Spring 1-1-2017

Performance-based Project Delivery Selection for Highway Design and Construction Projects

Arthur L. C. Antoine
University of Colorado at Boulder, ARAN2612@COLORADO.EDU

Follow this and additional works at: https://scholar.colorado.edu/cven_gradetds

 Part of the Civil Engineering Commons

PERFORMANCE-BASED PROJECT DELIVERY SELECTION FOR

HIGHWAY DESIGN AND CONSTRUCTION PROJECTS

by

ARTHUR L.C. ANTOINE

B.Sc., University of the West Indies, 2003

M.Sc., Texas A&M University, 2009

A thesis 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

Civil, Architectural, and Environmental Engineering

2017

This thesis entitled:

Performance-Based Project Delivery Selection for Highway Design and

Construction Projects

written by Arthur L.C. Antoine

has been approved for the Civil, Architectural, and Environmental Engineering

Department

_____

Keith R. Molenaar

_____

Matthew Hallowell

Date_____

The final copy of this thesis 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.

Antoine, Leslie Clement Arthur (Ph.D., Civil, Environmental, and Architectural
    Engineering)

Performance-Based Project Delivery Selection for Highway Design and
    Construction Projects

Thesis directed by Professor Keith R. Molenaar

Abstract

While agencies design and construct the vast majority of federally funded highways through the traditional design-bid-build (D-B-B) method, the use of alternative project delivery methods, construction manager/general contractor (CM/GC) and design-build (D-B) is increasing. This research makes contributions to construction engineering and management knowledge by successfully investigating the performance of highway construction projects in relation to project characteristics and project delivery methods. Results show that alternative project delivery methods are, viable options for shortening project durations, delivering projects at a faster pace to reduce impacts to road users, and establishing early cost certainty during project delivery. By conducting a novel quantitiative analysis of CM/GC versus D-B results reveal that CM/GC outperforms D-B for time savings during project delivery.

This study categorizes highway construction projects by the characteristics of size in terms of cost, type, and complexity to provide a practical means of analysis and to make results more applicable to the process of selecting appropriate project delivery methods. In the process, the author supplements an empirical study of 284 projects with experiential knowledge obtained from highway officials through a

rigorous Delphi study. The results provide new evidence that alternative contracting methods are superior to D-B-B for schedule compression and cost growth performance. However, D-B-B remains indispensable on certain projects. Findings are confirmed by the triangulation of information from the empirical data, the Delphi study results, and existing literature to provide useful recommendations for state highway agencies.

The ability to choose an appropriate project delivery method for efficient performance of a certain project holds merit with state highway agencies. Particularly, considering the vast amounts of money involved in US highway construction coupled with the current political climate that has heightened attention to expenditure on US infrastructure. With the urgent demand at this juncture for improvement of the status of US transportation infrastructure the application of the findings from this PhD research can aid highway agencies' selection of an appropriate project delivery method to achieve project goals, particularly cost and schedule performance objectives.

Dedication

Dedicated to my dear mother Isaline C. Antoine.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I - INTRODUCTION

1.0 Introduction

The traditional project delivery method for United States (US) highway projects is design-bid-build (D-B-B). The two primary alternative project delivery methods of design-build (D-B) and construction manager/general contractor (CM/GC). These alternative delivery methods are becoming increasingly important in the US highway construction industry. The vast majority of the U.S. highway system was built using the D-B-B delivery method. The use of D-B delivery began only in the 1990s and CM/GC after 2005 (FHWA, 2015). At the end of 2014, the number of states, or rather Departments of Transportation (DOTs), fully employing the CM/GC method increased to 17 and continues to grow, while D-B usage increased to 35 agencies including the Federal Lands Highway agency (FHWA, 2015).

Documented benefits of the two alternative project delivery methods include saving cost, improving constructability, enhancing innovation, reducing risk, shortening construction schedules and the potential to lower operational cost and/or project life-cycle costs (Songer and Molenaar, 1996; FHWA, 2015; Touran et al., 2011). Notwithstanding the potential benefits, the two alternative project delivery methods are not a panacea for project delivery challenges and so, the more traditional method of D-B-B remains indispensable. Consequentially, one of the main motivating factors for this dissertation is to provide insight on the selection of an appropriate delivery method for particular situations. This dissertation collected the largest and most comprehensive database of information on US highway project delivery to provide insights as to when agencies should select alternative delivery methods given a particular set of agency goals and project characteristics.

1.1 Observed Problem

With the ever-increasing demand to execute highway construction projects more quickly and within budget, DOTs are continuously revising and improving each project delivery method and the associated procurement procedures, payment methods and risk allocation. Any combination of the project delivery method and project characteristics can lead to differing results in project performance (Forgues and Koskela, 2008; Gransberg et. al., 2003). Therein lies the need to improve the understanding of the inter-relationships among these factors to determine how they ultimately affect project performance. Currently, some agencies select project delivery methods subjectively by relying on experiences, case studies, comparisons of projects or even, trial and error. There is a need for empirical evidence about how project delivery methods impact project performance.

State highway agencies or departments of transportation (DOTs) need to be efficient in every aspect of highway project delivery. Therein lies pressure on agency professionals who need to better align information available at the early stages of a project with the selection of a suitable project delivery method to achieve successful outcomes in project delivery performance. Few of the current project delivery method selection approaches are based on empirical project data. The inherent qualitative features of existing approaches can introduce biases which could adversely affect project performance. Of existing selection approaches the majority are not specific to any category of construction projects, they were developed to focus on construction generally. These prevailing selection approaches do not consider at an in-depth level, the nuances of project delivery as applied within the context of specific kind of construction nor do they consider project characteristics that are unique to certain kinds of construction projects.

As an alternative to the current options there is need for a new approach to selecting an appropriate project delivery method. To the extent feasible, this new

approach should be based on empirical project data. Additionally, this new approach should highlight highway construction project characteristics that are known from the inception of a project and are useful indicators of the likely performance of a selected project delivery method. The new approach should focus on selection of a suitable project delivery method with respect to specific project performance goals. This dissertation presents information that is needed for the development of a new project delivery method selection approach. Designed for specific application in US highway construction, the new selection approach can encourage more objective project delivery selection decision-making.

1.2 Literature Review

Motivated by the possibility of cost and time savings, researchers have studied ways to improve the process of selecting an appropriate project delivery method. The majority of these studies have focused on building (vertical) projects. These studies can only apply to the general context of highway construction from an academic and theoretical perspective. The majority of existing delivery method selection procedures can collectively be considered as qualitative approaches. Some researchers have built upon the work of those qualitative procedures to develop innovative ways of project delivery method selection. However, elements of those methods remain somewhat subjective.

Gordon (1994) was one of the first researchers to pioneer the topic of selecting an appropriate project delivery method. Gordon postulated that careful project delivery selection could lead to several benefits. He emphasized the need for compatibility between the type of owner and the type of project. He developed a method selection flowchart that owners could use to select or tailor an appropriate project delivery method for their needs. Even with advancements in the project delivery methods and associated terminology, much of what he contributed to the

3

construction engineering and management body of knowledge remains applicable to date. For example, Gordon (1994) specified the "contracting method" as having four main parts which still prevail as attributes of project delivery to date:

i.   Scope   =>   project tasks as contractually assigned to the contractor, e.g. design and/or construction.

ii. Organization   =>   the business entity with which the owner is contracting, e.g. general contractor, designer and builder as a single entity, or a construction manager.

iii. Contract   =>   Gordon's definition aligns with what is more commonly referred to as the payment method, e.g. lump-sum, unit price or guaranteed maximum price (GMP).

iv. Award   =>   the "procurement procedure" parallels Gordon's definition of "award" i.e. the method of selecting the contractor, e.g. low bid, best value, or based on qualifications.

Some researchers have explored a single project delivery method in order to highlight the benefits or challenges. Yates (1995) and Songer and Molenaar (1996), each focused on D-B. Their work presented advantages and disadvantages of the D-B method, definitions of a successful D-B project and, strategies required to achieve a successful D-B project. This was useful information to owners and practitioners as D-B use has grown in popularity; as clearly evident by the increased use of D-B by significant U.S. construction companies and the fact that owners are leaning towards D-B because of the collaborative advantages (ENR, 2015). Beard et al. (2001) and Gransberg et al. (2006) produced books dedicated solely to the D-B method which also highlighted benefits of the method through careful examination and case studies. The work of Migliaccio et al. (2009) focused on the nuances of D-B two phase procurement

by a case study of two significant projects and this established an understanding of D-B procurement for highway projects. However, Migliaccio et al. (2009) noted that collection of significant data on procurement schedule durations and project characteristics was warranted in order to better assess which factors affect the duration of D-B procurement and also to be able to identify variations of the two-phase selection approach. Though Lam et al. (2008) also solely focused on the D-B method, their work introduced innovative statistical techniques, such as factor analysis, to analyze qualitative data from survey respondents and produced a defining index for D-B project success.

As an aside to the approach to examine a singular project delivery method, Miller et al. (2000) were a proponents of the concept of simultaneously using multiple project delivery methods. Not to be mistaken for implying the simultaneous use of multiple delivery methods on a single project, Miller et al. (2000) proposed that it would be advantageous for the public sector to be legally permitted to choose any of the available project delivery methods rather than limiting options to a single method, say D-B-B.

In advancing the appropriate selection of project delivery methods, researchers have underscored the value of experiential knowledge and proceeded to develop collections of such knowledge for applying lessons learnt in past project delivery method selection to new projects. Kumaraswamy and Dissanayaka (2001), for example, established a knowledge-based advisory system to aid owners in making the project delivery method selection that would influence cost and schedule objectives for vertical building projects. Their work helped to aid project delivery method selection by highlighting important procurement and non-procurement variables that affect project performance. Their work was based on experiential knowledge of respondents to a survey. Kumaraswamy and Dissanayaka (2001) were prudent to highlight the limitations of their qualitative approach and make recommendations

that a wider and more detailed study be designed to collect a project-based data-set, to extend findings into other construction project categories and to be able to categorize projects into more homogeneous groupings. Luu et al. (2003; 2006) emphasized a case-based approach founded on collected experiential knowledge. Luu et al. (2003; 2006) produced a computerized database that could be used as a decision tool for owners to access collected experiential knowledge and to compare the retrieved information with current project scenarios.

Creative selection processes for project delivery methods were attained by the use of analytical hierarchical process (AHP) in work done by Al Khalil (2002) and by Alhazmi and McCaffer (2000). They essentially produced multi-criteria, multi-screening systems for project delivery method selection such as Alhazmi and McCaffer's (2000) project procurement system selection model (PPSSM). A potential flaw of approaching project delivery method selection in this manner is that explanations of the parameters or criteria used throughout the AHP can be vague and can easily be misconstrued by owners attempting to use this approach in practice. Another deficiency is this approach focusses on project delivery method selection with regard to owners' needs, preferences and goals for the project rather than on empirical project performance. To illustrate this, the AHP approach may consider the advantage of a particular project delivery method that allows the early start of construction but would not consider or examine the relation to actual construction completion time.

As a result of the multitude of differences in local practices or requirements and differences of the perceptions of experts with respect to the variables involved in project delivery a few researchers proceeded to create a selection criteria that accounted for the fuzziness of construction project delivery in the broad sense. Ng et al. (2002) and Chan (2007) both established fuzzy logic selection models for construction projects. Those researchers were inspired to address what they felt was

6

a deficiency of standard definitions of the parameters involved in project delivery method selection. Hence, they proposed models to overcome the need to establish universal definitions of project delivery attributes. It is noteworthy to mention that in the case of this PhD research with high specificity to US highway construction the issue of vague definitions does not present a problem. This is a result of the parameters of project delivery within the US highway construction context being well-established, documented, and defined by practicing state DOTs and especially, by the governing body for US highway construction, the Federal Highway Administration (FHWA).

Oyetunji and Anderson (2006) pointed out that, "structured, quantitative decision analysis processes have several benefits over the simplistic, holistic, and informal processes that typically characterize subjective evaluations." Over time researchers made attempts to derive quantitative approaches to investigate project delivery methods. Consequentially, multi-attribute utility/value theories were developed in which the encompassing decision making process was broken down into smaller components which could then be ranked and/or scored for comparison. Often, relative utility values of the components or attributes of project delivery would be determined on a numerical scale by survey respondents who had significant industry experience. Researchers whose work fell within this approach (Skitmore and Marsden, 1988; Love et al., 1998; Molenaar and Songer, 1998; Mahdi and Alreshaid, 2005; Oyetunji and Anderson, 2006) began to implement statistical techniques along with their conceived quantitative values to obtain an evaluation of project delivery method alternatives. However, the root of their quantitative values tended to be from subjective responses from industry practitioners and results were still devoid of any relation to empirical project performance.

Even some of the more recently developed project delivery selection methods (Tran, 2013; Tran et al., 2013; Harper, 2014) contain subjective elements in the

7

process of project delivery method selection. Tran (2013) developed a risk based model for the selection of project delivery methods for highway constructions projects in which the delivery selection model is innovatively connected with probabilistic risk analysis processes by the use of a complex statistical and computational approach. The result of Tran's work produces approximate cost distributions for D-B, D-B-B and CM/GC methods along with a sensitivity analysis showing exactly which risks impact the cost of the delivery methods. A major limitation hindering widespread industry use is that the model can only be used for projects costing over $100M and it cannot be used without probabilistic risk-based cost estimating which is an esoteric concept in the construction industry to some extent. Tran et al. (2013) developed a project delivery selection matrix that can be used to validate the project delivery method decision. The process incorporates workshops with agency personnel directly involved in project delivery and encourages discussion during the evaluation of project attributes, goals, and constraints that are compared/rated by a non-numerical system among different delivery methods.

Despite the wide array of academically developed project delivery method selection approaches, in practice, few formal or systematic selection processes are employed (Anderson and Damnjanovic, 2008; Tran et al. 2013). Nevertheless, of the selection procedures that are in use by agencies a common element is experiential knowledge, usually facilitated by some form of a workshop aimed at building consensus among project stakeholders (Kumaraswamy and Dissanayaka 2001; Luu et al. 2003 and 2006; ODOT, 2010; WSDOT, 2016; CDOT, 2016; MnDOT, 2013; Tran et al. 2013).

In conjunction with research on the selection of project delivery methods, research exists on the assessment of project delivery method performance. However, very few publications contain project delivery method performance for both D-B and CM/GC in the US highway sector. This is an understandable result given the

8

relatively new and growing use of CM/GC versus the more mature D-B or the traditional D-B-B method (FHWA 2015). In the project delivery method performance that includes both D-B and CM/GC, the researchers rely on the experiential knowledge of industry users of these delivery methods to determine which delivery method is superior in performance, however, results are mixed and remain uncertain as a consequence of the diversity of perspectives among research subjects (McGraw Hill Construction, 2014; Farnsworth et al. 2015; Bingham et al. 2016).

State highway agencies should evaluate every project's characteristics before selecting an appropriate project delivery method because these characteristics can point to the use of a particular delivery method, or at least one that is more likely to achieve desired performance goals (Forgues and Koskela 2008; Gransberg et al. 2003; Tran et al. 2013). This highlights the need to incorporate highway construction project characteristics into project delivery method selection as accomplished in this dissertation. Additionally, by addressing limitations of previous research on project delivery method, selection and performance the findings from this dissertation provide an up-to-date perspective on US highway construction and utilitarian information for the industry.

1.3 Point of Departure

Motivated by the possibility of cost and time savings, numerous attempts have been made towards improving procedures for the selection of an appropriate project delivery method. At the outset, the majority of procedures could collectively be considered as qualitative approaches. Many researchers have built upon the work of those qualitative procedures to develop innovative ways of project delivery method selection, however, elements of those methods remain somewhat subjective. Also, in advancing project delivery method selection, researchers have underscored the value of experiential knowledge and proceeded to develop collections

of such knowledge for applying lessons learnt in past project delivery method selection to new projects. These researchers were prudent to highlight the limitations of their approaches and make recommendations for improvements in future work. This PhD research addresses many of the aforementioned limitations of previous researchers' qualitative approaches and makes improvements based on the recommendations of previous research (Kumaraswamy and Dissanayaka, 2001; Migliaccio et al., 2009; Ng et al., 2002; Oyetunji and Anderson, 2006).

This PhD research has the strategic advantage of avoiding the limitations of past research efforts. It departs in multiple ways from the work done by researchers who have studied project delivery and project performance. Specifically, this paper addresses recommendations for, a wider and more detailed study, a study designed to collect a project-based dataset, the need to extend findings into other construction project categories, and the need to categorize projects and highway construction variables into more homogeneous groupings (Kumaraswamy and Dissanayaka 2001; Farnsworth et al. 2015; Chen et al. 2016).

This research is heavily based on empirical project information presenting an advantage over the use of qualitative project delivery method selection approaches in previous work and thereby reducing the possibility of inherent biases and other subjective elements. The majority of the quantitative research on the selection or performance of project delivery methods have used smaller sample sizes and samples of projects that are not highway construction (Hale et al, 2009; Debella and Ries, 2006; Ibbs et al, 2003; Molenaar and Songer, 1998). Currently, the data collected for this research forms the largest empirical dataset exclusive to highway construction project delivery. Another highlight of this research is that the focus is solely on US highway construction projects thus, results are highly specific and relevant, as opposed to previous research that contains a mix of projects from multiple sectors and/or from different countries.

10

Some of the previous research on project delivery focuses on a single delivery method, others did not consider CM/GC because of the lack of prevalent use of this delivery method in highway construction at the respective times of the research. The information for this dissertation is from a period in which several agencies have completed a substantial amount of D-B and CM/GC projects. These agencies are confidently moving beyond the experimental phase and the learning curve of using the alternative project delivery methods. For instance, it is notable that this research distinctly separates low bid procured D-B (D-B/LB) from best-value procured D-B projects (D-B/BV). The D-B/LB projects use price as the sole factor in selection while the D-B/BV projects use factors in addition to cost (e.g., time, technical solution, etc.). This first-of-a-kind analysis provides insights as to how procurement impacts D-B performance.

At this juncture, in the context of highway construction, ambiguous definitions are not a major problem because many of the parameters of project delivery are documented and defined by practicing state DOTs and especially, by the governing body for US highway construction, the FHWA. Hence, this dissertation avoids ambiguities in the explanations of DOTs by referencing established definitions.

Notably, as a project performance metric, the timing of cost certainty is much less studied in existing project delivery literature than the direct cost and schedule metrics. Nonetheless, earlier cost certainty is invaluable with specific regard to highway construction, particularly, considering the current political climate which has heightened attention of expenditures on infrastructure. The inclusion of the timing of the cost certainty metric in this research enhances both project and program management for agencies by showing how project delivery methods can reveal costs earlier for the optimal use of often limited capital.

Ultimately, this dissertation aims to equip DOTs with information relevant to executing highway construction projects on time and within budget. Aside from

contributions to the construction engineering and management (CEM) body of knowledge, findings from this research hold value for practitioners involved in highway construction projects by illustrating fundamental relationships among the variables involved in project delivery method selection that may consequentially influence project performance. By enabling agency professionals to align information available early during project development, i.e. project characteristics, with reliable indications of project performance the author hopes to promote a richer understanding of whether or not a selected project delivery method can achieve performance goals on particular highway construction projects.

1.4 Overarching Research Question

The selection of an appropriate project delivery method is critical for project success. The selection is made early during project development. This research seeks to enhance the decision-making process by answering the following overarching research question:

How do highway construction project characteristics interact with project delivery methods to affect performance?

In the process exploring the overarching research question the attributes of project delivery performance are investigated in detail by addressing the following sub-questions and hypotheses, which are organized by chapters within this dissertation.

Chapter 2 (Manuscript 1)

Research Questions:

- How do D-B-B, CM/GC and D-B highway project delivery methods affect project duration and project intensity?
- How D-B-B, CM/GC and D-B highway project delivery methods impact the timing of cost certainty during project delivery?

Chapter 3 (Manuscript 2)

Hypotheses:

- CM/GC does not affect procurement duration in comparison to D-B.
- CM/GC does not affect design duration in comparison to D-B.
- CM/GC does not affect construction duration in comparison to D-B.
- CM/GC does not affect project duration in comparison to D-B.

Chapter 4 (Manuscript 3)

Research Questions:

- How does the performance of project delivery methods change across the levels of complexity, project type and project cost for highway construction projects?
- How do department of transportation professionals judge the performance of project delivery methods for specific descriptions of highway construction projects?

1.5 Contributions to the Body of Knowledge

The urgent demand to improve the status of US transportation infrastructure at this time coupled with the issue of limited financial resources forces state highway agencies to deliver projects efficiently, particularly, within budgeted cost. The added pressure of public scrutiny prevails in the delivery of US highway construction projects, as a result agencies need to expedite the delivery of projects in order to

minimize impacts on the traveling public. Collectively, the information in this dissertation provides an up-to-date perspective on highway construction projects in the US and presents information that agencies can use to deliver projects efficiently using the respective highway project delivery methods.

This dissertation builds on the work of researchers who have called for a more empirically-based study of project performance to improve the selection of appropriate delivery methods (Kumaraswamy and Dissanayaka 2001; AECOM, 2003; McGraw Hill Construction, 2014; Farnsworth et al. 2015; Bingham et al., 2016). Findings in this dissertation heavily rely on empirical project data successfully supplemented with information from experiential knowledge and as warranted by previous researchers the author incorporates efforts to compare justifiably similar projects to obtain useful information (Ernzen and Schexnayder 2000; Shrestha et al. 2007 & 2012).

At this juncture, a quantitative empirical examination of the schedule performance of the alternative project delivery methods, D-B and CM/GC, does not exist. Also, the existing project delivery method selection approaches are based on qualitative and subjective elements which can potentially introduce biases that may adversely affect project performance. Structured, quantitative decision analysis processes have several benefits over the simplistic, holistic, and informal processes that typically characterize subjective evaluations (Oyetunji and Anderson 2006). Considering that agencies are selecting the alternative delivery methods to shorten project schedules, as presented in this dissertation, the analytical comparisons of the schedule performance of D-B and CM/GC using empirical data is highly warranted (Bingham et al. 2016), more so with the growing use of alternative project delivery methods.

The recommendations presented in this dissertation are the result of in-depth investigation of project delivery methods used on US highway construction projects

14

of various characteristics with regard to performance metrics that are of high interest to both academia and industry. These recommendations are validated by multiple sources of information and are highly applicable to practice with the potential to make great impact on how agencies execute the phases of highway project delivery including design, procurement and construction. Notably, this dissertation examines some of the lesser published project performance metrics such as, the timing of cost certainty during project delivery and project intensity. Although some literature exists on variations of these performance metrics in relation to other sectors of construction this dissertation examines these performance metrics in a manner that holds value to the highway construction industry. Thus, this research addresses an acute gap in construction engineering and management knowledge by contributing new information that state highway agencies can use to better align information available at the early stages of a project with the selection of an appropriate project delivery method to achieve desired project performance outcomes.

1.6 Dissertation Organization

  This dissertation is a compilation of three manuscripts related to project delivery method performance and selection for highway construction projects. These manuscripts are organized into dissertation chapters as follows:

Chapter 2 (Manuscript 1) - Examination of Project Duration, Project Intensity and Timing of Cost Certainty in Highway Project Delivery Methods

This chapter compares the project delivery methods that are frequently used in two separate bins of project cost, $2M to $10M and $10M to $50M. In the $2M-$10M the delivery methods of D-B-B and D-B/LB are compared. The delivery methods of D-B-

B, CM/GC and best value procured D-B/BV are compared in the $10M to $50M cost pool. Results show that the alternative project delivery methods of CM/GC and D-B are superior to the traditional D-B-B method for the performance metrics of project duration, project intensity and timing of cost certainty in both cost pools. In comparing the alternative project delivery methods in the $10M to $50M cost range the CM/GC method was found to outperform D-B/BV. This chapter shows that the alternative project delivery methods are viable options for, shortening project durations, establishing early cost certainty during project delivery, and delivering projects at a more intense pace.

Chapter 3 (Manuscript 2) – A Quantitative Comparison of D-B vs CM/GC Schedule Performance in Highway Construction Projects

The selection of D-B and CM/GC for schedule compression of highway construction projects prevails despite a dearth of quantitative analytical comparisons of the performance of these delivery methods. To address this gap in knowledge, this chapter explores the performance of D-B versus CM/GC projects for the metrics of, procurement, design, construction, and overall project duration. A univariate analysis of the schedule performance metrics shows that, on average, CM/GC projects have shorter procurement, design, and project durations than D-B and that projects using either delivery method have similar construction durations. A supplemental multivariate statistical analysis reveals the individual and interaction effects of project characteristics that affect schedule performance for more in-depth comparisons of D-B versus CM/GC schedule performance. The overall trend in the results from the multivariate analysis is that CM/GC has better schedule performance than D-B.

Chapter 4 (Manuscript 3) – Impact of Highway Project Characteristics on Project Delivery Performance

In this chapter, highway construction projects are categorized by the characteristics of size, type and complexity to provide a practical means of analysis and to make results more applicable to the process of selecting appropriate project delivery methods for highway project delivery. Information from an empirical examination of 284 projects is supplemented with information based on experiential knowledge obtained from highway project delivery experts through the Delphi technique. Findings are confirmed by the triangulation of information from the empirical data, the Delphi study results and existing literature to validate recommendations that are applicable in industry. The results provide new evidence that alternative project delivery methods are superior to D-B-B in terms of schedule compression and cost growth, however, D-B-B remains indispensable on certain projects. The results are useful to highway agency professionals for the selection of appropriate project delivery methods by indicating how highway construction project characteristics affect project delivery performance.

Chapter 5 – Conclusion

This chapter contains a summary of this dissertation's new contributions to the construction engineering and management (CEM) body of knowledge and distinguishes the theoretical and practical contributions. Also included is a discussion of limitations and recommendations for future work associated with this dissertation. The chapter concludes with reflections from the author about the research experience and how the knowledge acquired may impact career goals and professional aspirations.

1.7 Research Experience

Overall, the topic of this dissertation highly aligns with the author's research interests and the journey to accomplish this dissertation provided invaluable learning and research experiences from the outset. The journey has afforded the author an holistic understanding of US highway project delivery with particular focus on alternative project delivery methods. Consequentially, the author anticipates that the knowledge gained through comprehensively studying the associated processes of project delivery such as procurement procedures, payment methods, and risk allocation, will be indispensable in his professional career; more so, as it is all in relation to the US construction sector with the inherent intricacies of federal regulations and state legislation.

Through the research experience, the author has become acquainted with procedures for the selection of project delivery methods and remains aware that for more probable project success a suitable delivery method should be selected objectively. Aside from the CEM knowledge gained the author developed new analytical skills through learning and applying computational and statistical methods to manage and explore data. Ultimately, notwithstanding the academic achievements, the collective experiences have contributed to the professional development of the author through the social and collaborative efforts of working with fellow researchers and responsibilities for writing publications, assisting with grant applications and presenting findings in appropriate formats to various audiences.

This dissertation is a compilation of three manuscripts related to the performance of project delivery methods. These three manuscripts are intended for journal publications, however, in the process of conducting research for this dissertation the author produced other significant publications. These publications contribute to the CEM body of knowledge and have been well received based on the

high interest of industry personnel. The appendices to this dissertation contain the following publications that the author has worked to produce:

- "An Empirical Study Of The State-Of-Practice In Alternative Technical Concepts In Highway Construction Projects" - Transportation Research Record, Journal of the Transportation Research Board
- "Desired versus Realized Benefits of Alternative Contracting Methods on Extreme Value Highway Projects" - The Ninth International Structural Engineering and Construction Conference (ISEC-9).
- "The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects" - International Conference on Sustainable Design Engineering & Construction.
- "FHWA TechBrief: Alternative Contracting Method Performance In Us Highway Construction" – as part of FHWA national study: Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications (DTFH61-13-R-00019).

CHAPTER 2 (Manuscript 1) - EXAMINATION OF PROJECT DURATION, PROJECT INTENSITY AND TIMING OF COST CERTAINTY IN HIGHWAY PROJECT DELIVERY METHODS

2.0 Abstract

While agencies design and construct the vast majority of federally funded highways through the traditional design-bid-build (D-B-B) method, the use of construction manager/general contractor (CM/GC) and design-build (D-B) is increasing. Previous research papers on the performance of these delivery methods include projects of different characteristics and projects from different sectors. This paper examines solely US highway projects through a unique analysis of comparable projects. This paper compares the project delivery methods that are frequently used in two separate cost pools, $2M to $10M and $10M to $50M. In the $2M-$10M the delivery methods of D-B-B and low bid procured D-B (D-B/LB) are compared. The delivery methods of D-B-B, CM/GC and best value procured D-B (D-B/BV) are compared in the $10M to $50M cost pool. Results show that the alternative contracting methods of CM/GC and D-B are superior to the traditional D-B-B method for the performance metrics of project duration, project intensity and timing of cost certainty in both cost pools. In comparing the alternative contracting methods in the $10M to $50M cost range the CM/GC method was found to outperform D-B/BV, which has not yet been shown in the research literature. With pressure on state transportation agencies to be efficient with funds, the alternative contracting methods are viable options for shortening project durations, establishing early cost certainty during project delivery, and delivering projects at a more intense pace. The findings presented are useful for practitioners to better understand how project delivery methods can meet their needs for US highway construction.

2.1 Background & Motivation

It is pertinent to understand both the characteristics and the history of the alternative contracting methods for readers to interpret the findings and apply the results of this paper. Alternative contracting methods are any contractual method that is not a traditional design-bid-build (D-B-B) method. In US highway construction projects, there are two primary alternative contracting methods: design-build (D-B) and construction manager/general contractor (CM/GC). Few studies have compared D-B-B, D-B and CM/GC performance in the US highway sector. This is the understandable result of the relatively new and growing use of CM/GC versus the more mature D-B or the traditional D-B-B method.

The majority of the US highway network was built using the D-B-B delivery method which was solidified by the Miller Act of 1935 (Beard et al. 2001). Nationwide use of the alternative contracting methods within the transportation sector began with the enactment of FHWA's Special Experimental Project Number 14 (SEP-14) – Innovative Contracting in 1990 (FHWA 2002). The SEP-14 was enacted to allow state transportation agencies to use a variety of alternative contracting methods while testing and evaluating the use of these methods. Under the SEP-14 program, approximately 300 projects were proposed for D-B contracting between 1995 and 2002, 25 projects were proposed for CM/GC between 2003 and 2015 (FHWA 2016a). Although SEP-14 opened the door for the use of CM/GC, its growth within highway was relatively slow when compared to D-B (Gransberg and Shane, 2010). To facilitate greater CM/GC use, the Moving Ahead for Progress in the 21st Century Act (MAP-21) was enacted in July 2012 which removed the requirement for agencies to request FHWA approval to use CM/GC under the SEP-14 (FWWA 2012a). By the end of 2014, the number of state Departments of Transportation (DOTs) fully employing the CM/GC method increased to 17 and continues to grow. This growth lags behind D-B

usage, which included 34 state agencies and the Federal Lands Highway agency by the end of 2014 (FHWA, 2015).

Figures 2-1, 2-2, and 2-3 present an illustration of the project delivery phases for each of the project delivery methods. With D-B-B, the agency has full ownership of design development. Construction begins only after full design completion. As in D-B-B, CM/GC allows the agency to maintain full ownership of the design. Unlike D-B-B, the agency contracts with a construction manager (CM) early during design development for preconstruction services. When the design is mature enough, all parties agree upon a price for construction and the CM becomes the general contractor (GC) (CDOT, 2015). At this point the owner/agency contractually transfers the risk for, the final cost and duration of construction to the GC. As can be seen in Figure 2-2, CM/GC can release construction in phases/packages rather than a single fully completed design for construction of the entire project. Figure 2-2 shows just two construction packages for illustration, but there more than two are frequently used. Figure 2-3 separates the D-B process into low bid procured D-B (D-B/LB) and best value procured D-B projects (D-B/BV) with the latter being projects procured through selection factors in addition to cost. With D-B, a single entity contracted to perform both design and construction services, transferring the design risk to the contractor more fully than with CM/GC or D-B-B (Ellis 1991; AECOM, 2003).

◆ - Contract Award
"IFB" – Invitation for Bids
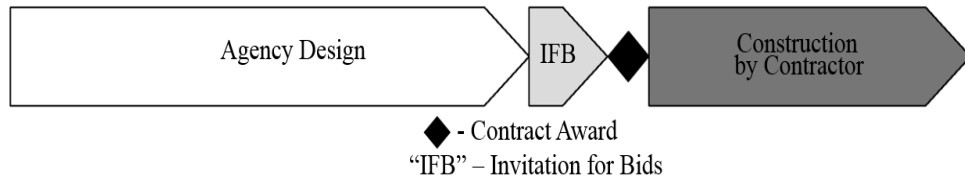
Figure 2-1. D-B-B method (not to scale)

◆ - Contract Award
"RFP" - Request for Proposal
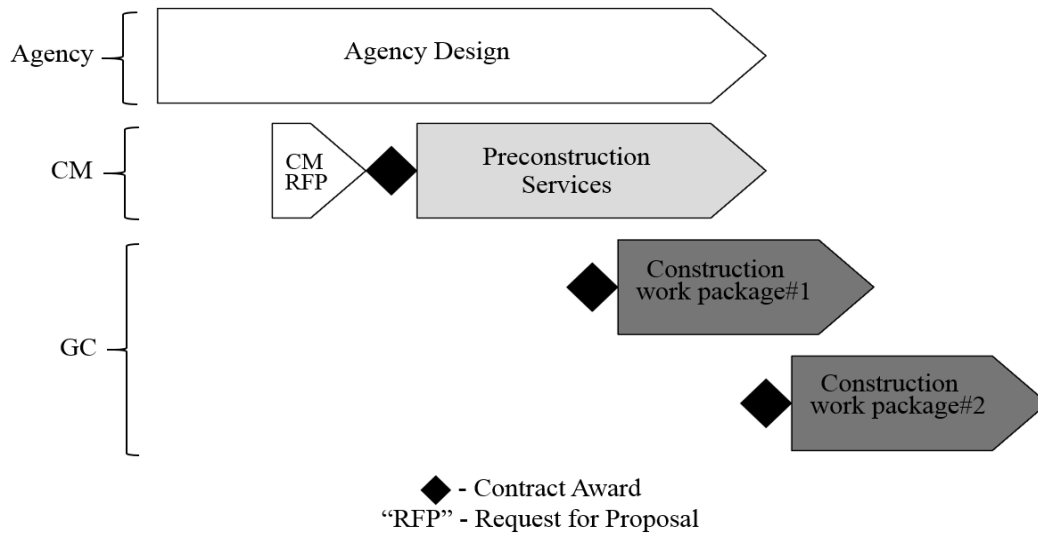
Figure 2-2. CM/GC method (not to scale)

◆ - Contract Award
"RFQ" - Request for Qualifications
"RFP" - Request for Proposal
*D-B/LB excludes "D-B RFQ"
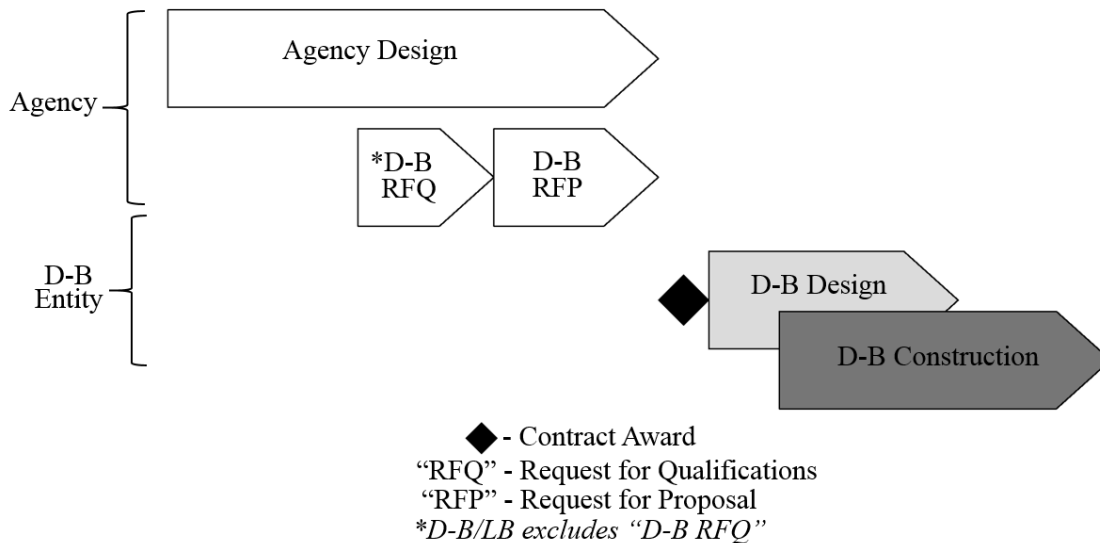
Figure 2-3. D-B methods (not to scale)

Aggressive schedule compression is the most influential factor when selecting alternative contracting methods (Touran et al. 2011). As a result of aging infrastructure, limited financial resources, and increased public scrutiny of transportation projects, highway construction agencies are turning to alternative contracting methods to reap the potential benefits, particularly schedule compression (AECOM, 2003; Forgues and Koskela, 2008; McGraw Hill Construction, 2014). The main incentive for developing alternative contracting methods is to shorten project schedules (Warne 2005; ODOT, 2009; Touran et al. 2011; Shrestha et al. 2012; Goftar et al. 2014). In light of these revelations, the focus of this research paper is to determine how project delivery methods impact project duration, project intensity, and the timing of the point of cost certainty during project delivery.

2.2 Previous Project Delivery Method Performance Studies

The need to have similar projects for the comparison of project delivery methods is recognized in the majority of previous research on the topic of project performance (Roth 1995; Konchar and Sanvido 1998; Ernzen and Schexnayder 2000; FHWA, 2006; Rojas and Kell 2008). Comparison of a highway project is only useful if the project is compared against similar projects (Shrestha et al. 2012). Acknowledging the need to compare similar projects the authors of this paper develop a defensible method to match similar projects among different project delivery methods.

Literature on project delivery method schedule performance shows that alternative contracting methods are superior to D-B-B (Gordon, 1994; Molenaar and Songer, 1998; Septelka and Goldblatt, 2005; Hale et al., 2009; Carpenter and Bausman, 2016; Farnsworth et al., 2015; Bingham et al., 2016). However, there is scarcity of literature on the comparison of CM/GC versus D-B schedule performance based on quantitative empirical data. At this juncture, a quantitative empirical

examination of the schedule performance of CM/GC versus D-B project delivery is warranted (Bingham et al., 2016).

Project duration is a straightforward schedule metric to study how long agencies are taking to deliver US highway construction projects through different project delivery methods. This is particularly relevant as agencies most frequently choose alternative contracting methods to shorten project duration (Warne 2005; Touran et al. 2011; Shrestha et al. 2012, Goftar et al., 2014). Project intensity is another useful schedule metric to study the rate of delivery of US highway construction projects. This metric provides an indication of the rate at which resources are invested in a project (Konchar and Sanvido 1998; Molenaar and Songer, 1998; Shrestha et al. 2012). The point of cost certainty during project delivery is the time at which an agency obtains a fixed and reliable cost. It is important for resource allocation. Early cost certainty is another reason why agencies select alternative contracting methods (Songer and Molenaar, 1996; Shrestha et al., 2007; Gransberg and Shane, 2010; Touran et al., 2011).

2.3 Point Of Departure

Much of the exiting body of knowledge with regard to empirical project performance contains a mix of projects from multiple sectors. In most cases, the projects studied were for vertical facilities (Konchar and Sanvido, 1998; Molenaar and Songer, 1998; Septelka and Goldblatt, 2005; Hale et al., 2009; Carpenter and Bausman, 2016). In this paper, the authors address recommendations for a more detailed study, designed to collect a project-based dataset that represents a specific and more homogeneous construction project category. The results in this paper are therefore specific and highly relevant to US highway construction. The unique analysis of comparable highway projects between delivery methods further enhances the pertinence of results.

25

In addition to the more commonly studied metric of project duration, this paper explores the less cited schedule performance metrics of the timing of cost certainty and project intensity. Early knowledge of project costs and the rate of project execution are important to highway construction agencies. Project intensity is a hybrid measure of the rate that resources are put into a project and a solid indicator of a highway construction project's delivery speed. In this paper the unit of measure for project intensity is dollars per day ($/day) unlike in the work of some previous researchers who have based the metric on the rate of completion of specific physical aspects of a project.

Given the existing academic body of knowledge and the practical need for understanding the performance of alternative delivery methods on similar projects, this research explores the following questions:

- How do D-B-B, CM/GC and D-B highway project delivery methods affect project duration and project intensity?
- How D-B-B, CM/GC and D-B highway project delivery methods impact the timing of cost certainty during project delivery?

2.4 Data Gathering And Matching Of Project Characteristics

The project information was acquired for this study by contacting personnel from 54 agencies across the US over the course of 18 months. Although time consuming, the authors found that a two-phase approach enhanced the data collection process. In the first phase, contract managers and estimators were contacted to request information on the general project characteristics, cost and schedule data from the historic contract administration or estimating records. The information obtained was pre-filled into project specific questionnaires, which were then sent to project managers who completed any remaining sections. Ultimately,

empirical project information was obtained for 136 projects completed between 2004 and 2015. The projects are solely from DOTs and the FHWA Office of Federal Lands Highway.

To lend objectivity to the study, the projects that used alternative contracting methods were randomly selected from agencies actively engaged in those delivery methods. Then the agencies supplied D-B-B projects that matched each D-B and CM/GC project according to set criteria. Ideally, the contract award date of the matching D-B-B projectts are within +/- 2 years and within +/-25% of the award cost of the corresponding D-B or CM/GC projects, additionally, attempts were made to have projects similar in scope. It should be noted that the matching of projects in this fashion did not employ a formal statistical technique in which two measurements are matched or paired and may come from the same observation (Dallal, 2015). In this study the matching of projects was done to influence the size of projects within the study with the aim of reducing the likelihood of comparing projects that were extremely contrary to each other or comparing projects that are extreme outliers.

The data from each project was obtained via a tested and well-structured questionnaire that was administered to agency professionals. The quality of the data was ensured both at the schema and instance levels through rigorous quality control techniques (Rahm and Do, 2000). Quality control was facilitated by double-checking responses with superior staff at the DOTs, and by manual and low-level programming checks for verification of correct data entry. Multi-source problems were minimal as there was no need to integrate data from multiple sources for a single project. Where necessary, the DOT professionals were able to pass on partially completed questionnaires to other individuals within their agency for provision of missing information. This served as an additional self-correcting or vetting process.

Down-sampling from the data set of 136 projects the authors sought the most consistent means to compare the project delivery methods based on projects with

similar characteristics. Through numerous iterations, the authors ascertained that certain delivery methods more frequently used within two distinct cost ranges. Hence, two smaller cost pools of projects are analyzed. The first cost pool includes projects with award costs from $2M to $10M. It compares 10 D-B-B and 10 D-B/LB projects since these are the delivery methods more frequently chosen for projects in this cost range. The second cost pool has projects with award costs from $10M to $50M and compares 10 D-B-B, 10 CM/GC, and 10 D-B/BV projects. Within each cost pool, the authors selectively chose projects that have similar characteristics across each project delivery method. Projects are similar based on the following criteria:

1. The award cost of each project is +/-25% of each other.

2. The complexity rating is similar, as based on the definitions provided in Table 2-1.

3. The facility type, i.e. road or bridge project, is similar.

4. The project type is similar, i.e. new construction or rehabilitation/renewal project, is similar.

Table 2-1. Complexity definitions (Anderson et al., 2007)

Most Complex (Major) Projects	Moderately Complex Projects	Non-complex (Minor) Projects
• New highways; major relocations • New interchanges • Capacity adding/major widening • Major reconstruction (4R; 3R with multi- phase traffic control) • Congestion management studies are required • Environmental Impact Statement or complex Environmental Assessment required	• 3R and 4R projects which do not add capacity • Minor roadway relocations • Non-complex bridge replacements with minor roadway approach work • Categorical Exclusion or non-complex Environmental Assessment required	• Maintenance betterment projects • Overlay projects, simple widening without right-of-way (or very minimum right-of-way take) little or no utility coordination • Non-complex enhancement projects without new bridges (e.g. bike trails) • Categorical Exclusion

Note: "3R" = Resurfacing, Restoration, Rehabilitation
       "4R" = New Construction/Reconstruction

2.5 Data Characteristics

As presented in Table 2-2, in the $2M to $10M cost pool the D-B-B and D-B/LB have similar average award costs of $4,776,575 and $4,745,533 respectively. Likewise, in the $10M to $50M cost pool the D-B-B, CM/GC, and D-B/BV projects have similar average award costs of $23,081,092, $23,912,981, and $18,604,503, respectively, as shown in Table 2-3. A statistical test, the t-test, confirmed that the differences among the average award costs of the project delivery methods are not statistically significant at the 95% confidence level in either cost pool.

Table 2-2. Award cost descriptives statistics for D-B-B and D-B/LB projects between $2M-$10M

Delivery Method	N	Mean	Std. Dev.	Min.	Median	Max.
D-B-B	10	$4,776,575	$2,592,518	$2,067,493	$4,935,703	$9,474,478
D-B/LB	10	$ 4,745,533	$2,013,985	$2,393,999	$4,140,000	$7,504,820

Table 2-3. Award cost descriptive statistics for D-B-B, CM/GC, D-B/BV projects between $10M-$50M

Delivery Method	n	Mean	Std. Dev.	Min.	Median	Max.
D-B-B	10	$23,081,092	$8,671,426	$11,429,469	$22,332,388	$37,574,315
C-M/G-C	10	$23,912,981	$8,849,869	$10,634,644	$21,571,119	$39,600,000
D-B/BV	10	$18,604,503	$10,169,378	$10,875,000	$15,149,741	$43,960,798

As shown in Table 2-4 the D-B-B and D-B/LB projects compared in the $2M to $10M cost pool have similar complexity ratings with the majority of projects in each delivery method having a rating of moderately complex. The two most complex D-B-B and two most complex D-B/LB projects in this cost pool drew the attention of the authors to investigate why these projects were rated as most complex. One of the D-B-B projects used technology that was completely new to the agency at that time. It involved construction of the first ever post-tensioned precast deck panel bridge in the state. The other D-B-B project had significant and ongoing right-of-way issues which

resulted in extreme scope changes that necessitated utility cell tower relocations to be included in the project's scope. Of the D-B/LB projects, in one project, as a result of the frequency of wildlife and vehicle collisions. The agency had commitments to provide wildlife mitigation features into the project's design and accommodate wildlife mitigation during construction. At the inception of the other D-B/LB the scope was just for rehabilitation of a bridge over a section of a railroad. However, further investigation of the rehabilitation needs of the structure revealed that the cost was similar in magnitude to the cost of full reconstruction/replacement which was significantly impacted by issues with the railroad.

Table 2-4. Distribution of the complexity rating for D-B-B and D-B/LB projects between $2M-$10M

Delivery Method	Complexity Rating		
-	Most	Moderate	Non-
D-B-B (n=10)	2	6	2
D-B/LB (n=10)	2	6	2

The D-B-B, CM/GC, and D-B/BV methods compared in the $10M to $50M cost pool also have similar complexity ratings with the majority of projects rated as most complex, as shown in Table 2-5. Upon investigation, the single D-B-B project in this cost pool is likely rated as non-complex because it was a straightforward pavement patch and rehabilitate job but the extent of the works along with necessary road-user accommodation works heightened the project's cost.

Table 2-5. Distribution of the complexity rating for D-B-B, CM/GC and D-B/BV projects between $10M-$50M

Delivery Method	Complexity Rating		
-	Most	Moderate	Non-
D-B-B (n=10)	6	3	1
CM/GC (n=10)	6	4	0
D-B/BV (n=10)	6	4	0

With regard to specific facility types, respondents gave the percentages of the work components for each project in the categories of road, bridge, and other work. For facility type, the qualitative explanations provided by respondents reveal that the category of "other work" includes work such as landscaping, guardrail installation and signalization. At the aggregate level in the award cost range from $2M to $10M, the D-B-B projects are on average 55% road, 40% bridge and 5% other work. The D-B/LB projects in this cost range are on average 43% road, 54% bridge and 3% other work. In the award cost range from $10M to $50M, at the aggregate level, the D-B-B projects are on average 73% road, 20% bridge and 7% other work. The CM/GC projects in this cost range are on average 72% road, 19% bridge and 9% other work. The D-B/BV projects are on average 46% road, 46% bridge and 8% other work. The higher percentage of bridge work is the only notable difference in this $10M to $50M pool.

With regard to specific project types, respondents provided percentages for the descriptions of new construction, rehabilitation/renewal (rehab/renew), and others. For project type, the qualitative explanations provided by respondents reveal that the

category of "others" describes projects that were for minor maintenance, replacement and/or restoration purposes. At the aggregate level in the award cost range from $2M to $10M, the D-B-B projects are on average 53% new construction, 47% rehab/renew, and 0% other. The D-B/LB projects in this cost range are on average 46% new construction, 54% rehab/renew, and 0% others. In the award cost range from $10M to $50M, at the aggregate level, the D-B-B projects are on average 15% new construction, 85% rehab/renew and 0% others. The CM/GC projects in this cost range are on average 18% new construction, 82% rehab/renew, and 0% other. The D-B/BV projects are on average 42% new construction, 47% rehab/renew, and 1% other. The higher percentage of rehab work is the only notable difference in this $10M to $50M pool.

2.6 Results And Discussion

This section presents a discussion of the findings within the metrics studied, project duration, the timing of cost certainty and project intensity. When comparing the results of this study to the aforementioned research in project delivery performance, readers should note a few key differences. The procurement process for highways is substantially longer than for building projects. Owners can procure building projects with less design and more performance-based requirements. Highway procurement have stringent requirements needed for highway construction safety and continuity within the road network. Furthermore, highway construction is more likely to be affected by issues such as National Environmental Policy Act (NEPA) and right-of-way requirements which need to be resolved, or at least thoroughly understood, prior to issuing an RFP. While previous research papers have

included projects with different characteristics, or even from different sectors, this paper presents an examination of alternative contracting methods specifically within the US highway construction sector. As previously mentioned, projects within the delivery methods in the respective cost pools are similar based on characteristics of award cost, complexity, facility type, and project type. For this manuscript, the means of the various durations have been compared on a pairwise basis among the delivery methods at the 95% confidence level by using appropriate statistical tests for means; i.e. the t-test and Mann Whitney U test for parametric and non-parametric cases respectively.

2.6.0 Project Duration

Agencies chose alternative contracting methods to shorten project durations, which the data from this study show they are achieving. Table 2-6 and Table 2-7 present the durations of each phase of project delivery for each cost pool studied. Project duration is based on the final duration, which includes all contract changes and/or builder delays. It should be noted that "construction duration" for D-B projects includes design-builder design and construction duration (i.e., the D-B contract duration from award to completion).

The mean costs of the D-B-B and D-B/LB projects in the $2M to $10M range are similar, allowing for an accurate comparison of the project, design and construction durations. The mean D-B/LB project duration is 46% shorter than D-B-B projects in this dataset. Agencies took approximately 76% less time for D-B/LB design as compared to the mean D-B-B agency design duration. The mean D-B/LB construction time, which includes both the design-builder design and construction time, is approximately 20% shorter than D-B-B on average.

33

The time savings of D-B/LB versus D-B-B confirms the well cited schedule acceleration benefit of D-B (Bennett et al., 1996; Konchar and Sanvido, 1998; NYDOT, 2002; SAIC, 2002; Ernzen et al., 2003; AECOM, 2003; Warne, 2005; Ellis et al., 2007). This acceleration is often attributed to being able to expedite procurement by the minimal design effort required of agencies and by the early start of construction which may overlap with design duration (Songer et at., 1996; ODOT, 2009; MnDOT, 2011; VDOT, 2011; CDOT, 2014; FDOT, 2016). Design duration is an integral process within overall project schedule (Gransberg and Shane, 2010). The shorter design duration with D-B/LB attests to the impact of early contractor involvement in the alternative contracting method, this helps to achieve schedule compression (Songer and Molenaar, 1996; McGraw Hill Construction, 2014; AECOM, 2003, Gransberg et al., 2003). Considering this analysis compares projects with similar characteristics an interesting finding is the 20% acceleration in construction speed with D-B/LB, this may also be a byproduct of early contractor input in design development which leads to improved constructability (Gransberg, 2013a).

Table 2-6. Durations for D-B-B and D-B/LB projects between $2M-$10M

Delivery Method	Mean Project Duration (days)	Mean Agency Design Duration (days)	Mean Procurement Duration (days)	Mean Construction Duration (days)
D-B-B (n=10)	1,431*	751*	51	477
D-B/LB (n=10)	773*	181*	116	380

* - indicates values that have a statistically significant difference from the other values within each column.

Table 2-7 summarizes the durations of the D-B-B, CM/GC and D-B/BV projects in the $10M to $50M cost pool. The mean CM/GC project duration is 69% and 53% shorter than D-B-B and D-B/BV, respectively. Shorter CM/GC mean durations are

seen in both design and construction. The shorter design duration for CM/GC is surprising because the CM/GC process, similar to D-B B, brings the design to 100% completion prior to contract award. The shorter CM/GC design duration is likely due to multiple factors. Having the construction manager on the team during design can lead to a shorter design length which allows the agency to fast-track the design (Gransberg, 2013a; Gransberg and Shane, 2010). In addition to gaining contractor input, there is no need to develop full designs for competitive bidding, as in D-B-B (Gransberg, 2013b). The shorter CM/GC construction duration is likely due, at least in part, to involving the contractor in the project design process (Gransberg, 2013a). In comparison to D-B/BV, the shorter durations of CM/GC may be the result of a shorter, less complicated request for proposals (RFPs) process. In D-B/BV the develop RFPs are often voluminous and sometimes need extended industry review periods along with lengthier agency evaluations (Migliaccio et al. 2009).

The shorter CM/GC project duration in comparison to D-B-B is a confirmation of previous literature findings (Konchar and Sanvido, 1998). It may be attributed to CM/GC's ability to release drawings for construction in separate work packages as designs/drawings are completed. The use of multiple work packages to speed construction is frequently cited as a CM/GC benefit (i.e. the overlap of design and construction) (Gransberg and Shane, 2010). However, CM/GC being shorter than D-B/BV is not common in previous research and this warrants further investigation to establish whether this is indeed a potential advantage of CM/GC versus D-B/BV.

D-B/BV also shows substantially shorter mean durations with 33%, 43% and 26% shorter project, design and construction durations compared to D-B-B. This shorter construction duration is also likely due to contractor involvement with the design (Kenig 2011; Gransberg, 2013a; Gransberg et al., 2003; Minchin et al. 2014), though it is notable that it includes the time for design-builder design.

Table 2-7. Durations for D-B-B, CM/GC and D-B/BV projects between $10M-$50M

Delivery Method	Mean Project Duration (days)	Mean Agency Design Duration (days)	Mean Procurement Duration (days)	Mean Construction Duration (days)
D-B-B (n=10)	2,106	1,117	67	865
CM/GC (n=10)	662*	281*	48**	349*
D-B/BV (n=10)	1,420	638	127**	639

* - indicates values that have a statistically significant difference from the other values within each column.
** - indicates values that have a statistically significant difference from each other while there is no difference when compared to the other values within each column.

In summary, agencies appear to be gaining substantial time savings with the use of alternative contracting methods. While these empirical findings are new, the overall time savings of alternative contracting methods are well-cited in literature as a benefit (Bennett et al., 1996; Konchar and Sanvido, 1998; NYDOT, 2002; SAIC, 2002; Ernzen et al., 2003; AECOM, 2003; Warne, 2005; Ellis et al., 2007), as is the faster design time (Songer et al., 1996; ODOT, 2009; MnDOT, 2011; VDOT, 2011; CDOT, 2014; FDOT, 2016). As the analysis compares projects that are similar in scope and award cost, the findings indicate how an agency can use an appropriate project delivery method to minimize public impact and the expenditure of agency resources.

2.6.1 Timing of the Point of Cost Certainty

Alternative contracting methods are providing agencies with much earlier cost certainty. Cost certainty equates to the point at which the agency obtains a reliable project cost. Agencies value early cost certainty for both, project and program management to better manage and allocate resources during project delivery because

early cost certainty facilitates the optimal use of, often limited, capital (Hastak, 2015). It can indicate the probability of completing a project within the budget agreed between clients and contractors (Xiao and Proverbs, 2003). Thus, achieving project cost certainty early during project delivery allows agencies to more efficiently manage the expenditure of project funds.

Figure 2-4 figuratively presents the point of cost certainty based on the magnitude of the mean, design, procurement, and construction durations for D-B-B and D-B/LB projects between $2M to $10M as shown in Table 2-8; only the mean cost certainty timing is statistically tested. In D-B-B, the initial contract cost, i.e. point of cost certainty, is known at the time of contract award. In D-B/LB, the initial contract cost is known at the point of design-builder selection. For D-B-B and D-B/LB projects in this pool, D-B/LB cost certainty is known more than 60% earlier. This finding confirms qualitative literature assertions (Songer and Molenaar, 1996; Shrestha et al. 2007; Gransberg and Shane, 2010; Touran et al., 2011). It also has value for agencies in planning their letting schedules.

Table 2-8. Timing of cost certainty for D-B-B and D-B/LB projects between $2M-$10M

Delivery Method	Start of Design to Start of Procurement (Days)	Procurement Duration (Days)	Construction Duration (Days)	Project Duration (Days)	Timing of Cost Certainty (Days)
D-B-B (n=10)	751	51	477	1,431	801*
D-B/LB (n=10)	181	116	380	773	297*

* - indicates values that have a statistically significant difference from the other values within each column.
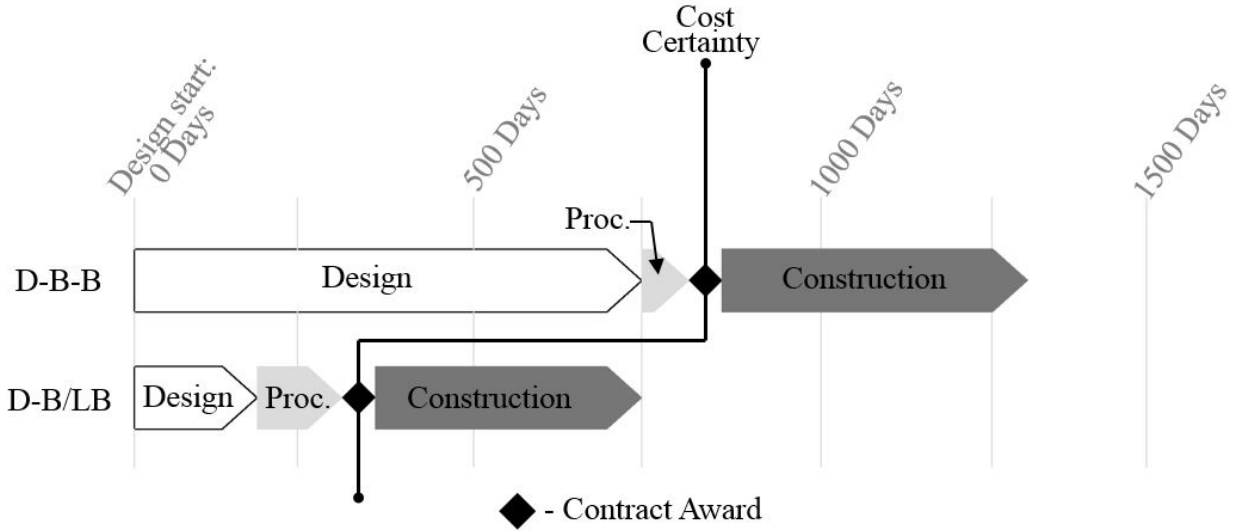
Figure 2-4 Point of cost certainty for D-B-B and D-B/LB projects between $2M-$10M

Figure 2-5 illustrates the point of cost certainty based on the mean design, procurement and construction durations for D-B-B, CM/GC, and D-B/BV projects between $10M to $50M as shown in Table 2-9; only the mean cost certainty timing is statistically tested. The potential reasons for the point of cost certainty in D-B-B and D-B/BV projects were previously explained with the D-B/LB results discussion. The point of cost certainty for CM/GC projects is known after the cost for the last construction package is established. CM/GC projects may have one or more construction packages. Figure 2-2 shows only two packages for simple illustrative purposes. For ease of illustration, Figure 2-5 combines all bid packages with the award of the last bid package and does not show the overlap of design and construction (although it does exist). When compared to D-B-B, the average point of cost certainty for CM/GC is more than 60% earlier. This confirms previous qualitative literature assertions (Gransberg and Shane, 2010; Touran et al., 2011). The point of cost certainty for D-B/BV is more than 40% earlier than D-B-B, which also confirms previous literature assertions (Songer and Molenaar, 1996; Shrestha et al. 2007; Gransberg and Shane, 2010; Touran et al., 2011). Notable, however, no

38

previous literature has asserted or shown that CM/GC provides earlier cost certainty

than D-B (Goftar et al. 2014).

Table 2-9. Timing of cost certainty for D-B-B, CM/GC and D-B/BV projects between $10M-$50M

Delivery Method	Start of Design to Start of Procurement (Days)	Procurement Duration (Days)	Construction Duration (Days)	Project Duration (Days)	Timing of Cost Certainty (Days)
D-B-B (n=10)	1,117	67	865	2,106	1,184**
CM/GC (n=10)	281	48	349	662	329**
D-B/BV (n=10)	638	127	639	1,420	765

*** - indicates values that have a statistically significant difference from each other while there is no difference when compared to the other values within each column.*
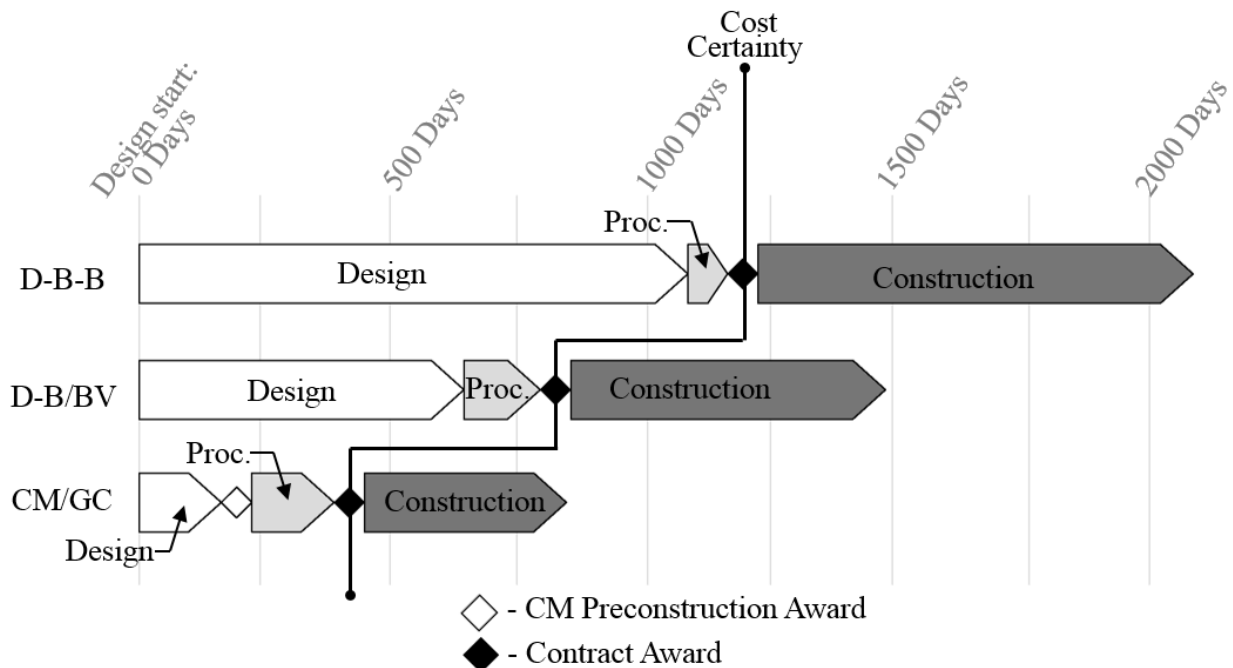
Figure 2-5 Point of cost certainty for D-B-B, CM/GC and D-B/BV projects between $10M-$50M

In summary, agencies are receiving cost certainty substantially quicker with alternative contracting methods. CM/GC early cost certainty is of special note and should be the focus of future research to solidify this feature as an advantage of CM/GC. With increasing funding deficits and the deterioration of existing infrastructure, it is vital that agencies efficiently plan and spend their funds. Cost certainty allows agencies to acquire better spending efficiency, and to better plan spending at both a project and programmatic level.

2.6.2 Project Intensity

In this paper, project intensity is a measure of how much money is spent per day during project delivery. Higher intensity equates to a faster rate of project delivery. Intensity is therefore an excellent measure of how agencies are minimizing the impact of highway construction on the traveling public by completing projects at a faster pace. Furthermore, the normalizing effect (i.e., the ratio of investment over duration) makes this metric ideal for comparing the project delivery methods. Project intensity is defined by the following equation:

$$Project\ Intensity = \frac{Final\ Cost\ (\$)}{Actual\ Project\ Duration\ (days)} \tag{1}$$

Table 2-10 provides the project intensity metrics for similar D-B-B and D-B/LB projects in the \$2M-\$10M cost range; only the mean project intensity is statistically tested. In comparison to similar D-B-B projects in the \$2M-\$10M cost range the project intensity of D-B/LB is higher; an unsurprising result since alternative contracting methods facilitate increased project intensity (Konchar and Sanvido, 1998).

Table 2-10. Project intensity for D-B-B and D-B/LB projects between $2M-$10M

Delivery Method	Mean ($/day)	Std. Dev. ($/day)	Min. ($/day)	Median ($/day)	Max. ($/day)
D-B-B (n=10)	4,431	3,129	838	3,710	11,101*
D-B/LB (n=10)	8,040	6,004	2,728	5,864	23,509*

* - indicates values that have a statistically significant difference from the other values within each column.

Table 2-11 provides the project intensity metrics for similar D-B-B, CM/GC and D-B/BV projects in the $10M-$50M cost range; only the mean project intensity is statistically tested. The shorter project duration and higher contract cost of the CM/GC and D-B/BV projects result in much higher project intensity than similar D-B-B projects in the $10M-$50M cost range. These results concur with literature that show increased project intensity is a benefit of CM/GC and D-B (Konchar and Sanvido, 1998; Septelka and Goldblatt, 2005; Carpenter and Bausman, 2016). However, the similar intensities of D-B-B and D-B/BV is surprising and warrants further examination.

Table 2-11. Project intensity for D-B-B, CM/GC and D-B/BV projects between $10M-$50M

Delivery Method	Mean ($/day)	Std. Dev. ($/day)	Min. ($/day)	Median ($/day)	Max. ($/day)
D-B-B (n=10)	17,202	16,985	4,723	13,021	63,397
CM/GC (n=10)	48,269	41,605	19,910	31,718	159,031*
D-B/BV (n=10)	18,679	11,412	3,846	16,768	42,393

* - indicates values that have a statistically significant difference from the other values within each column.

In summary, agencies appear to be placing more work within a shorter amount of time through alternative contracting methods. As serving the public is the number one goal of all governmental agencies, minimizing public impact is a welcomed benefit. This finding can aid agency personnel in choosing an appropriate project delivery method, particularly when projects are located in urban or heavy economic areas.

2.7 Conclusions

   The unique analysis of comparable projects in this paper provides intriguing new results that highlight key benefits of alternative contracting methods. Project duration for the D-B/LB projects is 46% shorter than the similar D-B-B projects. The mean CM/GC project duration is 69% and 53% shorter than D-B-B and D-B/BV, respectively. These results concur with findings from previous researchers which have shown that alternative contracting methods are providing shorter project durations than the traditional D-B-B method (Konchar and Sanvido, 1998; Molenaar and Songer, 1998; Septelka and Goldblatt, 2005; FHWA, 2006; Hale et al., 2009; Carpenter and Bausman, 2016). No previous highway construction research studies have included statistical tests for the differences in project duration between D-B and CM/GC projects. Nonetheless, the results in this paper show that CM/GC is shorter than D-B/BV by 53%. This accords with the trend for project duration in Shrestha et al. (2016) which shows that CM/GC is shorter than D-B by a more modest percentage of 18%. Shrestha's results were based on CM/GC projects restricted to three US states unlike in this paper with CM/GC projects from a wider geographic area.

   Alternative contracting methods are providing agencies with cost certainty at a point in time that is much earlier during project delivery than the traditional D-B-B method. The timing of cost certainty during highway project delivery has not been quantified by previous researchers. The results of this research address this gap in knowledge by quantitatively showing how the timing of cost certainty relates to different highway project delivery methods. This research provides a novel comparison of the timing of cost certainty among US highway construction project delivery methods. . For D-B/LB, the point of cost certainty is established more than 60% earlier than in similar D-B-B projects. When compared to similar D-B-B projects, the average point of cost certainty for CM/GC is more than 60% earlier. The average point of cost certainty for D-B/BV is more than 40% earlier than D-B-B. These results

all concur with the findings from previous research studies which show that early timing of the point of cost certainty is a benefit of the CM/GC method (Gransberg and Shane, 2010; Touran et al., 2011), and of the D-B method (Songer and Molenaar, 1996; Shrestha et al. 2007; Gransberg and Shane, 2010; Touran et al., 2011) over the traditional D-B-B delivery method. No previous studies compare the timing of the point of cost certainty between D-B and CM/GC. Nonetheless, in comparing CM/GC projects to similar D-B/BV projects in the $10M to $50M project cost range, the point of cost certainty is known approximately 40% earlier on CM/GC projects.

With regard to project intensity, the shorter project duration and higher contract cost of CM/GC and D-B/BV projects result in higher project intensity than similar D-B-B projects in the $10M-$50M cost range. In comparing D-B-B projects to similar D-B/LB projects in the $2M-$10M cost range, the project intensity of D-B/LB is higher. Again, these results coincide with the finding that the alternative contracting methods have faster project delivery than the traditional D-B-B method (Konchar and Sanvido, 1998; Molenaar and Songer, 1998; Septelka and Goldblatt, 2005; FHWA, 2006; Hale et al., 2009; Carpenter and Bausman, 2016). However, contrary to the results of the two previous research studies that have compared project intensity between D-B and CM/GC (Konchar and Sanvido 1998; Touran et al. 2011), this study found that CM/GC greatly outperforms D-B/BV. The difference is likely due to the lengthy D-B/BV procurement process that is required for highway construction projects.

With state transportation agencies constantly seeking ways to be more efficient with public funds for US highway construction, the alternative contracting methods of CM/GC and the two distinct forms of D-B, D-B/LB and D-B/BV, are viable options for shortening project durations. The alternative contracting methods are delivering projects at a faster pace to reduce impacts to road users, in addition to establishing early cost certainty during project delivery.

2.8 Limitations And Recommendations For Future Research

The collection of accurate project duration/schedule data proved challenging throughout the data collection for this study. Agency personnel found it challenging to provide the required data in sufficient detail for various reasons. Nevertheless, this paper accomplished the research objectives by selecting projects in which adequate data was provided on a small number of projects for design, construction, and project duration. With the provision of larger samples in future work, more in-depth analyses can be performed such as an examination of the design overlap duration in D-B projects and the phasing of work packages in CM/GC.

Although actual schedule data was obtained for the projects studied, as a result of the sparseness of the planned schedule data the authors are unable to compare schedule growth of the projects among the delivery methods. This is a consequence of the difficulty to obtain accurate project delivery planned schedule dates from agency design start through to construction completion from agencies, for various reasons. Future work to obtain accurate planned schedule data will facilitate an examination of the schedule growth metric among the project delivery methods.

As the use of alternative contracting methods continues to grow, particularly for the CM/GC method, research that considers larger sample sizes will be beneficial to industry and academia. Research with larger sample sizes may then facilitate statistical comparisons of other key performance metrics among the project delivery methods. In future, it would also be prudent to obtain accurate cost information for agencies' design costs for projects in each project delivery method.

2.9 Acknowledgements

The authors extend their sincere gratitude to the numerous agency professionals who contributed data to the study, to our partners at the FHWA for

CHAPTER 3 (Manuscript 2) - A QUANTITATIVE COMPARISON OF DESIGN-BUILD VS CONSTRUCTION MANAGER/GENERAL CONTRACTOR SCHEDULE PERFORMANCE IN HIGHWAY CONSTRUCTION PROJECTS

3.0 Abstract

Highway agency officials select design-build (D-B) and construction manager/general contractor (CM/GC) to compress project schedule. However, they select these methods despite a dearth of quantitative, empirical schedule performance analysis. To address this gap in knowledge, this paper compares the performance of 111 best-value D-B and CM/GC projects for the metrics of procurement, design, construction, and overall project durations. The univariate analysis of the schedule performance metrics shows that, on average, CM/GC projects have shorter procurement, design, and project durations than D-B. Project construction duration is the same using either delivery method. A supplemental multivariate statistical analysis reveals the individual and interaction effects of project characteristics that affect schedule performance for more in-depth comparisons of D-B versus CM/GC schedule performance. The overall trend in the results from the multivariate analysis is that CM/GC has better schedule performance than D-B. These results will provide better evidence for the selection of project delivery methods.

3.1 Background and Motivation

The choice of project delivery method can significantly influence project schedule performance (Gordon, 1994; Konchar and Sanvido, 1998; Molenaar and Songer, 1999; Forgues and Koskela, 2008; Gransberg et al., 2003; Tran, 2013; Franz, 2014). Shorter project durations is a documented benefit of the alternative

contracting methods of design-build (D-B) and construction manager/general contractor (CM/GC) (Songer and Molenaar, 1996; FHWA, 2015; Touran et al., 2011; Gransberg, 2013a; Russell et al., 1994). As a highway agency's main motivation for selecting D-B and CM/GC is most frequently schedule compression (Goftar et al., 2014; McGraw Hill Construction, 2014; Shrestha et al., 2014; Bingham et al., 2016), this paper empirically explores D-B and CM/GC schedule performance for the metrics of procurement, design, construction, and overall project durations.

In order to interpret the findings in this paper and to effectively apply the results, it is important to understand the D-B and CM/GC project delivery processes. With CM/GC the owner maintains full ownership of the design throughout the project. Early during design development the owner contracts with a construction manager (CM) for constructability reviews and other preconstruction services. In D-B, while agencies give up control of the final design to a design-builder they benefit from the convenience of a single contractual entity for both design and construction services.

In highway construction CM/GC procurement is mostly by qualifications based selection (QBS) or a best-value process which does not consider cost (Gransberg et al. 2015; FHWA SEP-14 website; FHWA 2002; Gransberg and Shane 2010, Gransberg and Shane, 2013; Gransberg et al. 2015). Also in CM/GC, a guaranteed maximum price (GMP) for the construction services is agreed between all parties during design development, subsequently, the CM becomes the general contractor (GC) to execute the work (Gransberg et al., 2015). The CM/GC method ultimately transfers the risk for the final cost and time of construction to the CM (Gransberg et al., 2015). The two primary procurement procedures for D-B in the highway sector are low-bid and best value (Molenaar et al. 2010; Beard et al. 2001; Xia et al. 2012). In D-B the design risk is fully transferred to the design-builder (Molenaar et al., 1999; AECOM, 2003; Chen et al. 2016).

Since agencies contract with a CM early during design development CM/GC allows agencies to tap contractors' industry experience to enhance project schedule performance. As accurately stated by Anderson and Damnjanovic (2008), "Contractor experience and expertise can aid the design team in preparing more cost effective traffic control plans, construction staging plans, and perhaps more realistic construction schedules." The D-B method also permits early involvement of the contractor and agencies benefit from contractors' industry experience to improve constructability, enhance innovation, and shorten schedules. In D-B agencies have minimal design work as they present proposers with detailed performance requirements rather than fully prepared designs.

The CM/GC and D-B methods overlap of design and construction to shorten project duration as opposed to D-B-B in which design and construction are sequential. In CM/GC, agencies release multiple construction packages to overlap design and construction (Gransberg and Shane 2010). As shown in Figure 3-1, the agency can release construction in phases rather than a single fully completed design for construction of the entire project. For illustrative purposes, Figure 3-1 shows just two overlapping construction work packages, but there can frequently be more than two. The early selection of the design-builder coupled with their ownership of the design facilitates the overlapping of design and construction in D-B. The D-B project delivery method is considered the "fastest" because of the ability to overlap design and construction. This means of achieving faster schedules is the main reason for the use of D-B (Songer and Molenaar 1996; Chen et al. 2016). Figure 3-2 illustrates the processes of D-B project delivery and the inherent overlap of design and construction.
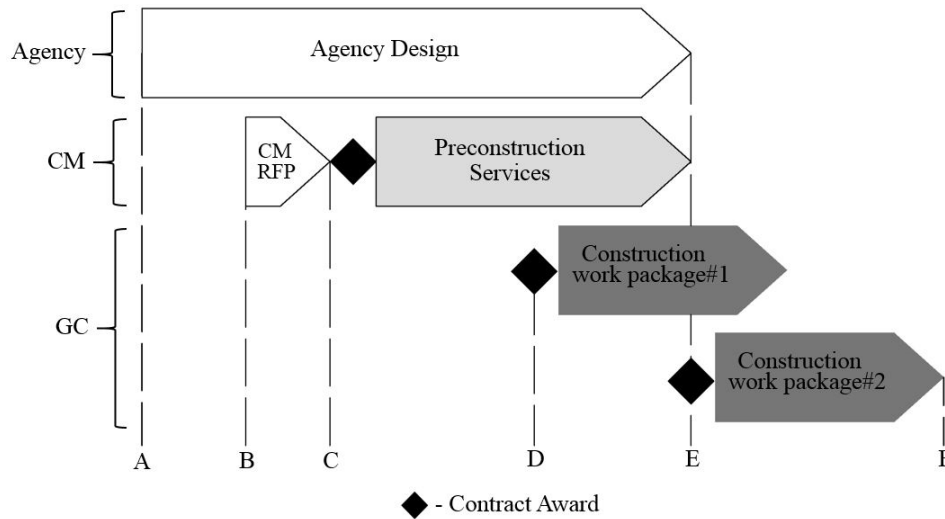
Figure 3-1. CM/GC Project Delivery Method
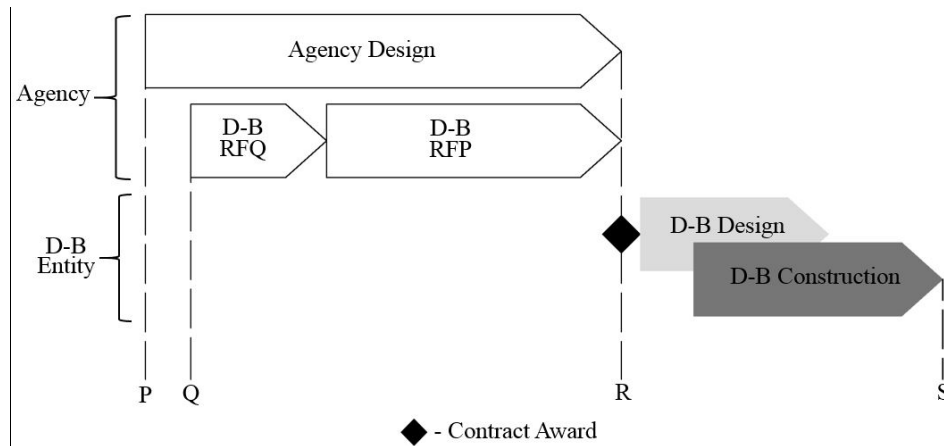
Figure 3-2. D-B Project Delivery Method

Alternative contracting methods are still relatively new to the highway construction industry (FHWA, 2015; Bingham et al. 2016). Consequentially, the lack of research with quantitative analyses of empirical schedule performance for D-B and CM/GC is likely the result of the low usage of the methods by state transportation agencies. The use of D-B delivery began in the 1990s and CM/GC after 2005 (FHWA, 2015). At the end of 2014, the number of states, or rather Departments of Transportation (DOTs), using the CM/GC method was at 17 and D-B use was at 35 (FHWA, 2015). Currently, the use of D-B is prevalent among state transportation agencies since D-B is relatively more mature than CM/GC. However several agencies

have completed a substantial amount of CM/GC projects to date. Hence, at this time there exists more empirical data on the alternative contracting methods.

The comparison of D-B versus CM/GC performance in this paper is innovative because there exists minimal studies that quantitatively compare these delivery methods. Comparison of the schedule performance of the two delivery methods is especially lacking. This is understandably a result of the relative infancy of CM/GC relative to D-B (MAP-21, 2012). With the passage of the Moving Ahead for Progress in the 21st Century Act (MAP-21) in July 2012 SEP-14 approval was no longer required for state transportation agencies to use CM/GC, at that point CM/GC was no longer considered experimental. However, FHWA does not yet have regulations for CM/GC as they do for D-B with the D-B Contracting Final Rule (2002). At the time of this study, the authors estimate that only 60 US highway CM/GC projects have been completed and by 8 agencies.

This paper addresses an acute gap in knowledge considering the dearth of quantitative comparisons between D-B and CM/GC highway project schedule performance. The limited literature available on the topic suggest D-B is superior (Konchar and Sanvido, 1998; McGraw Hill Construction, 2014; Shrestha et al., 2014; Farnsworth et al., 2015; Bingham et al., 2016). However, these results are not all highway project specific and the findings are frequently based on perceptions and opinions of construction industry personnel so there remains room for improvement. Since schedule compression is the most influential factor when selecting alternative delivery methods, this paper focuses on the schedule performance metrics of procurement, design, construction and overall project duration for US highway construction projects which used D-B and CM/GC.

3.2 Literature Review

Although numerous academic approaches exist for selecting an appropriate project delivery method, highway agencies use only a few in practice (Anderson and Damnjanovic 2008; Tran et al. 2013). Agencies frequently select project delivery methods subjectively. Nevertheless, structured, quantitative decision analysis is more advantageous than simple, holistic, and informal processes which typically characterize subjective evaluations (Oyetunji and Anderson 2006).

The existing project delivery method selection approaches do not provide a quantitative analytical comparison of D-B and CM/GC schedule performance. The few publications that examine D-B and CM/GC schedule performance are based on qualitative and subjective elements that have the potential to introduce biases that may adversely affect results. Seminal work on empirical comparisons of project delivery method performance by Konchar and Sanvido (1998) shows that D-B outperforms CM/GC with regard to schedule performance for building (vertical) projects. In the majority of subsequent research on project delivery method performance, of the publications which include a comparison of D-B versus CM/GC schedule performance, the results are based on experiential information, i.e. the perceptions and opinions of industry users (McGraw Hill Construction, 2014; Shrestha et al., 2014; Farnsworth et al., 2015; Bingham et al., 2016).

McGraw Hill Construction (2014) produced an extensive report detailing the opinions of owners, architects and contractors in the building sector. Regarding D-B and CM/GC schedule performance, the majority of people surveyed feel D-B is best to reduce schedule. Shrestha et al. (2014) designed a survey to assess the satisfaction level of owners on water and wastewater projects. Results show that survey respondents are more satisfied with D-B than CM/GC in all the issues studied except schedule performance. Farnsworth et al. (2015) examined the perceptions of public owners, contractors, and design engineers on transportation-related. The

participants' perceptions of D-B versus CM/GC providing any benefit to schedule were mixed (Farnsworth et al. 2015). In examining the preconceived perceptions of US transportation project owners, Bingham et al. (2016) found that respondents believe D-B delivers a project faster than CM/GC. However, they acknowledge as a limitation that their study is devoid of empirical quantitative project outcomes. The work of Bingham et al. (2016) presents a discrepancy which warrants further investigation, the owners' perceptions do not align with literature.

3.3 Point Of Departure

This paper presents a novel examination of D-B and CM/GC empirical schedule performance to address an acute gap in construction engineering and management knowledge. It does not rely on experiential judgements as found in previous research (McGraw Hill Construction, 2014; Shrestha et al., 2014; Farnsworth et al., 2015; Bingham et al., 2016). The new knowledge from this approach can help agencies make unbiased, objective selections of appropriate project delivery methods for highway construction projects. The findings in previous research may be justified for the mix of industries studied but this paper features a specific and highly relevant analysis based exclusively on US highway construction projects. Additionally, rather than studying a holistic group of D-B projects which can be of various forms, the projects in this paper are categorically D-B projects procured by best value procurement. Notably, the data for this paper is from projects completed between 2004 and 2015 so the information is from a period in which several agencies already completed a substantial number of CM/GC projects and are confidently moving beyond the experimental phase.

It is worth mentioning that the results of previous research papers that have compared perceptions of the benefits of D-B versus CM/GC could potentially include the biases of industry users (McGraw Hill Construction, 2014; Shrestha et al., 2014;

Farnsworth et al., 2015; Bingham et al., 2016). For instance, some individuals with more experience in D-B may have grown a preference towards this delivery method. This notion further validates the need to study D-B and CM/GC schedule performance using empirical project information.

While previous research explores metrics of schedule growth, construction or project delivery speed, this study directly examines the procurement, design, construction, and overall project durations of highway construction projects. Such an in-depth analysis brings to light the nuances of D-B in relation to CM/GC project delivery and presents the opportunity to learn how to improve these methods. The findings presented in this paper provide a better understanding of how state transportation agencies can meet the goal of schedule reduction using D-B and CM/GC by addressing the following hypotheses which are based on the general consensus of existing literature:

- CM/GC does not affect procurement duration in comparison to D-B.
- CM/GC does not affect design duration in comparison to D-B.
- CM/GC does not affect construction duration in comparison to D-B.
- CM/GC does not affect project duration in comparison to D-B.

3.4 Data Collection and Research Methods

This section describes the research methods used to obtain data, the data collection instrument, and the methods used for analysis of the information. The authors provide definitions of the project characteristic variables as obtained via the data collection questionnaire and definitions of the project performance variables.

Retrospective analysis of documented, historical project information presents several advantages in meeting the research objectives over the use of experiential information (Luftig 1992; Luftig and Jordan 1998; Chin 2001). By using empirical

project data to compare D-B and CM/GC schedule performance this paper provides quantitative findings that can promote unbiased, objective selections of the project delivery methods. This practical information is useful to agencies considering the increasing use of D-B and CM/GC, and agencies' motivations to reduce project schedules.

It is well established that removing extreme outliers increases the ability to make more accurate inferences from data. In the case of the data collected for this research, these extreme outliers are less likely to be the result of misreporting, sampling error or typographical error. It is more likely that extreme outliers are natural or consequential anomalies in the relevant metrics for exceptional projects. The authors conducted a series of examinations using box and whisker plots of the data to observe the resulting effects not removing any outliers, removing only extreme outliers, and removing all outliers. Using a standard outlier coefficient equal to 1.5, box and whisker plots illustrated the ranges of the data along with outliers and extreme outliers. Ultimately results/data are presented with only extreme outliers removed in order to keep legitimate project information while not compromising the quality of the data set. This approach maintains sufficient sample sizes to facilitate appropriate statistical tests that result in undistorted parameters and statistical estimates/comparisons. Extreme outliers were removed from the overall pool of each metric before separating the respective metrics by the project delivery methods studied.

Analysis by empirical methods provides a means to validate observations or experiments. This is advantageous because such an approach provides evidence of authentic phenomena, can be confirmed by testing, and is easily replicated for further research (Chin 2001). Tenets of empirical evaluation are internal validity and reliability achieved by the application of proper research techniques through an appropriately designed systematic study. In the process, the effect of any limiting or

confounding factors are identified and controlled (Luftig 1992; Luftig and Jordan 1998; Chin 2001). For this paper the authors employ research methods that are in accordance with these tenets.

For this paper, the authors obtained empirical project information for 111 projects completed using D-B (77) and CM/GC (34) between 2004 and 2015. It was imperative that the required information, particularly project schedule data, was obtained for these projects. This made the data collection effort even more challenging as many of the contacted agency personnel expressed difficulties in obtaining accurate schedule data for some projects, such projects are omitted from the sample used for this paper. The projects collected are from state DOTs and the FHWA Office of Federal Lands Highway. Notably, the CM/GC projects in this paper represent approximately 65% of the CM/GC projects that were available for analysis at the time of data collection. This statistic was substantiated by a robust review of relevant documentation and reports including, the FHWA's (2015) EDC-2 Final Report, the FHWA's SEP-14 active project list information (FHWA SEP-14 website), the FHWA's "Alternative Contracting", formerly, "Innovative Contracting", website (FHWA, 2002) and, the Design-Build Institute of America's (DBIA) milestone maps; with further verification through extensive collaboration via direct contact with numerous state transportation agency personnel and senior FHWA personnel.

The data from each project was obtained via a tested and well-structured questionnaire administered to agency professionals by email. The quality of the data was ensured both at the schema and instance levels through rigorous quality control techniques (Rahm and Do, 2000). Quality control in checking responses and in data entry was facilitated by double-checking responses with superior staff at the DOTs and by manual and low-level programming checks. Multi-source problems were minimal as there was no need to integrate data from multiple sources for a single project. Where necessary, the DOT professionals passed on partially completed

questionnaires to other agency individuals to provide missing information. This served as an additional self-correcting or vetting process.

A two-phase approach enhanced the data collection process. First, information was requested from highway agency estimators or contract managers on general project characteristics, cost and schedule data. Information to prefill questionnaires was typically available from contract administration or estimating personnel. Secondly, the authors sent prefilled project specific questionnaires to project managers to provide additional information. The following project information is used for this paper:

1. **Complexity** - rated as major, moderately or non-complex projects defined by the NCHRP Report 574 (Anderson et al. 2007) definitions shown in Table 3-1.
2. **Project Type**: rated as new construction/expansion (New) or rehabilitation/reconstruction (Rehab) projects.
3. Award Cost: the contract award cost or engineers estimate used as a measure in terms of the cost of the project, arranged into the practical ranges of $0-$10M, $10M-$20M, and $20M-$50M, and over $50M projects as a result of multiple trials to obtain appropriate bin sizes.
4. Key **project delivery schedule dates** were provided to calculate the schedule performance metrics as defined by the periods shown in Table 3-2.
5. **Percentage design completion** as an indication of the approximate level of design that the agency completed prior to issuing the D-B request for proposal (RFP) or before the construction management services began in CM/GC.

Table 3-1. Complexity definitions (Anderson et al., 2007)

Most Complex (Major) Projects	*Moderately Complex Projects*	*Non-complex (Minor) Projects*
• New highways; major relocations • New interchanges • Capacity adding/major widening • Major reconstruction (4R; 3R with multi-phase traffic control) • Congestion management studies are required • Environmental Impact Statement or complex Environmental Assessment required	• 3R and 4R projects which do not add capacity • Minor roadway relocations • Non-complex bridge replacements with minor roadway approach work • Categorical Exclusion or non- complex Environmental Assessment required	• Maintenance betterment projects • Overlay projects, simple widening without right-of-way (or very minimum right-of-way take) little or no utility coordination • Non-complex enhancement projects without new bridges (e.g. bike trails) • Categorical Exclusion

Note: "3R" = Resurfacing, Restoration, Rehabilitation
*   "4R" = New Construction/Reconstruction*

Table 3-2. Schedule performance metrics

Schedule Performance Metric	Start	End
Procurement duration CM/GC: B to C D-B: Q to R	advertisement or solicitation date	contract award (CM's preconstruction contract in CM/GC)
Design duration CM/GC: A to E D-B: P to Q	start of agency design	end of agency design
Construction duration CM/GC: D to F D-B: R to S	construction start (notice to proceed date)	construction end (substantial completion)
Project duration CM/GC: A to F D-B: P to S	start of agency design	construction end (substantial completion)

Note: Letters *A* to *F* and *P* to *S* are as signified respectively in Figure 3-1 (CM/GC) and Figure 3-2 (D-B).

Aside from having adequate empirical data, an appropriate statistical approach was critical to assess how project delivery methods interact with the project

characteristics in relation to the schedule performance metrics. The analysis of variance (ANOVA) statistical method, of a factorial design, is appropriate and the ease of interpreting results makes it the ideal statistical method for the required analyses. This statistical method can reveal the effects of multiple independent variables, also referred to as treatment factors, on a single dependent variable. More importantly, the main advantage of ANOVA is that, in addition to revealing the effects of each independent variable, their joint effects or interaction effects on the dependent variable are revealed (Pedhazur, 1982; Sheskin, 2011; Rutherford, 2011).

In this paper the authors employ a 4-way ANOVA with a factorial design. To illustrate the structure of an ANOVA with a factorial design, a simpler 2-way fixed factor crossed factorial design is shown in Figure 3-3. This design is a 2 x 3 factorial design in which factor A has two levels and a factor B has three levels equating to six possible combinations of the levels of the factors. The cells created by the cross partitioning are indicated by A1B1, A1,B2 and so on, the measurements of the dependent variable are contained within these cells.

		Levels of factor B		
		B$_1$	**B$_2$**	**B$_3$**
Levels of factor A	**A$_1$**	A$_1$B$_1$	A$_1$B$_2$	A$_1$B$_3$
	A$_2$	A$_2$B$_1$	A$_2$B$_2$	A$_2$B$_3$

Figure 3-3. Structure of a 2 x 3, 2-way fixed factor crossed factorial design (Pedhazur, 1982)

In the ANOVA with a factorial design the subcategories or levels of the independent variables combine to form a "cross partition" or cell. These cells are disjoint and exhaust all cases, i.e. all measurements of the continuous dependent variable (Pedhazur, 1982). A natural occurrence in the case of the ANOVA for this paper is missing cases, a result of not having a specimen for each cell. In this study, there is not a dependent variable measurement for every possible combination of the levels of the independent variables. This is realistic as it is virtually impossible to

have a dependent variable measurement for each cell and likely, highway construction agencies are not selecting each project delivery method for every possible scenario of project characteristic combinations. Thus, the factorial design is non-orthogonal because there are unequal cell frequencies and this necessitates an unweighted means analysis to negate the effect of these unequal cell frequencies (Pedhazur, 1982; Sheskin, 2011; Rutherford, 2011). This is an added feature of using the ANOVA method for this paper, it is appropriate to analyze data with missing cases.

It should be noted that the results of the ANOVA are based on the highest order interaction effect found for each of the duration metrics by using all of the available data with extreme outliers omitted. Figure 3-4 illustrates the typical order of assessment for any significant, individual and/or interaction effects, in the output of a 4-way ANOVA. Whenever a significant interaction effect is found, only the highest order interaction effects are considered for post hoc analyses as it is improper to assess the individual effects of the factors in the presence of any significant interaction effect, even though the individual effect of a factor is significant (Pedhazur, 1982; Sheskin, 2011; Rutherford, 2011). Likewise, it is improper to assess the effect of any lower order interactions in the presence of any higher order significant interaction. This rule effectively means that, if for instance the 3-way interaction effect of project delivery method, complexity and award cost is significant for a duration metric, one cannot assess the effect of say the 2-way interaction of project delivery method and complexity, even if the latter, second order interaction is found significant.
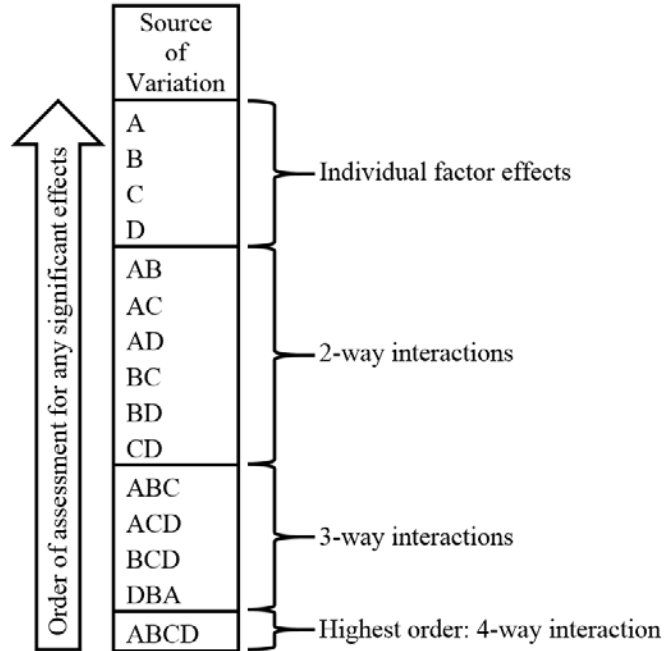
Figure 3-4. Hierarchy of the individual and interaction effects in a 4-way ANOVA

Subsequent to the ANOVA, the authors conduct appropriate post hoc analyses by calculation of the critical mean difference between the respective duration metrics of D-B versus CM/GC to determine statistically significant differences. The Critical Mean Difference (CMD) is the minimum difference between any two group means that are significant at the given level of alpha (MVP Stats, 2014). The following equation is used for calculation of the critical mean difference:

$$CMD = Q_{(k,df(MSE))}\sqrt{\frac{MSE}{2}\left[\frac{1}{n1} + \frac{1}{n2}\right]} \qquad (1)$$

Where:
k = number of tests
MSE = Mean Square Error term
n1 = first group sample size
n2 = second group sample size
Q = Studentized Range Statistic (Sheskin, 2011)

The findings presented in this paper provide a better understanding of how state transportation agencies can meet the goal of schedule reduction using D-B and CM/GC by addressing the following hypotheses which are based on the general consensus of existing literature:

- CM/GC does not reduce procurement duration in comparison to D-B.
- CM/GC does not reduce design duration in comparison to D-B.
- CM/GC does not reduce construction duration in comparison to D-B.
- CM/GC does not reduce project duration in comparison to D-B.

Recognizing that project characteristics along with the project delivery method are factors that can affect schedule performance the ANOVA statistical method is ideal to reveal the individual effects of these factors in addition to their interaction effects on each of the duration metrics studied in this paper.

3.5 Data Characteristics

Table 3-3 presents information collected on the procurement methods used for the D-B and CM/GC projects in this study. Seventy-nine percent of D-B projects were procured by best value procedures. The 77 D-B projects used at least one non-price factor in addition to cost and are classified as D-B best-value procurement. Procurement for CM/GC projects was split between best-value and qualifications-based selection. Table 3-4 displays information on the project characteristics for the D-B and CM/GC projects. Table 3-5 shows the percentage design completion. It is notable that both CM/GC and D-B have projects in which the contractor is engaged when the percentage design completion is above 35%, which is a relatively high percentage for contractor engagement on both of these delivery methods.

Table 3-3. Use of Procurement Methods

Procurement Procedure	CM/GC Avg. (n = 34)	D-B Avg. (n = 77)
Low bid	0%	0%
Best value	47%	100%
Qualification-based	41%	0%
Other or not classified	12%	0%

Table 3-4. Project characteristics

Project Delivery Method	N	Avg. Award Cost ($)	Complexity			Project Type	
			Most	Mod.	Non-	New	Rehab.
CM/GC	34	$35M	65%	32%	3%	50%	50%
D-B	77	$45M	57%	38%	5%	66%	34%

Table 3-5. Percentage design completion

Project Delivery Method	N	Frequency of % Design Completion at initial Advertisement/Solicitation				
		0% – 20%	21%– 35%	36%– 60%	61%– 90%	100%
CM/GC	19	7	7	2	3	0
D-B	25	7	12	2	2	2

3.6 Results and Discussion

This section presents results and a discussion of trends for each of the schedule performance metrics. Within each schedule performance metric, D-B and CM/GC are compared for the various project phases (e.g., design, procurement, etc.) to ascertain a robust view of how the processes lead to schedule reduction. Extreme outliers are removed from the overall pool of each schedule performance metric before separating the respective durations by the project delivery methods studied. Since normality assumptions are not satisfied for any of the durations, the Wilcoxon-Mann-Whitney Test is used to compare D-B versus CM/GC within each schedule performance metric. It should be noted the sample size is different for each results table because the

respective schedule performance metrics could only be calculated using the CM/GC and D-B projects that have the relevant project delivery schedule dates. A supplemental multivariate analysis, which considers highway construction project characteristics, is conducted to examine the schedule performance of D-B versus CM/GC at a more detailed level.

3.6.0 Procurement Duration

The results for procurement duration in Table 3-6 show that on average CM/GC procurement duration is 70% shorter than D-B, statistically significant at the 95% confidence level. For the projects studied in this paper, D-B average procurement duration is 11% of the average D-B project duration as opposed to CM/GC average procurement duration equating to 5% of the average CM/GC project duration. It should also be noted that CM/GC procurement is completed concurrently with design while D-B requires a break in the design process for design-builder selection. Regardless of procurement procedure that agencies employ with CM/GC procurement, best value or QBS, duration is still shorter than with D-B. This implies, that for D-B to achieve a reduction of procurement duration equivalent to CM/GC, agencies need to implement changes to their D-B procurement process.

Table 3-6. Procurement duration

Procurement Duration							
Project Delivery Method	**n**	**Mean**	**Std. Dev**	**Low**	**Median**	**High**	**test of means p-value**
CM/GC	15	48	24	15	45	94	0.000
D-B	51	160	74	35	148	316	

The main difference between CM/GC and D-B procurement is that CM/GC does not require bidders to submit any cost information (Gransberg and Shane 2010).

Currently, agencies do no QBS for D-B procurement. In D-B agencies spend a great amount of time in the procurement process preparing solicitation documents and evaluating documents submitted bidders (Songer and Molenaar, 1996; Gransberg and Shane 2010). Less focus on cost as a selection factor greatly simplifies the procurement process in terms of agency preparation of solicitation documents, bidders' preparation of a responsive proposal, and agency proposal evaluations (AECOM, 2003; Farnsworth et al., 2015; Ramsey et al., 2016; Chen et al., 2016). Hence, a major reason for the shorter procurement duration of CM/GC versus D-B. With CM/GC, evaluation of bidders is simplified to an assessment of a written statement of qualifications with an interview or presentation in which agencies keep focus on the bidding construction manager's qualifications and experience (Gransberg and Shane, 2010).

3.6.1 Design Duration

In examining design duration it is important to note that in both D-B and CM/GC the majority of projects are at or below 35% design completion at the time of any initial advertisement/solicitation. As a side note, 15% of the CM/GC projects are solicited over 35% design completion as opposed to 8% of the D-B projects. An appropriate two sample proportion test at the 95% confidence level confirms there is no statistically significant difference between the proportions of CM/GC and D-B/BV projects solicited with over 35% design completion.

Table 3-7. Design duration

Project Delivery Method	n	Mean	Std. Dev	Low	Median	High	test of means p-value
CM/GC	24	548	681	55	375	3,053	0.000
D-B	17	662	683	36	300	2,772	

The design duration results in Table 3-7 show a statistically significant difference between the average design duration of D-B and CM/GC, with CM/GC having a 17% shorter design duration. This is extremely notable as the data compares 100% complete design in CM/GC with only the portion of design in the RFP for D-B projects. This is a compounding effect of the lengthy D-B procurement process. The results also attest to the impact of early contractor involvement in CM/GC versus D-B. Considering that CM/GC's procurement duration is shorter the contractor is involved earlier than in D-B and it is likely that design starts earlier with possibly, a quicker progression through to design completion to be able to release work packages. Another notion is that the structure of the contractual relationships in CM/GC permits agencies to impose greater schedule pressures on the contractor than with D-B.

3.6.2 Construction Duration

The results for construction duration shown in Table 3-8 reveal that the difference between the construction duration means for D-B and CM/GC is not statistically significant at the 95% confidence level. Noticeably, even the minimum and maximum values for construction duration are very similar. It should be noted that "construction duration" for the D-B projects covers the D-B entity's contract duration from award to substantial completion and therefore includes both design and construction durations.

Table 3-8. Construction duration

Project Delivery Method	n	Mean	Std. Dev	Low	Median	High	test of means p-value
			Construction Duration				
CM/GC	34	568	457	112	416	2,025	0.578
D-B	75	822	434	122	748	2,007	

Gransberg and Shane (2010), note that no project delivery team member is better qualified to develop and control the sequence of work than the contractor. Evidently, with regard to construction duration, agencies using either D-B or CM/GC are equally benefitting from having the contractor participate in design development consequentially leading to an efficient construction process (Anderson and Damnjanovic, 2008).

Despite the equivalent performance for construction duration, contractors are of the perception that CM/GC is worse at impacting design and constructability compared to D-B (Farnsworth et al. 2015). The contractors' perception is likely a result of the loss of control during the construction process. For instance, with CM/GC, owners are more capable of imposing an open book policy to oversee contractors' affairs in order to maintain better control during construction through intervention processes such as auditing subcontractor bids and the contractor's budget (Gransberg and Shane, 2010; Farnsworth et al., 2015).

3.6.3 Project Duration

Table 3-9 presents the project durations for the D-B and CM/GC projects in this study. There is a statistically significant difference between the mean project duration for D-B and CM/GC. The results indicate that CM/GC projects in this pool are on average 31% shorter than D-B. As discussed in the previous sections the time savings appear to come from shorter procurement and design durations with CM/GC.

By examining the duration of each process of project delivery the compounding effect of the lengthier D-B procurement becomes more apparent. The next section will discuss interactions of these results with project characteristics more fully through the ANOVA analysis.

Table 3-9. Project duration

Project Delivery Method	n	Mean	Std. Dev	Low	Median	High	test of means p-value
CM/GC	25	1,045	852	204	750	3,846	0.012
D-B	21	1,517	825	643	1,255	3,647	

It should be noted that these results are contrary to the majority of D-B versus CM/GC literature which shows that industry users consider D-B to deliver projects faster than CM/GC (Songer and Molenaar, 1996; Chen et al., 2016; McGraw Hill Construction, 2014; Bingham et al., 2016). However, this finding concurs with the notion of respondents in the work of Shrestha et al. (2014) and Farnsworth et al. (2015). There can be numerous reasons for the shorter CM/GC project duration versus D-B, the authors distinctly avoid implying causality and do not attribute it to the particular project delivery method. To further understand and identify underlying origins for the relative reduction of project duration by CM/GC the authors provide examinations of the other processes involved in project delivery, i.e. procurement, design, and construction.

3.6.4 Multivariate Statistical Analysis

Project characteristics can point to the use of a particular project delivery method and can lead to differing results in project performance (Gransberg et al., 2003). To examine D-B versus CM/GC schedule performance at a more detailed level,

the authors provide a supplemental multivariate analysis of each duration metric by a 4-way ANOVA statistical method of a non-orthogonal factorial design accompanied with post hoc analyses where relevant. The ANOVA results and the results for post hoc analyses of the D-B versus CM/GC schedule performance metrics are provided as an appendix to this paper. Post hoc analyses are presented for the project, construction and, procurement durations. Post hoc analysis for design duration is not needed because none of the individual factors have a significant effect nor is there is any significant interaction effect. Observing the results of the ANOVA analysis, although not all of the differences between the D-B and CM/GC schedule performance are statistically significant, the overall trend is that CM/GC has a shorter duration within each duration metric. To better understand the tables provided in the appendix, note that each table presents the post hoc analysis results for a different project delivery duration metric. The critical mean difference (CMD) is provided just to indicate the difference in means needed for significance but the result of the comparison as a yes/no indication is also provided.

The project characteristics of complexity and project type along with the project delivery method have a significant interaction effect on the procurement duration metric. Table 3-10 in the appendix to this paper shows the results for the procurement duration post hoc analyses. The available procurement duration empirical data permitted 4 pairs of comparisons of D-B versus CM/GC performance. The only comparison with no statistically significant difference is between non-complex, new, D-B and CM/GC projects. All other comparisons show a statistically significant result:

- Most complex, new projects: CM/GC 84% shorter than D-B
- Most complex, rehabilitation projects: CM/GC 59% shorter than D-B
- Moderately complex, rehabilitation projects: CM/GC 65% shorter than D-B

In addition to the project delivery method the project characteristics of complexity, project type, and project size have a significant interaction effect on construction duration. Table 3-11 shows the results for the construction duration post hoc analyses. Supplemental to the univariate analysis of construction duration this multivariate approach highlights differences in performance of D-B and CM/GC at the more detailed level of actual project descriptions. Of the nine comparisons accomplished using the empirical data, four show a statistically significant result:

- $10M-$20M, most complex, rehabilitation projects: CM/GC 63% shorter than D-B
- $10M-$20M, moderately complex, rehabilitation projects: CM/GC 54% shorter than D-B
- $20M-$50M, most complex, rehabilitation projects: CM/GC 59% shorter than D-B
- $20M-$50M, moderately complex, rehabilitation projects: CM/GC 53% shorter than D-B

The significant interaction effect on project duration is produced by the project delivery method and the project characteristics of complexity, and project type. Table 3-12 shows the results for the project duration post hoc analyses. Only 1 out of 4 possible comparisons shows a statistically significant result, i.e. for most complex, rehabilitation projects CM/GC is 39% shorter than D-B.

Although the multivariate statistical method, by design, compensates for an unequal sample size of projects in the pairwise comparisons of D-B versus CM/GC schedule performance, this approach brings to light limitations of the empirical data with regard to the sample size. The deconstruction of the empirical project data into project descriptions which are based on the relevant variables which form interaction

effects reduces the number of projects available for each comparison. Nonetheless, the approach taken in this paper provides an expedient, precursory example of how researchers can apply a multivariate statistical approach to reveal practical findings for the construction industry. This puts future researchers on the topic in an advantageous position as agencies continue to use the alternative contracting methods and the amount of empirical project information increases. Researchers will be equipped to meet the recommendations for a wider, more detailed study designed to collect a project-based data-set and will be able to categorize projects into more homogeneous groupings to extend findings into specific construction project categories (Kumaraswamy and Dissanayaka 2001).

3.7 Recommendations

As agencies continue to use the alternative contracting methods of D-B and CM/GC, they should avail themselves of the quantitative empirical performance of the two methods. With CM/GC procurement duration being shorter than in D-B, it is apparent that agencies are executing the procurement process differently in D-B versus CM/GC. This implies, that for D-B to achieve schedule reduction on a similar scale to CM/GC, agencies need to implement changes to their D-B procurement. If schedule savings are the pre-eminent factor, agencies should consider QBS D-B procurement procedures to avoid the lengthy best-value procurement process. If agencies wish to increase competition through competitive best value D-B processes, they must realize this process will result in longer project schedules.

Design duration is one of the integral processes of overall project schedule (Gransberg and Shane, 2010) so it is not surprising that the design duration results align with the trend for project duration with CM/GC projects being shorter than D-B. Likely, shorter procurement leads to an earlier start of design with CM/GC and possibly, a quicker progression through to design completion because of the release

70

of work in packages. Another consequential advantage of the reduced procurement duration in CM/GC is that agencies engage with contractors earlier during project delivery than in D-B. This earlier timing of engagement of the parties enhances schedule compression (Konchar and Sanvido 1998; Molenaar et al. 1999; El Asmar et al. 2010).

3.8 Conclusion

State transportation agencies are motivated to use of the alternative contracting methods of D-B and CM/GC to achieve schedule compression on highway construction projects. However, their selection of these methods is frequently based on subjective judgements influenced by the perceptions and opinions of industry users who have experience in using those project delivery methods. The experiential information from industry users' cannot be discredited, but it can increase in value if supplemented with quantitative empirical data and investigations of discrepancies.

The findings in this paper supplement the experiential information in existing literature by addressing the gap in knowledge created by a dearth of quantitative comparisons of the schedule performance of D-B and CM/GC based on empirical data. The univariate analyses of the schedule performance metrics show that on average CM/GC projects have shorter procurement, design, and overall project durations than D-B projects. Projects using either of the two delivery methods perform the same for construction duration. Notably, D-B construction schedules in this analysis include both design and construction due to the terms of the D-B contract. Ultimately, CM/GC procurement is shorter than with D-B leading to an earlier start of design with the contractor involved. Consequentially, there seems to be a quicker progression through to the completion of design, a possible by-product of releasing work in packages with CM/GC to effectively overlap design and construction.

Recognizing that the project characteristics of complexity, award cost and project type, along with the project delivery method are factors that affect schedule performance, a multivariate statistical method is used to reveal the individual effects of these factors in addition to their interaction effects on each of the duration metrics. Although, not all of the differences between the D-B and CM/GC projects are statistically significant, the overall trend in the results from the multivariate analysis is that CM/GC has better schedule performance than D-B in the majority of cases.

3.9 Limitations and Scope for Future Work

The primary limitation of this work is the small amount of CM/GC data available due to the novelty of the method in US highway construction. In future work, the collection of additional data would be beneficial to compare the schedule growth of D-B versus CM/GC projects. Additionally, it would be prudent to explore any relationship between duration metrics, particularly procurement duration, and schedule growth. Larger sample sizes are ideal for empirical evaluations. As agencies continue to use D-B and CM/GC an increased sample size could provide greater power to identify statistically significant differences and can enhance results by possibly revealing higher order interactions through the ANOVA statistical method.

CHAPTER 4 (Manuscript 3) - IMPACT OF HIGHWAY PROJECT CHARACTERISTICS ON PROJECT DELIVERY PERFORMANCE

4.0 Abstract

Schedule compression and cost growth are motivating factors for agency officials in the selection of alternative project delivery methods. This study explores the performance of design-build (D-B) and construction manager/general contractor (CM/GC), the two primary alternative contracting options for highway construction, against the traditional design-bid-build (D-B-B) method. Data analysis reveals that it is important to make a distinction between D-B projects that were procured by low bid (D-B/LB) and those procured by best value (D-B/BV). This study categorizes highway construction projects by the characteristics of size, type and complexity to provide a practical means of analysis and to make results more applicable to the process of selecting appropriate project delivery methods. Though necessary for application, this project categorization increases the number of projects required for an empirical analysis beyond a quantity which is practically available from industry. This hinders the empirical examination of project delivery method performance at an in-depth analytical level. Consequently, this study supplements an empirical study of 284 projects with experiential knowledge obtained from highway officials through a rigorous Delphi study. Findings in this paper are confirmed by the triangulation of information from the empirical data, the Delphi study results, and existing literature. The results provide new evidence that alternative contracting methods are superior to D-B-B in terms of schedule compression and cost growth, however, D-B-B remains indispensable on certain projects. The recommendations provide highway agency officials with information that is useful for the selection of project delivery methods

by indicating how highway construction project characteristics can affect project delivery performance.

4.1 Introduction

The traditional project delivery method of design-bid-build (D-B-B) and the two alternative contracting methods of design-build (D-B) and construction manager/general contractor (CM/GC) play very important roles in the US highway construction industry. The vast majority of the U.S. highway system was built using the D-B-B delivery method. The use of D-B delivery began only in the 1990s and CM/GC after 2005 (FHWA, 2015). At the end of 2014, the number of states or rather Departments of Transportation (DOTs) fully employing the CM/GC method increased to 17 and continues to grow, while D-B usage increased to 35 agencies including the Federal Lands Highway agency (FHWA, 2015).

Documented benefits of the two alternative contracting methods include saving cost, improving constructability, enhancing innovation, reducing risk, shortening construction schedules and the potential to lower operational cost and/or project life-cycle costs (Songer and Molenaar, 1996; FHWA, 2015; Touran et al., 2011). Notwithstanding the potential benefits, the two alternative contracting methods are not a panacea for project delivery challenges and so, the more traditional method of D-B-B remains indispensable in some situations. However, state transportation agencies are motivated to use of the alternative contracting methods of D-B and CM/GC to achieve the potential benefits of schedule compression and controlling cost growth on highway construction projects. Research shows that the most influential factors when selecting alternative contracting methods are schedule compression and controlling cost growth (ODOT, 2009; Touran et al., 2011; Goftar et al., 2014).

Departments of Transportation (DOTs) are continuously revising and improving the way they use project delivery methods. A consequential result of the

current to rehabilitate the status of US transportation infrastructure on time and within budget (American Infrastructure Report Card, 2017). Of particular importance to DOTs, more so, with the growing use of alternative contracting methods, is the need to know when to use a particular project delivery method for a certain project. In other words, agencies are interested in knowing whether a particular project delivery method is suitable for specific descriptions of highway construction projects from the outset of a project.

4.2 Background & Motivation

The American Infrastructure Report Card (2017) by the American Society of Civil Engineers (ASCE) rates America's Infrastructure at a GPA of "D+" and highlights the status of aging infrastructure across the US. The ASCE report (2017) warrants an increase in infrastructure investment from 2.5% to 3.5% of U.S. Gross Domestic Product (GDP) by 2025. With such an urgent demand for improvement of the status of US transportation infrastructure, state highway agencies need to construct projects efficiently, that is, within proposed schedules and cost. With added pressures of limited financial resources and increased public scrutiny, agencies need select project delivery methods that are suitable to achieve desired schedule and cost growth performance on particular projects. Agencies need recognize that the chosen project delivery method along with a project's characteristics can significantly influence project performance (Gordon, 1994; Konchar and Sanvido, 1998; Molenaar and Songer, 1998; Gransberg et al. 2003; Tran, 2013; Tran et al. 2013; Molenaar et al., 2014; Franz, 2014). Recognizing that project characteristics are integral in the selection of an appropriate project delivery method, this paper presents structured, categories of descriptions of highway construction projects based on well-defined highway construction project characteristics that may be known from the outset of a project.

75

The empirical project information collected for this paper currently forms the largest empirical data-set exclusive to the topic of US highway construction project delivery, in spite of this achievement there are limitations to the use of this data-set for research. Although the empirical project data is analyzed at an aggregate level to provide an up-to-date perspective on the use and performance of project delivery methods, the categorization of project descriptions as presented in this paper reduces the number of projects available from the empirical database for each highway construction project description. This is realistic as agencies are not using each project delivery method for every possible project. The reduction of the available sample size for each project description restricts the use of precise analytical techniques such as statistical methods. Consequently, the authors supplement the empirical data with experiential knowledge obtained from a Delphi study in which experts judge the performance of the project delivery methods for the categorized project descriptions.

The scope of this paper is to determine the performance of project delivery methods, D-B-B, CM/GC, D-B/LB, and D-B/BV for specific descriptions of highway construction projects with regard to project duration and cost growth. In this regard, the Delphi technique is ideal to aggregate the judgements of experts for collection of reliable experiential knowledge. The main advantages are that the Delphi method provides a means to obtain consensus without having to bring participants together for a physical meeting and it incorporates features for reducing bias in the structure of the process.

4.3 Literature Review

Some researchers use subjective descriptions of projects in their work, e.g., Debella and Ries (2006) who refer to projects costing greater than $10M as "large", "complex" projects. Gransberg (2013) presents a useful means of assessing a project's

complexity, which although useful for comparing projects, does not present details of other significant project characteristics. Other researchers rely on programmatic descriptions of projects e.g. the Federal Highway Administration's (FHWA) definition of a cost limit of $50M for "large" projects (FHWA, 2014). However, such descriptions in policy are in specific relation to program objectives such as the FHWA value engineering federal-aid program in this case and these descriptions still lack details of other significant project characteristics that are necessary for the selection of an appropriate delivery method.

Knowledge of a project's characteristics is critical for success because these characteristics can point to the use of a particular delivery method, which is more likely to achieve desired schedule or cost performance, therefore, agencies need to evaluate every project's characteristics before selecting an appropriate project delivery method (Forgues and Koskela 2008; Gransberg et al. 2003; Tran et al. 2013). Four main project characteristics found to influence the selection of delivery methods for road projects include, project size in terms of cost, project type based on technical requirements, complexity based on technical aspects in addition to the project's environment/locale, and the critical completion date, which relates to schedule/duration (Gransberg et al. 2003; Anderson and Damnjanovic 2008; ODOT, 2009).

In the research on project delivery performance that includes both D-B and CM/GC, researchers rely on the experiential knowledge of industry users of these delivery methods to determine superior performance (McGraw Hill Construction, 2014; Farnsworth et al. 2015; Bingham et al. 2016). Farnsworth et al. (2015) found mixed perceptions about D-B versus CM/GC performance among public owners, contractors, and designers on transportation projects. Both McGraw Hill Construction (2014) and Bingham et al. (2016) reveal that project owners believe D-B delivers a project faster than CM/GC although perceptions of cost benefits are

mixed. Notably, Bingham et al. (2016) acknowledge that owners' perception of the D-B schedule advantage over CM/GC does not align with literature. This presents a discrepancy that warrants further investigation.

Varieties of approaches exist for the selection of an appropriate project delivery method (Skitmore and Marsden, 1988; Gordon, 1994; Molenaar and Songer, 1998; Al Khalil, 2002; Oyetunji and Anderson, 2006; ODOT 2009; Tran, 2013; Tran et al., 2013). Despite the wide array of selection approaches, in practice, few formal or systematic selection processes are employed (Anderson and Damnjanovic, 2008; Tran et al. 2013). Of the selection procedures that are in use by agencies a common element is experiential knowledge usually facilitated by some form of a workshop aimed at building consensus among project stakeholders (Kumaraswamy and Dissanayaka 2001; Luu et al. 2003 and 2006; ODOT, 2010; WSDOT, 2016; CDOT, 2016; MnDOT, 2013; Tran et al. 2013). This highlights the value of a posteriori knowledge.

4.4 Point Of Departure

This paper addresses limitations of previous research on project delivery method, selection and performance. Specifically, this paper addresses recommendations for, a wider and more detailed study, a study designed to collect a project-based data-set, the need to extend findings into other construction project categories, and the need to categorize projects and highway construction variables into more homogeneous groupings (Kumaraswamy and Dissanayaka 2001; Farnsworth et al. 2015; Chen et al. 2016).

The policy, programmatic and ad hoc project descriptions employed by previous project delivery researchers are based on a single project characteristic variable at a time and do not present details of other project characteristics significant to project delivery performance. In previous research, the data contains a mix of projects from multiple sectors and from different countries, in many cases the sampled projects are

78

for vertical (building) structures. Some of the existing literature on project delivery focus on a single delivery method while many do not include the CM/GC method. Another limitation in previous project delivery research is that the information on alternative contracting methods is from a period when many agencies were engaging on their first D-B or CM/GC project. At that time agencies inexperienced in alternative project delivery were not yet over the learning curve as some of the projects were still in an experimental phase as part of the FHWA's Special Experimental Project No. 14 (SEP-14) (FHWA SEP-14 website).

Of studies that have relied on experiential knowledge obtained from group methods to compare project delivery performance the results are based on groups of individuals who have diverse perspectives of performance since they originate from different entities involved in project delivery (AECOM, 2003; McGraw Hill Construction, 2014; Farnsworth et al., 2015; Bingham et al., 2016). These entities, public agencies, construction companies, and engineering/design firms, approach project delivery with very different objectives in terms of cost and schedule. Also, some of the previous studies that have relied on experiential knowledge are based on groups of individuals restricted to specific geographic locations. The experiential knowledge obtained from the Delphi study in this paper is from a highly qualified group of experts whose experiences are specifically related to US highway construction projects and the experts are from states spanning across the US that have experience in using the alternative contracting methods; these features enhance the generalizability of findings from the Delphi study.

The information for this paper is from a period in which several agencies have completed a substantial amount of D-B and CM/GC projects. These agencies are confidently moving beyond the experimental phase and the learning curve of using these delivery methods. The distinct separation of D-B projects procured by low bid (D-B/LB) from those procured using selection factors in addition to cost (D-B/BV) is

another highlight in this paper. At this juncture, in the context of highway construction, ambiguous definitions are not a problem because many of the parameters of project delivery are documented and defined by practicing state DOTs and especially, by the governing body for US highway construction, the FHWA. Hence, this paper avoids ambiguities in the explanations of parameters and variables by referencing established definitions. Ultimately, the results from this paper provide, an up-to-date perspective on the types of projects in US highway construction, and indications of project performance based on the selected project delivery method. Notably, this research avoids the use of ad hoc categories of project descriptions and by focusing solely on US highway construction projects the results are highly applicable and relevant. The new knowledge helps agencies make objective selections of appropriate delivery methods for specific highway construction projects by addressing the following research questions:

- How does the performance of project delivery methods change across the levels of complexity, project type and project cost for highway construction projects?
- How do state highway agency professionals judge the performance of project delivery methods for specific descriptions of highway construction projects?

4.5 Research Methods

The authors executed a two-phase approach to accomplish the research objectives. Firstly, the empirical data was gathered and analyzed, then the supplemental experiential knowledge was obtained and examined. This approach allows the authors to fully explore the empirical data and experiential knowledge to discover and validate findings from multiple perspectives.

4.5.1 Phase 1 – Empirical Data Collection

For this paper, the authors acquired empirical project information for 284 projects completed between 2004 and 2015. The information is from state DOTs and the FHWA Office of Federal Lands Highway and the projects were completed using the D-B-B, CM/GC, D-B/LB, and D-B/BV delivery methods. The information for each project was obtained via a tested and well-structured questionnaire administered to agency professionals. The quality of the data was ensured both at the schema and instance levels through rigorous quality control techniques (Rahm and Do, 2000). Quality control was facilitated by double-checking responses with superior staff at the agencies and by manual and low-level checks to verify data entry. Multi-source problems were minimal as there was no need to integrate data from multiple sources for a single project. Where necessary, the DOT professionals were able to pass on partially completed questionnaires to other individuals within their agency for provision of missing information. This served as an additional self-correcting or vetting process. Though time consuming, the authors found that a two-phase approach enhanced the data collection process. In the first phase, contract managers were contacted to request information on the project characteristics including cost, and schedule data. The information was then pre-filled into project specific questionnaires and sent to project managers to complete remaining sections. The project characteristic variables used to categorically describe highway construction projects in this paper are:

1. Project Type: rated as new construction/expansion (New) or rehabilitation/reconstruction (Rehab).
2. Complexity: rated as major complex, moderately complex or non-complex projects as defined by the NCHRP Report 574 (Anderson et al. 2007) definitions, shown in Table 4-1.

81

3. Project size: in terms of the cost of the project, this can be the engineer's estimate or the award cost, arranged into the practical ranges of $0-$10M, $10M-$20M, and $20M-$50M projects.

Table 4-1. Complexity definitions (Anderson et al., 2007)

Most Complex (Major) Projects	*Moderately Complex Projects*	*Non-complex (Minor) Projects*
• New highways; major relocations • New interchanges • Capacity adding/major widening • Major reconstruction (4R; 3R with multi-phase traffic control) • Congestion management studies are required • Environmental Impact Statement or complex Environmental Assessment required	• 3R and 4R projects which do not add capacity • Minor roadway relocations • Non-complex bridge replacements with minor roadway approach work • Categorical Exclusion or non- complex Environmental Assessment required	• Maintenance betterment projects • Overlay projects, simple widening without right-of-way (or very minimum right-of-way take) little or no utility coordination • Non-complex enhancement projects without new bridges (e.g. bike trails) • Categorical Exclusion

Note: "3R" = Resurfacing, Restoration, Rehabilitation
       "4R" = New Construction/Reconstruction

The project performance metrics studied in this paper, are project duration and cost growth. Project duration is a useful schedule metric to study how long agencies are taking to deliver US highway construction projects using different project delivery methods. Project duration is a straightforward metric, a measure of the time from the start date of agency design to the date of substantial completion of the project (Songer and Molenaar, 1996; Migliaccio et al., 2009; McGraw Hill Construction, 2014; Gransberg et al., 2013a). This duration is the final project duration which includes all substantial contract changes and/or builder delays. Cost growth, another key performance metric, is the cost at contract award compared to the final contract cost, a measure of the magnitude of cost over/under-runs (Konchar and Sanvido, 1998;

Molenaar and Songer, 1998; AECOM, 2003; Debella and Ries, 2006). In comparing project costs from different times it is important to adjust for inflation. The National Highway Construction Cost Index (NHCCI) by the FHWA is used to convert all costs to equivalent costs in June 2015. This conversion permits a fair comparison of project costs from different delivery methods.

4.5.2 Phase 2 – Experiential Knowledge Acquisition

The experiential information for this paper is obtained from the Delphi method in which experts judge the performance of the project delivery methods for the categorized descriptions of highway construction projects. The Delphi technique is appropriate to meet the objective of this paper by aggregating the judgements of a group of agency personnel with adequate qualifying experience to be considered experts in highway construction project delivery. Key features of the Delphi technique which make it advantageous as a method of obtaining expert opinion are, anonymity, iteration, controlled feedback, and the statistical aggregation of group response (Rowe and Wright 1999). Hallowell and Gambatese (2010) discusses construction-related Delphi studies and provides a holistic guide to implementing the Delphi technique for construction engineering and management (CEM) researchers, they also provide a succinct description of the Delphi technique:

"The Delphi technique, originally developed by the Rand Corporation to study the impact of technology on warfare, allows researchers to maintain significant control over bias in a well-structured academically rigorous process using the judgment of qualified experts... The Delphi method is a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic."

The parameters for the Delphi method were set by the authors in advance of executing the method. The authors had to identify and select expert participants based on pre-defined qualifying criteria and develop the questionnaires for the rounds of questioning. The number of panelists needed was set at a minimum of 8 to a maximum of 20 experts, allowing for a maximum attrition rate of 60% while keeping the required number of panelists above the minimum recommended in literature on the Delphi method (Hallowell and Gambatese 2010). The planned, sequence, format of the rounds and the type of feedback provided to participants in each round of questioning during the Delphi study was as follows:

a. Round 1 – Initial questionnaire distributed.

b. Round 2 – Issue Round 2 questionnaire which shows participants the aggregate response from Round 1 and where there is consensus for each judgement. Solicit feedback as remarks or reasons for outlying responses or changed responses. The participants should be shown their response from the previous round.

c. Round 3 – Issue questionnaire but solicit input only for judgments with no consensus and/or stability after Round 2. Show the aggregate response from Round 2 along with the remarks obtained from Round 2. Solicit new remarks and show the participant their response from the Round 2.

d. Any necessary subsequent rounds - Issue questionnaire but solicit input only for judgments with no consensus and/or stability after the previous round, show the aggregate response from the previous round along with the remarks. Solicit new remarks and show the participant their response from the previous round.

In executing the Delphi method for this paper, respondents provided an input/response for the individual judgments of performance for each alternative contracting method, i.e. CM/GC, D-B/LB, and D-B/BV, in relation to the performance of the traditional D-B-B delivery method which was used as a baseline. Termination of each judgment after each round of the Delphi was made on the basis of a measure of consensus and stability in the responses from round to round as suggested by Kalaian and Kasim (2012). The question format for the Delphi method asked respondents to input a quantitative value for their judgment of the performance of the respective alternative contracting methods for a described project, relative the D-B-B performance value. An example of a project description is, a "moderately complex, new, $5M" project. If respondents feel that they would not use or recommend a particular project delivery method for the described project then an "X" is input as a response. As a result of this format of questioning the participants can provide both a categorical variable and/or a continuous variable as a response for each judgment in the Delphi.

Consensus and stability are assessed for each form of variable, the categorical variable by non-parametric methods and the continuous variable by parametric methods. Examples prevail in literature of consensus and stability assessments by non-parametric methods (Rayens and Hahn 2000; Weir et al. 2006; Kalaian and Kasim 2012; Giannarou and Zervas 2014) and by parametric methods (Clark and Wenig 1999; Olumide et al. 2010; Hallowell and Gambatese 2010b; Kalaian and Kasim 2012). For the categorical variable consensus is achieved when 50% or more of the respondents indicate an "X" for the particular judgment in the Delphi. The categorical variable requires a nonparametric method to analyze stability, as such the McNemar change test is used to assess a shift in the responses of the experts for each judgment between two consecutive rounds of questions. The categorical variable is deemed stable when the McNemar change test is not significant at the 95%

confidence level (p > 0.05). For the continuous variable consensus is achieved when the absolute deviation about the median (ADM) is less than or equal to 0.1. (ADM ≤ 0.1). For the continuous variable the Spearman's rank correlation coefficient is used to measure the stability responses between two consecutive rounds of questions. An advantage of the Spearman's rank correlation coefficient is that it not only indicates the level of correlation of responses between two consecutive rounds of questions, it can also indicate the direction of correlation be it positive or negative. The continuous variable is deemed stable when the test for the Spearman's rank correlation coefficient is significant at the 95% confidence level (p ≤ 0.05).

In Round 1 of the Delphi study respondents were required to provide an input for 14 descriptions of highway construction projects for each of the alternative contracting methods, CM/GC, D-B/LB, and D-B/BV, totaling 42 judgments for project duration and 42 judgments for cost growth. The criteria for assessing the aggregate response that was reported to participants during each round the Delphi followed a specific format. For the categorical variable the aggregate response is reported as the percentage of the respondents that input the categorical variable "X". The aggregate response for the continuous variable is reported as the median value. Ultimately, the information acquired through the Delphi method supplements the empirical data in order to meet the objective of indicating project delivery method performance for categorized project descriptions based on highway construction project characteristics.

4.6 Data Characteristics

This section details the characteristics of the empirical and experiential data.

4.6.1 Empirical Data Characteristics

The empirical project data provides an holistic update on the project delivery methods used for US highway construction. At the overall level, the average award cost for the projects from all project delivery methods is $27,140,363, the projects range in award costs from $69,108 to $357,760,287. Table 4-2 shows in aggregate the project cost information from the empirical data. Contractor design costs are included for the D-B projects whereas no design costs are included for the D-B-B and CM/GC projects. Table 4-2 also shows the distribution of the project delivery methods within the empirical data. The traditional D-B-B projects are the largest proportion, as expected CM/GC is the smallest proportion since this method is relatively the newest of the project delivery methods. Notably, the CM/GC projects in the empirical database represent approximately 65% of the CM/GC projects that were available nationally at the time of data collection. This statistic is substantiated by a robust review of relevant documentation and reports including, the FHWA's (2015) EDC-2 Final Report, the FHWA's SEP-14 active project list information (FHWA SEP-14 website), the FHWA's "Alternative Contracting", formerly, "Innovative Contracting", website (FHWA, 2002), and the Design-Build Institute of America's (DBIA) milestone maps, with further verification through direct contact with numerous state transportation agency personnel and senior FHWA personnel.

Table 4-2. Aggregate information from the empirical data

	Proportion in database (%)	Mean Award Cost ($)	Min. Award Cost ($)	Max. Award Cost ($)
D-B-B (n = 134)	47%	$20,286,637	$1,390,828	$235,936,099
CM/GC (n = 34)	12%	$36,328,010	$69,108	$68,826,264
D-B/LB (n = 39)	14%	$10,646,348	$622,317	$357,760,287
D-B/BV (n = 77)	27%	$43,364,854	$69,108	$357,760,287
Overall in empirical data (n = 284)	100%	$27,140,363	$183,202	$252,052,326

4.6.2 Experiential Knowledge – Expert Respondents Characteristics

The approach taken in this paper is to supplement empirical data with experiential knowledge obtained from the Delphi method. The quality and consequential value of this experiential knowledge depends on the knowledgeability and expertise of participants (Rowe and Wright 1999; Skulmoski et al., 2007; Giannarou and Zervas 2014). Participants in the Delphi study had to meet at least 4 out of 5 of the following selection criteria to qualify to participate in the Delphi study:

i. Has worked a minimum of 10 years in the highway design and construction industry.

ii. Works in an agency's alternative project delivery, contracts/procurements or other relevant section which directly oversees/influences project delivery method selection.

iii. Has published on the topic of highway project delivery methods.

iv. Has a Professional Engineer (PE) certification.

v. Has completed a highway project using at least two of the relevant project delivery methods.

The authors commenced the Delphi method in this paper by initiating contact with a preliminary list of 30 agency personnel identified as potential expert participants. Subsequent to initial contacting 18 experts were selected to commence the Delphi study based on their qualifications and their interest and availability to participate. All of the 18 experts who commenced the Delphi study met the 4 out of 5 requirement for the expert selection criteria, 15 of these experts met all 5 of the expert selection criteria. There was a 100% response rate for Round 1 from the 18 experts. The response rate for Round 2 was 94% with only one of the 18 experts unable to participate. The response rate dropped to 78% for Round 3 with 14 respondents.

Of the 14 experts who completed the third and final round of the Delphi, 12 of these experts met all 5 of the expert selection criteria. In aggregate, the 14 experts who completed the Delphi study have an average of over 20 years work experience in project delivery for highway design and construction projects; the minimum work experience is 9 years and the maximum is 34 years. All 14 of the experts work in an agency's relevant section or department which directly oversees or influences the selection of project delivery methods. Only 2 of the experts have not been involved in any publications on the topic of highway project delivery methods. Only one of the 14 participants do not have P.E. certification but has an Engineer in Training (EIT) certification. Collectively, the experts have worked on over 200 projects which used alternative contracting methods. All 14 experts have worked on D-B-B projects, 2 of the experts have not worked on CM/GC, 7 experts have not worked on D-B/LB, and 2 experts have not worked on D-B/BV projects. These statistics attest to the exceptionally high quality of the expert panel for the Delphi study in this paper.

Another feature of the Delphi method for this paper that substantiates the quality of the expert participants is that all of the experts are from states that have experience in using the alternative contracting methods, CM/GC and/or D-B, based on the FHWA's (2015) EDC-2 Final Report. The locations of employment of the experts are well distributed throughout the agencies in the US which have significant experience in using alternative contracting methods; the locations/agencies include, Arizona, California, Colorado, Florida, Massachusetts, Michigan, Minnesota, Nevada, Utah, Wisconsin, the Office of Federal Lands Highway (FLH) - Eastern Federal Lands Highway Division (EFLHD), Central Federal Lands Highway Division (CFLHD) and the Western Federal Lands Highway Division (WFLHD).

4.7 Results & Discussion

This section presents results from the two-phase approach to accomplish the research objectives. For phase 1 the results for each performance metric, i.e. project duration and cost growth, is presented from examination of the empirical data at the aggregate level. Extreme outliers are removed from the overall pool of each performance metric, i.e. the project duration and cost growth. These metrics are calculated using the following equations:

$$Project\ Duration =\ construction\ end\ date - start\ date\ of\ agency\ design$$
(1)

$$Cost\ Growth =\ \frac{Final\ Contract\ Cost - Awarded\ Contract\ Amount}{Awarded\ Contract\ Amount}$$
(2)

The phase 2 results present the information collected by the Delphi process for each performance metric, along with discussions of the observed trends of performance for the respective project characteristics and project delivery methods. It must be noted that the results for phase 2 represent the perceptions of the experts based on their collective experiential knowledge of the advantages or disadvantages in project delivery method performance with specific regard to each performance metric. In other words, the results within project duration show trends of the project delivery methods' performance in relation to the objective of schedule compression, likewise, the performance trends within cost growth are in relation to the objective of controlling cost overruns.

The findings in the majority of existing literature on CM/GC versus D-B schedule performance are based on experiential knowledge from the perceptions and opinions of industry users of these delivery methods. It is notable that the results in this paper more clearly distinguish CM/GC versus D-B schedule and cost growth performance by presenting results as quantitative values of performance relative to

D-B-B. This presents a unique contribution to knowledge in contrast to the mixed perceptions of CM/GC versus D-B schedule performance in previous research.

Within the discussion of the phase 2 results, the authors proceed to validate useful findings by a triangulation of information from the empirical data, from the Delphi method (quantitative results and qualitative feedback), and from existing literature. This is done to improve the validity of all findings in this paper. Validated results which are applicable in industry are presented in the recommendations section of this paper.

4.7.1 Phase 1 – Empirical Data

At the aggregate level the empirical data shows that agencies are expediting overall project delivery time without significantly increasing cost growth by using alternative contracting methods. Table 4-3 shows the overall project durations for the empirical database. These durations are final project durations which include all contract changes and/or builder delays. Accurate duration data were more difficult to obtain than cost data, as a result, the mean project durations in Table 4-3 are calculated with fewer projects than in Table 4-2 for the project costs. At the aggregate level, when compared to D-B-B the mean project duration for the CM/GC projects is 46% shorter and the mean D-B/BV project duration is 22% shorter than D-B-B. These results are noteworthy considering that the mean award costs for CM/GC and D-B/BV projects are approximately twice that of the D-B-B projects; essentially, projects that are twice as large are being built in half the time by using alternative contracting methods. The mean D-B/LB project duration is approximately 50% shorter than D-B-B but the mean D-B/LB award cost is approximately half of the D-B-B projects' mean.

Table 4-3. Project Duration from the empirical data

Contract Method	Proportion in database (%)	Mean Project Duration (Days)	Min. Project Duration (Days)	Max. Project Duration (Days)
D-B-B (n=77)	27%	1,948	205	6,364
CM/GC (n=25)	9%	1,045	204	3,846
D-B/LB (n=18)	6%	889	90	1,487
D-B/BV (n=21)	7%	1,517	643	3,647
Total (n=141)	**50%**	**1,589**	**90**	**6,364**

The cost at contract award compared to the final contract cost is a key performance metric, cost growth. Table 4-4 shows the results of cost growth calculations for the empirical data with extreme outliers removed. The mean cost growth for each project delivery method is shown along with descriptive statistics which describe the dispersion in the data. Results from t-tests on the aggregate cost growth data reveal no statistically significant difference in mean cost growth between any of the project delivery methods at the 95% confidence level. A result that warrants further investigation is that the cost growth of the CM/GC projects is the lowest at 0.9%. Cost growth for the other delivery methods range between 2.8% and 4.1%.

Table 4-4. Cost growth from the empirical data

Contract Method	Mean (%)	Median (%)	St. Dev. (%)	Min (%)	Max (%)
D-B-B (n=129)	4.1%	2.3%	9.5%	-21.8%	33.1%
CM/GC (n=31)	0.9%	0.8%	6.0%	-12.0%	14.5%
D-B/LB (n=36)	2.8%	0.7%	5.7%	-5.6%	19.0%
D-B/BV (n=74)	4.0%	1.9%	5.5%	-4.5%	19.6%
Total (n=270)	**3.5%**	**1.9%**	**7.8%**	**-21.8%**	**33.1%**

4.7.2 Phase 2 – Experiential Knowledge

This section presents results from the Delphi method for each performance metric, i.e. project duration and cost growth, along with discussions of the observed trends of performance for the respective project characteristics and project delivery

methods. The results represent the perceptions of the experts based on their collective experiential knowledge of the advantages or disadvantages in project delivery method performance with specific regard to each performance metric. In other words, the results within project duration show trends of the project delivery methods' performance in relation to the project goal of schedule compression, likewise, the performance trends within cost growth are in relation to the project goal of controlling cost overruns. To enhance the validity of the findings, the authors proceed to validate useful results by a triangulation of information from the empirical data, from the Delphi method (quantitative results and qualitative feedback), and from existing literature. In the next section of this paper validated results are presented as recommendations for application in industry.

In executing the Delphi study, although some judgments achieved consensus after round 1, respondents were again required to input a response for all 84 cost and schedule judgments along with qualitative feedback during round 2. At the end of round 2, 12% of the project duration judgments did not achieve consensus or stability, judgments that achieved both consensus and stability were dropped from the questionnaire before proceeding with round 3. All the cost growth judgments achieved consensus at the end of round 2 but 57% were not stable so these required respondents' input during round 3. All remaining judgments achieved consensus and stability at the end of round 3.

The available literature on project delivery method performance show that the alternative contracting methods are superior to the traditional project delivery method, D-B-B, in terms of cost and schedule performance (Gordon, 1994; AECOM, 2003; McGraw Hill Construction, 2014; Farnsworth et al., 2015; Bingham et al., 2016). The purpose of this paper is not to revisit this established superiority of the alternative contracting methods but rather, to reveal the performance of the alternative contracting methods relative to the well-known D-B-B method in a

93

quantitative manner for categorized highway construction project descriptions. In the process the results reveal instances where certain alternative contracting methods are not recommended for a particular project with regard to project duration or cost growth performance. Readers should note that when an alternative contracting method is not recommended there is likely no significant benefit in using the alternative contracting method instead of the traditional D-B-B method.

4.7.2.1 Project Duration

With regard to project duration, the results from the Delphi method reveal that alternative contracting methods are not recommended for non-complex projects. Tables 4-5 and 4-6 display the results from the Delphi method for project duration.

Table 4-5. Project duration – most complex projects

Project Duration Performance Relative to D-B-B						
Complexity:	**Most Complex Projects**					
Project Type:	**New Projects**			**Rehab. Projects**		
Project Size ($)	**$0-$10M**	**$10M-$20M**	**$20M-$50M**	**$0-$10M**	**$10M-$20M**	**$20M-$50M**
D-B-B Baseline:	**100%**			**100%**		
CM/GC	96%	90%	90%	93%	90%	85%
D-B/LB	X	X	80%	X	90%	80%
D-B/BV	90%	85%	80%	X	85%	80%

Table 4-6. Project duration – moderately complex projects

Project Duration Performance Relative to D-B-B						
Complexity:	**Moderately Complex Projects**					
Project Type:	**New Projects**			**Rehab. Projects**		
Project Size ($)	**$0-$10M**	**$10M-$20M**	**$20M-$50M**	**$0-$10M**	**$10M-$20M**	**$20M-$50M**
D-B-B Baseline:	**100%**			**100%**		
CM/GC	X	90%	85%	X	X	90%
D-B/LB	X	X	90%	X	X	85%
D-B/BV	X	85%	85%	X	X	85%

With regard to project duration, the results show that the alternative contracting methods are recommended for projects of larger sizes, higher complexity and for new projects. This result is supported by previous research which reveals that agencies are achieving benefits in terms of schedule by using the alternative contracting methods on larger, more complex projects (Gordon, 1994; AECOM, 2003, Minchin et al. 2014). The qualitative feedback received during the Delphi method

contained numerous comments that validate this trend of use for the alternative contracting methods such as:

- *"I think that you will achieve the greatest benefit on larger, complex projects with alternative delivery - the more complex and high cost, the more likelihood for innovation and savings in time and money."*
- *"I do believe that alternative delivery will provide some savings in time and money on larger projects because the contractors will approach the job differently."*

With CM/GC, it is apparent that more time savings are achieved on projects of larger sizes and higher complexity. In particular, the results show that most complex, rehabilitation projects can achieve 5% more time savings than most complex, new projects. Within the moderately complex category, this trend is reversed with the moderately complex, new projects achieving 5% more time savings than the moderately complex, rehabilitation projects. The results also show that CM/GC use is not recommended for moderately complex, rehabilitation projects of smaller project sizes. These results concur with literature in that CM/GC permits agencies to enhance projects schedule performance. Previous research shows that agencies achieve improved schedule performance with CM/GC by the early involvement of contractors in project delivery, agencies are able to tap the contractor's industry experience to develop more practical, accurate and efficient schedules (Gransberg and Shane, 2010; Martinez et al., 2007; Kuhn, 2007; Touran 2006). Also of relevance here is that rehabilitation projects are the common project type that is accelerated by agencies, especially when these projects are located in urban settings and are typically, larger, more complex projects (Anderson and Damnjanovic 2008). Several comments from the experts align with the CM/GC findings and reveal that the

experts are aware of the benefits of early contractor involvement; a particular statement stands out, "With CM/GC it is possible a complex rehab project could benefit from contractor input for staging, and some innovation."

Among the alternative contracting methods, D-B outperforms CM/GC for most complex, new and rehabilitation projects of any size. In relation to D-B-B, schedule performance is very similar for both forms of D-B for most of the project categories. Except for most complex, rehabilitation projects, D-B/LB is not recommended for smaller project sizes likely because of administrative burden. A statement that indicates that experts are of this notion is, "A project this size doesn't benefit enough to justify the cost of additional resources, procurement, and stipends." The limited literature available on CM/GC versus D-B schedule performance collectively suggest that D-B is superior (Konchar and Sanvido, 1998; McGraw Hill Construction, 2014; Shrestha et al., 2014; Bingham et al., 2016). The perceptions of the experts in this study align with such literature however further investigation of this finding is warranted using empirical data, particularly as the industry trend is to use D-B/LB on smaller projects in practice (Alleman et al. 2016; FHWA 2013). The Delphi study results reveal that the experts recommend D-B/BV for smaller projects sizes, this presents a discrepancy with literature and practice in which D-B/LB is thought to have less administrative burden and is more frequently used on smaller projects (Alleman et al. 2016; FHWA 2013). With regards to experts' perceptions on the performance of D-B/LB versus D-B/BV performance, feedback from the Delphi study show that experts consider D-B/BV is superior to D-B/LB as evident by statements such as, "Overall costs and time - my personal opinion is that you save more money and time with a D-B Best Value bid vs a D-B Low-Bid." The results showing that D-B/BV is superior to D-B/LB is likely an indication that the experts recognize the possibility of enhanced schedule performance as a byproduct of the procurement method used for a D-B project (Molenaar et al. 1999; Migliaccio et al. 2010). In this

regard, the experts' perceptions align with literature which suggests that two-step D-B procurement, i.e. RFQ and RFP solicitations, leads to more qualified bidders with a better track records of schedule performance than in the case of the lowest cost bidder winning the contract (Chen et al. 2016).

4.7.2.2 Cost Growth

Managing cost growth is a major reason why agencies choose the alternative contracting methods over the traditional D-B-B method. With regard to cost growth, the results from the Delphi method reveal that the alternative contracting methods are not recommended for non-complex projects. Tables 4-7 and 4-8 show the results from the Delphi method for cost growth.

Table 4-7. Cost growth – most complex projects

Cost Growth Performance Relative to D-B-B						
Complexity:	**Most Complex Projects**					
Project Type:	**New Projects**			**Rehab. Projects**		
Project Size ($)	**$0-$10M**	**$10M-$20M**	**$20M-$50M**	**$0-$10M**	**$10M-$20M**	**$20M-$50M**
D-B-B Baseline:	7%	6%	5%	6%	5%	4%
CM/GC	4%	2%	1%	2%	2%	1%
D-B/LB	X	2%	3%	X	3%	3%
D-B/BV	4%	4%	3%	5%	4%	3%

Table 4-8. Cost growth – moderately complex projects

Cost Growth Performance Relative to D-B-B						
Complexity:	**Moderately Complex Projects**					
Project Type:	**New Projects**			**Rehab. Projects**		
Project Size ($)	**$0-$10M**	**$10M-$20M**	**$20M-$50M**	**$0-$10M**	**$10M-$20M**	**$20M-$50M**
D-B-B Baseline:	6%	5%	4%	5%	4%	3%
CM/GC	1%	1%	1%	1%	1%	1%
D-B/LB	X	2%	3%	X	3%	3%
D-B/BV	3%	3%	2%	3%	3%	2%

With cost growth as the performance metric in mind the results contain less restrictions on the use of the alternative contracting methods for projects of smaller sizes on most complex and moderately complex projects than when the experts focus on project duration. Again, the overall trend in the results illustrates that alternative contracting methods are achieving improved cost growth performance over D-B-B. The superior cost performance of the alternative contracting methods is well

99

documented in literature (Gordon, 1994; Songer and Molenaar 1996; Konchar and Sanvido, 1998; AECOM, 2003; Minchin et al 2013; McGraw Hill Construction, 2014; Goftar et al. 2014; Bingham et al., 2016). Additionally, previous research notes that economies of scale are associated with larger projects and that cost growth is linked to the economy of scale (Creedy et al. 2010). This supports the finding in this paper that as project size increases there is a tendency for cost growth to reduce. Nonetheless, the dollar amount or value of cost growth can likely be greater for larger projects even though the cost growth percentage is less than that of a smaller project. Qualitative feedback from the Delphi method that support this finding include:

- *"I personally feel you will almost always see some increased costs - but my estimates [for the alternative contracting methods] are less than what I expect with D-B-B."*
- *"With this being a complex project - yet higher cost - you will still see some increase in cost but the overall % will be lower for alternative methods."*
- *"My thought is that at $20M-$50M, innovation and efficiencies begin to be more substantial using alternative delivery, D-B-B or Low Bid will limit those opportunities…"*

The CM/GC delivery method exhibits the best cost growth performance among the alternative contracting methods. Notably, the results from the empirical data in this paper parallel this finding from the experiential knowledge obtained from the Delphi study. While on moderately complex projects, CM/GC cost growth performance is the same for new and rehabilitation projects of any size. The cost growth performance of CM/GC improves as project size increases on most complex projects of any project type. Previous literature based on experiential knowledge supports the result that CM/GC is the superior alternative contracting method for

cost performance (McGraw Hill Construction, 2014; Farnsworth et al., 2015; Bingham et al., 2016). The work of Alleman et al. (2016) also highlights that CM/GC cost growth performance is superior, particularly on larger project sizes, based on quantitative, empirical project data. Based on literature, CM/GC's superior cost growth performance may be attributed to the collaborative environment among all parties involved in project delivery, thus leading to innovation and other efficiencies (Gransberg and Shane 2010; Kenig 2011; Minchin et al. 2014). An additional feature of CM/GC that attributes to better cost growth performance is cited in literature as the guaranteed maximum price (GMP) payment method typically used on CM/GC projects (Gransberg and Shane 2010; Chen et al. 2016). The GMP payment method improves cost growth performance because any costs incurred above the agreed GMP are the responsibility of the contractor so there is typically no cost liability with the agency. The following comments from the Delphi method support the trends observed in relation to CM/GC:

- "Cost growth for projects at this complexity level [moderately complex] would not vary much, based on the whether they are new projects or rehab."
- "For Rehab projects there is usually not as much opportunity for innovation so there will not be much fluctuation in costs."
- "With an Upset Price/GMP, our costs should not grow beyond normal change conditions increases in a project."

Of the alternative contracting methods, D-B/LB is the only method with a restriction in usage, the experts do not recommended D-B/LB for any project of the smallest size ($0-$10M). Again, this contradicts with literature which suggests that in practice D-B/LB is mostly used on smaller projects. For the most complex, new and rehabilitation projects D-B/LB cost growth performance is slightly better than D-

B/BV. For the moderately complex, new and rehabilitation projects D-B/LB and D-B/BV cost growth is similar. Regardless of complexity and project type D-B/LB cost growth does not vary significantly but D-B/BV cost growth improves as project size increases on most complex projects of any project type. Notably, for moderately complex rehabilitation projects both D-B/LB and D-B/BV cost growth performance is the same as D-B-B, this trend prevails except when D-B/BV is used for the $20M-$50M projects in this category.

The slightly better cost growth performance of D-B/LB versus D-B/BV for most complex, new and rehabilitation projects is also contradicts existing literature. The scant available literature on the topic indicates that D-B/BV is superior to D-B/LB in terms of cost performance (Molenaar et al., 1999; Chen et al. 2016), although, Migliaccio et al. (2010) found no evidence that the different D-B procurements affect cost growth. Based on literature D-B/BV is better because of the increased scope definition and higher percentage of design completion before contract award when compared to D-B/LB (O'Connor and Vickroy 1985). In theory, these features of D-B/BV should permit contractors to submit lower costing bids than if they had to account for more uncertainty or risks because of the lesser scope definition and lower percentage of design completion with D-B/LB. In this regard, it remains uncertain if this trend of better D-B/LB cost growth performance is because the experts in the Delphi method are bearing in mind higher costs to the agency because of the increased resources and administrative burden required with D-B by best value procurement. No comments from the experts shed light on the contradiction with literature presented by the results of the Delphi study showing D-B/LB to have better cost growth performance than D-B/BV. However, there are comments which indicate that experts are considering other factors such as risk allocation during selection of project delivery methods. This is likely the reason the experts recommend the use of D-B/BV over D-B/LB for certain projects. Several statements from the experts

102

highlight that agency personnel are thinking about risks during the selection of project delivery methods:

- *"DBB is all owner risk, DB is a risk sharing exercise and it puts risk in the hands of those best suited to handle it."*
- *"Generally, we would not use this delivery method [D-B/BV] for a project this size [$0-$10M]. The expense of the procurement and the stipends isn't really justified by the potential risk transfer."*
- *"I feel that D-B/LB would not give room for innovation and higher complexity may be harbinger of unknown risks, with D-B/BV I feel there is more room for innovation and risk reduction."*

A feature of the results that warrants further consideration is that D-B/LB is still recommended over D-B-B when D-B/LB cost growth performance equates to D-B-B cost growth performance for the large size ($20M-$50M) moderately complex rehabilitation projects. No comments from the Delphi method help clarify this finding, although, several of the comments already listed show that the experts are thinking about other factors during delivery method selection and that experts consider the potential efficiencies achieved through the opportunities for innovation on alternative contracting methods. Another notion is provided by literature which shows that agency directed change orders are the most common change order type in D-B projects for various reasons, most notably because agencies often try to increase the scope of D-B projects to expend any excess/savings from budgeted funds (Bordat et al. 2004; Koch et al. 2010; Alleman et al. 2016). This may be a reason why D-B/LB is recommended despite its cost growth performance being equal to D-B-B.

In conclusion, it should be noted that both the empirical data and Delphi/experiential data are susceptible to error. The empirical data pool is

103

necessarily small in size due to the number of completed CM/GC US highway projects at the time of this study. The pool of experts for this study is undoubtedly qualified, but they also have relatively little experience with CM/GC due to the novelty of this delivery method. Finally, the referenced existing literature is primarily based on qualitative results that could be subject to biases or a lack of complete information. All of these factors point to the need for further research. The discovered contradictions introduce uncertainty in the reliability of some of the results from the multiple sources of information and the inconsistency does not permit the validation of findings by triangulation of results. Therein lies the opportunity to conduct further research to clarify the contradictions in order to produce reliable results that will be useful as recommendations for application in highway construction project delivery. Additionally, future research that incorporates techniques such as case studies and/or interviews can better reveal the possible reasons for some of the contradictions and unsubstantiated results.

4.8 Conclusion

The contributions of this research to the existing body of knowledge are twofold. Firstly, it provides an holistic update on the performance of project delivery methods for US highway construction projects based on empirical project data. Secondly, by relying on the collective experiential knowledge of experts involved in US highway construction project delivery, it provides practical indications of the cost growth and schedule performance of project delivery methods for US highway construction projects.

Overall, while the results confirm that alternative contracting methods are superior to the traditional D-B-B method in terms of cost and schedule performance, the results highlight instances in which D-B-B remains indispensable. The results and recommendations as presented provide new, fundamental knowledge about

project delivery method performance with regard to particular highway construction project descriptions. Equipped with this new knowledge, i.e. indications of which project delivery methods can result in superior performance, agency professionals can better align information available at the early stages of project development with the appropriate project delivery method to achieve optimum outcomes in terms of cost growth and project duration.

4.9 Recommendations

The findings from this paper present information that can enhance the decision-making process of project delivery method selection by state highway agencies. The results provide useful quantitative indications of the likely performance of the predominantly used project delivery methods in US highway construction. In this section the findings from this paper are presented as recommendations applicable in industry.

Overall, the results reflect agencies' main motivation for selecting the alternative contracting methods to shorten overall project duration. Additionally, the alternative contracting methods are achieving improved cost growth performance over the traditional D-B-B delivery method. The best project delivery method to control cost growth is CM/GC. The alternative contracting methods are recommended for use on projects of larger sizes, higher complexity, and especially for new projects in which more time savings are achieved. Using the alternative contracting methods on larger, more complex projects enhances the associated economies of scale, i.e. as project size and complexity increase, cost growth reduces. In process of selecting project delivery methods these recommendations should be considered in parallel with agencies motivations in relation to other factors involved in project delivery. As exemplified in the results of this paper, the contradictions in findings from different sources of information is a likely consequence of such motivations.

4.10 Acknowledgments

CHAPTER 5 - CONCLUSION

5.0 Introduction

This dissertation expands the body of construction engineering and management (CEM) knowledge with specific regard to project performance and the selection of project delivery methods for US highway construction. The contributions are beneficial to both academic researchers and construction industry professionals. This chapter discusses the theoretical and practical contributions, limitations, and recommendations for future work, associated with this dissertation. The chapter concludes with reflections from the author's about the research experience and how the knowledge acquired may impact career goals and professional aspirations.

5.1 Summary of Contributions

This research makes new contributions to the CEM body of knowledge by successfully investigating the performance of highway construction projects in relation to project characteristics and project delivery methods. The results improve the understanding of the inter-relationships among these factors and how they affect performance on particular projects. Equipped with this new knowledge, state highway agencies can better align information available at the early stages of a project with the selection of an appropriate project delivery method to achieve successful outcomes in terms of schedule compression, early timing of cost certainty during project delivery, controlling cost growth, and managing project intensity. Notably, the timing of cost certainty during highway project delivery has not been quantified by previous researchers. The results of this research paper address this gap in knowledge by quantitatively showing how the timing of cost certainty relates different highway project delivery methods. This research provides a novel

comparison of the timing of cost certainty among US highway construction project delivery methods.

A highlight feature of this dissertation is the timeliness of the information on project delivery. Particularly considering that, at this time, agencies are more experienced in D-B and CM/GC since these delivery methods are no longer in the experimental phase of the FHWA's SEP-14 (FHWA SEP-14 website). Notably, although CM/GC is relatively the newest among the project delivery methods the information on CM/GC projects in this dissertation represents approximately 65% of the CM/GC projects that were completed in the US at the time of data collection. This sample size is substantiated by a robust review of relevant documentation and reports including, the FHWA's (2015) EDC-2 Final Report, the FHWA's SEP-14 active project list information (FHWA SEP-14 website), the FHWA's "Alternative Contracting", formerly, "Innovative Contracting", website (FHWA, 2002), and the Design-Build Institute of America's (DBIA) milestone maps; with further verification through direct contact with state highway agency personnel and senior FHWA personnel.

As a whole, this dissertation provides straightforward indications of whether or not a project delivery method is likely to achieve desired performance by building on previous delivery method selection approaches and project performance research. Figure 5-1 illustrates how the contributions of this research fit in a pivotal position, i.e. central, within the periphery of research and practice areas in relation to project delivery method (PDM) selection and project performance. The findings of this research heavily rely on empirical project data successfully supplemented with information from experiential knowledge. Collectively, the recommendations highlight features of individual project delivery methods with regard to performance, and the research effort and results provide fundamental information to develop a new systematic process for selecting delivery methods suitable for highway construction

projects. While there is no single project delivery selection system that can be applied for the overall US construction sector, publicly-funded higway projects are well-suited to the development of a definitive project delivery selection system. Especially at this time when the use of alternative contracting methods is increasing among state highway agencies.
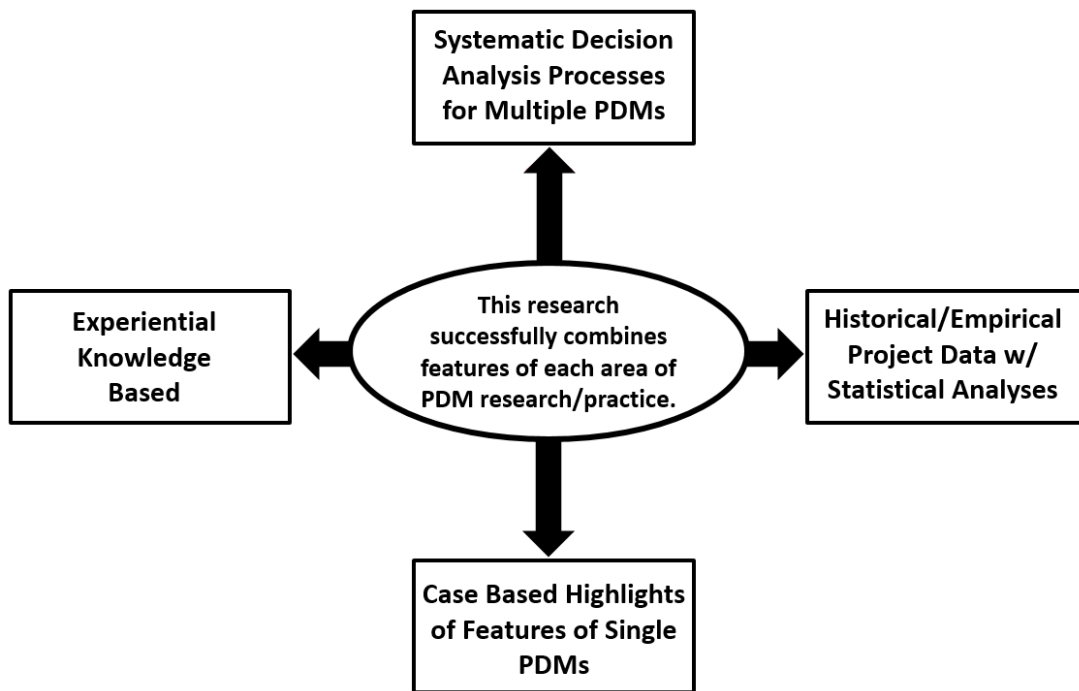
Figure 5-1. Contributions within the periphery of project delivery research and practice areas

5.1.0 Theoretical Contributions

The results of this dissertation present fundamental contributions to CEM research. The theoretical contributions add to the study of project delivery method selection and to the study of project performance in multiple ways. As far as possible, this PhD research is heavily based on empirical project information. This presents an advantage over the use of purely qualitative information by reducing the possibility of inherent biases and other subjective elements. The quantitative approaches to

project delivery method selection in previous research are based on comparisons of performance metrics among project delivery methods to attempt to display which project delivery method may be superior (Hale et al, 2009; Debella and Ries, 2006; Konchar and Sanvido, 1998). This new research not only provides comparisons but also exposes, from multiple perspectives, previously undiscovered relationships among highway construction project delivery methods and project characteristics. By referencing definitions that are well established and documented by practicing state DOTs and the FHWA this research successfully avoids ambiguities in the explanations of highway project delivery attributes that have plagued previous studies (Luu et al. 2003 & 2006).

This dissertation builds on the work of researchers who have called for a more empirically-based study of project performance to improve the selection of appropriate delivery methods (Kumaraswamy and Dissanayaka 2001; AECOM, 2003; McGraw Hill Construction, 2014; Farnsworth et al. 2015; Bingham et al., 2016). Findings in this dissertation heavily rely on empirical project data successfully supplemented with information from experiential knowledge and as warranted by previous researchers the author incorporates efforts to compare justifiably similar projects to obtain useful information (Ernzen and Schexnayder 2000; Shrestha et al. 2007 & 2012).

The majority of existing research that includes any quantitative examination of project delivery methods have used smaller sample sizes and samples of projects that are not highway construction (Hale et al, 2009; Debella and Ries, 2006; Ibbs et al, 2003; Molenaar and Songer, 1998). The empirical database of information collected for this research currently forms the largest empirical data-set exclusive to US highway construction project delivery making results highly specific and relevant. While previous research on project delivery performance contains a mix of projects from multiple sectors and from different countries, not only does this research focus

solely on US highway construction projects the need for comparisons of performance using projects of similar characteristics is acknowledged (Ernzen and Schexnayder 2000; Shrestha et al. 2012). As a result, this research presents a unique and defensible method for the comparing project delivery performance using justifiably more comparable pools of projects, this enhances the pertinence of the results.

Previous research on project delivery performance lacks empirically-based findings in relation to CM/GC. This is an understandable consequence since this delivery method is relatively newer among D-B and D-B-B and not many agencies used CM/GC in highway construction at the respective times of previous research. At this juncture, this research contains on information based on a larger number of completed CM/GC highway projects than any other publications on the topic of project delivery performance. Additionally, this research makes a distinction between D-B/LB and D-B/BV projects. This detailed analysis provides insights into how procurement methods impact D-B performance. The highlight theoretical contribution of this research is that by supplementing results from the full exploration of the available empirical data with information based on experiential knowledge obtained from highway project delivery experts through the Delphi technique this research provides a new level of granularity that is not possible with any of the previous empirical studies of project delivery (Konchar and Sanvido, 1998; AECOM, 2003; McGraw Hill Construction, 2014; Farnsworth et al., 2015).

5.1.1 Practical Contributions

With the urgent demand for improving the status of US transportation infrastructure, this PhD research presents practical contributions that are of value to industry. These contributions focus solely on US highway construction, hence, assuring the reliability of findings for this sector of construction. Firstly, this research provides a timely and up-to-date review of US highway construction projects

111

with regard to project delivery and performance. Existing project delivery method selection approaches involve complex statistical or computational processes (Alhazmi and McCaffer 2000; Al Khalil 2002; Tran 2013). Rather than presenting concepts which are esoteric to the construction industry the findings from this research are presented in formats that facilitate ease of understanding. Before implementing any of the recommendations from this dissertation project delivery practitioners need to consider in parallel other issues that may affect decision-making such as, restrictions posed by state procurement legislation, agencies' internal culture and preferred level of control over design and agencies' ability to handle the inherent processes of the alternative project delivery methods.

Recognizing the dearth of standard frameworks for selecting an appropriate project delivery method for highway construction projects, this research promotes the systematic selection of project delivery methods by presenting useful information that can indicate performance on particular highway construction projects. The straightforward format of the findings in this research should promote the potential wide-spread application of a systematic project delivery method selection approach (ODOT 2009; MnDOT, 2013). The practical indications of performance in this dissertation can greatly enhance the project delivery decision-making process for any highway construction agency (ODOT 2010; WSDOT, 2016; CDOT, 2016). The indications of performance can be used as a stand-alone reference or can be used to supplement the decision-making process of other structured project delivery method selection approaches to help build consensus e.g. the workshops of the Project Delivery Selection Matrix for highway projects (Tran et al. 2013).

Highway agencies' project delivery personnel are thoroughly familiar with D-B-B. So by highlighting the performance of alternative project delivery methods in relation to D-B-B, even though agency personnel may be new to CM/GC or D-B, they can reference the results of this research and relate the quantitative findings to their

112

agency's D-B-B historical performance or their personal knowledge of D-B-B performance. The inexperience of decision makers can lead to difficulties when dealing with the complex interrelationships of project delivery processes (Luu et al. 2003; Chan 2007). Noting the worth of experiential knowledge (Kumaraswamy and Dissanayaka 2001; Luu et al. 2006; Bingham et al. 2016) this dissertation presents an invaluable reference of project delivery method performance based on aggregated experiential knowledge from highway project delivery experts. This one-stop reference to collective, high quality experiential knowledge is a vital professional tool for inexperienced highway project delivery decision makers. Ultimately, this dissertation presents fundamental information that supports the development of a utilitarian tool to facilitate project delivery method selection for highway construction projects. The indications of the relative performance of project delivery methods for key performance metrics on specific highway construction projects can be integrated into some form of a decision support system which can be integral to agencies' internal project development processes and enhance delivery method selection by agency personnel.

5.2 Limitations

As far as possible, the conclusions of this PhD research are validated by relying on the most appropriate research procedures for examination and analysis of the information relevant for the study. Nevertheless, limitations of the data and methodologies are inevitable and need to be acknowledged. Throughout this dissertation the author distinctly avoids implying causality and does not attribute findings directly to a particular project delivery method. More in-depth qualitative techniques are warranted to identify and further understand underlying causes for the results in this research.

The novelty of the CM/GC method posed challenges during the research for this dissertation during the collection of data. Also, the generalizability of CM/GC related results is affected because CM/GC usage is still growing and not as wide-spread as the other delivery methods. Nonetheless, the research accomplishments of this dissertation can serve as a model to analyze CM/GC performance as use of the delivery method increases among state highway agencies and more empirical data becomes available.

In aggregate, the empirical data obtained for this research is useful for a high-level examination of the topics studied. However, the reduction of sample size as the data is deconstructed by highway construction project characteristics and delivery methods restricts examination at a more detailed level. This restriction in sample size hinders the use of precise statistical analysis methods, especially in cases where the sample size falls below the limit of the Central Limit Theorem. For instance, this is observable in Chapter 3 during the exploration of CM/GC versus D-B schedule performance at a more detailed level when the data is deconstructed by project characteristics.

A limitation of small sample size with respect to any empirically based project delivery study is that an instance of performance from a single project cannot justifiably be highlighted as a reliable indication. Researchers cannot quantitatively prove that an instance of project delivery performance that is based on a single project is not an outlier. Information from a single project can be useful if presented via some other research method, say case based study. In this way, academia and industry can use the singular project as a lessons learned case to highlight practical examples of how procedures may have led to the instance of performance, be it satisfactory or unsatisfactory performance.

The collection of sufficient project schedule data proved extremely challenging throughout the data collection effort for this dissertation. The collection of

appropriate data on the design, procurement and construction durations of the different project delivery methods is warranted to better assess schedule performance, especially in relation to proposed or planned durations (Migliaccio et al. 2009). Agency personnel found it especially challenging to provide the required schedule data in adequate detail, planned or forecasted schedule information was particularly difficult to obtain. So a thorough examination of schedule growth among the project delivery methods could not be accomplished because of the sparseness of the planned schedule data obtained for this dissertation. Other information of scant quantity that limit possible examinations of project delivery are agencies' design costs in each project delivery method and the percentage of design completed by an agency before contract award for each project delivery method.

With the shortcomings of empirical data this dissertation incorporates information based on experiential knowledge of highway project delivery. However, despite the high quality of the expert panel for the Delphi technique executed for this dissertation the contradictions of the some findings with existing project delivery literature could be a result of the relatively small number of participants in comparison to other studies that have relied on experiential knowledge. Although, it is still notable that in this research there is high consistency in the qualifications and experiences of the expert participants and this reduces the possibility of mixed perceptions and uncertain results.

5.3 Recommendations for Future Research

The knowledge gained in the process of this research builds on the work of previous researchers who have examined project delivery methods and project performance. This dissertation exposes opportunities to conduct further research on the topics. Much of the future work stems from the limitations stated in the previous section. This section of the dissertation provides advice for future research efforts

and provides guidance to future researchers by pointing out feasible approaches to study other key highway construction project delivery attributes. As previously mentioned, to further understand and identify the underlying causes for the results in this research more in-depth qualitative techniques will be needed in future research. Qualitative research techniques such as case studies, observation/simulation and interviews hold merit to lead to a better understanding of the causes behind some of the correlations.

The empirical data obtained for this research is useful for a high-level examination of the topics studied. However, because of the categorizing effect of deconstructing the data by highway construction project characteristics and project delivery method, the consequential reduction of sample size restricts the use of high-level, computational or statistical analyses. As the use of alternative project delivery methods continues to grow, particularly the CM/GC method, research based on larger sample sizes will be beneficial to industry and academia by showing statistical comparisons of key performance metrics among the project delivery methods. Inherent with larger sample sizes is greater ability to discover statistically significant differences in performance, i.e. there is increased statistical power.

In future work it would prudent to obtain information on other project delivery variables of interest such as agencies' design costs, the percentage of design completed by an agency before contract award, and on the overlap of design and construction in the alternative delivery methods. The information on agency design costs and percentage of design completed before contract award can be useful for investigating the administrative burden of project delivery methods to reveal new insights on agencies preferences of particular project delivery methods. In-depth study of the overlap of design and construction in the alternative project delivery methods presents additional opportunities to discover whether D-B or CM/GC is more efficient in terms of schedule performance. Also, with larger samples of relevant

project schedule data future research can accomplish an examination of schedule growth among the highway construction project delivery methods and explore for any relationships between schedule performance metrics and the durations of project delivery processes; in particular, discovery of the impact of procurement durations on project schedule performance for highway projects would be of high value to the industry.

There is scope for the application of appropriate multivariate statistical methods to enhance CEM research. A major feature of a larger sample size is the ability to apply complex computational or statistical analysis methods with increased statistical power to identify statistically significant differences in the performance of project delivery methods. As a practical example of the potential application of multivariate statistical methods, a more complex statistical model such as a decision tree could potentially reveal new inter-relationships among highway project delivery attributes. With specific regard to project delivery method selection, if sufficient and suitable data is obtained there are multivariate statistical approaches that can model project delivery decision making to profoundly improve objective project delivery decisions and lead to more probable success in project performance. Particular methods could include an appropriate form of regression analysis. A major advantage of complex computational or statistical methods is the ability to build tested models for reliable predictions of project delivery method performance. Building on the work of this dissertation which shows the path to develop substantial quantitative indications of project delivery performance new researchers can focus effort towards collecting adequate empirical data to build dependable prediction models that could be customized, application specific and invaluable to the US highway construction sector.

The fundamental relationships among highway project delivery attributes and project performance still need to be explored further. By incorporating any new

knowledge with complex computational techniques there is the potential to be able to predict project performance using respective project delivery methods. Presenting this predictive capability to the highway construction industry in the form of a utilitarian decision support system can be beneficial to state highway agencies that aspire to delivery US highway projects more efficiently. Ultimately, the research accomplished for this dissertation builds on previous project delivery research and collectively, the results from this dissertation support the development of a decision support system for project delivery method selection in highway construction.

Future researchers should be cognizant of the potential advantages and disadvantages of the prospective format of a new decision support system. For instance, strategic considerations would be to develop the system as a digital application or computer software or in a hard copy physical format. Other considerations include development of the decision support system in a format that can foster the ease of distribution and control of access to any updated versions. The decision support system should have the ability to incorporate features that sustain continuous data collection by soliciting feedback from users. This feedback can be used to continuously evaluate performance of the system and to determine if any improvements are necessary. While there are multiple options for the format of a new decision support system, it is critical that the system is designed to be user-friendly by providing an easy to follow interface that masks the intricacies of any required calculations or analyses. In facilitating the straightforward use of the decision support system by agency professionals there is potential to encourage more wide-spread application of systematic project delivery decision making in industry.

5.4 Retrospective Summary and Future Aspirations

Aside from the many contributions of this PhD research in terms of theory, potential practical applications, and tangible recommendations for advancing

additional research, the experience provided an invaluable, holistic learning opportunity. Through the journey of conducting the research necessary for this dissertation the author has gained a comprehensive insight of US highway construction project delivery. In particular, the research efforts have afforded the author the chance to expand erudition of the associated issues of project delivery in the areas of alternative delivery methods, procurement, payment procedures, risk allocation, early contractor involvement, constructability, innovation, and project cost and schedule performance. The data collection effort was significantly challenging as it involved a multidisciplinary approach, contacting and following up with numerous state agency personnel. However, as a result, the author remains connected to an extensive network of contacts who are directly involved in US highway construction project delivery. This rich network of contacts exists by the author cultivating professional relationships with intrigued agency personnel through their interest in the results and objectives of this research. The connections to highway project delivery professionals is bound to hold value to the author who aspires to continue his professional career in the engineering/construction industry.

A novel finding in this dissertation is in regards to the schedule performance of CM/GC versus D-B. Intuitively, it is easier to comprehend how the D-B method can achieve schedule compression by the convenience of contracting a single entity for design and construction. However, the author believes that the CM/GC method holds other advantages besides superior schedule performance as shown in this dissertation and the use of this delivery method will inevitably grow to the point where CM/GC is widely accepted as the norm, especially for high costing complex projects. The author foresees that CM/GC will soon be established in the US highway construction industry with federally mandated standard procedures and documented manuals similar to the current status of the D-B method. The author's assertion of the balloon in CM/GC usage is based on the notion that with the dynamic complexities

involved in construction it makes sense to deliver projects through a more collaborative process that fosters integration of the skills and expertise of the parties involved in project delivery. In the author's opinion the project delivery method that is ideally structured to enable effective collaboration and integration of the entities involved in project delivery is CM/GC.

The findings from this dissertation may be transient considering that academia and industry continue to push the limits of research and application of the current highway project delivery methods. What is likely to stand the test of time from this dissertation is the demonstration of appropriate research procedures to obtain reliable information to develop a decision support system that can enhance the selection of appropriate project delivery methods. Other US construction sectors have developed their own variations of project delivery methods unique to the circumstances of the types of projects undertaken. For instance, progressive design-build is widely used in the water sector as an alternative contracting method. The repetitive nature of highway construction using public funds in the US facilitates the development of a definitive project delivery selection system for this sector.

Even in its current format, the information from this dissertation can improve existing project delivery method selection approaches. For instance, participants in the inherent consensus building workshops of some of the existing project delivery method selection approaches may be reluctant or hesitant to make decisions if they are wary of their inexperience on the matter of project delivery or a specific project delivery method. Supplementing these workshops with the quantitative indications of highway project delivery method performance from this dissertation can greatly aid decision making and consensus building. Coincidentally, this can be a useful feature of project delivery decision making by exemplifying how other industries or specific institutions can follow some form of empirically based, highly relevant indications of performance for project delivery method options.

As evident by the interest garnered among the expert participants of the Delphi technique in this dissertation, the indications of project delivery method performance for particular projects are worthwhile to industry. These experts were eager to see the quantitative results from the aggregation of their experiential knowledge. Some experts even commented that they would willingly defer their individual project delivery method decisions to a decision based on some form of collective professional expertise. Furthermore, the experts expressed that they would be more confident in project delivery method decisions that are established through the rigors of academic research that simultaneously involves the experiences of practicing professionals rather than an isolated academic approach. Thus, the views of the experts reinforce the value of this dissertation's research and show that the results have high potential to be applied in industry.

The ability to choose an appropriate project delivery method for efficient performance of a certain project holds merit with personnel from all the respective entities involved in project delivery including agency personnel, consultants and contractors. This notion is reinforced considering the vast amounts of money involved in US highway construction coupled with the current political climate that has heightened attention to expenditure on US infrastructure. The author recognizes the worth of the knowledge gained in preparing this dissertation and actively seeks out prospective industry employers who would appreciate the value of the author's proficiency in project delivery. To the author the ideal professional position in a company would be one that offers opportunities to continue to learn about project delivery through research and the direct application of findings. However, the knowledge from this dissertation offers the author the scope to pursue prospective industry positions that may be associated to project management duties on federally funded highway or transportation projects and the learning from the intellectual

journey permits the extension of the author's competencies into other categories of construction project delivery that are of interest to him in practice.

With ever increasing pressures for agencies to execute highway construction projects on time and within budget the selection of an appropriate project delivery method is critical for project success. In most cases, the selection of the project delivery method is done early during project development. Therein lies the opportunity for the contributions from this research to enhance the project delivery decision-making process by providing a richer understanding of whether or not a selected project delivery method can achieve project performance goals on particular highway construction projects. Ultimately, the results establish new fundamental knowledge about project delivery methods and project performance for US highway construction projects. Equipped with this new knowledge agency professionals can better align information available at the early stages of a project with the appropriate project delivery method to achieve successful performance outcomes.

REFERENCES

AECOM Consulting and Science Application International Corporation (AECOM), 2003. "Design-build effectiveness study – As required by TEA-21 Section 1307(f)." US DOT Advisory Team slides, AECOM, Birmingham, Ala.

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

Alleman, D., Antoine, A., Schrilla, M., & Molenaar, K. (2017). "The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects." The Ninth International Structural Engineering and Construction Conference (ISEC-9), Resilient Structures and Sustainable Construction, CPM-15.

Allen, L. N. (2001). "Comparison of Design-Build to Design-Bid-Build as a Project Delivery Method." Thesis, Naval Postgraduate School, Monterey, CA.

American Society of Civil Engineers (ASCE), 2017. "American Infrastructure Report Card", available online: http://www.infrastructurereportcard.org/grades/ [Accessed: 07/06/2017]

Anderson, S. and Damnjanovic, I. (2008). Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion. NCHRP Synthesis Report #379. National Cooperative Highway Research Program. Transportation Research Board. Washington, DC.

Anderson, S., Molenaar, K., & Schexnayder, C., 2007. "Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction." Final Report for NCHRP Report 574.

Anderson, S.D. and I. Damnjanovic, 2008. NCHRP Synthesis 379: Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion, Transportation Research Board of the National Academies, Washington, D.C., 2008, 77 pp.

Beard, J., Loukakis, M. C., and Wundram, E. C. (2001). Design-build: Planning through development, McGraw-Hill, New York.

Bennett, J., Pothecary, E., and Robinson, G. (1996). "Designing and Building a World-Class Industry." The University of Reading Design and Build Forum Report. University of Reading, Centre for Strategic Studies in Construction.

Bingham, E., Asmar, M., and Gibson, G., Jr. (2016) Project Delivery Method Selection: Analysis of User Perceptions on Transportation Projects. Construction Research Congress 2016: pp. 2110-2118.

Bogus, S. M., Shane, J. S., and Molenaar, K. R. (2010). "Contract payment provisions and project performance: An analysis of municipal water and wastewater facilities." Public Works Manage. Policy, 20(10), 1–12.

Bordat, C., McCullouch, B., & Sinha, K. (2004). "An analysis of cost overruns and time delays of INDOT projects." Joint Transportation Research Program, 11.

Carpenter, N. and Bausman, D. (2016). "Project Delivery Method Performance for Public School Construction: Design-Bid-Build versus CM at Risk." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0001155 , 05016009.

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

Chen, Q., Jin, Z., Xia, B., Wu, P., and Skitmore, M. (2016). "Time and Cost Performance of Design–Build Projects." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0001056, 04015074.

Chen, Q., Jin, Z., Xia, B., Wu, P., and Skitmore, M., (2015). "Time and Cost Performance of Design–Build Projects." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0001056, 04015074.

Chin, D. (2001). Empirical evaluation of user models and user-adapted systems. User Modeling and User-Adapted Interaction, 11(1-2):181–194.

Clark, A. and Wenig, W. (1999). "Identification of Quality Characteristics for Technology Education Programs: A North Carolina Case Study." Journal of Technology Education Vol. 11 No. 1.

Colorado Department of Transportation (CDOT), (2016). "Project Delivery Selection Matrix." Available online: https://www.codot.gov/business/designsupport/innovative-contracting-and-design-build/pdsm [Accessed: June 18, 2017].

Colorado Department of Transportation (CDOT), Innovative Contracting Program, (January, 2015). "Construction Manager/General Contractor Manual."

Colorado Department of Transportation (CDOT) Business Center, (2014). "Project Delivery Selection Workshop Summary." https://www.codot.gov/business/designsupport/innovative-contracting-and-design-build/pdsm/project-delivery-selection-approach-blank-form/view. [Accessed May 15, 2016]

Creedy, G. R., Skitmore, M., and Wong, J. K. W. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects." J. Constr. Eng. Manage., 136(5), 528–537.

Dallal, E. G. (2015). Paired Data/Paired Analyses. In The Little HanD-Book of Statistical Practice. http://www.tufts.edu/~gdallal/paired.htm Accessed June 10, 2015.

Debella, D. and Ries, R., (2006). "Construction Delivery Systems: A Comparative Analysis of Their Performance within School Districts." J. Constr. Eng. Manage., 132(11), 1131–1138.

Design-Build Institute of America (DBIA), 2014. Design-Build Done Right: D-B Best Practices, v.2.0, updated February 2014.

Design-Build Institute of America (DBIA), 2015. "Choosing a project delivery method: a D-B done right primer",

https://www.dbia.org/about/Documents/db_primer_choosing_delivery_method.pdf
[Accessed: September 1, 2016]

Design-Build Institute of America (DBIA). "DBIA Milestone: The Maps", available online: http://www.dbia.org/about/Pages/DBIA-Milestone-The-Maps.aspx. [Accessed: July 31, 2015]

Dodson, T. (2013). "Controlling complexities and cost." CE News: Bus. Technol. Civ. Eng., 24(12), 28–29.

El Asmar, M., Lotfallah, W., Whited, G., and Hanna, A. S. (2010). "Quantitative methods for design-build team selection." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000194, 904–912.

Ellis, R. D., Pyeon, J., Herbsman, Z. J., Minchin, E. and Molenaar, K.R. (2007). "Evaluation of Alternative Contracting Techniques on FDOT Construction Projects." Florida Department of Transportation.

Ellis, R. D., Herbsman, Z. J., and Kumar, A. (1991). "Evaluation of the FDOT Design/Build program." Florida Department of Transportation.

Ernzen, J., Williams, R., and Brisk, D. (2003) "Arizona DOT Study: Design-Build vs. Design-Bid- Build - Comparing Cost and Schedule," https://www.fhwa.dot.gov/reports/designbuild/designbuild2.htm. . [Accessed December 31, 2014].

Farnsworth, C., Warr, R., Weidman, J., and Mark Hutchings, D. (2015). "Effects of CM/GC Project Delivery on Managing Process Risk in Transportation Construction." J. Constr. Eng. Manage., Volume 142, Issue 3.

Federal Highway Administration (FHWA), 2002. Special Experimental Projects No. 14 - Alternative Contracting (formerly Innovative Contracting), available online: https://www.fhwa.dot.gov/programadmin/contracts/sep_a.cfm. [Accessed: July 31, 2015].

Federal Highway Administration (FHWA), (2016). "Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications," Federal Highway Administration Project, Contract No. DTFH61-11-D-00009, 2013-2016.

Federal Highway Administration (FHWA). (2016a). "SEP-14 Active Project List" http://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm. [Accessed January 9, 2016].

Federal Highway Administration (FHWA), 2015. Every Day Counts initiative, EDC-2 Final Report.

Federal Highway Administration (FHWA), SEP-14 Active Project List, available online:
http://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm?sort=technique.
[Accessed: July 31, 2015]

Federal Highway Administration (FHWA), Value Engineering Final Rule, (2014), pp. 52972- 52977, Vol. 79, No. 172. https://www.gpo.gov/fdsys/pkg/FR-2014-09-05/pdf/2014-21020.pdf Accessed December 30, 2015.

Federal Highway Administration (FHWA), "Final Design-Build Rule for SAFETEA-LU Section 1503" https://www.fhwa.dot.gov/programadmin/contracts/fedreg071408.cfm. [Accessed: September 01, 2016].

Federal Highway Administration (FHWA). "Alternative Contracting Methods (ACMs) Library for Construction Manager/General Contractor (CM/GC)" https://www.fhwa.dot.gov/construction/contracts/acm/ [Accessed: September 01, 2016]

Federal Highway Administration (FHWA), (2012). "Every Day Counts initiative," Construction Manager/General Contractor. http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/pdfs/edc_cm_gm.pdf [Accessed September 12, 2016].

Federal Highway Administration (FHWA), (2015a). SEP-14 Active Project List, available online: http://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm?sort=technique. [Accessed: July 03, 2015].

Federal Highway Administration (FHWA), (2013). Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications. Federal Highway Administration Project, Contract No. DTFH61-11-D-00009, 2013-2016.

Federal Highway Administration (FHWA). (2012a). Moving Ahead for Progress in the 21st Century Act ("MAP-21") https://www.gpo.gov/fdsys/pkg/PLAW-112publ141/pdf/PLAW-112publ141.pdf [Accessed January 9, 2016].

Federal Highway Administration (FHWA), (2006). "Design-build effectiveness study," Washington, DC.

Federal Register, December 10, 2002, Volume 67, No. 237.

Florida Department of Transportation (FDOT). "PROJECT SELECTION GUIDELINES."
http://www.dot.state.fl.us/construction/designbuild/DBRules/DBRulesMain.shtm. [Accessed May 15, 2016]

Forgues, D. D., and Koskela, L. (2008). "Can procurement affect design performance?" Journal of Construction Procurement, 14 (2), 2008, 130-141.

Franz, B. (2014). "Modeling the role of team integration and group cohesion in construction project performance." Dissertation: The Pennsylvania State University.

Garcia, C., Huebschman, R., Abraham, D., and Bullock, D. (2006). "Using GPS to Measure the Impact of Construction Activities on Rural Interstates." J. Constr. Eng. Manage., 10.1061/(ASCE)0733-9364(2006)132:5(508), 508-515.

Giannarou, L. and Zervas, E. (2014). "Using Delphi Technique to Build Consensus in Practice." Int. Journal of Business Science and Applied Management, Volume 9, Issue 2.

Goftar, N., El Asmar, M., and Bingham, E. (2014). "A Meta-analysis of Literature Comparing Project Performance between Design-Build (DB) and Design-Bid-Build (DBB) Delivery Systems." Construction Research Congress 2014: pp. 1389-1398.

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

Gransberg, D. D., Badillo-Kwiatkowski, G. M., and Molenaar, K. R., (2003). "Project delivery comparison using performance metrics." AACE International Transactions, 2003, pg. CS21.

Gransberg, D. D., and Senadheera, S. P. (1999). "Design-build contract award methods for transportation projects." J. Transp. Eng., 10.1061/(ASCE)0733-947X(1999)125:6(565), 565–567.

Gransberg, D. D., Badillo-Kwiatkowski, G. M., and Molenaar, K. R., 2003. "Project delivery comparison using performance metrics." AACE International Transactions, 2003, pg. CS21.

Gransberg, D.D., and J.S. Shane, (2010). "Construction Manager-at-Risk Project Delivery for Highway Programs," NCHRP Synthesis 402, ISBN: 978-9-14301-1, 2010, 127pp.

Gransberg, D. D., and Shane, J. S. (2013). Defining Best Value for Construction Manager/General Contractor Projects: The CMGC Learning Curve. Journal of Management in Engineering.

Gransberg, D.D., (2013a). "Case Studies of Early Contractor Design Involvement to Expedite the Delivery of Emergency Highway Projects," Transportation Research Record No. 2347, Journal of the Transportation Research Board, National Academies, 2013, pp. 19-26.

Gransberg, D. (2013b). "A Guidebook for Construction Manager-at-Risk Contracting for Highway Projects," NCHRP Project 10-85.

Gransberg, D., Shane, J., Anderson, S., Lopez del Puerto, C., and Schierholz, J. (2015). Guide for Implementing Construction Manager/General Contractor Project Delivery on Highway Projects. NCHRP 10-85, Transportation Research Board, National Academies, January 2015, 81 pp.

Hale, D., Shrestha, P., Gibson, G., Jr., and Migliaccio, G. (2009). "Empirical Comparison of Design/Build and Design/Bid/Build Project Delivery Methods." Journal of Construction Engineering and Management, 135(7), 579–587.

Hallowell, M., and Gambatese, J. (2010). "Qualitative Research: Application of the Delphi Method to CEM Research." J.Constr.Eng.Manage., 136(1), 99-107. Journal of the Transportation Research Board, National Academies, 2013, pp. 19-26.

Hastak, D. M. (2015). "Skills & Knowledge of Cost Engineering," AACE International.

Ibbs, C. W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). "Project delivery systems & project change: Quantitative analysis." J. Constr.Eng. Manage. 129(4), 382-387.

Kalaian, S. and Kasim, R. (2012). "Terminating Sequential Delphi Survey Data Collection." Practical Assessment, Research & Evaluation, Volume 17, Number 5.

Kenig, M., 2011. Project delivery systems for construction, Associated General Contractors of America, Washington, DC.

Koch, J. E., Gransberg, D. D., & Molenaar, K. R. (2010). Project administration for Design-Build contracts: A primer for owners, engineers, and contractors. American Society of Engineers.

Konchar, M., and Sanvido, V. (1998). "Comparison of US project delivery systems." J. Constr. Eng. Manage., 124(6), 435-444.

Kuhn, S., 2007. "Preconstruction Services: Add Value with More than Just Estimating," Construction Business Owner, Feb. 2007.

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

Luftig, J. and Jordan, V. (1998). Design of Experiments in Quality Engineering, McGraw-Hill/Irwin Publishing Company.

Luftig, J. (1992). An Overview of Total Quality Management, Luftig & Warren, International.

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.

Martinez, P.H., Y. Rashida, and V. MacMurray, 2007. "Construction Manager's Responsibilities: Pre-Design, Design and Pre-Construction Phase," American Bar Association, Chicago, Ill., Jan. 2007, 58 pp.

McGraw Hill Construction, (2014). "Project Delivery Systems: How They Impact Efficiency and Profitability in the Buildings Sector." SmartMarket Report.

Migliaccio, G., Bogus, S., and Chen, A. (2010). "Effect of duration of design- build procurement on performance of transportation projects." Transp. Res. Rec., 2151, 67–73.

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.

Minchin, E., et al., 2014. "NCHRP report 787: Guide for design management on design-build and construction manager/general contractor project." Transportation Research Board, Washington, DC.

Minchin, R., Jr., Li, X., Issa, R., and Vargas, G. (2013). "Comparison of Cost and Time Performance of Design-Build and Design-Bid-Build Delivery Systems in Florida." J. Constr. Eng. Manage., 139(10), 04013007.

Minnesota Department of Transportation (MnDOT), Office of Construction and Innovative Contracting (OCIC), (2011, August). "Design-Build Manual." http://www.dot.state.mn.us /designbuild/documents/online/DB_Manual.pdf. [Accessed May 15, 2016]

Molenaar, K., Harper, C., and Yugar-Arias, I., (2014). "Guidebook for selecting alternative contracting methods for roadway projects: project delivery methods, procurement procedures, and payment provisions." Transportation Pooled Fund Program Study TPF-5(260), August 1, 2014.

Molenaar, K., Songer, A., and Barash, M., 1999. "Public-sector design/build evolution and performance", J. Manage. Eng., 174, 214–223.

Molenaar, K.R. and Songer, A.D. (1998). "Model for Public Sector Design-Build Project Selection." Journal of Construction Engineering and Management, Vol. 124, No. 6, November/December 1998, pp. 467-479.

Molenaar, K. R., and Gransberg, D. D. 2001. "Design-builder selection for small highway projects." J. Manage. Eng., 174, 214–223.

Molenaar, K., Sobin, N., and Antillon, E., 2010. "A synthesis of best value procurement practices for sustainable design-build projects in the public sector." J. Green Build., 5(4), 148–157.

MVPstats — Help page, update 01/15/2014. Available online at: http://mvpprograms.com/help/mvpstats/CriticalMeanDifference [Accessed: October 18, 2016]

New York State Department of Transportation (NYDOT) (2002). "Design-Build Practice Report" https://www.dot.ny.gov/programs/repository/db_procurement_rpt_mar03.pdf [Accessed July 27, 2016]

Nikou Goftar, V., El Asmar, M., and Bingham, E. (2014). "A Meta-analysis of Literature Comparing Project Performance between Design-Build (DB) and Design-Bid-Build (DBB) Delivery Systems." Construction Research Congress 2014: pp. 1389-1398.

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., and Vickroy, G. (1985). Control of construction project scope. Constr. Industry Inst., University of Texas at Austin, Tex.

Ohio Department of Transportation (ODOT), (2009, April). "Design Build Scope Manual." http://www.dot.state.oh.us/Divisions/ConstructionMgt/design-build/DesignBuild /Design_Build_scope_manual_4-17-09.pdf [Accessed May 15, 2016]

Olumide, A., Anderson, S. and Molenaar, K. (2010). "Sliding-Scale Contingency for Project Development Process." Transportation Research Record: Journal of the Transportation Research Board, No. 2151, Transportation Research Board of the National Academies, Washington, D.C., pp. 21–27.

Oregon Department of Transportation (ODOT), (2010). "Project Delivery Guide 2010."

Oregon Department of Transportation (ODOT), (2009). "Development of a Decision Model for Selection of Appropriate Timely Delivery Techniques for Highway Projects", Final Report SPR 646.

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.

Pedhazur, E. J., 1982. "Multiple Regression in Behavioral Research," 2nd ed., New York: Holt, Potter, K., and Sanvido, V., 1995. "Implementing a design-build prequalification system." J. Mgmt. Engrg., ASCE, 11(3), 30–34.

Potter, K., and Sanvido, V., 1994. "Design-build prequalification system," J. Mgmt. Engrg., ASCE, 10(2), 48–56.

Rahm, E., and H. H. Do., (2000). "Data Cleaning: Problems and Current Approaches." In Bulletin of the IEEE Computer Society Technical Committee on Data Engineering, Vol. 23, Issue 4, pp. 3-13.

Ramsey, D., El Asmar, M., and Gibson, G., Jr. (2016). "Quantitative Performance Assessment of Single-Step versus Two-Step Design-Build Procurement." J. Constr. Eng. Manage., Volume 142, Issue 9.

Rayens, M. and Hahn, E. (2000). "Building Consensus Using the Policy Delphi Method." Policy, Politics, & Nursing Practice, Vol. 1 No. 4, 308-315.
Rinehart, & Winston, Chapter 10, pp. 334-385.

Roth, M. B. (1995). "An Empirical Analysis of United States Navy Design/Build Contracts." M.S. Thesis, University of Texas at Austin, Austin, TX.

Roth, M. B. (1995). "An Empirical Analysis of United States Navy Design/Build Contracts." M.S. Thesis, University of Texas at Austin, Austin, TX.

Rowe, G., and Wright, G. 1999. "The Delphi technique as a forecasting tool: Issue and analysis." Int. J. Forecast., 15, 353–375.

Russell, J., Swiggum, K., Shapiro, J., Alaydrus, A., 1994. "Constructability Related to TQM, Value Engineering, and Cost/Benefits", Journal of Performance of Constructed Facilities 8(1), 31-45.

Rutherford, A., 2011. "ANOVA and ANCOVA: A GLM Approach", 2nd Edition, John Wiley & Sons, Inc.

SAIC (2002), Survey for Illinois DOT on the Current Use of Design-Build, http://www.fhwa.dot.gov/programadmin/contracts/survey02.cfm. [Accessed July 27, 2016].

Sanvido, V. E., and Konchar, M. D. (1997). "Project delivery systems: CM at risk, design-build, design-bid-build." Technical Report No. 133, CII, Austin, Texas

Scott, S., Molenaar, K. R., Gransberg, D. D., and Smith, N. C., 2006. "Best-value procurement methods for highway construction projects." NCHRP Rep. No. 561, Transportation Research Board, Washington, DC.

Septelka, D. and S. Goldblatt, (2005). "Survey of General Contractor/ Construction Management Projects in Washington State," State of Washington Joint Legislature Audit and Review Committee Report, Olympia, 117 pp.

Sheskin, D., J., 2011. "Handbook of Parametric and Nonparametric Statistical Procedures", Fifth Edition, Chapman and Hall/CRC.

Shrestha, P. P., Maharjan, R., Shakya, B., (2016), "Performance of Design Build versus Construction Manager/ General Contractor for Highway Projects", Transportation Research Board Annual Meeting, 2016, Paper No.16-0210.

Shrestha, P., Maharjan, R., Shakya, B., and Batista, J. (2014) Alternative Project Delivery Methods for Water and Wastewater Projects: The Satisfaction Level of Owners. Construction Research Congress 2014: pp. 1733-1742.

Shrestha, P., O'Connor, J., and Gibson, G., (2012), "Performance Comparison of Large Design-Build and Design-Bid-Build Highway Projects", Journal of Construction Engineering and Management, 2012, 138(1): 1-13.

Shrestha, P. P., Migliaccio, G. C., Gibson, G. E., and O'Connor, J. T. (2007), "Benchmarking of Large Design-Build Highway Projects: One-to-One Comparison and Comparison with Design Bid-Build Projects", Journal of the Transportation Research Board, No.1994,17-25.

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

Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007). The Delphi method for graduate research. Journal of Information Technology Education, 6, 1-21.

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.

Songer, A. D., Molenaar, K. R. and Robinson, G. D., (1996a). "Selection factors and success criteria for design-build in the USA and UK," Journal of Construction Procurement, 2(2), 69–82.

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., 2006. "Owners Risk Reduction Techniques Using a CM," CMAA Research Report, Construction Management Association of America, Washington, D.C., 2006, 55 pp.

Tran, D. (2013). "A risk-based model to select delivery methods for highway design and construction." Dissertation: University of Colorado.

Tran, D., Harper, C., Molenaar, K., Haddad, N., & Scholfield, M. (2013). "Project Delivery Selection Matrix for Highway Design and Construction." Transportation Research Record: Journal of the Transportation Research Board (2347), 3-10.

Virginia Department of Transportation (VDOT), (2011). "Design-Build Procurement Manual."
http://www.virginiadot.org/business/resources/ipd/DB_Manual_FinalCopy20111011.
pdf [Accessed May 15, 2016]

Warne, T. R. (2005). "Design build contracting for highway projects: A performance assessment." Tom Warne & Associates, LLC. South Jordan, UT.

Washington Department of Transportation (WSDOT), (2016). "Project Delivery Method Selection Guidance."

Weir, C., Hicken, B., Rappaport, H. and Nebeker, J. (2006). "Crossing the Quality Chasm: The Role of Information Technology Departments." American Journal of Medical Quality, Vol. 21, No. 6.

Xiao, H., and Proverbs, D. G. (2003). "Cost Certainty and Time Certainty: An International Investigation," in Association of Researches in Construction Management ARCOM 19th Annual Conference (Vol. 2, pp. 23-31).

Young, R., Wolffing, C., & Tomasini, M. (2005). Highway construction impacts on Wyoming businesses. Transportation Research Record: Journal of the Transportation Research Board, (1924), 94-95.

APPENDIX A

ANOVA results and the results for post hoc analyses of the D-B versus CM/GC schedule performance metrics

APPENDIX A

ANOVA results and the results for post hoc analyses of the D-B versus CM/GC schedule performance metrics

Chapter 3 (Manuscript 2)
Title: A Quantitative Comparison of Design-Build vs Construction Manager/General Contractor Schedule Performance in Highway
Construction Projects

Table 3-10. Procurement duration

Variables with a significant Interaction: Project Delivery Method (PDM)*Complexity*Project Type

PDM	Complexity	Project Type	n	Mean Proc. Dur.		PDM	Complexity	Project Type	n	Mean Proc. Dur.	Critical Mean Difference (CMD)	Statistically Significant
CM/GC	Most	New	5	32	vs	D-B	Most	New	18	196	45	**YES**
	Most	Rehab	4	55	vs		Most	Rehab	8	133	54	**YES**
	Mod.	Rehab	3	44	vs		Mod.	Rehab	10	124	58	**YES**
	Non	New	1	75	vs		Non	New	1	141	125	NO

Table 3-11. Construction duration
Variables with a significant Interaction: Project Delivery Method (PDM)*Project Size*Complexity*Project Type

PDM	Project Size ($)	Complexity	Project Type	n	Mean Constr. Dur.		PDM	Award Cost	Complexity	Project Type	n	Mean Constr. Dur.	Critical Mean Difference (CMD)	Stat. Sig.
CM/GC	$0-$10M	Mod.	New	2	357	vs	D-B	$0-$10M	Mod.	New	6	588	378.3	NO
	$0-$10M	Mod.	Rehab	3	377	vs		$0-$10M	Mod.	Rehab	5	562	265.5	NO
	$0-$10M	Non	New	1	113	vs		$0-$10M	Non	New	1	267	459.8	NO
	$10M-$20M	Most	New	3	754	vs		$10M-$20M	Most	New	2	504	296.8	NO
	$10M-$20M	Most	Rehab	1	330	vs		$10M-$20M	Most	Rehab	4	901	363.5	**YES**
	$10M-$20M	Mod.	Rehab	2	364	vs		$10M-$20M	Mod.	Rehab	2	783	325.1	**YES**
	$20M-$50M	Most	New	4	828	vs		$20M-$50M	Most	New	10	854	192.3	NO
	$20M-$50M	Most	Rehab	4	376	vs		$20M-$50M	Most	Rehab	4	908	229.9	**YES**
	$20M-$50M	Mod.	Rehab	2	320	vs		$20M-$50M	Mod.	Rehab	4	681	281.6	**YES**

Table 3-12. Project duration
Variables with a significant Interaction: Project Delivery Method (PDM)*Complexity*Project Type

PDM	Complexity	Project Type	n	Mean Project duration		PDM	Complexity	Project Type	n	Mean Project duration	Critical Mean Difference (CMD)	Statistically Significant
CM/GC	Most	New	6	1,383	vs	D-B	Most	New	9	1,645	329	NO
	Most	Rehab	7	1,249	vs		Most	Rehab	3	2,047	431	**YES**
	Mod.	New	1	750	vs		Mod.	New	2	1,184	765	NO
	Mod.	Rehab	7	935	vs		Mod.	Rehab	7	1,220	334	NO

APPENDIX B

An Empirical Study Of The State-Of-Practice In Alternative Technical Concepts In Highway Construction Projects of the D-B versus CM/GC schedule performance metrics

Abstract:

State departments or transportation (DOTs) are encouraging early involvement of contractors in highway design and construction through the solicitation of Alternative Technical Concepts (ATCs) during procurement. This approach provides DOTs with the opportunity to tap industry experience and expertise for design alternatives. ATCs can improve constructability, enhance innovation, shorten schedules, reduce risk and ultimately save costs. In fact, DOTs have documented significant cost savings from ATCs on a project-by-project basis. This paper provides an up-to-date perspective on the types of projects currently using ATCs in US highway construction based on empirical data from a national study of 250 projects completed by DOTs and the Office of Federal Lands Highway. These projects were completed through design-build, construction manager/general contractor and design-bid-build project delivery methods and only forty (40) of the projects solicited ATCs during procurement. The quantitative findings presented in this paper were facilitated by the use of the project information from the national study complimented by an extensive literature review on the use of ATCs in the US highway construction sector. It was found that DOTs used ATCs on 51% of the 70 design-build projects procured by best-value selection in the study. Given that only 2% of the 116 design-bid-build projects and 5% of the 38 low-bid design-build projects in this study used ATCs and, that no construction manager/general contractor projects used ATCs there appears to be an opportunity to capitalize on the benefits of ATCs in projects using those delivery methods.

APPENDIX C

Desired versus Realized Benefits of Alternative Contracting Methods on Extreme Value Highway Projects

Abstract:

Highway agencies choose alternative contracting methods (ACMs) to for a wide variety of reasons, primarily their potential for superior cost and schedule performance. Most literature focuses on these two factors by analyzing aggregate datasets covering a wide-ranging contract values. These analyses create two voids that this paper attempts to explore: (1) ACMs provide a wide variety of benefits, which cost and schedule performance alone do not identify; and (2) projects of differing contract values benefit differently. This paper investigates the selection criteria for ACMs and why US agencies chose ACMs for projects at the extreme ends of the cost spectrum (defined as projects at the upper and lower 10th percentiles for each delivery method) and what benefits are realized, above and beyond cost and schedule performance. These findings are presented through a survey of 291 US projects, interviews of sixteen US agency representatives, literature review, agency ACM manual content analysis.

Source:

https://www.isec-society.org/ISEC_PRESS/ISEC_09/html/CPM-15.xml

APPENDIX D

The Use and Performance of Alternative Contracting Methods on Small Highway Construction Projects

Abstract:

Highway agencies choose alternative project delivery methods to save time and control costs. Large, high-profile, design-build and construction manager/general contractor projects give the impression that alternative project delivery methods are only applicable to larger, more complex projects. This research reports on a sample of 291 US highway projects, more than half of which are under $20 million in final cost. The study provides empirical evidence of how alternative project delivery methods relate to small project successes, specifically design-build successes. The data for this study includes design-bid-build, design-build, and construction manager/general contractor highway projects completed between 2004 and 2015. The results are useful for governmental agencies, suggesting time savings may be achieved on small projects through the use of alternative contracting methods with no negative impacts on cost growth.

Source:

http://www.sciencedirect.com/science/article/pii/S1877705816301242

APPENDIX E

FHWA TechBrief: Alternative Contracting Method Performance In US Highway Construction

TECHBRIEF: ALTERNATIVE CONTRACTING METHOD PERFORMANCE IN US HIGHWAY CONSTRUCTION

FHWA Publication Number: FHWA-HRT-17-100

FHWA Contact: Roya Amjadi, HRDS-20, (202) 493-3383, roya.amjadi@dot.gov

This document is a technical summary of the Federal Highway Administration report *Alternative Contracting Method Performance in US Highway Construction* (DTFH61-13-R-00019).

OBJECTIVE

The findings presented in this TechBrief are based on empirical data from the Federal Highway Administration (FHWA) national study *Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications* (FHWA DTFH61-11-D-00009).[1] The study includes documented lessons learned associated with alternative contracting methods construction manager/general contractor (CM/GC) and design–build (D–B). D–B is broken down into D–B/low bid (D–B/LB) and D–B/best value (D–B/BV), the latter being projects procured using selection factors in addition to cost. Additionally, the study includes lessons learned associated with the use of alternative technical concepts (ATCs), which are defined by the National Cooperative Highway Research Program (NCHRP) Synthesis 455 as "a request by a proposer to modify a contract requirement, specifically for that proposer's use in gaining competitive benefit during the bidding or proposal process."[2]

The FHWA national study collected a first-of-a-kind dataset from 291 completed highway projects. The data currently form the largest empirical database of project information exclusive to highway construction. The findings provide guidance for State departments of transportation (DOTs) to assist in determining when to use alternative contracting methods to maximize project objectives relating to cost, schedule, and intensity performance metrics. Intensity is a critical metric of project performance because projects with a greater intensity can have a shorter impact on the traveling public. This TechBrief addresses the following questions:

- What is the state of practice in the use of alternative contracting methods?

- For what project size, complexity, and risk characteristics are agencies applying alternative contracting methods?

- How do alternative contracting methods affect cost certainty and cost growth?

- How do alternative contracting methods affect project delivery speed and schedule growth?

- How do alternative contracting methods affect the production rates or project intensity (i.e., dollars/day of work in place)?

INTRODUCTION

History of Alternative Contracting Methods on Federally Funded Highways

Contracting methods create an environment for successful project delivery. There are three primary contracting methods for federally funded highways: design–bid–build (D–B–B), D–B, and CM/GC. The vast majority of the U.S. highway system was built with the D–B–B delivery method. The use of D–B delivery began in the 1990s; CM/GC delivery began after 2005.[3] By the end of 2014, the number of State DOTs using D–B had grown to 35 and the number using CM/GC to 17.[3] Potential benefits of the two alternative contracting methods, D–B and CM/GC, include saving project costs, lowering operational costs and/or project lifecycle costs, improving constructability, enhancing innovation, reducing risk, expediting project delivery, and shortening construction schedules. Notwithstanding these potential benefits, the two alternative contracting methods can create challenges for both agencies and industry.

Definitions of Project Delivery Methods

Figure 1 provides a graphic depiction of the project delivery methods explored in this study, which are defined as follows:

- **D–B–B.** This is the traditional delivery method where the agency contracts separately for design and construction services, the bid is based on complete (100 percent) plans and specifications, and design and construction occur sequentially. D–B–B is typically a unit-priced contract, but it can also include lump-sum items.

- **CM/GC.** The agency procures professional services on a qualifications or best-value basis from a construction manager during the design phase to offer suggestions on innovations, cost and schedule savings, and constructability issues. Upon completion of the design or individual design packages, the contractor and agency negotiate a price for the construction contract, and then the construction manager acts as a general contractor to complete construction. The contract can employ a guaranteed maximum price administered on a cost-reimbursable basis, unit price, or lump-sum contract.

- **D–B.** The agency contracts with one entity to complete the design and construction of a project under a single contract, typically a lump sum with allowances or unit cost items to address risk. D–B has been implemented using various procurement approaches, including qualified low bid (LB) and best-value (BV).
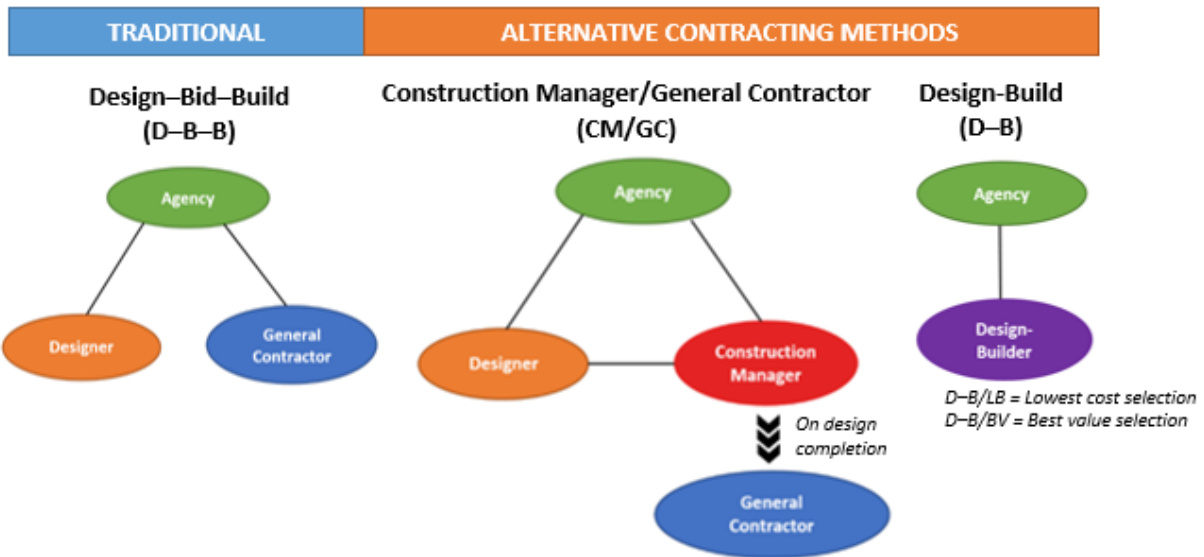
Figure 1. Diagram. Project delivery methods.

DATA COLLECTION

To lend objectivity to this study, alternative contracting method projects were randomly selected from agencies actively engaging in D–B and/or CM/GC methods. Corresponding D–B–B projects were then selected according to set criteria; ideally, the contract signing/award date and the award cost of the D–B–B projects were within plus or minus 2 years and plus or minus 25 percent, respectively, as compared to D–B or CM/GC projects. Attempts were also made to have projects that were similar in scope and types of work where possible. Despite this rigorous approach to data collection, limitations existed in the data because there were large D–B and CM/GC projects for which no comparable D–B–B projects were available from the respective agencies.

The research team ultimately collected valid data from 291 completed projects. Figure 2 shows the distribution of data collected throughout the United States. The research team achieved a diverse set of data from all regions of the country. Florida contributed the most projects, coinciding with their long-term use of alternative contracting methods. Utah, Arizona, Colorado, Oregon, and Maine all contributed D–B–B, CM/GC, and D–B projects.
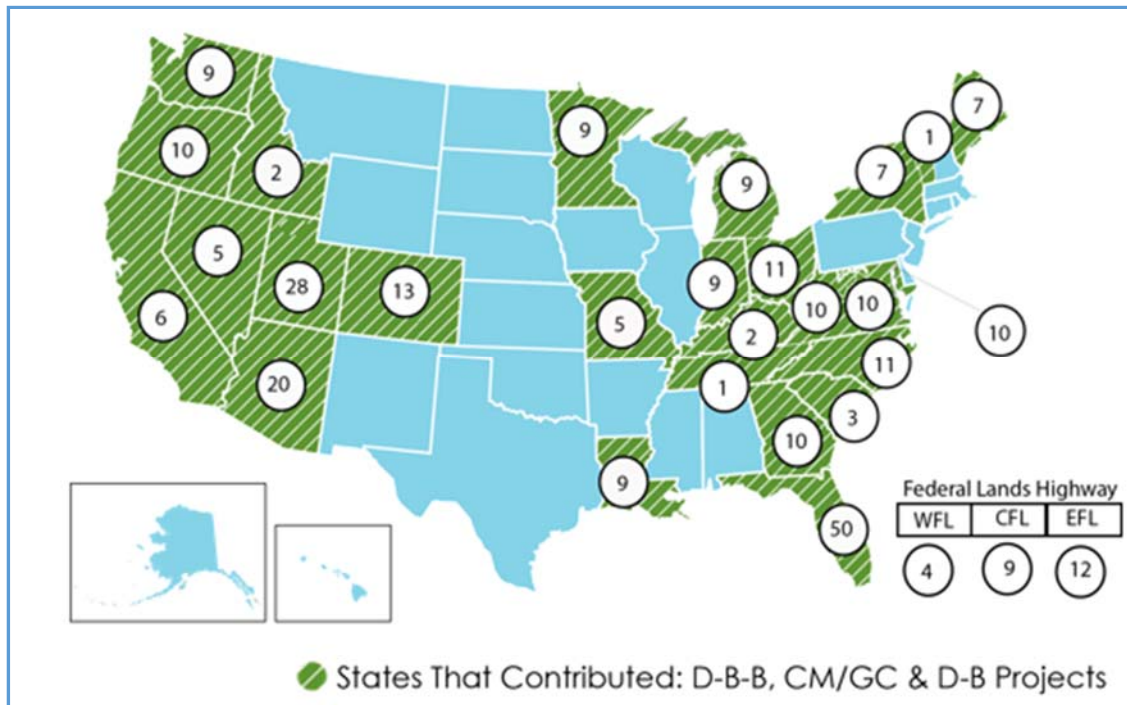
Figure 2. Illustration. Summary of States contributing data (n=291).

RESULTS AND DISCUSSION

This TechBrief begins with a discussion of the population characteristics in terms of the proportions of the project contracting methods, complexity, risk, procurement methods, ATCs, and payment methods. It then describes costs in terms of overall project size and the application of alternative contracting methods on small projects. A discussion of overall project duration and the timing of cost certainty and project intensity follows. The TechBrief concludes with a discussion of how the traditional and alternative contracting methods relate to cost and schedule growth.

Data collection for this study took almost 18 months, and data validation lasted an additional 6 months. The research team is indebted to the agency personnel for their generous time and thoughtful completion of the project questionnaires. As shown throughout the results and discussion, some project representatives were unable to report certain data, and therefore not all data points were available from every project. The team reported the maximum number of data points available, excluding extreme outliers where applicable, for the various variables/metrics as noted in each table and figure (e.g., procurement). Consequently, the reader should expect some variance in the number of projects between analyses of these variables/metrics.

Contracting Methods

D–B–B projects comprise the largest proportion of the study data (47 percent). CM/GC projects make up the smallest proportion (12 percent)—CM/GC being the newest contracting method—

with only 14 agencies stating that they were working on CM/GC projects at the time of this study. Another reason for the low number of CM/GC was that many agencies were still working on their first projects during data collection, and the study required that only completed projects qualified for analysis. Many D–B projects were available because agencies have been using this method for a long time. This large number of D–B projects allows for a comparison of D–B/LB and D–B/BV, which comprise 14 percent and 27 percent of the dataset, respectively. Figure 3 displays the proportions of projects by contracting methods.
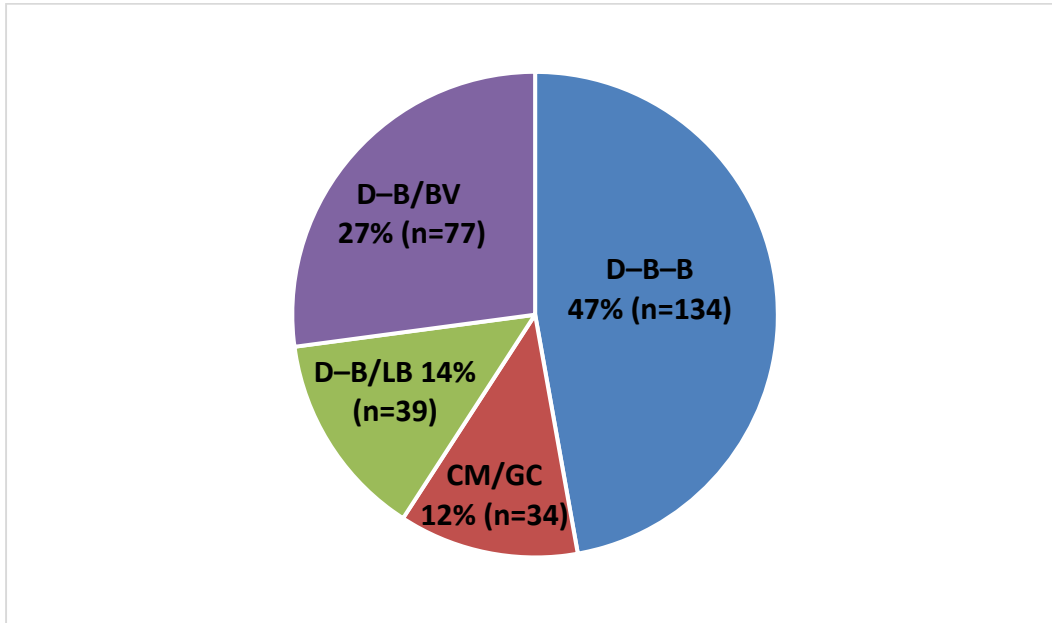

Figure 3. Pie chart. Proportions of projects by contracting methods (n=284).
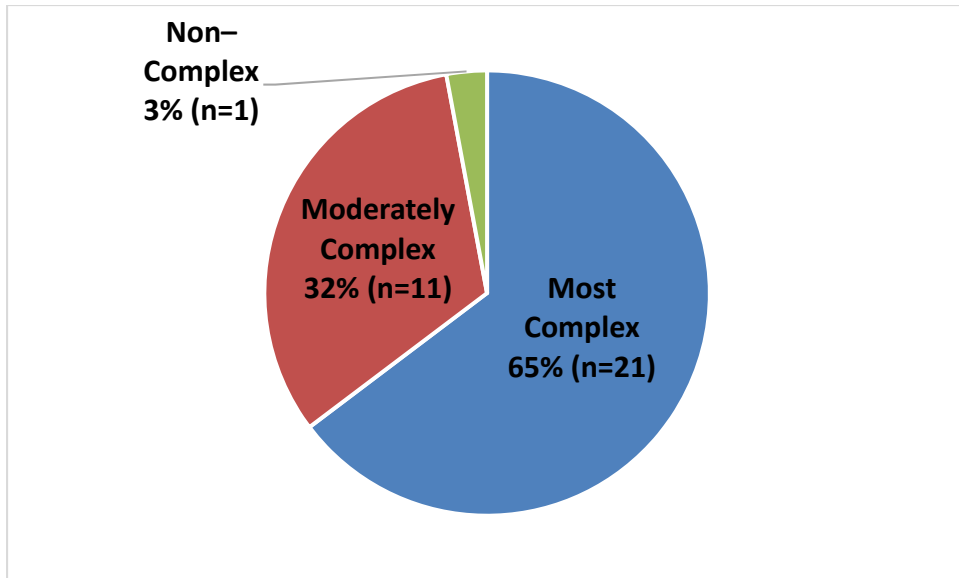
Level of Project Complexity

Each project was classified on the basis of complexity definitions found in the NCHRP Report 574.[4] As shown in figure 4, the majority of projects belong to the Most Complex category with 48 percent. Figure 4 also shows that 38 percent and 14 percent of projects are in the Moderately Complex and Non-Complex categories, respectively. Figure 5 through figure 8 show the proportions of each level of complexity within the contracting methods. The D–B/LB projects are less complex than the D–B/BV projects, and the CM/GC projects have the highest proportion of Most Complex projects.
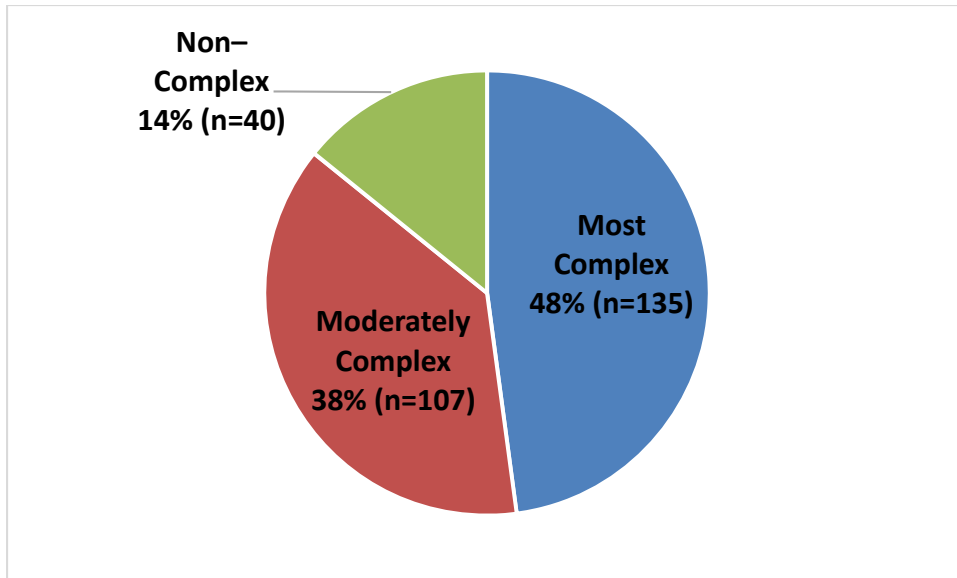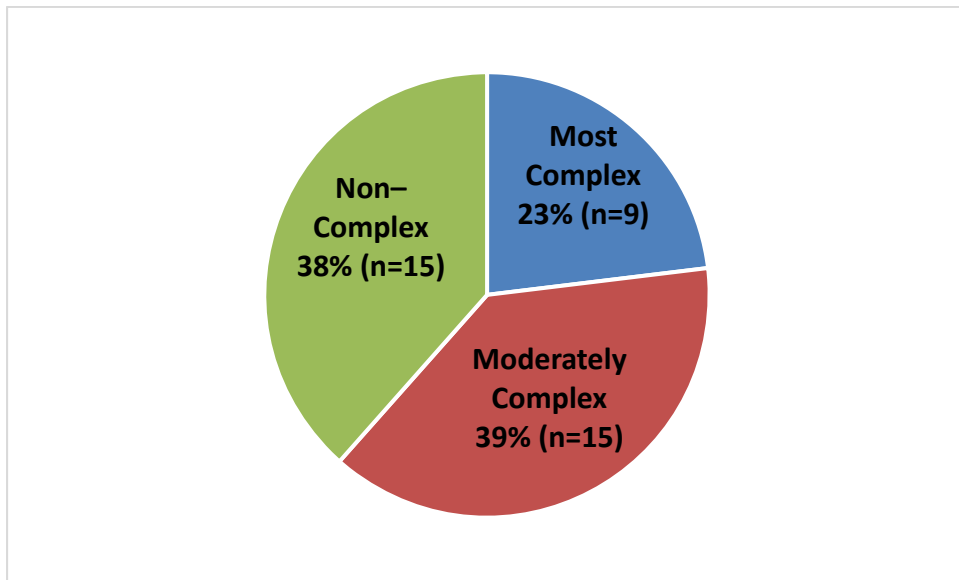
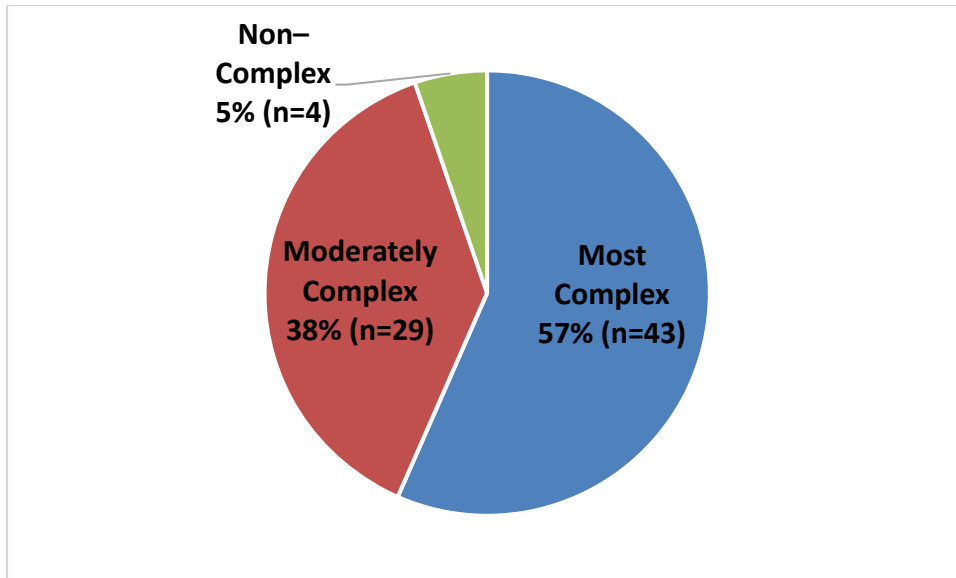**Figure 4. Pie chart. Overall project complexity (n=282).**
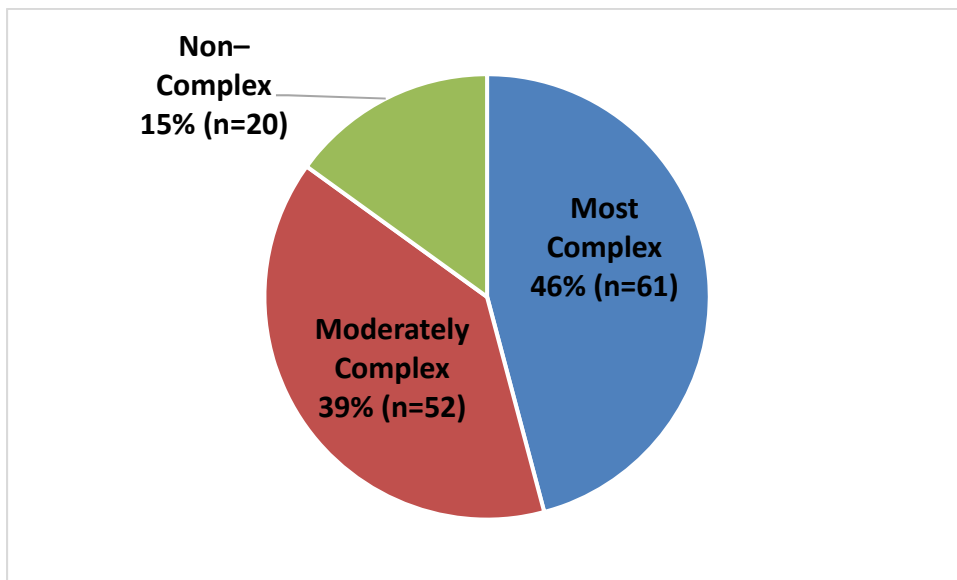
Figure 5. Pie chart. D–B–B project complexity (n=133).

Figure 6. Pie chart. CM/GC project complexity (n=34).

Figure 7. Pie chart. D–B/LB project complexity (n=39).

151

Figure 8. Pie chart. D–B/BV project complexity (n=76).

Project Risk and Delivery Methods

By conducting a thorough literature review and through discussions with agencies, engineers, and contractors, the research team developed a list of 31 risks that could affect project delivery performance. For each project, agencies were asked to rate the impact of these risk factors on the cost and schedule performance of the project on a scale from 1 (insignificant cost or time impact) to 5 (more than a 10-percent cost increase or schedule delay). To rank the risks in terms of impact on project performance, the research team calculated the scores of 31 risk factors associated with each delivery method. The risk score, or criticality, of each risk factor was calculated using the equation below.

$$Criticality = \frac{\sum_1^5 (n_i * r_i)}{\max(r_i) * \sum_1^5 n_i}$$

(1)

Where:
    r_i = rating of each risk factor.
    n_i = total number of responses associated with the rating r_i.

In examining the top risks among the project delivery methods, the following eight risk factors were perceived by questionnaire respondents to have a high impact on project performance regardless of the delivery method (D–B–B, CM/GC, D–B/LB, or D–B/BV):

1. Delays in completing railroad agreements.

2. Project complexity.

3. Uncertainty in geotechnical investigation.

4. Delays in right-of-way process.

5. Unexpected utility encounter.

6. Work zone traffic control.

7. Challenges to obtain environmental documentation.

8. Delays in delivery schedule.

Two additional risk factors were found to have a substantial influence on D–B–B delivery: scope definition and construction sequencing/staging/phasing. Three additional risk factors were found to have a substantial influence on CM/GC delivery: constructability in design; delays in procuring critical materials, labor, and equipment; and construction sequencing/staging/phasing. Two additional risk factors were found to have a substantial influence on D–B/LB and D–B/BV delivery: environmental impacts and difficulty in obtaining other agencies' approvals. Agencies should consider these risks when selecting delivery methods, and they should explicitly address them in the procurement and contract documents. The Project Delivery Selection section of this TechBrief provides guidance on how these risks relate to project delivery selection.

Use of Procurement Methods

Table 1 shows information collected on the procurement methods for each delivery method. As expected, the vast majority of D–B–B projects were procured through low bid. However, there were exceptions, primarily in the use of A+B procurement. Procurement for CM/GC projects was split between best-value and qualifications-based selection. The D–B project procurements were split between best value and low bid. Thirty-nine D–B projects used price as the only procurement factor and were classified as D–B/LB. The other 77 D–B projects used at least one non-price factor in addition to cost and were classified as D–B/BV.

Table 1. Procurement procedure.

Procurement Procedure	D–B–B (n=134)	CM/GC (n=34)	D–B/LB (n=39)	D–B/BV (n=77)
Low bid	80%	0%	100%	0%
A+B (Cost + Time)	13%	0%	0%	18%
Best value	1%	47%	0%	61%
Qualification-based	1%	41%	0%	0%
Other or not classified	5%	12%	0%	21%

Alternative Technical Concepts

Soliciting ATCs during procurement is a method to invite early contractor input on a project. Agencies can benefit from industry experience and expertise through design and construction proposals determined to be equal to or better than the base scope in the Request for Proposal (RFP). Research shows that ATCs can improve constructability, enhance innovation, shorten schedules, reduce risks, and ultimately save costs on a case-by-case basis. However, no studies have examined the application of ATCs at an aggregate level.

Table 2 shows the use of ATCs on the projects in this study. The FHWA Every Day Counts (EDC) program promotes ATC in all contracting methods. The data collection for this research found that ATCs are used primarily by agencies in D–B/BV. However, the vast majority of these projects

153

were completed prior to the EDC initiatives; this could explain the lower use on D–B–B projects. The lack of ATC use on CM/GC projects resulted because the construction manager portion of the contract provided contractor input with no ATC process; this phenomenon was confirmed through agency interviews after data collection. The lower use of ATCs on D–B/LB projects is attributable to the smaller size and less complex nature of the projects in this pool.

Table 2. The use of ATCs across project delivery methods.

Categories	ATCs	No ATCs
D–B–B (n=123)	2	121
CM/GC (n=34)	0	34
D–B/LB (n=38)	2	36
D–B/BV (n=74)	40	34

Table 3. D–B/BV complexity with and without ATCs.

Categories	Non-Complex (%)	Moderately Complex (%)	Most Complex (%)
D–B/BV with ATCs (n=40)	0	30	70
D–B/BV without ATCs (n=34)	12	44	44

Table 3 shows a trend toward the use of ATCs on more complex D–B/BV projects. As revealed in interviews with project personnel, agencies employ ATCs in the Most Complex projects to minimize cost and maximize contractor innovation. Further discussion of the impact of ATCs on engineering estimates and cost growth is presented later in this TechBrief.

Use of Payment Methods

The use of payment methods (i.e., the form of contract) correlates with the selection of the delivery method. Table 4 summarizes the payment method results. D–B–B predominantly uses unit price, while both D–B/LB and D–B/BV projects primarily use lump-sum payment methods. CM/GC predominantly uses unit price or guaranteed maximum price; this choice appears to be based solely on the preference of each agency.

Table 4. Payment method.

Payment Method	D–B–B (n=134)	CM/GC (n=34)	D–B/LB (n=39)	D–B/BV (n=77)
Lump sum	2%	3%	85%	91%
Cost reimbursable	2%	0%	0%	0%
Unit price	93%	38%	5%	0%
Guaranteed maximum price	0%	56%	0%	4%
Other or not classified	3%	3%	10%	5%

Project Cost

Because the studied projects were completed between 2004 and 2015, it was important to adjust them for inflation. The FHWA's National Highway Construction Cost Index was used to convert all project costs to equivalent costs in June 2015. This conversion allowed a fair comparison of project costs at the same point in time.

At the aggregate level, the average award cost for projects from all contracting methods was $27,140,363. These projects ranged in award cost from a minimum of $69,108 to a maximum of $357,760,287. Table 5 shows the average project cost by contracting method. It should be noted that contractor design costs are included for the D–B projects; no design costs are included for the D–B–B and CM/GC projects.

Table 5. Average project award cost.

Contract Method	Mean Cost	Median Cost	Standard Deviation	Minimum Cost	Maximum Cost
D–B–B (n=134)	$20,286,637	$12,438,075	$28,422,651	$183,202	$252,052,326
CM/GC (n=34)	$36,328,010	$19,167,399	$51,451,029	$1,390,828	$235,936,099
D–B/LB (n=39)	$10,646,348	$4,384,177	$14,534,668	$69,108	$68,826,264
D–B/BV (n=77)	$43,364,854	$22,127,526	$63,149,386	$622,317	$357,760,287
Total (n=284)	**$27,140,363**	**$13,949,364**	**$43,922,075**	**$69,108**	**$357,760,287**

Publicized success of large, high-profile D–B and CM/GC projects gives the impression that alternative contracting methods are applicable only to larger projects. The data collected for this study show that alternative contracting methods are widely applied on small projects. As shown in table 6, more than half of the CM/GC and D–B/LB projects are under $20 million in value, and more than half of the D–B/LB projects are less than $5 million in value. On average, D–B/BV is used on larger projects; however, 45 percent of the D–B/BV projects are less than $20 million in value. Agencies appear to use alternative contracting methods on projects of all sizes.

Table 6. Use of contracting methods on small projects.

Contract Method	Contract Award Over $20M (%)	Contract Award Under $20M (%)	Contract Award Under $10M (%)	Contract Award Under $5M (%)
D–B–B (n=134)	35	65	41	29
CM/GC (n=34)	47	53	29	21
D–B/LB (n=39)	18	82	72	51
D–B/BV (n=77)	55	45	25	12
Total (n=284)	**39**	**61**	**39**	**26**

Average Project Duration

Agencies frequently choose alternative contracting methods to shorten project durations; the data from this study show that they are achieving this objective. Table 7 shows the overall project durations with separate analyses of agency design and construction. These are final project durations that include all contractual changes and/or builder delays. Accurate duration data were more difficult to obtain than project cost data, particularly for agency design. As a result, the mean project durations in table 7 were calculated with fewer projects than in table 5 for project cost. Note that the mean project duration is longer than the sum of the design and construction durations because procurement times and other agency administrative tasks are not shown. Additionally, note that construction duration for D–B projects includes design-builder design *and* construction duration (i.e., the D–B contract duration from award to completion).

When compared to D–B–B, the mean project duration for the CM/GC projects was 48 percent shorter. The mean D–B/BV project duration was 15 percent shorter than D–B–B. These results are noteworthy considering that the mean project costs for CM/GC and D–B/BV projects are approximately twice that of the D–B–B projects. Essentially, projects that are twice as large are being built in half the time by using alternative contracting methods. The mean D–B/LB project duration was approximately 50 percent shorter than D–B–B, but the mean D–B/LB project cost was approximately half of the D–B–B projects' mean.

Table 7. Average project duration.

Contract Method	Mean Cost	Mean Project Duration (Days)	Mean Agency Design Duration (Days)	Mean Construction Duration (Days)*
D–B–B (n=74)	$21,687,447	1,774	932	642
CM/GC (n=24)	$41,368,952	929	361	511
D–B/LB (n=18)	$12,249,585	889	268	435
D–B/BV (n=21)	$48,532,458	1,516	662	837
Total (n=137)	**$28,010,219**	**1,470**	**710**	**620**

*Construction duration for D–B projects includes design-builder design and construction (i.e., the D–B contract duration).

The mean agency design durations in table 7 are notably shorter for CM/GC and D–B projects. The extremely short design duration for CM/GC is surprising because, with CM/GC, the agency brings the design to 100 percent completion—similar to D–B–B. This is likely because of multiple factors. Having the construction manager on the team allows the agency to fast-track the design. In addition to gaining contractor input, there is no need to develop full designs for competitive bidding, as in D–B–B. Moreover, there is no need to develop D–B RFPs, which are sometimes voluminous and often have long industry review periods. While not as short as CM/GC, the mean D–B agency design duration is shorter than that of D–B–B. The design percent complete at the RFP was reported to be less than 30 percent for more than 75 percent of the D–B projects reporting this information. Although the RFP process can be complex, it can take less time than developing full designs.

D–B/LB and D–B/BV contract methods had the lowest and highest mean construction durations, respectively. The D–B/LB projects had the shortest construction duration, perhaps because of the smaller size of these projects and the higher level of design completion at the time of award. The longer D–B/BV mean construction duration was probably driven by two factors: D–B/BV methods had the largest mean cost, and the construction durations included the design builder's design time and coordination with other agencies.

Because the mean costs of the projects in table 7 vary substantially, the research team analyzed two smaller pools of more projects. The first pool involved the smallest projects ranging from $2 to $10 million in award costs. Since D–B–B and D–B/LB are most frequently chosen for projects in this cost range, only these two methods were analyzed. Table 8 includes all projects from the data with verified project, design, and construction durations.

Table 8. Average duration for D–B–B and D–B/LB projects between $2M and $10M

Contract Method	Mean Cost	Mean Project Duration (Days)	Mean Agency Design Duration (Days)	Mean Construction Duration (Days)
D–B–B (n=19)	$4,958,329	1,506	795	508
D–B/LB (n=10)	$4,745,533	773	181	380
Total (n=29)	**$4,884,951**	**1,253**	**584**	**464**

As shown in table 8, the mean costs of the D–B–B and D–B/LB projects are similar, allowing for a more accurate analysis of the project, design, and construction durations. The mean D–B/LB project duration was 49 percent shorter than that of D–B–B projects in this dataset. Agencies took approximately 77 percent less time for design for D–B/LB as compared to the mean D–B–B agency design duration on these projects. However, the mean D–B/LB construction time, which included both the design-builder design and construction time, was nevertheless approximately 25 percent shorter on average. D–B/LB appears to be delivering substantially shorter durations on projects in the $2 to $10 million range.

For larger projects, the data provided a natural grouping of projects from $10 to $50 million in size, as shown in table 9. D–B–B, CM/GC, and D–B/BV are included in this analysis because these contracting methods are most frequently used in this cost range. Table 9 includes all projects from the data with verified project, design, and construction durations.

Table 9. Average duration for D–B–B, CM/GC, and D–B/LB projects between $10M and $50M.

Contract Method	Mean Cost	Mean Project Duration (Days)	Mean Agency Design Duration (Days)	Mean Construction Duration (Days)
D–B–B (n=34)	$21,188,585	2,130	1,139	818
CM/GC (n=10)	$23,912,981	662	281	349
D–B/BV (n=10)	$18,604,503	1,420	638	639

| Total (n=54) | $21,214,569 | 1,726 | 904 | 699 |

Table 9 summarizes the D–B–B, CM/GC, and D–B/BV projects in the $10 to $50 million cost range. Although the mean cost of the CM/GC projects was approximately 11 percent higher than D–B–B and 22 percent higher than D–B/BV, the mean CM/GC project duration was 69 percent and 43 percent shorter than D–B–B and D–B/BV, respectively. Shorter CM/GC mean durations were observed in both design and construction. A shorter CM/GC construction duration is likely— at least in part—because of contractor involvement in project design processes. D–B/BV also showed substantially shorter mean durations with 33 percent, 44 percent, and 22 percent shorter project, design, and construction durations, respectively, as compared to D–B–B; these results are consistent with findings from 2 decades of studying project delivery methods. Like CM/GC, this shorter construction duration is likely because of contractor involvement with the design. The duration is also notable considering its inclusion of time for design-builder design. These results suggest that agencies are gaining substantial time savings by using alternative contracting methods.

Overall Schedule and Point of Cost Certainty

Table 7 through table 9 display the substantial time savings in project duration from the use of alternative contracting methods. Alternative contracting methods also provide agencies with much earlier cost certainty, which is the point at which the agency has a reliable project cost. Agencies value cost certainty for both project and program management. Table 10 shows the point of cost certainty based on mean design and construction duration for D–B–B and D–B/LB projects from $2 to 10 million (see table 8). The procurement items and design–construction overlap are estimated for illustrative purposes. In D–B–B, the initial contract cost (i.e., point of cost certainty) is known after the design is complete. In D–B/BV, the initial contract cost is known at the point of design-builder selection. For D–B–B and D–B/LB projects in this pool, D–B/LB cost certainty is known more than 60 percent earlier. For these smaller projects, early cost certainty has value for planning, programming, and letting schedules.

Table 10. Timing of cost certainty for D–B–B and D–B/LB projects between $2M and $10M.

Contract Method	Mean Timing of Cost Certainty (Days)	Mean Project Duration (Days)
D–B–B (n=19)	802	1,506
D–B/LB (n=10)	297	773

Table 11 shows the point of cost certainty based on the mean design duration (refer to Table 9) and procurement durations for D–B–B, CM/GC, and D–B/BV projects from $10 to $50 million. The explanation for the point of cost certainty in D–B–B and B–B/BV projects was previously explained. The point of cost certainty for CM/GC projects is known after the cost for the last construction package has been agreed upon as CM/GC projects may have one or more construction

packages. When compared to D–B–B, the average point of cost certainty for CM/GC is more than 60 percent earlier for the projects in this study. The point of cost certainty for D–B/BV in this range is approximately 40 percent earlier than D–B–B.

Table 11. Timing of cost certainty for D–B–BD–B–B, CM/GCGC, and D–B/BV projects between $10M– and $50M.

Contract Method	Mean Timing of Cost Certainty (Days)	Mean Project Duration (Days)
D–B–B (n=10)	1184	2,130
CM/GC (n=10)	329	662
D–B/BV (n=10)	765	1,420

Project Intensity

Project intensity is a measure of how much money is spent per day on a project.

$$\text{Project Intensity} = \frac{\text{Final Cost (\$)}}{\text{Actual Project Duration (days)}}$$

(2)

A high project intensity means putting more work in place faster. Projects with a greater intensity can have a shorter impact on the traveling public. With so much highway design and construction occurring in urban settings (i.e., reconstruction and renewal), intensity is an excellent measure of how agencies are serving the traveling public. Table 12 provides the project intensity metrics for each delivery method. The shorter project duration and higher contract cost of the CM/GC and D–B/BV projects, as shown in table 7 through table 9, result in a much higher project intensity than D–B–B. The lower project intensity of D–B/LB can be attributed to the smaller project size.

Table 12. Project intensity.

Contract Method	Mean Cost	Mean Project Intensity ($/Days)	Minimum Project Intensity ($/Days)	Maximum Project Intensity ($/Days)
D–B–B (n=74)	$21,687,447	12,802	269	123,566
CM/GC (n=24)	$41,368,952	46,450	3,618	159,031
D–B/LB (n=18)	$12,249,585	12,816	894	49,892
D–B/BV (n=21)	$48,532,458	28,527	1,930	204,341
Total (n=136)	**$28,010,219**	**21,181**	**269**	**204,341**

Award Growth (Engineer's Estimate to Award)

Award growth is one measure of project cost performance; the more common cost-growth metric is discussed later in this TechBrief. Award growth is the ratio of the difference between the contract award cost of a project and the engineer's estimate, calculated as shown in the equation below. This metric gives an indication of trends in the accuracy of agency cost estimating; it can also show projects that experience significant change in cost during procurement.

$$\text{Award Growth} = \frac{\text{Award Cost} - \text{Engineer's Estimate}}{\text{Engineer's Estimate}} \times 100$$

(3)

Table 13. Award growth.

Contract Method	Mean (%)	Median (%)	Standard Deviation (%)	Minimum (%)	Maximum (%)
—D–B–B (n=129)	–9	–8	18	–51	42
CM/GC (n=31)	3	3	6	–13	15
D–B/LB (n=37)	–5	–7	32	–58	104
D–B/BV (n=71)	–7	–7	22	–51	77
Total (n=268)	**–6**	**–6**	**21**	**–58**	**104**

As shown in Table 13, the mean award growth is lowest for D–B–B projects and highest for CM/GC projects. The data do not provide causes for these trends, but some logical hypotheses can be put forth. For instance, the low award growth in D–B–B projects could be a result of more competition and agencies' use of historic unit pricing for estimates. Similarly, the positive award growth in CM/GC could result from less competition and the use of negotiated pricing. Notably, the CM/GC projects provide the most award certainty (i.e., the smallest standard deviation). Statistical tests for significance show that CM/GC has a higher average award growth when compared to each of the other three methods at a 95-percent confidence level, (p=0.00 vs. D–B–B, p=0.03 vs. D–B/LB, and p=0.00 vs. D–B/BV). However, cost certainty is significantly more accurate for CM/GC than for the other three methods, as indicated by the narrower dispersion around the mean (standard deviation=6 percent). From a statistical significance perspective, D–B–B, D–B/LB, and D–B/BV have no difference in means of award growth at the 95-percent confidence level.

This study also examined the impact of ATCs on award growth. Analysis showed that the use of ATCs does not create a statistically significant difference on award growth, leading to the conclusion that it likely does not have an impact on the accuracy of engineers' estimates. Award growth was found to be -7 percent and -6 percent for the D–B/BV projects with and without ATCs, respectively. While this study could not measure the savings achieved through ATC use, it did determine that ATCs are not correlated with award growth.

Cost Growth (Award to Final)

Cost growth—the cost at contract award compared with the final contract cost—is a key performance metric. In this study, cost growth is calculated by the formula below. Table 14 shows the results of cost-growth calculations with extreme outliers removed.

$$\text{Cost Growth} = \frac{\text{Final Contract Cost} - \text{Awarded Contract Amount}}{\text{Awarded Contract Amount}} \times 100 \tag{4}$$

Table 14. Cost growth (award to final).

Contract Method	Mean (%)	Median (%)	Standard Deviation (%)	Minimum (%)	Maximum (%)
D–B–B (n=129)	4.1	2.3	9.5	–21.8	33.1
CM/GC (n=31)	0.9	0.8	6.0	–12.0	14.5
D–B/LB (n=36)	2.8	0.7	5.7	–5.6	19.0
D–B/BV (n=74)	4.0	1.9	5.5	–4.5	19.6
Total (n=270)	**3.5**	**1.9**	**7.8**	**–21.8**	**33.1**

Table 14 displays the mean cost growth for each contract method along with statistics describing the dispersion of the data. The results from comparative statistical tests reveal that there is no statistically significant difference in cost growth between any of the contract methods at the 95-percent confidence level, which includes CM/GC, although the cost growth of the CM/GC projects is the lowest at 0.9 percent. Cost growth for the other delivery types ranges between 2.8 and 4.1 percent. In summary, agencies are expediting the overall project delivery time and gaining early cost certainty (as shown in **Error! Reference source not found.** and **Error! Reference source not found.**) without witnessing additional cost growth in the construction contract. This is particularly notable given the early award of D–B and CM/GC projects.

This study also examined the correlation between ATCs and cost growth. The use of ATCs did correlate with higher cost growth. Cost growth was found to be 6 percent for D–B/BV projects with ATCs and 2 percent for D–B/BV projects without ATCs, a difference that was statistically significant at the 95-percent level. The higher cost growth could contribute to a variety of causes, including the higher project complexity (see table 3). Nonetheless, D–B/BV projects in the study pool with ATCs did experience higher cost growth, and this issue needs additional study.

Change Orders

Table 15 shows the causes of changes within each contracting method as an average percent of the contract award amount. These causes were reported by the project managers in 162 of the projects in the database.

Table 15. Impact of change order categories as an average percentage of contract value.

Change Orders	D–B–B (n=65)	CM/GC (n=19)	D–B/LB (n=21)	D–B/BV (n=57)	Total (n=162)
Agency directed	1.2%	0.7%	1.6%	1.9%	1.5%
Plan quantity changes	1.1%	0.3%	0.6%	0.2%	0.6%
Unforeseen conditions	2.4%	1.5%	1.8%	1.8%	2.0%
Plan errors and omissions	0.9%	0.6%	0.1%	0.5%	0.6%
Other	0.1%	0.2%	0.8%	0.3%	0.3%
Total impact as a percentage of award cost*	**5.8%**	**3.4%**	**5.0%**	**4.7%**	**5.0%**

*Total impact as a percentage of award cost differs from the cost growth in table 14 because of the smaller sample size of projects with detailed change order data available.

Overall, unforeseen conditions have the largest change order impact across the contracting methods; this finding coincides with other change order studies. No delivery method seems to be immune to the effect of unforeseen conditions on change orders. However, agencies could be transferring some of the risk for unforeseen conditions to the contractors through alternative contracting methods, as reflected in the lower change order trend with the D–B and CM/GC methods.

Agency-directed change orders have the second greatest impact on change orders. D–B/BV projects have the highest level of agency-directed change orders; CM/GC projects have the lowest. Higher levels of agency-directed change orders could be expected in D–B because of the lower level of design at the time of award. However, agency changes can have either negative or positive impacts on project goals. Negative impacts occur with incomplete scopes or lack of clarity in the RFP. Positive changes can add value to a project that was awarded below budget. Moreover, more than half of the agency-directed change orders in the database occurred in projects in which the project award was lower than the engineer's estimate. Many of the owner-directed changes could have added value to the project within the budget.

Increases due to plan quantity changes, plan errors, and omission changes agree with what would be expected between delivery methods. D–B–B has the largest percentage of plan quantity changes, which is likely attributable to the designs being performed by the agency and the pricing being predominantly unit price. Plan errors and omissions are also highest in D–B–B. CM/GC plan errors and omissions should be lower because of the early involvement of the general contractor. D–B plan errors and omissions should be lower because the risk for this change is primarily transferred to the design builder.

In the "other" category, respondents provided qualitative descriptions of the reasons for change orders. The most common responses were value engineering by the contractor, changes directed by non-agency stakeholders, and negotiated settlements of multiple claims.

Schedule Growth

Due to the difficulty in obtaining reliable planned, agency-designed start data, only 49 of the 291 projects were available for this analysis. The project schedule growth findings were that 31 D–B–B projects had an average of 8-percent growth and 8 CM/GC projects had an average of 2-percent

growth. Because the dataset included only three D–B/LB and three D–B/BV projects that submitted the required data to make this analysis, their findings are not presented. Given the early procurement of alternative contracting methods, higher schedule growth might be expected, but D–B–B has the highest mean project schedule growth. However, there are not enough data to make any substantial conclusions.

Mean construction schedule growth data were more readily available than overall project-schedule growth data because the start date for construction relates to the contract time. Reliable mean construction schedule data were available for 146 projects as shown in Table 16. Construction schedule growth is calculated as follows:

$$\text{Construction Schedule Growth} = \frac{\text{Actual Const. Duration} - \text{Planned Const. Duration}}{\text{Planned Const. Duration}} \times 100 \qquad (5)$$

Table 16. Construction schedule growth (award to final).

Contract Method	Mean	Median	Standard Deviation	Minimum	Maximum
D–B–B (n=63)	10%	0%	38%	-65%	118%
CM/GC (n=13)	31%	0%	76%	-30%	199%
D–B/LB (n=20)	-11%	-6%	18%	-44%	19%
D–B/BV (n=50)	15%	7%	31%	-71%	81%
Total (n=146)	**11%**	**0%**	**40%**	**-71%**	**199%**

Construction schedule growth showed a wide range of results for all contracting methods. For all the projects in this pool, there were time savings of up to 71 percent and delays of up to 199 percent. D–B/LB was the only contracting method with an average construction time savings (mean and median). CM/GC had the largest mean construction schedule growth, but this was because of a few projects with extremely high growth. The median construction schedule growth for CM/GC was 0 percent. D–B–B similarly had a median construction schedule growth of 0 percent. D–B/BV had a schedule growth of 15 percent and 7 percent for mean and median, respectively. Unfortunately, the data collection did not address the reasons for construction schedule growth in a similar manner to change orders. However, it can be assumed safely that some of the construction schedule growth for D–B/BV and CM/GC occurred because of value-adding changes. These results should be viewed in light of the substantial time savings that are realized from alternative contracting methods. The time savings shown in table 7 through table 9 are measured from actual project durations, which include construction schedule growth.

PROJECT DELIVERY SELECTION

To assist agencies in selecting delivery methods, the results of this study have been integrated into a Project Delivery Selection Matrix (PDSM) that was developed through the FHWA and Colorado DOT's Next-Generation Transportation Construction Management Pooled Fund Study. The PDSM provides a formal approach for selecting project delivery methods for highway projects. The process uses a series of evaluation worksheets and forms to guide agency staff and project team members through a project delivery selection workshop. The result is a brief Project Delivery

Selection Report that matches the unique goals and characteristics of each individual project. The primary objectives of the PDSM are as follows:

- Present a structured approach to assist agencies in making project delivery decisions.

- Assist agencies in determining if there is a dominant or optimal choice of a delivery method.

- Provide documentation of the selection decision.

The PDSM tool can be downloaded at **http://www.colorado.edu/tcm/project-delivery-selection-matrix**.

SUMMARY

The information presented in this TechBrief provides an up-to-date perspective on the types of alternative contracting method projects ongoing in the U.S. highway industry. Agencies are using alternative contracting methods on projects of all sizes to reap potential benefits, as illustrated by the high frequency of use of the CM/GC, D–B/BV, and D–B/LB methods on projects valued under $20 million. As expected, agencies are saving substantial time in project delivery, with 40-to-60-percent savings over D–B–B average project durations. They are also greatly accelerating the point of cost certainty in the project development process. Contrary to intuition, the alternative contracting methods do not seem to have an impact on cost growth when compared to the traditional D–B–B method or among themselves. With regard to project intensity, the alternative contracting methods are facilitating project delivery at a faster pace in terms of the rate of resources invested in the project per day. In summary, this study found that alternative contracting methods are shorter in duration, have an earlier cost certainty, and have a higher project intensity. In essence, agencies are getting more work in place with less disruption to the traveling public. Agencies are also using alternative contracting methods on projects of all sizes and do not appear to be seeing any significant cost-growth issues. With the use of alternative contracting methods increasing nationwide, the analysis of empirical project data in this study provides insightful results that can help agencies select appropriate project delivery methods. However, agencies must realize that the results shown in this TechBrief are based on average performance from many projects. Any single project can perform substantially better or worse than the average. Contracting methods provide the environment for success, but they by no means guarantee it.

REFERENCES

1. Federal Highway Administration. (2013). "Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications." Federal Highway Administration Project, Contract No. DTFH61-11-D-00009, 2013–2016.

2. National Cooperative Highway Research Program. (2014). *NCHRP Synthesis 455: Alternative Technical Concepts for Contract Delivery Methods.* Transportation Research Board of the National Academies, Washington, DC.

3. Federal Highway Administration. (2015). *Every Day Counts, EDC-2 Final Report*. 2015. pp. 22–25 and 69–72. Available online: https://www.fhwa.dot.gov/everydaycounts/reports/edc-2-finalreport/, last accessed June 10, 2016.

4. National Cooperative Highway Research Program. (2007). *NCHRP Report 574: Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction*. National Cooperative Highway Research Program of the Transportation Research Board, Washington, DC.