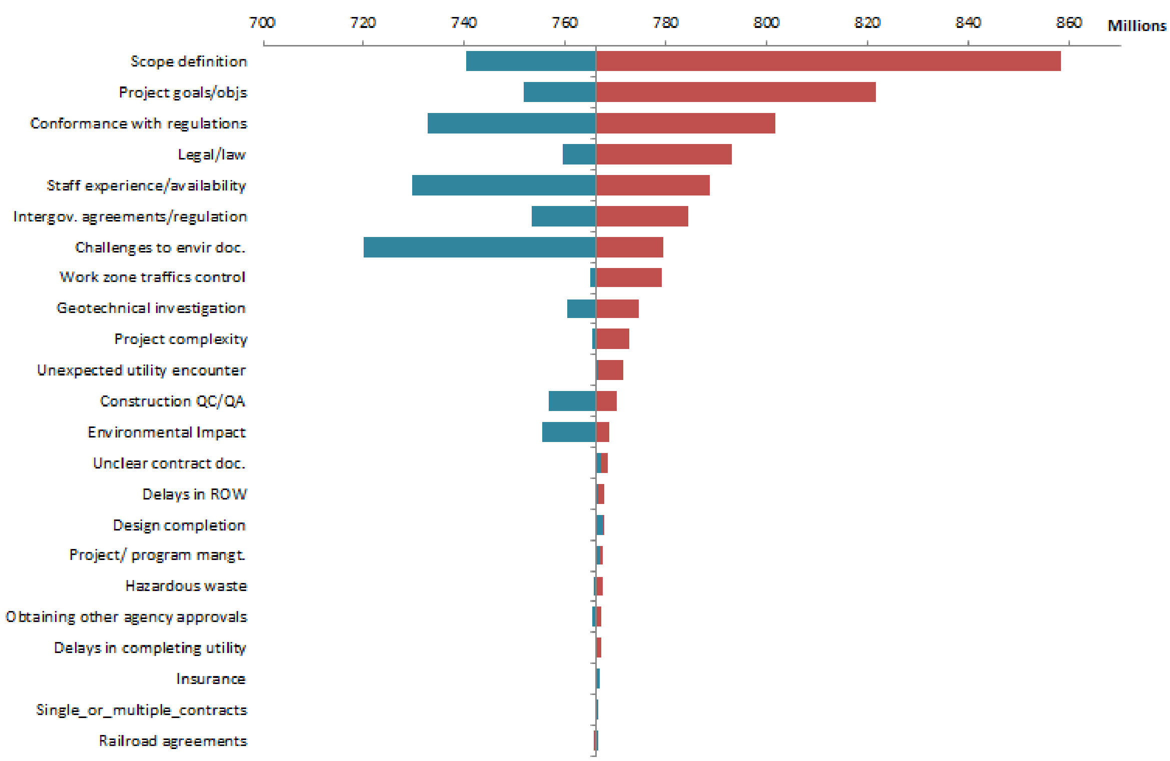


**Fig. 3c. Tornado Diagram for DB Selection for I-395 Reconstruction Project, Florida**

The sensitivity analyses from these results can provide agencies with insights into mitigation strategy that minimize the risks and maximize the project performance with each project delivery method. The variations in result correspond to varying project type, size, complexity, and risk profile of each project.

The risk-based model is considered valid because it provides consistent results with these three state DOTs and useful information relating to the variable sensitivity analysis. However, additional case studies will provide insights into which specific risks relate to specific project characteristic and project risk profiles. These insights may in turn lead to simplified selection models that require fewer inputs and less intensive simulation.

2. ***Including additional sensitivity analyses for model interaction and outcomes.*** The risk-based selection model presented in this dissertation rigorously investigated the sensitivity analysis for delivery risk factors. Nevertheless, it has not taken into account the sensitivity analyses for model interaction and model outcomes. Future research could explore the impact of sensitivity of the cross-impact relationship on the project outcomes to understand further the model behavior. For example, the decision makers could change all of the cross-impact relationships obtained from embedded data input and project participant data input into "SLI+", "MOD+", or "SIG+" to investigate the influence of strength of the cross-impact relationships on the project outcomes. Additionally, the decision makers can change initial project outcome states to better understand the model behavior by examining the change of project outcomes from the model simulation. For example, the decision makers can assume that the project outcomes

could be “high-risk type—the large standard deviation”, “normal type—the normal standard deviation” or “low-risk type—the small standard deviation” graphically illustrated in Figure 4.

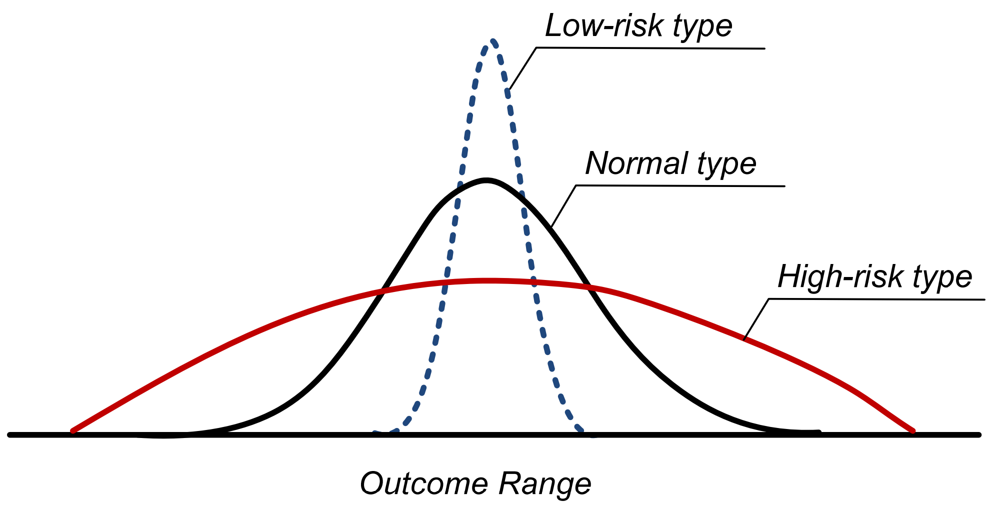


**Fig. 4. Sensitivity Analysis Results for Initial Project Outcomes**

By comparing the project outcomes from the model simulation, the decision maker could obtain more useful information relating to the impact of initial project outcomes on different project delivery methods.

3. ***Expanding the model to more explicitly include schedule risks.*** The risk-based selection model presented in this research implicitly models schedule risks through their impact on cost. It does not explicitly model project delays due to schedule uncertainty or schedule risk events. There are various techniques to model schedule risks more explicitly. These techniques include more direct and quantifiable schedule-cost relationships and/or critical path method modeling techniques. While the costs ranges from the risk-based cost estimates used for input into the model include schedule risks, the embedded data and cross-impact analysis input do

not require, and the model does not simulate, explicit schedule risks. Further model development and testing to include explicit schedule risks should be done. Analyses of these results will determine if it improves model accuracy or provides additional insights for decision makers.

4. ***Improving the understanding of the impact of risk on CMGC projects***. This study collected data from numerous relevant experts in the transportation industry, including representatives from 43 state DOTs, designers, engineers, and contractors. However, some experts mentioned that the CMGC delivery method was limited in use in their states at the time of data collection. As a result, they responded to the survey questionnaire based on their perceptions or "learning" experience on the CMGC delivery method instead of "real project" experience. While the CMGC data satisfied the statistical assumptions for the input level of the risk-based model, more data on CMGC projects will enhance the model validity and application. In the future, additional research is necessary to investigate the impact of risk on CMGC projects.

5. ***Adding procurement procedures and payment provisions.*** The research presented in this dissertation only focused on project delivery method selection. In fact, the project delivery methods, procurement procedures, and payment provisions are interconnected. Future research could investigate how the critical risk factors in each method influence the selection of an appropriate procurement procedure and payment provision. For example, based on the sensitivity analysis results from the risk-based model, we know which risks have greatest impact on the selected delivery method. It would be interesting to know whether or not these risks have a significant impact on the procurement and payment method selection.

6. ***Including other performance measurements into the model***. The risk-based model presented in this dissertation focused on project cost. The expansion to project schedule was previously discussed. Other important project performance aspects such as project quality, repair or maintenance cost, or sustainability issues could be added to the model to investigate further the benefits and drawbacks of each delivery method. The value of the output for these performance measures will need to be weighed with the complexity of the model that is needed to accurately predict their outcome.

7. ***Creating a new model for small highway projects.*** The risk-based model was designed for highway projects with costs in excess of $100 million. For highway projects in the $25-100 million range, the model may not provide accurate results. More effort is required for the data collection to evaluate delivery risk factors and model interaction. In addition, for the small highway projects, when the probabilistic cost risk analysis results are not available, the data collection for the model input is a time consuming process and could lead to confusion for the project participants who are not familiar with the probabilistic risk analysis. To overcome this limitation, simpler modes that combine risk registers and delivery risk factors for small highway projects would be useful. These models will help agencies in understanding the impact of risk and uncertainty on their small projects.

8. ***Integrating public-private partnership project delivery methods into the model***. The risk-based model presented in this paper focuses on three fundamental delivery methods in highway design and construction projects: DBB, DB, and CMGC. The model does not consider the

public-private partnership (PPP) method that has recently increased in use in the highway industry across the nation. Typically, the financial aspect is one of the main reasons to use PPP. Thus, future work may need to consider additional risk factors surrounding project finance and modify the cross-impact matrix to include PPP in the model.

9. ***Developing an interactive and practical computer tool***. Because the risk-based model relies heavily on mathematical structure and Monte Carlo simulation, it works separately from the data collection process and it is complex for state DOTs to some degree. In the future, the author will develop a computer-based model that integrates the data collection phase into the model; decision makers can freely change the input based on their risk preference and project characteristics to analyze the model output. In addition, the author will develop a friendly "spread sheet" environment model to help state DOTs more easily conduct the data collection as well as run the model and analyze the results.

10. ***Expanding the model to other sectors in the construction industry.*** Another limitation was that this study only focused on the project delivery method selection for highway design and construction projects. Future research could expand the model to other sectors in the construction industry such as buildings, water and wastewater, aviation and transit. In addition, while the risk-based model was aimed at investigating the impact of risk and uncertainty on the project delivery method selection process, the computational structure of the model can be used to deal with other types of decision making under uncertainty such as asset management, go or no-go decision for international construction projects, or international design-build/ design-build-operate-transfer projects. Additional survey questionnaires, interviews, case

studies, and modeling will be required for these studies to identify other risk variables, outcome criteria and their interactions to adapt this research to these topics.

11. ***Considering the role of risk-aversion in the model***. Although the model was constructed from a rich database and the data validity and reliability process was rigorously analyzed to eliminate unqualified data points, the model does not take into account the role of participants' risk-aversion. The importance of risk-aversion in the decision-making process has been recognized in the literature (e.g., Keeney and Raiffa 1976). Generally, risk-averse decision makers tend to overestimate possible losses and limit state probabilities. Research shows that governments and their regulatory agencies often show risk-neutral attitudes in their decisions, but for the low probability and high consequence risk events they tend to be risk-averse (Stewart at al. 2011). In this study, the project manager, program manager, engineer, designer, utility manager, and other stakeholders may have different tolerance of risk. It is beneficial to discover how the risk tolerance of each stakeholder impacts the delivery decision for highway projects. This opens many interesting research topics such as integrating utility theory or cumulative prospect theory into the risk-based model.

12. ***Applying the Bayesian network to enhance the accuracy of the model input.*** Finally, the major part of the input for the risk-based model was based on practitioners' judgments. Although data collected from experts is the typical process in construction engineering and management research, future research can employ Bayesian statistics and Bayesian networks to enhance the accuracy of the model input. A Bayesian network is a convenient graphical expression for high dimensional probability distributions representing complex relationships

between a large numbers of variables (Tran 2013). It has been employed extensively for encoding uncertain expert knowledge in areas of artificial intelligence, diagnosis, and risk management (Heckerman et al. 1995; Weber et al. 2012). There is an interrelationship between the Bayesian network and our risk-based model that sparks many interesting topics for future research. For example, the relationship between delivery risk variables can be represented by the Bayesian network to gauge the initial probabilities inputs and their interaction. Additional case studies and modeling efforts will be required for investigating this interrelationship.

## ANTICIPATED IMPACT OF THE RESEARCH

There are several areas of impact anticipated from the results of this dissertation. First of all, this research will help highway agencies document risks, costs, and benefits associated with projects delivered under DBB, DB, and CMGC. This documentation will help state DOTs determine when to use each delivery method to realize maximum benefits with regards to project type, size, and complexity. This process may help highway agencies evaluate project delivery method selection consistently from state to state. Additionally, the risks, cost, and benefit documentation plays an important role in selecting procurement procedures and payment provisions required after the project delivery selection.

Second, the risk-based model developed from this dissertation leverages the current cutting-edge risk-based cost estimating methods that have emerged in the transportation industry in the past few years. This research could provide the impetus for conducting risk analysis at the very beginning of the project development process and enhance risk management culture in state DOTs. The integration of probabilistic cost/schedule risk analysis into the project delivery method selection process will play a pivotal role to the success of highway design and construction projects. By analyzing the outcomes of the risk-based model, state DOTs will identify which risk factors are critical for each delivery method and how they influence project performance.

The third anticipated impact from this dissertation consists of a new approach to decision support in construction engineering and management. The "semi-stable cross-impact analysis" concept that builds upon the multivariate analysis results may have a significant impact on decision making problems under uncertainty in that it significantly reduces effort of knowledge acquisition required for the cross-impact matrix. In addition, the computational tools based on the cross-impact analysis techniques can be used to evaluate other project decision problems (e.g., assesses management or go/no-go decision models). The computer implementation is also attractive as a means to disseminating research results.

Finally, this dissertation gains traction in investigating the role of risk aversion in the project delivery selection model. Risk preference corresponding to different project delivery methods can be examined by using utility function or cumulative prospect theory based on various risk profiles, different decision makers' backgrounds, project characteristics and locations, etc. Using the Bayesian network to model impact of risk on delivery selection is another promising anticipated impact from this research.

## REFERENCES


Abowitz, D. A., and Toole, T. M. (2009). "Mixed method research: Fundamental issues of design, validity, and reliability in construction research." *Journal of Construction Engineering and Management*, 136(1), 108–116.

Diekmann, J. E. (1983). "Probabilistic estimating: mathematics and applications." *Journal of Construction Engineering and Management*, 109(3), 297–308.

FHWA. (2006a). Design-Build Effectiveness Study, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

Gordon, C. M. (1994). "Choosing appropriate construction contracting method." *Journal of construction engineering and management*, 120(1), 196–210.

Heckerman, D., Geiger, D., & Chickering, D. M. (1995). Learning Bayesian networks: The combination of knowledge and statistical data. *Machine learning*, *20*(3), 197-243.

Keeney, R. L., and Raiffa, H. (1976). "Decisions with multiple objectives. 1976." *John Wiley&Sons, New York.*

Mahdi, I. M., and Alreshaid, K. (2005). "Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP)." *International Journal of Project Management*, 23(7), 564–572.

Molenaar, K. R, Gransberg, D., Scott, S., Downs, D., and Ellis, R. (2008). "NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R., and Gransberg, D. D. (2001). "Design-builder selection for small highway projects." *Journal of Management in Engineering*, 17, 214

Oyetunji, A. A., and Anderson, S. D. (2006). "Relative effectiveness of project delivery and contract strategies." *Journal of Construction Engineering and Management*, 132(1), 3–13.

Shane, J., Molenaar, K., Anderson, S., and Schexnayder, C. (2009). "Construction project cost escalation factors." J. Manage. Eng., 25(4), 221–229.

Stewart, M. G., Ellingwood, B. R., and Mueller, J. (2011). "Homeland security: a case study in risk aversion for public decision-making." *International Journal of Risk Assessment and Management*, 15(5), 367–386.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). "Selection of Project Delivery Method in Transit: Drivers and Objectives." *Journal of Management in Engineering*, 27(1), 21–27

Touran, A. (1992). Risk modeling and measurement in construction. *Civil Engineering Practice*, *7*(1), 29-46.

Tran, D. (2013). "An Efficient Search Strategy for Aggregation and Discretization of Attributes of Bayesian Networks Using Minimum Description Length" *Ms Thesis*, Department of Applied Mathematics, University of Colorado, Boulder.

Weber, P., Medina-Oliva, G., Simon, C., & Iung, B. (2012). Overview on Bayesian networks applications for dependability, risk analysis and maintenance areas. *Engineering Applications of Artificial Intelligence*, 25(4), 671-682.

## INTEGRATED REFERECNES


AASHTO (2008) Design-Build Procurement Guide, *American Association of State Highway and Transportation Officials*, Washington, D.C.

Abowitz, D. A., and Toole, T. M. (2009). "Mixed method research: Fundamental issues of design, validity, and reliability in construction research." *Journal of Construction Engineering and Management*, 136(1), 108–116.

Al Khalil, M. I. (2002). "Selecting the appropriate project delivery method using AHP." *International Journal of Project Management*, 20(6), 469-474.

Alarcon L. E (1992). "Project performance modeling: a methodology for evaluating project execution strategies," *PhD dissertation*, Dept. of Civil Engineering, University of California, Berkeley.

Alarcón, L. F., and Ashley, D. B. (1996). "Modeling project performance for decision making." *Journal of Construction Engineering and Management*, 122(3), 265–273.

Alder, R. (2007). "UDOT Construction Manager General Contract (CMGC) Annual Report," Engineering Services and Bridge Design Section, *Utah Department of Transportation Project Development Group*, Salt Lake City.

Alhazmi, T., and McCaffer, R. (2000). "Project procurement system selection model." *Journal of Construction Engineering and Management*, 126(3), 176–184.

Anderson, S. D., Molenaar, K. R., and Schexnayder, C. J. (2009). "NCHRP Report 625: Procedures Guide for Right-of-Way Cost Estimation and Cost Management." *National Cooperative Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Anderson, S., Molenaar, K. R., and Schexnayder, C. (2007). "NCHRP Report 574: Guidance for Cost Estimation and Management for Highway Projects during Planning, Programming, and Preconstruction." *National Cooperative Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Associated General Contractors (2004) . *Project delivery systems for construction*, Associated General Contractors of America, Arlington, VA.

Bayraktar, M. E., & Hastak, M. (2009). A decision support system for selecting the optimal contracting strategy in highway work zone projects. *Automation in Construction*, 18(6), 834-843.

Beard, J. L., Loulakis, M. C., Wundram, E. C. (2001). *Design-Build: Planning Through Development*, McGraw-Hill, New York, NY.

Bhargava, H. K., King, A. S., and McQuay, D. S. (1995). "Decision Net: An architecture for modeling and decision support over the World Wide Web." Proc., 3rd Int. Conf. on Decision Support System, International Society for Decision Support Systems, Austin, Tex., 499–506.

Chan, C. T. W. (2007). "Fuzzy procurement selection model for construction projects." *Construction Management and Economics*, 25(6), 311-618.

Clemen, R. T. and Reilly, T. (2004). *Making hard decisions with Decision Tools Suite*, Druxbury Press, Pacific Grove, Calif.

Construction Industry Institute (2003). *Owner's Tool for Project Delivery and Contract Strategy Selection User's Guide*, Research Summary IR165-2.

Construction Industry Institute (CII 1997) "Project Delivery Systems: CM at Risk, Design-Build, Design- Bid-Build," *Research Summary RS 133*, Austin, Texas.

*Construction Project Management Handbook (2006) Federal* Transit Administration, Washington D.C.3–7.

Costello, A. B., and Osborne, J. W. (2005). "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis." *Practical Assessment, Research & Evaluation*, 10(7), 1–9.

Creedy, G. D., Skitmore, M., and Wong, J. K. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects." *Journal of Construction Engineering and Management*, 136(5), 528–537.

DBIA. (2011). Industry Research and Reports, http://www.dbia.org/pubs/research/rsmeans110606.htm (Accessed 09/09/2012)

DBIA. (2012). State Statute Report, http://www.dbia.org/NR/rdonlyres/27DEBA31-342B-4177-B6E0-AE8D9108D518/0/statestatuterpt120411.pdf (Accessed 09/10/2012)

Debella, D. C., and Ries, R. (2006). "Construction delivery systems: A comparative analysis of their performance within school districts." *Journal of construction engineering and management*, 132, 1131.

Diekmann, J. E. (1983). "Probabilistic estimating: mathematics and applications." *Journal of Construction Engineering and Management*, 109(3), 297–308.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., and Strahan, E. J. (1999). "Evaluating the use of exploratory factor analysis in psychological research." *Psychological methods*, 4(3), 272–299.

FHWA (2004). "Major Project Program Cost Estimating Guidance." http://www.fhwa.dot.gov/ipd/project_delivery/tools_programs/cost_estimating/guidance.htm (accessed July 7, 2013)

FHWA (2006a). "Guide to Risk Assessment and Allocation for Highway Construction Management", *Federal Highway Administration, U.S. Department of Transportation, American Association of State Highway Transportation Officials, and the National Cooperative Highway Research Program,* Washington, DC.

FHWA (2006b). Design-Build Effectiveness Study, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

FHWA. (2002). Design-Build Contracting: Final Rule. *Federal Register,* 67(237).

FHWA. (2009). Current Design-Build Practices for Transportation Projects, *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC.

Flyvbjerg, B., Holm, M., and Buhl, S. (2002). "Underestimating costs in public works projects: Error or lie?" J. Am. Plan. Assn., 68 (3), 279– 295.

Friedlander, M. C. (1998). "Design/build solutions." *Journal of Management in Engineering*, 14(6), 59-64.

Ghavamifar, K., and Ali Touran, F. (2009). "Owner's risks versus control in transit projects." *Journal of Management in Engineering*, 25(4), 230-233.

Ghavamifar, K., and Touran, A. (2008). "Alternative Project Delivery Systems: Applications and Legal Limits in Transportation Projects." *Journal of Professional Issues in Engineering Education and Practice*, 134, 106.

Gordon, C. M. (1994). "Choosing appropriate construction contracting method." *Journal of construction engineering and management*, 120(1), 196–210.

Gordon, T., and Hayward, H. (1968). ''Initial experiments with the cross impact method of forecasting.'' *Futures*, Guilford, England, 1(2), 100– 116.

Gransberg, D. D., and Molenaar, K. R. (2004). "Analysis of owner's design and construction quality management approaches in design/build projects." *Journal of Management in Engineering*, 20(4), 162–169.

Gransberg, D. D., K. R. Molenaar, and Datin, J. N. (2008). *NCHRP Synthesis 376: Quality Assurance in Design-Build Projects,* Transportation Research Board of the National Academies, Washington, D.C.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for design-build projects: a primer for owners, engineers, and contractors*. American Society of Civil Engineers. Reston, VA.

Gransberg, D. D., Koch, J. A., and Molenaar, K. R. (2006). *Preparing for Design-Build Projects: a Primer for Owners, Engineers, and Contractors*. American Society of Civil Engineers. Reston, VA.

Gransberg, D., and Shane, J. (2010). "NCHRP Synthesis of Highway Practice 402: Construction Manager-at-Risk Project Delivery for Highway Programs." *Transportation Research Board of the National Academies, Washington, DC*.

Gurry, W. W., and Smith, R. J. (1995). "Allocation of Risk in Design/Build Project." *Proceedings of the 1995 Construction Congress*, San Diego, CA.

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2009). *Multivariate Data Analysis*. Prentice Hall.

Hale, D. R., Shrestha, P. P., Gibson Jr, G. E., Migliaccio, G. C. (2009). "Empirical comparison of design/build and design/bid/build project delivery methods." *Journal of Construction Engineering and Management*, 135, 579.

Han, S. H., and Diekmann, J. E. (2001). ''Approaches for making risk-based Go/No-Go decision for international projects.'' *J. Constr. Eng. Manage.*, 127(4), 300–308.

Hastak, M. (1994). "Decision support system for project cost control strategy and planning." Ph.D. thesis, Purdue Univ., West Lafayette, Ind.

Heckerman, D., Geiger, D., & Chickering, D. M. (1995). Learning Bayesian networks: The combination of knowledge and statistical data. *Machine learning*, *20*(3), 197-243.

Higbee, J. B. (2002). "Geotechnical issues with large design-build highway projects." *Transportation Research Record: Journal of the Transportation Research Board*, 1808(1), 144–152.

Honton, E.J., Stacey, G.S. and Millet, S.M. (1985) *Future Scenarios: The BASICS Computational Method*, Battelle Technical, Columbus, OH

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). "Project delivery systems and project change: Quantitative analysis." *Journal of Construction Engineering and Management*, 129(4), 382-387.

Kaiser, H. F. (1958). "The varimax criterion for analysis rotation in factor analysis." *Psychometrika*, 23, 187–200.

Keeney, R. L., and Raiffa, H. (1976). "Decisions with multiple objectives. 1976." *John Wiley&Sons, New York*.

Kim, J. O., and Mueller, C. W. (1978). *Factor analysis: Statistical methods and practical issues*. Sage Publications, Inc.

Kim, K. J., Kreider, C. A., and Valiquette, M. D. (2009). "North Carolina Department of Transportation's Practice and Experience with Design-Build Contracts." *Transportation Research Record: Journal of the Transportation Research Board*, 2116(-1), 47–52.

Knapp, T. R. (1990). "Treating ordinal scales as interval scales: an attempt to resolve the controversy." *Nursing Research*, 39(2), 121–123.

Konchar, M., and Sanvido, V. (1998). "Comparison of US project delivery systems." *Journal of Construction Engineering and Management*, 124(6), 435–444.

Kumaraswamy, M. and Dissanayaka, S. (2001). "Developing a decision support system for building project procurement." *Building and Environment*, 36(3), 337-349.

Lam, E. W. M., Chan, A. P. C., Chan, D. W. M., and others. (2008). "Determinants of successful design-build projects." *Journal of Construction Engineering and management*, 134, 333.

Love, P. E .D. Edwards, D. J., Irani, Z., and Sharif, A. (2012). Participatory action research approach to public sector procurement selection. *ASCE Journal of Construction Engineering and Management*, Vol.138, No.3, 2012, pp. 311–22

Love, P. E. ., Skitmore, M., and Earl, G. (1998). "Selecting a suitable procurement method for a building project." *Construction Management & Economics*, 16(2), 221–233.

Luu, D. T., Ng, S. T., and Chen, S. E. (2003). "Parameters governing the selection of procurement system–an empirical survey." *Engineering, Construction and Architectural Management*, 10(3), 209–218.

Luu, D. T., Ng, S. T., Chen, S. E. and Jefferies, M. (2006). "A Strategy for evaluating a fuzzy case-based construction procurement selection system." *Advances in Engineering Software*, 37, 159-171.

Mahdi, I. M., and Alreshaid, K. (2005). "Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP)." *International Journal of Project Management*, 23(7), 564–572.

Migliaccio, G., Gibson, G., O'Connor, J., and others. (2009). "Procurement of Design-Build Services: Two-Phase Selection for Highway Projects." *Journal of Management in Engineering*, 25, 29.

Miller, J. B., Garvin, M. J., Ibbs, C. W., and Mahoney, S. E. (2000). "Toward a new paradigm: Simultaneous use of multiple project delivery methods." *Journal of Management in Engineering*, 16(3), 58–67.

Mitchell (1977) Scenario Generation limitation and development in CIA, *Futures*, Guilford, England

Molenaar, K. R, Gransberg, D., Scott, S., Downs, D., and Ellis, R. (2008). "NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R. (2005). "Programmatic cost risk analysis for highway megaprojects." *Journal of Construction Engineering and Management*, 131(3), 343–353.

Molenaar, K. R. and Songer, A. D. (1998). "Model for public sector design-build project selection", *Journal of Construction Engineering and Management*, 124(6), 467-479.

Molenaar, K. R., and Gransberg, D. D. (2001). "Design-builder selection for small highway projects." *Journal of Management in Engineering*, 17, 214

Molenaar, K. R., Anderson S., and Schexnayder, C. (2010). "NCHRP Report 658: Guidebook on risk analysis tools and management practices to control transportation project costs." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R., Gransberg, D., Scott, S., Downs, D., and Ellis, R. (2008). "NCHRP 20-7/Task 172: Recommended AASHTO Design-Build Procurement Guide." *Transportation Research Board of the National Academies, Washington, DC.*

Molenaar, K. R., Songer, A. D., and Barash, M. (1999). "Public-sector design/build evolution and performance." *Journal of Management in Engineering*, 15(2), 54-62.

Ng, S. T., Luu, D. T., Chen, S. E. and Lam K. C. (2002). "Fuzzy membership functions of procurement selection criteria." *Construction Management and Economics*, 20, 285–296

O'Connor, J. T., Gibson, G. E., Jr., Migliaccio, G. C., and Shrestha, P. P. (2006). "Organizational structures and communications on the SH 130 project." *Center for Transportation Research*, Univ. of Texas at Austin, Austin, Tex.

Osipova, E., and Eriksson, P. E. (2011). "How procurement options influence risk management in construction projects." *Construction Management and Economics*, 29(11), 1149–1158.

Oyetunji, A. A., and Anderson, S. D. (2006). "Relative effectiveness of project delivery and contract strategies." *Journal of Construction Engineering and Management*, 132(1), 3–13.

Parsons, Touran, A., and Golder Assoc. (2004). "Risk Analysis Methodologies and Procedures," *Federal Transit Administration*.

Platje, A., and Seidel, H. (1993). "Breakthrough in Multiproject Management: How to Escape the Vicious Circle of Planning and Control." *International Journal of Project Management*, 11(4), 209–213.

Roberds, B., McGrath, T., Molenaar, K.R., Loulakis, M., and Ferragut, T. (2010). "NCHRP-SHRP Project R-09: Guide for the Process of Managing Risk on Rapid Renewal Projects" *Strategic Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Rojas, E. M., and Kell, I. (2008). "Comparative analysis of project delivery systems cost performance in Pacific Northwest public schools." *Journal of Construction Engineering and Management*, 134, 387.

Rubin, R., and Wordes, D. (1998). "Risky business." *Journal of Management in Engineering*, 14 (6), 36–43.

Rwelamila, P. D., and Meyer, C. (1999). "Appropriate or default project procurement systems?" *Cost Engineering*, 41(9), 40–44.

Sargent, R. G. (2012). "Verification and validation of simulation models." *Journal of Simulation*, 7(1), 12–24.

Shane, J., Molenaar, K., Anderson, S., and Schexnayder, C. (2009). "Construction project cost escalation factors." J. Manage. Eng., 25(4), 221–229.

Shrestha, P. P., Migliaccio, G. C., O'Connor, J. T., and Gibson, G. E. (2007). "Benchmarking of Large Design-Build Highway Projects: One-to-One Comparison and Comparison with Design-Bid-Build Projects." *Transportation Research Record: Journal of the Transportation Research Board*, 1994(-1), 17–25.

Shrestha, P. P., O'Connor, J. T., and Gibson Jr, G. E. (2012). "Performance Comparison of Large Design-Build and Design-Bid-Build Highway Projects." *Journal of Construction Engineering and Management*, 138, 1.

Skitmore, R. M. and Marsden, D. E. (1988). "Which procurement system? Towards a universal procurement selection technique." *Construction Management and Economics*, 6, 71-89.

Songer, A. D., and Molenaar, K. R. (1996). "Selecting design-build: public and private sector owner attitudes." *Journal of Management in Engineering*, 12(6), 47–53.

Stewart, M. G., Ellingwood, B. R., and Mueller, J. (2011). "Homeland security: a case study in risk aversion for public decision-making." *International Journal of Risk Assessment and Management*, 15(5), 367–386.

Stewart, M. G., Ellingwood, B. R., and Mueller, J. (2011). "Homeland security: a case study in risk aversion for public decision-making." *International Journal of Risk Assessment and Management*, 15(5), 367–386.

Touran, A. (1992). Risk modeling and measurement in construction. *Civil Engineering Practice*, *7*(1), 29-46.

Touran, A., Gransberg, D. D., Molenaar, K. R., and Ghavamifar, K. (2011). "Selection of Project Delivery Method in Transit: Drivers and Objectives." *Journal of Management in Engineering*, 27(1), 21–27.

Tran, D., and Molenaar, K. (2012). "Critical Risk Factors in Project Delivery Method Selection for Highway Projects." American Society of Civil Engineers, Construction Research Congress 331–340.

Tran, D., and Molenaar, K. (2013). "The Impact of Risk on Design-Build Selection for Highway Design and Construction Projects." *Journal of Management in Engineering*.

Tran, D., Harper, C. M., Molenaar, K. R., Haddad, N. F., & Scholfield, M. M. (2013). A Project Delivery Selection Matrix for Highway Design and Construction. *Journal of Transportation Research Board.*

Warne, T. R. _2005_. *Design build contracting for highway projects: A performance assessment*, Tom Warne & Associates, LLC.

Weber, P., Medina-Oliva, G., Simon, C., & Iung, B. (2012). Overview on Bayesian networks applications for dependability, risk analysis and maintenance areas. *Engineering Applications of Artificial Intelligence*, 25(4), 671-682.

Wood, H. P., Kassoff, H., McGrath, T., Malley, W. G., Rose, D. C., and Skinner, N. (2011). “NCHRP 20-24/Task 71: Guide for Managing NEPA-Related and Other Risks in Project Delivery.” *Transportation Research Board of the National Academies, Washington, DC*.

Yates, J. (1995). “Use of design/build in E/C industry.” *Journal of Management in Engineering*, 11(6), 33–38.

Weber, P., Medina-Oliva, G., Simon, C., & Iung, B. (2012). Overview on Bayesian networks applications for dependability, risk analysis and maintenance areas. *Engineering Applications of Artificial Intelligence*, 25(4), 671-682.

## APPENDIX I: DEFINITIONS OF DELIVERY RISK FACTORS

| Risk | Risk Title | Description |
|---|---|---|
| 1 | Challenges to appropriate environmental documentation | The risk involves a change in environmental regulations, unforeseen formal National Environmental Policy Act (NEPA) consultation, an insufficient environmental study, or required environmental clearance. |
| 2 | Environmental impacts | Project may encroach into historic site, endangered species, wetland, coastal and scenic zone, wildlife, or the risk involves unexpected environmental constraints during planning and construction. |
| 3 | Uncertainty in geotechnical investigation | This risk may include unforeseen ground conditions, inappropriate design, contamination, ground water, settlement, chemically reactive ground, incomplete survey, and inadequate geotechnical investigation. |
| 4 | Work zone traffics control | The risk relates to unforeseen construction window because of problems with maintenance of traffic, unexpected plans and detours, and/or rainy season requirements. |
| 5 | Unexpected utility encounter | Required relocations of certain utilities are unknown; the risk relates to unforeseen conditions (e.g., seasonal requirements during utility relocation, utility company workload, financial condition or timeline). |
| 6 | Delays in completing utility agreements | The challenge in obtaining utility agreements is due to disagreement over responsibility to move, over cost-sharing or inadequate pool of qualified appraisers. |
| 7 | Delays in right-of-way (ROW) process | The delay of construction is due to the large number of parcels and businesses, acquisition of ROW required. |
| 8 | Delays in completing in railroad agreements | Because of the complex nature of the railroad involvement, obtaining railroad agreement may take longer time. |
| 9 | Third-party delay during construction | The risk involves a delay in the construction phase because of unforeseen third-party issues (e.g., railroad conflict, utility conflict, or work-window restrictions). |
| 10 | Difficulty in obtaining other agency approvals | The risk relates to new permits, new information required for permits, delays in agreements from Federal, State, or local agencies. |
| 11 | Defined and non-defined hazardous waste | The risk involves an incomplete analysis of hazardous waste site due to unexpected environmental constraints or unanticipated issues. |
| 12 | Project complexity | The risk relates to complex structures, unexpected ground conditions, environmental issues, unforeseen design and technical issues, and challenges in level of interaction between stakeholders |

| | | |
|---|---|---|
| 13 | Scope definition | The risk of an incomplete scope definition leads to new or revised designs, added workload or time, rework and change orders (scope creep.) |
| 14 | Project goals/objectives | Project goals and objectives (schedule, cost, and deliverables) are not well-defined or understood. |
| 15 | Project funding | The risk of funding delay or shortfall may could significantly impact project goals and objectives. |
| 16 | Staff experience/availability | This risk relates mainly to the level of experience and availability of staff in application of various delivery methods. |
| 17 | Project and program management issues | The risk involves a lack of understanding of complex internal procedures or functional units not available or overloaded. |
| 18 | Constructability in design | The risk relates to unresolved constructability items, complex project features, and unforeseen construction windows. |
| 19 | Problems with material quality and availability | The lack of material availability and quality results in delays in schedule and increasing project cost. |
| 20 | Delays in procuring critical materials, labor, and specialized equipment | The delay in procuring materials, labors, and equipment is due to unexpected constraints, unforeseen requirements, and complex structure. |
| 21 | Significant increase in material, labor, equipment cost | The risk involves market forces, unanticipated escalation in material, labor, and equipment costs. |
| 22 | Conformance with regulations/guidelines/design criteria | The risk relates to difficulties in conforming to guidelines, design criteria, and regulations (e.g., new or revised design standard, consultant design not up to department standards, and unforeseen design exceptions required) |
| 23 | Intergovernmental agreements and jurisdiction | The risk relates to intergovernmental agreement between the agency and other agencies (e.g., political factors, local community objections) |
| 24 | Legal challenges and changes in law | This risk involves a threat of lawsuits due to new permits or additional information required. |
| 25 | Community relationship issues | Unexpected issues with the community relationship cause a risk to project management and project delivery. |
| 26 | Unclear contract documents | The risk involves the ambiguities in the contract documents (e.g., incentive payment clauses, impact of long lead items, changes during construction). |
| 27 | Single or multiple contracts | This risk relates to difficulties in multiple contractor interfaces (e.g., lack of coordination/communication). |
| 28 | Insurance in contract | The risk relates to uncertainty in the availability of insurance coverage under which contractors accepts significant insurance risk from agencies. |
| 29 | Annual inflation rates | The risk involves a change in value due to deviation of the actual market consistent value and/or liabilities from the expected value due to inflation. |
| 30 | Construction market conditions | The risk relates to construction market changing (e.g., bid prices on similar work components on other projects varying considerably.) |

| | | |
|---|---|---|
| 31 | Issues related to strikes/labor disputes | Strikes, disputes, or unforeseen labor issues directly result in project schedule delays and adding additional cost. |
| 32 | Delays in delivery schedule | The risk involves uncertainty in the overall project delivery schedule (pressure to deliver project on an accelerated schedule, underestimated support resources, or overly optimistic delivery schedule.) |
| 33 | Construction sequencing/staging/phasing | The risk relates to insufficient or limited construction or staging areas, unforeseen construction window, or rainy season requirements. |
| 34 | Construction QC/QA process | This risk relates to the impact project objectives due to continued evaluation and assessments of the activities of construction. |
| 35 | Design QC and QA | This risk involves the project objectives due to continued evaluation and assessments of the activities of development of plans, design and specifications, advertising and awarding of contract. |
| 36 | Design errors and omissions | The risk relates to errors in plans, specifications, and estimates in the design phase and causes negative outcomes to project cost and schedule. |
| 37 | Changes in design standards/criteria | The risk involves flexibility within the design criteria to achieve a balanced design (cost, safety, mobility, social and environmental impacts, and the needs of the project). |
| 38 | Design exceptions | The risk relates to the need for considering design exceptions (e.g., unforeseen encounter situations to obtain the appropriate design solution). |
| 39 | Design completion | This risk relates to inaccurate assumptions on technical issues, unforeseen design exception, incomplete quantity estimates at the level of design completion. |

## APPENDIX II: SURVEY QUESTIONNAIRES

You have been personally selected to participate in a study to develop a risk-based project delivery selection approach for transportation projects. The goal of this questionnaire is to establish a list of critical risk factors in the project delivery method selection process. This questionnaire asks you to rate the significance of a variety of risk factors on the selection of a project delivery method. These risk factors have been identified through previous research on more than $10 billion dollars of transportation projects.

Thank you for your time and your thoughts in filling out this questionnaire. Your response is vital to the success of this study, and we would very much appreciate your efforts. The questionnaire should take only 20-30 minutes to complete. Your individual privacy will be maintained in all published and written data resulting from this study. Preliminary results of the aggregate responses are available immediately upon completion of this survey.

### General Information: Past Project Experience

Please share your professional experience and background information in the following questions. Your individual privacy and the name of your company will not be published in any of the results. Your response will be completely confidential.

1. What best describes the type of organization for which you work:

   ❍ Public owner agency
   ❍ Private owner agency
   ❍ Design-build firm
   ❍ General contractor
   ❍ Engineering/Design firm
   ❍ Specialty contractor firm
   ❍ Other, please specify

   ______________________________________________

2. Please provide your job title or describe your professional position:

   ______________________________________________

3. How many years of professional experience in the transportation sector approximately do you have?

   ______________________________________________

4. Please complete the following information (Note: we are collecting names only to avoid duplication when aggregating results):
   - First Name: ______________________
   - Last Name: ______________________
   - Organization: ______________________

5. Please provide your email address if you would like to be contacted with the results of this effort or if you are willing to be available for additional questions.

- ❑ Please do not contact me with the results
- ❑ I am available for additional questions
- ❑ Email address (if available for questions):

______________________________________________

## Impact of Risk Factors on the Selection of Project Delivery Methods

Please use the following scale to rate the significance of each risk factor on the selection of a project delivery method. In addition, please feel free to give comments on your choice.

1 = Not Applicable (N/A)
2 = Very Low Impact
3 = Low Impact
4 = Moderate Impact
5 = High Impact
6 = Very High Impact

6. Please rate the impact of risk caused by *challenge to appropriate environmental documentation* (e.g., Distributed computing environment (DCE) vs. Environmental assessment (EA) vs. Environmental impact statement (EIS)) and all the related consequential events (e.g., change in design, scope, and construction costs) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

7. Please rate the impact of risk caused by *geotechnical investigation* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

8. Please rate the impact of risk caused by *the use of single vs. multiple contracts* (e.g., difficulties in multiple contractor interfaces) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

9. Please rate the impact of risk caused by *challenge to project funding* (e.g., funding delay, funding shortfall) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

10. Please rate the impact of risk caused by *the uncertain annual inflation rate* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

11. Please rate the impact of risk caused by *difficulty in conformance with regulations/guidelines/documentation* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

12. Please rate the impact of risk caused by *design errors and omissions* (e.g., errors in plans/specs/estimates) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

13. Please rate the impact of risk caused by *challenge to material quality and availability* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

14. Please rate the impact of risk caused by *project and program management issues* (e.g., workload management, executive oversight) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

15. Please rate the impact of risk caused by *delays in right-of-way (ROW*) – uncertainty in the time required for ROW plan development and approval process for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

16. Please rate the impact of risk caused by *challenge to defined and non-defined hazardous waste* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

17. Please rate the impact of risk caused by issues related to *constructability of designs* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

18. Please rate the impact of risk caused by *challenge to delivery schedule* – uncertainty in the overall project delivery schedule from scoping through design, construction, and opening to the public for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

19. Please rate the impact of risk caused by *unexpected utility encounter* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

20. Please rate the impact of risk caused by *insurance* - uncertainty in the availability of insurance coverage for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

21. Please rate the impact of risk caused by *challenge to staff experience and availability* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Design-Build**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| **Construction Manager/General Contractor**<br>Please give reasons for your choice: | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |

22. Please rate the impact of risk caused by *delays in completing utility agreements* (e.g., delay due to disagreement over responsibility to move, over cost-sharing) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

23. Please rate the impact of risk caused by *challenge to community relations* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

24. Please rate the impact of risk caused by *difficulty in work zone traffic control* (e.g., problems with maintenance of traffic, issues related to proposed plans, detour) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

25. Please rate the impact of risk caused by *challenge to railroad agreements* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

26. Please rate the impact of risk caused by difficulty in *obtaining other agency approvals* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

27. Please rate the impact of risk caused by *uncertainty in material, labor, equipment costs* beyond what is included in inflation rates for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

28. Please rate the impact of risk caused by *third-party delay during construction* (e.g., railroad conflict, utility conflicts, and work-window restrictions) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

29. Please rate the impact of risk caused by problems with *construction Quality Control/Quality Assurance (QC/QA)* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

30. Please rate the impact of risk caused by uncertainty in *scope definition* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

31. Please rate the impact of risk caused *by unclear contract document* – ambiguities in the contract documents for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

32. Please rate the impact of risk caused by problems with *design exceptions* –the need for design exceptions to federal/state/local regulations for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

33. Please rate the impact of risk caused by *delays in in procuring critical materials, labor, and specialized equipment* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

34. Please rate the impact of risk caused by *unclear project definition* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

35. Please rate the impact of risk caused by *challenges to environmental impact* (uncertain wetland mitigation, meandering, and connectivity) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

36. Please rate the impact of risk caused by *changes in design standards/criteria* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

37. Please rate the impact of risk caused by *legal challenges and changes in law* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

38. Please rate the impact of risk caused by *problems with design Quality Control/Quality Assurance (QC/QA) process* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

39. Please rate the impact of risk caused by *design completion issues* - uncertainty in the level of design completion at the time of the project delivery selection for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

40. Please rate the impact of risk caused by *uncertainty in planned construction sequencing/staging/phasing* for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

41. Please rate the impact of risk caused by *challenge to intergovernmental agreement and regulation* – uncertainty in coordinating with related government agencies and jurisdiction for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

42. Please rate the impact of risk caused by problems with *construction market conditions* (e.g., availability of contractor, pricing strategies of contractors) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

43. Please rate the impact of risk caused by *strikes/labor disputes* (e.g., labor issues, contract negotiation) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

44. Please rate the impact of risk caused by *challenge to project complexity* (e.g., the level of interaction between people, technical issues, and process) for each delivery method.

| | N/A | Very Low Impact | Low | Moderate | High | Very High Impact |
|---|---|---|---|---|---|---|
| **Design-Bid-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Design-Build** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |
| **Construction Manager/General Contractor** | ❍ 1 | ❍ 2 | ❍ 3 | ❍ 4 | ❍ 5 | ❍ 6 |
| Please give reasons for your choice: | | | | | | |

# APPENDIX III:  PROJECT CASE STUDIES

This Appendix presents the results of the data collection of three highway projects: the I-35 Reconstruction Project in Florida, the Rt. 295 and 42/ I-76 Project in New Jersey, and the Lake Bridges Project in Kentucky for the model testing process. Seven experts were participated in the risk-based delivery workshop for Florida project; six for New Jersey project, and seven for Kentucky project.  The workshop experts included the project manager, program manager, engineer, designer, utility manager, and an FHWA representative. The results of these three workshops briefly summarize below.

## 1. The I-35 Reconstruction Project in Florida

### 1.1 Project Information

The Florida DOT initiated a Project Development and Environment (PD&E) Study in 2004 to determine and document the feasibility of improving the geometric, operational and safety deficiencies of the I-395 corridor. The PD&E study was completed with the approval of the Record of Decision (ROD) from the FHWA in 2010. The Interstate 395 project involves the rebuilding of the I-395 corridor from its terminus at the west of the I-95/Midtown Interchange (I-95/State Road 836/I-395) to its corridor terminus at the West Channel Bridges of US 41/MacArthur Causeway, approximately 1.4 miles. I-395 is an interstate principal arterial and major east-west connector serving Miami Beach and the nearby ports.  The project cost estimate at the 70% of confidence level is $835 million in year of expenditure. The anticipated completion date is October 2021.  The major work on this project includes: (1) building new elevated ramps (one eastbound and one westbound) that will provide direct linkage between I-95 and I-395; (2) improving roadway design including updating the alignment and upgrading the roadway surface; (3) creating a visually appealing bridge; and (4) building vertically higher structures that will improve the visual quality of the bridge.

## 1.2 Estimating Initial Probability for Risk Variables

| Risk ID | Risk Title | Risk's Status | | Initial Probability | Notes |
|---|---|---|---|---|---|
| | | Status | Name | | |
| 1 | Risks caused by challenges to appropriate environmental documentation | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |
| | | SUM | | 1.00 | |
| 2 | Risks caused by environmental impacts | 1 | High | 0.10 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.75 | |
| | | SUM | | 1.00 | |
| 3 | Risks caused by uncertainty in geotechnical investigation | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | SUM | | 1.00 | |
| 4 | Risks caused by work zone traffics control | 1 | High | 0.75 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.10 | |
| | | SUM | | 1.00 | |
| 5 | Risks caused by unexpected utility encounter | 1 | High | 0.80 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.05 | |
| | | SUM | | 1.00 | |
| 6 | Risks caused by delays in completing utility agreements | 1 | High | 0.60 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.10 | |
| | | SUM | | 1.00 | |
| 7 | Risks caused by delays in right-of-way (ROW) process | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | SUM | | 1.00 | |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Risks caused by delays in completing in railroad agreements | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 9 | Risks caused by difficulty in obtaining other agency approvals | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 10 | Risks caused by defined and non-defined hazardous waste | 1 | High | 0.70 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 11 | Risks caused by project complexity | 1 | High | 0.80 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.05 | |
| | | **SUM** | | 1.00 | |
| 12 | Risks caused by scope definition | 1 | High | 0.75 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 13 | Risks caused by project definition | 1 | High | 0.75 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 14 | Risks caused by staff experience/availability | 1 | High | 0.20 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 15 | Risks caused by project and program management issues | 1 | High | 0.20 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 16 | Risks caused by constructability in design | 1 | High | 0.60 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 17 | Risks caused by delays in procuring critical materials, labor, and specialized equipment | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |

| | | | | | |
|---|---|---|---|---|---|
| 18 | Risks caused by significant increase in material, labor, equipment cost | 1 | High | 0.30 | |
| | | 2 | Medium | 0.60 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 19 | Risks caused by conformance with regulations/guidelines/design criteria | 1 | High | 0.20 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.30 | |
| | | **SUM** | | 1.00 | |
| 20 | Risks caused by intergovernmental agreements and jurisdiction | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 21 | Risks caused by legal challenges and changes in law | 1 | High | 0.70 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 22 | Risks caused by unclear contract documents | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 23 | Risks caused by single or multiple contracts | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 24 | Risks caused by insurance in contract | 1 | High | 0.20 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.30 | |
| | | **SUM** | | 1.00 | |
| 25 | Risks caused by annual inflation rates | 1 | High | 0.20 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.50 | |
| | | **SUM** | | 1.00 | |
| 26 | Risks caused by construction market conditions | 1 | High | 0.30 | |
| | | 2 | Medium | 0.60 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 27 | Risks caused by delays in delivery schedule | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |

| | | | | | |
|---|---|---|---|---|---|
| 28 | Risks caused by construction sequencing/staging/phasing | 1 | High | 0.20 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.30 | |
| | | **SUM** | | 1.00 | |
| 29 | Risks caused by construction QC/QA process | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 30 | Risks caused by design QC and QA | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 31 | Risks caused by design completion | 1 | High | 0.20 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.50 | |
| | | **SUM** | | 1.00 | |

## 1.3 Estimating Initial Probability for Project Outcomes

| **Project Outcome** | **States** | **Values ($ million)** | **Initial Prob.** |
|---|---|---|---|
| Project Cost | Very Low | $ 632.2 | 10% |
| | Low | $ 723.8 | 20% |
| | Average | $ 792.4 | 40% |
| | High | $ 863.2 | 20% |
| | Very High | $ 978.1 | 10% |

## 1.4 Estimating Cross-Impact Relationships

| For DBB delivery method | Construction Risk | Schedule Risk | Third-party Risk | Constructability Risk | Market Risk | Complexity Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | SIG+ | MOD+ | MOD+ | SIG+ | MOD+ |
| Schedule Risk | MOD+ | | MOD+ | NO | MOD+ | SIG+ |
| Third-party Risk | SLI+ | MOD+ | | NO | SLI+ | MOD+ |
| Constructability Risk | MOD+ | MOD+ | NO | | NO | SIG+ |
| Market Risk | NO | SLI+ | NO | NO | | MOD+ |
| Complexity Risk | SLI+ | MOD+ | SLI+ | SIG+ | NO | |
| **Project Cost** | MOD+ | MOD+ | SLI+ | SLI+ | SIG+ | SIG+ |

| For DB delivery method | Scope Risk | Third-party Risk | Construction Risk | Complexity Risk | Management Risk | Regulation Risk | Level of Design Risk |
|---|---|---|---|---|---|---|---|
| Scope Risk | | SIG+ | MOD+ | SIG+ | SLI+ | MOD+ | SLI+ |
| Third-party Risk | MOD+ | | SLI+ | SIG+ | SLI+ | MOD+ | NO |
| Construction Risk | MOD+ | SIG+ | | MOD+ | MOD+ | SLI+ | SLI+ |
| Complexity Risk | MOD+ | NO | MOD+ | | MOD+ | SLI+ | NO |
| Management Risk | MOD+ | SIG+ | SLI+ | MOD+ | | MOD+ | NO |
| Regulation Risk | MOD+ | MOD+ | SLI+ | MOD+ | SLI+ | | SLI+ |
| Level of Design Risk | MOD+ | SLI+ | SLI+ | SIG+ | SLI+ | SLI+ | |
| **Project Cost** | MOD+ | SLI+ | SIG+ | MOD+ | SLI+ | MOD+ | NO |

| For CMGC delivery method | Construction Risk | Constructability Risk | Regulation Risk | Complexity Risk | Third-party Risk | Management Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | MOD+ | MOD+ | SIG+ | SLI+ | MOD+ |
| Constructability Risk | NO | | SLI+ | SIG+ | SLI+ | MOD+ |
| Regulation Risk | SLI+ | SLI+ | | SLI+ | MOD+ | SLI+ |
| Complexity Risk | MOD+ | MOD+ | MOD+ | | MOD+ | SLI+ |
| Third-party Risk | SLI+ | SLI+ | MOD+ | SLI+ | | MOD+ |
| Management Risk | MOD+ | MOD+ | MOD+ | MOD+ | MOD+ | |
| **Project Cost** | SLI+ | SLI+ | MOD+ | SIG+ | SLI+ | MOD+ |

## 2. The Rt. 295 and 42/ I-76 Direct Connection Project in New Jersey

### 2.1 Project Information

The Rt. 295 and 42/I-76 Direct Connection Project was initiated due to the large volumes of traffic utilizing the Interchange, high accident rates, and through-traffic weaving movements. The main purpose of this project is to relieve the bottleneck at the Interchange by constructing a direct connection on I-295 and other highway improvements that will reduce congestion and enhance traffic operations and safety throughout the project area. These improvements include a six lane mainline which continues through the Interchange, elimination of dangerous merging and weaving movements, upgrades to ramp geometry and the addition of shoulders throughout the Interchange. The planned improvements include 12 new or reconstructed bridges, 1 culvert extension, 1 boat section, 21 retaining walls and 11 noise walls. The boundary of this project includes southerly on I-295 to Creek Road, northerly on I-295 to Route 168, southerly on Route 42 to Leaf Avenue and northerly on I-76 to Route 130. The project also includes improvements to several local streets, including Browning Road, Bell Road and Creek Road. In addition, an Intelligent Transportation System (ITS) Contract will add a number of ITS devices on the four approaches to the interchange and add Adaptive Signal Control to the Route 130 and Route 168 corridors. The estimate at the 70% confidence level is $873 million in year of expenditure. The overall project completion is estimated in November 2021.

### 2.2 Estimating Initial Probability for Risk Variables

| Risk ID | Risk Title | Risk's Status | | Initial Probability | Notes |
|---|---|---|---|---|---|
| | | Status | Name | | |
| 1 | Risks caused by challenges to appropriate environmental documentation | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |

| | | | | | |
|---|---|---|---|---|---|
| | | SUM | | 1.00 | |
| 2 | Risks caused by environmental impacts | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | SUM | | 1.00 | |
| 3 | Risks caused by uncertainty in geotechnical investigation | 1 | High | 0.60 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.10 | |
| | | SUM | | 1.00 | |
| 4 | Risks caused by work zone traffics control | 1 | High | 0.80 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.05 | |
| | | SUM | | 1.00 | |
| 5 | Risks caused by unexpected utility encounter | 1 | High | 0.20 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.30 | |
| | | SUM | | 1.00 | |
| 6 | Risks caused by delays in completing utility agreements | 1 | High | 0.10 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.60 | |
| | | SUM | | 1.00 | |
| 7 | Risks caused by delays in right-of-way (ROW) process | 1 | High | 0.70 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.10 | |
| | | SUM | | 1.00 | |
| 8 | Risks caused by delays in completing in railroad agreements | 1 | High | 0.00 | |
| | | 2 | Medium | 0.00 | |
| | | 3 | Low | 1.00 | |
| | | SUM | | 1.00 | |
| 9 | Risks caused by difficulty in obtaining other agency approvals | 1 | High | 0.25 | |
| | | 2 | Medium | 0.25 | |
| | | 3 | Low | 0.50 | |
| | | SUM | | 1.00 | |
| 10 | Risks caused by defined and non-defined hazardous waste | 1 | High | 0.20 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.50 | |
| | | SUM | | 1.00 | |
| 11 | Risks caused by project complexity | 1 | High | 0.50 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.20 | |
| | | SUM | | 1.00 | |

| | | | | | |
|---|---|---|---|---|---|
| 12 | Risks caused by scope definition | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 13 | Risks caused by project definition | 1 | High | 0.05 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.85 | |
| | | **SUM** | | 1.00 | |
| 14 | Risks caused by staff experience/availability | 1 | High | 0.05 | |
| | | 2 | Medium | 0.05 | |
| | | 3 | Low | 0.90 | |
| | | **SUM** | | 1.00 | |
| 15 | Risks caused by project and program management issues | 1 | High | 0.10 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 16 | Risks caused by constructability in design | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 17 | Risks caused by delays in procuring critical materials, labor, and specialized equipment | 1 | High | 0.20 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.30 | |
| | | **SUM** | | 1.00 | |
| 18 | Risks caused by significant increase in material, labor, equipment cost | 1 | High | 0.40 | |
| | | 2 | Medium | 0.40 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 19 | Risks caused by conformance with regulations/guidelines/design criteria | 1 | High | 0.15 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.65 | |
| | | **SUM** | | 1.00 | |
| 20 | Risks caused by intergovernmental agreements and jurisdiction | 1 | High | 0.20 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 21 | Risks caused by legal challenges and changes in law | 1 | High | 0.20 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.50 | |
| | | **SUM** | | 1.00 | |
| 22 | | 1 | High | 0.10 | |

| | | | | | |
|---|---|---|---|---|---|
| | Risks caused by unclear contract documents | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 23 | Risks caused by single or multiple contracts | 1 | High | 0.70 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 24 | Risks caused by insurance in contract | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 25 | Risks caused by annual inflation rates | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 26 | Risks caused by construction market conditions | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 27 | Risks caused by delays in delivery schedule | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 28 | Risks caused by construction sequencing/staging/phasing | 1 | High | 0.60 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.10 | |
| | | **SUM** | | 1.00 | |
| 29 | Risks caused by construction QC/QA process | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 30 | Risks caused by design QC and QA | 1 | High | 0.10 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 31 | Risks caused by design completion | 1 | High | 0.15 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.35 | |
| | | **SUM** | | 1.00 | |

## 2.3 Estimating Initial Probability for Project Outcomes

| Project Outcome | States | Values ($ million) | Initial Prob. |
|---|---|---|---|
| Project Cost | Very Low | $771.89 | 10% |
| | Low | $823.94 | 20% |
| | Average | $854.42 | 40% |
| | High | $885.11 | 20% |
| | Very High | $943.23 | 10% |

## 2.4 Estimating Cross-Impact Relationships

| For DBB delivery method | Construction Risk | Schedule Risk | Third-party Risk | Constructability Risk | Market Risk | Complexity Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | MOD+ | MOD+ | NO | NO | MOD+ |
| Schedule Risk | SIG+ | | MOD+ | MOD+ | SLI+ | MOD+ |
| Third-party Risk | SLI+ | MOD+ | | SLI+ | NO | NO |
| Constructability Risk | NO | MOD+ | SLI+ | | SLI+ | SLI+ |
| Market Risk | MOD+ | SLI+ | NO | SLI+ | | SLI+ |
| Complexity Risk | SLI+ | MOD+ | SLI+ | SLI+ | NO | |
| **Project Cost** | SIG+ | MOD+ | SLI+ | SLI+ | SLI+ | MOD+ |

| For DB delivery method | Scope Risk | Third-party Risk | Construction Risk | Complexity Risk | Management Risk | Regulation Risk | Level of Design Risk |
|---|---|---|---|---|---|---|---|
| Scope Risk | | SIG+ | MOD+ | MOD+ | MOD+ | MOD+ | MOD+ |
| Third-party Risk | SIG+ | | SLI+ | SIG+ | SIG+ | SIG+ | SIG+ |
| Construction Risk | MOD+ | MOD+ | | MOD+ | MOD+ | MOD+ | MOD+ |
| Complexity Risk | SIG+ | MOD+ | MOD+ | | MOD+ | MOD+ | MOD+ |
| Management Risk | MOD+ | NO | MOD+ | MOD+ | | SLI+ | SLI+ |
| Regulation Risk | MOD+ | SIG+ | SLI+ | SIG+ | SIG+ | | NO |
| Level of Design Risk | MOD+ | MOD+ | MOD+ | MOD+ | SLI+ | MOD+ | |
| **Project Cost** | MOD+ | MOD+ | SIG+ | MOD+ | MOD+ | SLI+ | MOD+ |

| For CMGC delivery method | Construction Risk | Constructability Risk | Regulation Risk | Complexity Risk | Third-party Risk | Management Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | SIG+ | MOD+ | MOD+ | MOD+ | MOD+ |
| Constructability Risk | MOD+ | | SLI+ | SLI+ | MOD+ | MOD+ |
| Regulation Risk | SLI+ | NO | | NO | NO | SLI+ |
| Complexity Risk | MOD+ | MOD+ | MOD+ | | MOD+ | SLI+ |
| Third-party Risk | SLI+ | SLI+ | MOD+ | MOD+ | | MOD+ |
| Management Risk | SLI+ | SLI+ | SLI+ | MOD+ | SLI+ | |
| **Project Cost** | MOD+ | SLI+ | SLI+ | MOD+ | SLI+ | MOD+ |

# 3. The Lake Bridges Project—US68/KY 80 Corridor in Kentucky

## 3.1 Project Information

The Kentucky Transportation Cabinet (KYTC) proposes to continue and complete the widening and improvements to the existing two-lane US 68/KY 80, from KY 94 at Aurora in Marshall County for approximately 17 miles to the western terminus of the Cadiz Bypass in Trigg County. The western terminus of this project is the recently relocated and widened four lane section of US 68 between Kenlake State Resort Park and the city of Mayfield. The eastern terminus of this project is the western terminus of the Cadiz Bypass. Outside of the two public recreation areas, the project corridor is comprised of a mixture of commercial, residential, and agricultural land.

The primary purpose of the US 68/KY 80 corridor reconstruction is to correct numerous geometric deficiencies of the existing roadway and the two major bridges (Eggner's Ferry Bridge and Lawrence Memorial Bridge over Kentucky Lake and Lake Barkley, respectively). The correction of those deficiencies would provide a safer travel way for persons using US 68/KY 80, satisfy the demands of the traveling public in 2025, and meet current design standards. A secondary purpose for this project is to enhance regional tourism and economic development by vastly upgrading this principal east-west highway which serves as the only highway into and through the Land between the Lakes. The project cost estimate at the 70% of confidence level is $583.1 million in year of expenditure. The anticipated completion date is October 2017.

## 3.2 Estimating Initial Probability for Risk Variables

| Risk ID | Risk Title | Risk's Status | | Initial Probability | Notes |
|---|---|---|---|---|---|
| | | Status | Name | | |
| 1 | Risks caused by challenges to appropriate environmental documentation | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | SUM | | 1.00 | |
| 2 | Risks caused by environmental impacts | 1 | High | 0.20 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.60 | |
| | | SUM | | 1.00 | |
| 3 | Risks caused by uncertainty in geotechnical investigation | 1 | High | 0.40 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.10 | |
| | | SUM | | 1.00 | |
| 4 | Risks caused by work zone traffics control | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |
| | | SUM | | 1.00 | |
| 5 | Risks caused by unexpected utility encounter | 1 | High | 0.30 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.60 | |
| | | SUM | | 1.00 | |
| 6 | Risks caused by delays in completing utility agreements | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | SUM | | 1.00 | |
| 7 | Risks caused by delays in right-of-way (ROW) process | 1 | High | 0.50 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.20 | |
| | | SUM | | 1.00 | |
| 8 | Risks caused by delays in completing in railroad agreements | 1 | High | 0.00 | |
| | | 2 | Medium | 0.00 | |
| | | 3 | Low | 1.00 | |
| | | SUM | | 1.00 | |
| 9 | Risks caused by difficulty in obtaining other agency approvals | 1 | High | 0.30 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.40 | |
| | | SUM | | 1.00 | |

| | | | | | |
|---|---|---|---|---|---|
| 10 | Risks caused by defined and non-defined hazardous waste | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 11 | Risks caused by project complexity | 1 | High | 0.15 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.65 | |
| | | **SUM** | | 1.00 | |
| 12 | Risks caused by scope definition | 1 | High | 0.05 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 13 | Risks caused by project definition | 1 | High | 0.10 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 14 | Risks caused by staff experience/availability | 1 | High | 0.20 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.60 | |
| | | **SUM** | | 1.00 | |
| 15 | Risks caused by project and program management issues | 1 | High | 0.05 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.85 | |
| | | **SUM** | | 1.00 | |
| 16 | Risks caused by constructability in design | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 17 | Risks caused by delays in procuring critical materials, labor, and specialized equipment | 1 | High | 0.20 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.50 | |
| | | **SUM** | | 1.00 | |
| 18 | Risks caused by significant increase in material, labor, equipment cost | 1 | High | 0.25 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 19 | Risks caused by conformance with regulations/guidelines/design criteria | 1 | High | 0.15 | |
| | | 2 | Medium | 0.60 | |
| | | 3 | Low | 0.25 | |
| | | **SUM** | | 1.00 | |
| 20 | | 1 | High | 0.05 | |

| | | | | | |
|---|---|---|---|---|---|
| | Risks caused by intergovernmental agreements and jurisdiction | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.75 | |
| | | SUM | | 1.00 | |
| 21 | Risks caused by legal challenges and changes in law | 1 | High | 0.05 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.85 | |
| | | **SUM** | | 1.00 | |
| 22 | Risks caused by unclear contract documents | 1 | High | 0.15 | |
| | | 2 | Medium | 0.30 | |
| | | 3 | Low | 0.55 | |
| | | **SUM** | | 1.00 | |
| 23 | Risks caused by single or multiple contracts | 1 | High | 0.05 | |
| | | 2 | Medium | 0.15 | |
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 24 | Risks caused by insurance in contract | 1 | High | 0.00 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.90 | |
| | | **SUM** | | 1.00 | |
| 25 | Risks caused by annual inflation rates | 1 | High | 0.05 | |
| | | 2 | Medium | 0.25 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 26 | Risks caused by construction market conditions | 1 | High | 0.10 | |
| | | 2 | Medium | 0.20 | |
| | | 3 | Low | 0.70 | |
| | | **SUM** | | 1.00 | |
| 27 | Risks caused by delays in delivery schedule | 1 | High | 0.30 | |
| | | 2 | Medium | 0.50 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 28 | Risks caused by construction sequencing/staging/phasing | 1 | High | 0.40 | |
| | | 2 | Medium | 0.40 | |
| | | 3 | Low | 0.20 | |
| | | **SUM** | | 1.00 | |
| 29 | Risks caused by construction QC/QA process | 1 | High | 0.25 | |
| | | 2 | Medium | 0.40 | |
| | | 3 | Low | 0.35 | |
| | | **SUM** | | 1.00 | |
| 30 | Risks caused by design QC and QA | 1 | High | 0.00 | |
| | | 2 | Medium | 0.20 | |

| | | | | | |
|---|---|---|---|---|---|
| | | 3 | Low | 0.80 | |
| | | **SUM** | | 1.00 | |
| 31 | Risks caused by design completion | 1 | High | 0.00 | |
| | | 2 | Medium | 0.10 | |
| | | 3 | Low | 0.90 | |
| | | **SUM** | | 1.00 | |

## 3.3 Estimating Initial Probability for Project Outcomes

| Project Outcome | States | Values ($ million) | Initial Prob. |
|---|---|---|---|
| Project Cost | Very Low | $521.20 | 10% |
| | Low | $554.86 | 20% |
| | Average | $572.81 | 40% |
| | High | $589.96 | 20% |
| | Very High | $620.81 | 10% |

## 3.4 Estimating Cross-Impact Relationships

| For DBB delivery method | Construction Risk | Schedule Risk | Third-party Risk | Constructability Risk | Market Risk | Complexity Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | MOD+ | MOD+ | SIG+ | MOD+ | SIG+ |
| Schedule Risk | SIG+ | | SLI+ | MOD+ | SLI+ | MOD+ |
| Third-party Risk | SLI+ | SLI+ | | SLI+ | NO | SLI+ |
| Constructability Risk | MOD+ | SLI+ | SLI+ | | SLI+ | MOD+ |
| Market Risk | NO | SLI+ | NO | MOD+ | | SLI+ |
| Complexity Risk | NO | NO | SLI+ | MOD+ | SLI+ | |
| **Project Cost** | MOD+ | SLI+ | SLI+ | SIG+ | MOD+ | MOD+ |

| **For DB delivery method** | Scope Risk | Third-party Risk | Construction Risk | Complexity Risk | Management Risk | Regulation Risk | Level of Design Risk |
|---|---|---|---|---|---|---|---|
| Scope Risk | | MOD+ | SLI+ | MOD+ | MOD+ | NO | MOD+ |
| Third-party Risk | MOD | | NO | SLI+ | NO | NO | SLI+ |
| Construction Risk | SIG+ | MOD+ | | SIG+ | MOD+ | SLI+ | SIG+ |
| Complexity Risk | MOD+ | MOD+ | MOD+ | | NO | SLI+ | SLI+ |
| Management Risk | MOD+ | SLI+ | MOD+ | SLI+ | | MOD+ | MOD+ |
| Regulation Risk | SLI+ | NO | SLI+ | SLI+ | SLI+ | | NO |
| Level of Design Risk | MOD+ | SLI+ | SLI+ | MOD+ | MOD+ | MOD+ | |
| **Project Cost** | MOD+ | SLI+ | SIG+ | MOD+ | SLI+ | SLI+ | SLI+ |

| **For CMGC delivery method** | Construction Risk | Constructability Risk | Regulation Risk | Complexity Risk | Third-party Risk | Management Risk |
|---|---|---|---|---|---|---|
| Construction Risk | | SIG+ | MOD+ | MOD+ | SLI+ | MOD+ |
| Constructability Risk | SLI+ | | SLI+ | SIG+ | NO | SLI+ |
| Regulation Risk | NO | SLI+ | | SLI+ | SLI+ | NO |
| Complexity Risk | SLI+ | MOD+ | SLI+ | | SLI+ | SLI+ |
| Third-party Risk | MOD+ | SLI+ | NO | SLI+ | | MOD+ |
| Management Risk | SLI+ | MOD+ | SLI+ | SLI+ | NO | |
| **Project Cost** | MOD+ | MOD+ | MOD+ | MOD+ | SLI+ | SLI+ |

# APPENDIX IV: MODEL PROGRAMMING – C++ CODE

```
// Copyright (C) 2013, Daniel Tran and Keith Molenaar. All rights reserved.
//
// This code uses Mersenne Twister random number generator -- a C++ class MTRand
// Copyright (C) 1997 - 2002, Makoto Matsumoto and Takuji Nishimura,
// copyright (C) 2000 - 2003, Richard J. Wagner.
//
// Redistribution and use in source and binary forms, with or without modification, are
// permitted provided that the following conditions are met:

//   1. Redistributions of source code must retain the above copyright
//      notice, this list of conditions and the following disclaimer.
//
//   2. Redistributions in binary form must reproduce the above copyright
//      notice, this list of conditions and the following disclaimer in the
//      documentation and/or other materials provided with the distribution.
//
//   3. The names of its contributors may not be used to endorse or promote
//      products derived from this software without specific prior written
//      permission.
//
// THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS
// "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT
// LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR
// A PARTICULAR PURPOSE ARE DISCLAIMED.  IN NO EVENT SHALL THE COPYRIGHT OWNER OR
// CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL,
// EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO,
// PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR
// PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF
// LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING
// NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS
// SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

#include <iostream>
#include <vector>
#include <cmath>
#include <float.h>
```

```
#include <fstream>
#include <cstdlib>
#include <ctime>
#include <string>
#include "MTRandom.h"


using namespace std;
vector<string> varLayer1;
vector<string> varLayer2;
vector<string> varLayer3;
double Layer1Pr[50][3];
double Layer2Pr[10][3];
double Layer3Pr[2][5];
double tempLayer1Pr[50][3];
double tempLayer2Pr[10][3];
double tempLayer3Pr[2][5];
int StateLayer1[50][4];
int StateLayer2[10][4];
int StateLayer3[2][6];
int recordStateLayer1[50][3];
int Layer1[50][50][4];
int Layer2[10][3][4];
int FV[2][5];
int Type1[3][3][3];
int Type2[3][5][3];
int L1, L2, L3;
int randOrder[50][2];
void input();
void inputImpact();
void resetInitialProbability();
void resetState();
void randomOrder(int varNum);


int main()
{
	int i, j, k, temp, Index, count;
	double Prob, CV, PriorPr;
	double PostPr[5];
```

```
double TotalPr=0;
double cummulative;

MTRand::uint32 seed[ MTRand::N ];
for( int n = 0; n < MTRand::N; ++n )
       seed[n] = 23 * n;
MTRand mtrand1( seed );

ofstream Output;
Output.open("Output file.txt");

input();

inputImpact();

for (i=0; i<L1; i++)
{
       for (j=1; j<=3; j++)
              Output << varLayer1[i] << "_" << j << "    ";

}

for (i=0; i<L2; i++)
{
       for (j=1; j<=3; j++)
              Output << varLayer2[i] << "_" << j << "    ";

}

for (i=0; i<L3; i++)
{
       for (j=1; j<=5; j++)
              Output << varLayer3[i] << "_" << j << "    ";

}
Output << endl;

for (i=0; i<L3; i++)
{
       for (j=0; j<5; j++)
              FV[i][j]=0;
}
cout << endl;
for (i=0; i<L3; i++)
{
       for (j=0; j<5; j++)
              cout << FV[i][j] << "  ";
}

for (i=0; i<50; i++)
{
       for (j=0; j<3; j++)
              recordStateLayer1[i][j]=0;
}

resetInitialProbability();
```

```
	resetState();

// LAYER1---------------------------

	// Select the order of first layer variables

	randomOrder(L1);

	for (i=0; i<L1; i++)
	{
	// -----------Randomize and report the state of variables in Layer 1
		temp = randOrder[i][1];     //Index of variable that is happening
		Prob = mtrand1();

		if (Prob <= tempLayer1Pr[temp][0])
		{
			StateLayer1[temp][0]=0;
			StateLayer1[temp][1]=1;
			recordStateLayer1[temp][0]++;
		}
		else
		{
			if (Prob <= (tempLayer1Pr[temp][0]+tempLayer1Pr[temp][1]))
			{
				StateLayer1[temp][0]=1;
				StateLayer1[temp][2]=1;
				recordStateLayer1[temp][1]++;
			}
			else
			{
				StateLayer1[temp][0]=2;
				StateLayer1[temp][3]=1;
				recordStateLayer1[temp][2]++;
			}
		}
		for (j=0; j<Layer1[temp][0][0]; j++)
		{
			for (k=0; k<3; k++)
			{
				Index = Type1[StateLayer1[temp][0]][k][Layer1[temp][j+1][1]-
			1];

				if (Index>=0)
					CV = fabs(static_cast<double>(Index))+1;
				else
					CV = 1/(fabs(static_cast<double>(Index))+1);
				PriorPr = tempLayer1Pr[Layer1[temp][j+1][0]][k];
				PostPr[k]=PriorPr*CV/(1-PriorPr+PriorPr*CV);
				TotalPr = TotalPr + PostPr[k];
			}

	//--- Rescaling Posterior probabilities so that they sum up to 1
			for (k=0; k<3; k++)
			{
			tempLayer1Pr[Layer1[temp][j+1][0]][k]= PostPr[k]/TotalPr;
			}
			TotalPr=0;
```

```
        }

    // ---Calculate posterior probability of i's Layer 2 neighbors


        for (j=0; j<Layer1[temp][0][2]; j++)
        {
            for (k=0; k<3; k++)
            {
                Index = Type1[StateLayer1[temp][0]][k][Layer1[temp][j+1][3]-
            1];

                if (Index>=0)
                    CV = fabs(static_cast<double>(Index))+1;
                else
                    CV = 1/(fabs(static_cast<double>(Index))+1);
                PriorPr = tempLayer2Pr[Layer1[temp][j+1][2]][k];
                PostPr[k]=PriorPr*CV/(1-PriorPr+PriorPr*CV);
                TotalPr = TotalPr + PostPr[k];
            }
    //--- Rescaling Posterior probabilities so that they sum up to 1
            for (k=0; k<3; k++)
            {
                tempLayer2Pr[Layer1[temp][j+1][0]][k]= PostPr[k]/TotalPr;
            }
            TotalPr=0;

        }
    }


// LAYER2----------------------------

    //Randomize order of happening for variables in Layer 2.
    randomOrder(L2);

    for (i=0; i<L2; i++)
    {
    // -----------Randomize and report the state of variables in Layer 2
        temp = randOrder[i][1];
        Prob = mtrand1();


        if (Prob <= tempLayer2Pr[temp][0])
        {
            StateLayer2[temp][0]=0;
            StateLayer2[temp][1]=1;
        }
        else
        {
            if (Prob <= (tempLayer2Pr[temp][0]+tempLayer2Pr[temp][1]))
            {
                StateLayer2[temp][0]=1;
                StateLayer2[temp][2]=1;
            }
            else
            {
```

```
                    StateLayer2[temp][0]=2;
                    StateLayer2[temp][3]=1;
                }
        }

// ---Calculate posterior probability of i's Layer 2 neighbors
        for (j=0; j<Layer2[temp][0][0]; j++)
        {

                for (k=0; k<3; k++)
                {
                    Index = Type1[StateLayer2[temp][0]][k][Layer2[temp][j+1][1]-
                1];

                    if (Index>=0)
                        CV = fabs(static_cast<double>(Index))+1;
                    else
                        CV = 1/(fabs(static_cast<double>(Index))+1);
                    PriorPr = tempLayer2Pr[Layer2[temp][j+1][0]][k];
                    PostPr[k]=PriorPr*CV/(1-PriorPr+PriorPr*CV);
                    TotalPr = TotalPr + PostPr[k];
                }
//--- Rescaling Posterior probabilities so that they sum up to 1
                for (k=0; k<3; k++)
                {
                tempLayer2Pr[Layer2[temp][j+1][0]][k]= P
ostPr[k]/TotalPr;
                }
                TotalPr=0;

        }

// Calculate posterior probability of i's Layer 3 neighbors
        for (j=0; j<Layer2[temp][0][2]; j++)
        {

                for (k=0; k<5; k++)
                {
                    Index = Type2[StateLayer2[temp][0]][k][Layer2[temp][j+1][3]-
                1];

                    if (Index>=0)
                        CV = fabs(static_cast<double>(Index))+1;
                    else
                        CV = 1/(fabs(static_cast<double>(Index))+1);
                    PriorPr = tempLayer3Pr[Layer2[temp][j+1][2]][k];
                    PostPr[k]=PriorPr*CV/(1-PriorPr+PriorPr*CV);
                    TotalPr = TotalPr + PostPr[k];
                }

//--- Rescaling Posterior probabilities so that they sum up to 1
                for (k=0; k<5; k++)
                {
                    tempLayer3Pr[Layer2[temp][j+1][2]][k]= PostPr[k]/TotalPr;
                }
                TotalPr=0;
        }
}
```

```
// LAYER 3---------------------------
	for (i=0; i<L3; i++)
	{
// -----------Randomize and report the state of variables in Layer 3
		Prob = mtrand1();
		cummulative=tempLayer3Pr[i][0];
		if (Prob <= cummulative)
		{
			StateLayer3[i][0]=0;
			StateLayer3[i][1]=1;
			FV[i][0]=FV[i][0]++;
		}
		else
		{
			cummulative = cummulative + tempLayer3Pr[i][1];
			if (Prob <= cummulative)
			{
				StateLayer3[i][0]=1;
				StateLayer3[i][2]=1;
				FV[i][1]=FV[i][1]++;
			}
			else
			{
				cummulative = cummulative + tempLayer3Pr[i][2];
				if (Prob <= cummulative)
				{
					StateLayer3[i][0]=2;
					StateLayer3[i][3]=1;
					FV[i][2]=FV[i][2]++;
				}
				else
				{
					cummulative = cummulative + tempLayer3Pr[i][3];
					if (Prob <= cummulative)
					{
						StateLayer3[i][0]=3;
						StateLayer3[i][4]=1;
						FV[i][3]=FV[i][3]++;
					}
					else
					{
						StateLayer3[i][0]=4;
						StateLayer3[i][5]=1;
						FV[i][4]=FV[i][4]++;
					}
				}
			}
		}
	}

	for (i=0; i<L1; i++)
	{
		for (j=0; j<3; j++)
			Output << StateLayer1[i][j+1] << "   ";

	}
```

```
	for (i=0; i<L2; i++)
	{
		for (j=0; j<3; j++)
			Output << StateLayer2[i][j+1] << "   ";

	}

	for (i=0; i<L3; i++)
	{
		for (j=0; j<5; j++)
			Output << StateLayer3[i][j+1] << "   ";

	}
	Output << endl;



	Output.close();

	int dummy;
	cin >> dummy;

	return 0;
}

void input()
{
	int i,j,k, index;
	char  var;
	string temp,next;
	ifstream fin;

	fin.open("List_of_variables.txt");
	if (fin.fail())
	{
		cout << "Fail to open input file";
		exit(1);
	}

	fin >> L1 >> L2 >> L3;


//---------VARIABLE NAME & INITIAL PROBABILITIES

	// ------ Layer 1 variables
	for (i=0; i<L1; i++)
	{
		fin >> next >> Layer1Pr[i][0] >> Layer1Pr[i][1] >> Layer1Pr[i][2];
		varLayer1.push_back(next);
	}

	// ------ Layer 2 variables
	for (i=0; i<L2; i++)
	{
		fin >> next >> Layer2Pr[i][0]>> Layer2Pr[i][1] >> Layer2Pr[i][2];
		varLayer2.push_back(next);
	}
```

```
	// ------ Layer 3 variables
	for (i=0; i<L3; i++)
	{
		fin >> next >> Layer3Pr[i][0] >> Layer3Pr[i][1] >> Layer3Pr[i][2]>>
Layer3Pr[i][3]>> Layer3Pr[i][4];
		varLayer3.push_back(next);
	}
	fin.close();
	fin.clear();
	Output1.close();


	//------ Layer 1

	fin.open("Layer_1_neighbors.txt");
	if (fin.fail())
	{
		cout << "Fail to open input file";
		exit(1);
	}

	for (i=0; i<L1; i++)
	{
		fin >> next;


		fin >> Layer1[i][0][0];

		if (Layer1[i][0][0]!=0)
		{
			for (j=0; j< Layer1[i][0][0]; j++)
			{
				fin >> temp;

				for (k=0; k<L1; k++)
				{
					if (temp == varLayer1[k])
						Layer1[i][1+j][0]=k;
				}

				fin >> Layer1[i][1+j][1];
			}
		}


		fin >> Layer1[i][0][2];

		if (Layer1[i][0][2]!=0)
		{
			for (j=0; j< Layer1[i][0][2]; j++)
			{
				fin >> temp;

				for (k=0; k<L2; k++)
				{
					if (temp == varLayer2[k])
						Layer1[i][1+j][2]=k;
```

```
					}

					fin >> Layer1[i][1+j][3];
				}
			}
		}
		fin.close();
		fin.clear();

		//------ Layer 2

		fin.open("Layer_2_neighbors.txt");
		if (fin.fail())
		{
			cout << "Fail to open input file";
			exit(1);
		}

		for (i=0; i<L2; i++)
		{
			fin >> next;

			fin >> Layer2[i][0][0];

			if (Layer2[i][0][0]!=0)
			{
				for (j=0; j< Layer2[i][0][0]; j++)
				{
					fin >> temp;

					for (k=0; k<L2; k++)
					{
						if (temp == varLayer2[k])
							Layer2[i][1+j][0]=k;
					}

					fin >> Layer2[i][1+j][1];
				}
			}

			fin >> Layer2[i][0][2];

			for (j=0; j< Layer2[i][0][2]; j++)
			{
				fin >> temp;

				for (k=0; k<L3; k++)
				{
					if (temp == varLayer3[k])
						Layer2[i][1+j][2]=k;
				}

				fin >> Layer2[i][1+j][3];

			}
		}
		fin.close();
```

```
        return;

}

void inputImpact()
{
        int i, j, next;
        ifstream fin;

        fin.open("Type1_SLI.txt");
        if (fin.fail())
        {
                cout << "Fail to open input file";
                exit(1);
        }

        for (i=0; i<3; i++)
        {
                for (j=0; j<3; j++)
                {
                        fin >> next;
                        Type1[i][j][0]=next;
                }
        }
        fin.close();
        fin.clear();


        fin.open("Type1_MOD.txt");
        if (fin.fail())
        {
                cout << "Fail to open input file";
                exit(1);
        }

        for (i=0; i<3; i++)
        {
                for (j=0; j<3; j++)
                {
                        fin >> Type1[i][j][1];
                }
        }
        fin.close();
        fin.clear();


        fin.open("Type1_SIG.txt");
        if (fin.fail())
        {
                cout << "Fail to open input file";
                exit(1);
        }

        for (i=0; i<3; i++)
        {
                for (j=0; j<3; j++)
                {
                        fin >> Type1[i][j][2];
```

```
        }
    }
    fin.close();
    fin.clear();


    fin.open("Type2_SLI.txt");
    if (fin.fail())
    {
        cout << "Fail to open input file";
        exit(1);
    }

    for (i=0; i<3; i++)
    {
        for (j=0; j<5; j++)
        {
            fin >> Type2[i][j][0];
        }
    }
    fin.close();
    fin.clear();


    fin.open("Type2_MOD.txt");
    if (fin.fail())
    {
        cout << "Fail to open input file";
        exit(1);
    }

    for (i=0; i<3; i++)
    {
        for (j=0; j<5; j++)
        {
            fin >> Type2[i][j][1];
        }
    }
    fin.close();
    fin.clear();


    fin.open("Type2_SIG.txt");
    if (fin.fail())
    {
        cout << "Fail to open input file";
        exit(1);
    }

    for (i=0; i<3; i++)
    {
        for (j=0; j<5; j++)
        {
            fin >> Type2[i][j][2];
        }
    }
    fin.close();
    fin.clear();
```

```
        return;
}

void resetInitialProbability()
{
        int i,j;

        for (i=0; i<L1; i++)
        {
                for (j=0; j<3; j++)
                        tempLayer1Pr[i][j] = Layer1Pr[i][j];
        }

        for (i=0; i<L2; i++)
        {
                for (j=0; j<3; j++)
                        tempLayer2Pr[i][j] = Layer2Pr[i][j];
        }

        for (i=0; i<L3; i++)
        {
                for (j=0; j<5; j++)
                        tempLayer3Pr[i][j] = Layer3Pr[i][j];
        }

        return;
}

void resetState()
{
        int i, j;

        for (i=0; i<L1; i++)
        {
                for (j=0; j<4; j++)
                        StateLayer1[i][j]=0;
        }

        for (i=0; i<L2; i++)
        {
                for (j=0; j<4; j++)
                        StateLayer2[i][j]=0;
        }

        for (i=0; i<L3; i++)
        {
                for (j=0; j<6; j++)
                        StateLayer3[i][j]=0;
        }

        return;
}

void randomOrder(int varNum)
{
        int i, j, k, temp;
```

```
        MTRand mtrand1;

        for (i=0; i<50; i++)
        {
                randOrder[i][0]=0;
                randOrder[i][1]=0;
        }

        randOrder[0][0]=mtrand1.randInt();
        randOrder[0][1]=0;

        for (i=1; i<varNum; i++)
        {
                temp = mtrand1.randInt();

                randOrder[i][0]=temp;
                randOrder[i][1]=i;

                for (j=0; j<i; j++)
                {
                        if (temp == randOrder[j][0])
                        {
                                i = i-1;
                                break;
                        }
                        if (temp < randOrder[j][0])
                        {
                                for (k=i; k>j; k--)
                                {
                                        randOrder[k][0]=randOrder[k-1][0];
                                        randOrder[k][1]=randOrder[k-1][1];
                                }
                                randOrder[j][0]=temp;
                                randOrder[j][1]=i;
                                break;
                        }
                }
        }

        return;

}
```