An Empirical Comparison of Project Delivery Method Performance

For Highway Construction Projects

By

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ABSTRACT

The intent of this study was to provide an empirical analysis of project performance between the traditional design-bid-build (DBB) method and alternative design-build (DB) method of project delivery for highways. The study examined five major performance metrics: cost growth, schedule growth by notice to proceed, schedule growth by construction start date, award growth and construction engineering inspection cost factor. The data were collected from six selected state departments of transportation (DOT): Florida, Indiana, Oregon, North Carolina, Ohio, and Utah. These six DOTs have significant experience on using the DB project delivery method. Totally, more than 15,000 projects were mined and analyzed. To create a comparable pair between DBB and DB projects, six contract size bins were defined: projects under $2M, $2M - $5M, $5M - $10M, $10M - $20M, $20M - $50M, and over $50M. Performance data were collected from the six states by direct DOT official interviews and were mapped to the exploratory metrics. Three rounds of mining were conducted to accomplish the comparable sets of projects: missing data point removal, outlier removal, and project pairing by the bin-sampling method. Projects were matched one-to-one between DBB and DB at +/- 15% of contract award amount and +/- 1 year of respective project construction start date. The results of analysis showed that on average, the cost growth for DB projects is higher than the cost growth for DBB projects for smaller project ranges and lower than DBB projects for larger project ranges. The schedule growth based on notice to proceed dates and construction start dates on DB was found less than that for DBB projects across all sampled states and for all project sizes. DBB produced more negative award growth than DB for all contract size bins. For CEI factor, DBB showed higher mean values than DB for five out of the six contract size ranges.

DEDICATION

I dedicate this Master's Thesis to my loving family members, to whom I am forever grateful for their endless love, guidance, and support of all my endeavors. I am appreciative for their encouragement and faith in taking this journey with me: Mom, Dad, and Taylor – all of my success is because of and for you. Thank you.

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CHAPTER I - INTRODUCTION

1.1 Background

Throughout the last two decades, alternative delivery methods have been developed to allow for flexibility in the process of design, bidding, and building of highway projects. The existing legislature requiring the selection of the lowest bidder in public projects has still limited many construction projects to the traditional design-bid-build (DBB) system of delivery. However there has been increasing demand by the traveling public for department of transportation (DOT) agencies to deliver highway projects faster and cheaper (at very least as close to budgeted cost and time as possible) while preserving the same level of quality. Currently DOT officials are searching for a delivery system that creates greater value for the tax budget dollar, minimizes construction disputes between entities, and increases collaboration for innovation and constructability (quality). Recent legislative changes have allowed for a shift in project delivery systems and procurement, specifically allowing for innovative contracting systems, particularly the design-build (DB) method, to be used in several jurisdictions. This can be seen in the success of the SEP-14 (Special Experiment Project No. 14 – Innovative Contracting 2009) Initiative on the federal project level. DB is becoming an increasingly popular delivery method due to the growing impact on project performance in the areas of cost and schedule (Tran and Molenaar 2014).

1.2 Motivation

As the level of investigation into DB delivery and other alternative contracting methods (ACMs) grows, public agencies are eager for detailed empirical material to report the performance efficiencies of these systems compared to traditional DBB delivery. Additionally, these new studies are counted on to assist in the delivery method selection for future highway projects. Since there is currently no national-level analysis of data concerning highway projects utilizing the DB system, this thesis is designed to explore the performance of delivery methods and confirm the perceived benefits or costs of alternative project delivery.

1.3 Problem Statement and Research Objectives

The main objective of this study was to provide an empirical analysis of project performance between the traditional DBB method and alternative DB project delivery for highways. The research problem comprised several elements. In order to gauge project performance, the first element was to decide what method is best suited for analyzing a large set of project data. The second element involved deciding how to equate cost and schedule data from the record systems between states using differing terminologies and classifications for construction contracts. Since DB and DBB are inherently separate delivery systems, creating equivalent measurement parameters was also a significant challenge. When all procedural elements of the research problem were solved using the research methodology, the eventual task was formulating comparable sets of projects for analysis using the measurement system.

1.4 Research Contributions

This research thesis broadens the performance knowledge about DB on highway projects by using a landmark sample size of recorded projects. These project samples were collected from six state DOTs with significant experience on using alternative delivery methods. The study is one of the first research efforts that quantitatively compares project performances between DBB and DB projects based on empirical data. Further, this study performed statistical analysis of highway project data by size segmentation, a process not previously attempted in detail in wake of insufficient samples. The findings from this study will encourage future research on project performance measurement under other alternative delivery methods such as construction management at risk, public-private-partnership (PPP), alternative technical concepts, indefinite delivery/indefinite quantity (ID/IQ), or the alliance relationship contracting model.

1.5 Reader's Guide to this Thesis

Chapter 2, Background and Literature Review, introduces the main characteristics of the DBB and DB delivery systems as they relate to highway projects. Next in the chapter the process of delivery system selection and history of alternative delivery implementation in public agencies are discussed. The most significant material in Chapter 2 is the conclusive performance review of delivery systems, which provides a detailed summary of the past performance studies on construction projects and the research gap on which this thesis builds.

Chapter 3 continues with the point of departure from previous performance analysis studies and the research topics covered. Within this chapter the associated research questions to the general research problem are presented.

Chapter 4 contains the overview of the research methodology employed in the study. The basis for the research, the Stanford CIFE Horseshoe, will be explained and the application to this research is detailed. The section shows the development concepts of the exploratory metrics that will be used for the quantitative performance measurement of the project data. Supplementary definitions of terms used for the contract data points are also provided to explain how the metric formulas function across each state DOTs data populations. The author also gives an introductory description of the project data attributes. The data narrative concludes with the discussion of the project data use for delivery method performance measurement.

The data analysis of this thesis in Chapter 5 shows the data manipulation processes and the production of the performance trends for DBB and DB. The data cleaning results are divided into the combined data by state and project size level. Chapter 5 also describes the statistical tests used for the analysis process.

Chapter 6 presents the findings of the performance trends at the comprehensive and size levels. This chapter will include both how the data was analyzed and what the outcome of this analysis was. The metric results for the DBB and DB methods are discussed and interpreted for significant relationships.

Chapter 7 provides the conclusions to the presented research problem. In addition the limitations of the study and recommendations for future research are included.

CHAPTER II – BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the two project delivery methods examined for this study: design-bid-build (DBB) and design-build (DB). The first section focuses on background information for each delivery system. The proceeding material reviews DB implementation history and method selection. This chapter concludes with the main findings in the literature from investigations in project performance for non-transportation and transportation related work.

2.2 Project Delivery Systems

A project delivery system is a process of designing and constructing any facility. Miller (1999) defines a project delivery method as a way for "owners/clients to deliver and finance constructed facilities" or "a process by which the components of design and construction- including the roles and responsibilities, sequence of activities, material costs, and labor- are combined to deliver a project" (Loulakis and Haufman 2000). Highway projects in particular have a specific phase sequence, including feasibility studies, planning, road schematics, detailed design, right-of-way (ROW) acquisition, utility adjustment, construction, operation, and periodic maintenance.

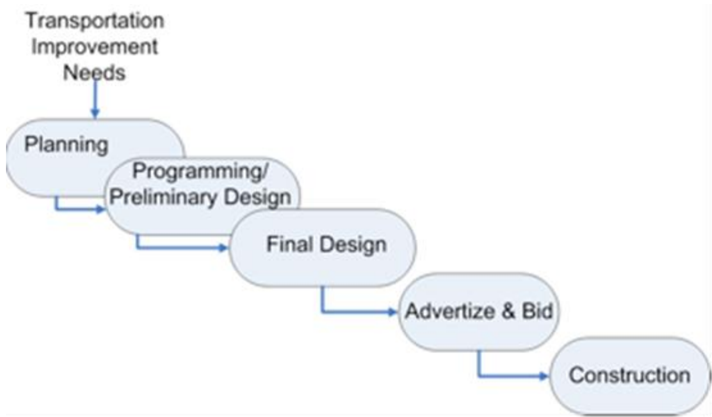


Figure 2.1 Typical Project Development Phases for Highway Projects (Anderson et al. 2007b)

The Construction Industry Institute (CII) classifies three fundamental delivery systems including: DBB, DB, and construction manager/general contractor (CM/GC) - also known as construction manager-at-risk (CMR) (Construction Industry Institute 1997).

2.2.1 Traditional Project Delivery: DBB Method

DBB is the fundamental delivery system for construction projects in both the building and transportation sectors across the U.S. For centuries before the 1920's construction projects were mostly constructed using a master-builder method of various forms, until construction material specialization gave DBB precedence on horizontal construction for decades (Minchin et al. 2013) In this traditional method, the owner retains an architect/engineer (A/E) to furnish complete design services, advertises and then awards a lump sum construction contract to a separate contractor based on the designer's completed construction documents and the prospective contractor's qualifications (Ibbs et al. 2003; Mahdi and Alreshaid 2005). In DBB, the owner "owns" the details of design during construction and, as a result, is financially liable for costs of errors and omissions encountered during the building phase (Mitchell 1999, Tran and Molenaar 2014a). The most common approach to awarding the construction contract is to solicit bids from different construction companies; since selection is based entirely on cost, usually the lowest bid wins the project. Although while DBB is mostly on a low-bid basis, contracts can be awarded by negotiation or best value – however there is no incentive for the builder to minimize costs of change orders and most designers and constructors can compete for a DBB contract without restriction (Touran et al. 2009, Molenaar and Tran 2015). In essence, under DBB, two separate contracts, with two separate entities, are used by owners to complete one construction project, which includes two solicitations and procurement steps (Hale et al. 2009). That separation can create the significant potential for scope changes and differing financial interests between the owner and contractor, leading to disputes and costly changes (Konchar 1997; Steiman et al. 2009). For DBB projects awarded by best-value or negotiation, the probability of a miscalculated low bid is reduced and the builder retains more incentive to perform in a manner that will reflect well in their next best-value selection (FDOT 2006, Molenaar and Gransberg 2001). Regardless of the award method, DBB involves less construction input than DB or CM/GC and thus the designer or agency CM must be relied upon for any constructability reviews (Touran et al. 2009). It is noted that DBB continues to be the most frequently used on projects by public agencies because of the award to the lowest bidder and the apparent maximum value for tax-dollar funding (Molenaar et al. 1999). Figure 2.2 illustrates a typical contractual responsibility diagram for the DBB method.

Figure 2.2: DBB Project Delivery Framework (Makatura Inc., 2013)

2.2.2 Alternative Project Delivery: CM/GC Method

CM/GC projects are identified by a contract between an owner and construction manager who assumes the risk for the final cost and time of construction. The main contractual components of this system are illustrated below in Figure 2.3. Usually CM/GC stipulates a guaranteed maximum price, above which the project owner is not responsible for payment. The CM/GC contract is awarded during the design phase and provides preconstruction services including estimating, scheduling, and detection of construction/ quality issues (called constructability) – (NCHRP Report 787). The CM/GC system creates a departure from DBB in two distinct ways. First this method allows for bringing the construction expertise into the design process to increase constructability (Capps 1997). Second, the CM/GC method provides an opportunity for phased design (work portions bid and subcontracted at any time), advanced ordering of long-lead items, real-time construction pricing capability, and overlap of other construction activities (Branca 1997; Konchar 1997; Gransberg and Shane 2010). Researchers have shown that the CM/GC delivery method is deemed most successful when risk is jointly managed between owner and construction manager (Gransberg et. al 2012). The main advantage advocated for using CM/GC methods is to provide professional management of all phases in the project life to an owner that does not possess those capabilities in their organization (Touran et. al 2011).

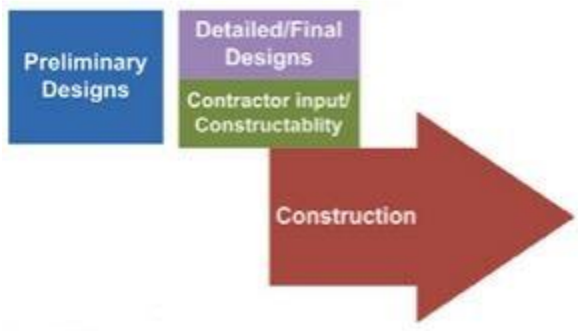


Figure 2.3: CM/GC Project Delivery Framework (FHWA 2006)

2.2.3 Alternative Project Delivery: DB Method

The fastest growing and most-proven system being utilized in place of the traditional DBB method is DB, in which the owner awards a contract to a single entity designer-builder that handles both the design and construction tasks of the project (Branca 1987). Gransberg and Senadheera (1999) conducted a national survey of 15 DOTs and discovered that DB, in low-bid, adjusted score, or best value form was the alternative method of choice commissioned by all. Like CM/GC, the DB system gives the builder input early in the design process and thus compresses the delivery period to the greatest extent of any of the three methods (Touran et al. 2011). The designer-builder is liable for all design and construction costs (single point of responsibility for owner) and normally must provide a firm, fixed price in its project proposal (El Wardani et al. 2006; Ibbs et al. 2003; Graham 2001). Sometimes, the DB contractor is also responsible for utility adjustments and ROW acquisition, thus creating the ability to start construction activities before a detailed design is completed. Among the main advantages of the DB system, qualifications, price and design concept are all considered as part of the contractor selection process; this is known as best-value selection(Steiman et al. 2009). Also better cost certainty, reduced design errors, and improved risk management are offered under this system (FHWA 2006). The attraction to faster construction methods like DB by public transportation agencies resulted from the growing impatience by the traveling public with the lengthy bridge and highway construction phases that are usually a part of traditional DBB systems (Minchin et al. 2013).

Figure 2.4: DB Project Delivery Framework (Makatura Inc., 2013)

In 1969, the Department of Defense authorized turnkey-style construction for producing military housing that created shortened project schedules and lower costs (Molenaar et al. 1999). DB expanded to the public project areas of warehouses, municipal structures (i.e. courthouses), civil distribution facilities (i.e. postal centers) medical/laboratory facilities, and progressively to highways (Powers 1997). Continuing in the early 1980's the U.S. Army Corps of Engineers developed a one and two-step facility acquisition process for non-housing facilities, while the U.S. Navy followed suit as it began awarding DB under the Newport method in 1985. Arguably one of the most significant events in the history of DB implementation was the 1996 Federal Acquisition Reform Act, known as the "Clinger-Cohen Act" (Loulakis, 2003; Hale et. al, 2009) which authorized the use of DB on federal projects. This legislation guaranteed continual DB public sector growth and established the two-step delivery process as the best for overall budget and schedule performance (Migliaccio et al. 2009, Molenaar et al. 1999; Ramsey et al. 2014). Procuring federal funding for projects by DB became easier in 1998 when they were proven to comply with states' own contract procurement statutes (Minchin et al. 2013).

A report by Gransberg and Molenaar (2008) examined the evolution of DB implementation in state agencies for publically funded construction projects to the state-of-practice today. This report states the percentage of non-residential building projects in DB has risen in the past 20 years from $18 billion in 1986 to $250 billion in 2006. Certain states including California and Oklahoma have authorized DB use on public buildings without extending broad authority to their DOTs. This use has been concentrated primarily on mass transit and toll projects, where potential revenue has justified a compressed construction schedule (Gransberg and Molenaar, 2008). By 2004, the FHWA approved more than 300 DB projects worth approximately $14 billion in 32 states. However, the resistance to DB adoption in public agencies for the past decade has been motivated by the apprehension toward the effects of: (1) outsourcing design and construction engineering toward downsizing public works labor forces; (2) decreased project design/quality control, and (3) the possible phase-out of traditional delivery altogether (Scott et al. 2006). National Society of Professional Engineers (NSPE) Statement 1726 for example, claimed: (1) quality will be degraded and tax dollars overspent on re-design and inspection, and (2) the design process will be compromised by decisions falling to other parties on the DB team. The findings of Gransberg and Molenaar (2008) refuted these early claims, showing that DB implementation does not at this time eliminate traditional DBB practice in state agencies – two thirds of respondents said DB projects make up less than 10% of their total construction programs to date. Successful DB use requires highly experienced agency engineers, thus traditional delivery programs will always be needed to train entry-level personnel; the workloads of agency engineers will only shift in DB to more oversight, review, and approval tasks (Hanna et al. 2008). The following sections discuss the delivery method selection process and main performance findings from non-transportation and transportation studies in the literature.

2.3 Content Analysis of Performance Metrics

Many studies have attempted to compare the project performance associated with different project delivery or contracting methods. Although there are a wide range of performance metrics, the key metrics are often related to project cost, schedule, and quality. This section briefly summarizes major findings from alternative contracting method (ACM) performance studies in both non-transportation and transportation projects.

2.3.1 Non-Transportation Studies

Table 2.3.1: Non – Transportation Study Summary

Summary of Project Performance Comparison for Non-Transportation Projects						
Studies	ACMs	# Projects	Project types /Agencies	Major Findings	Statistical Results	
					Test	p-value
COST GROWTH						
Roth (1995)	D-B vs. D-B-B	6	Naval Facilities	D-B = 6.5% , D-B-B = 11.4%	t-test	p = 0.304
Kochar and Sanvido (1998)	D-B vs. D-B-B	351	Industrial and buildings	5.2% less in D-B	Mul. Analysis	R^2 = 0.24
Molenaar et al. (1999)	DB vs. DBB	104	Industrial, buildings (5% highways)	59% of D-B projects were with 2% or better of the established budget	NA	NA
Allen (2001)	DB vs. DBB	89	Naval Facilities	15% less in D-B	NA	NA
Ibbs et al. (2003)	DB vs. DBB	67	Industrial and buildings	7.8% more in D-B	N/A	N/A
Hale et al. (2009)	D-B vs. D-B-B	77	Naval Facilities	2% less in D-B	ANOVA	p=0.011
TOTAL COST/UNIT COST						
Roth (1995)	D-B vs. D-B-B	6	Naval Facilities	10% less in D-B	t-test	p = 0.083
Bennett et al. (1996)	D-B vs. D-B-B	332	NA	13% less in D-B	Mul. Analysis	R^2 = 0.51
Kochar and Sanvido (1998)	D-B vs. D-B-B	351	Industrial and buildings	6% less in D-B	Mul. Analysis	R^2 = 0.99
Hale et al. (2009)	D-B vs. D-B-B	77	Naval Facilities	4.5% less in D-B	ANOVA	p = 0.756
SCHEDULE GROWTH						
Kochar and Sanvido (1998)	D-B vs. D-B-B	351	Industrial and buildings	11.4% less in D-B	Mul. Analysis	R^2 = 0.24
Molenaar et al. (1999)	DB vs. DBB	104	Industrial, buildings (5% highways)	77% of D-B projects were with 2% or better of the established schedule	NA	NA
Ibbs et al. (2003)	DB vs. DBB	67	Industrial and buildings	2.4% less in D-B	N/A	N/A
DELIVERY TIME						
Bennett et al. (1996)	D-B vs. D-B-B	332	NA	30 % faster in D-B	Mul. Analysis	R^2 = 0.80
Kochar and Sanvido (1998)	D-B vs. D-B-B	351	Industrial and buildings	33% faster in D-B	Mul. Analysis	R^2 = 0..87

The earliest primary investigation for non-transportation projects by Roth (1995) on six Naval facility projects concluded DB produced 4.7% less cost growth and 10% more cost saving than DBB. However, these performance differences were not found statistically significant at the five percent level (α = 5%). Konchar and Sanvido (1998) conducted the first rigorous empirical comparison, using uni-variate test sorting by system, facility and owner type and by multi-variate regressions of 351 industrial and commercial building project data from surveyed owners and contractors in their landmark Construction Industry Institute (CII) study. The sample size was varied by size range from 500 to 200,000 m^2 and by six project types. The used 196 projects in the regression analysis to identify ten variables explaining the variation in cost growth (including commercial terms, project team chemistry, facility type, complexity, and legal constraints) and eight variables contributing to schedule growth variance (including subcontractor experience, facility type, and as planned duration). The multi-variate regression results were classified as primary (high statistical confidence) and secondary (reduced statistical confidence). The investigators concluded that DB had 5.2% less cost growth than DBB and 11.4% less schedule growth than DBB, though both trends did not meet statistical significance at the 95% confidence level.

Pocock (1996) compared the performance of traditional and alternative delivery approaches with 209 military construction projects. The metrics utilized in that study were schedule growth, cost growth, and design deficiencies. Pocock (1996) calculated degree-of-interaction (DOI) scores for 38 projects in the sample size, with scatter plots showing that as DOI scores rose, project performance quickly improved and then eventually leveled off. The regression analysis revealed that partnered projects averaged least schedule growth (p-value 0.09), design build projects averaged lowest schedule growth and design deficiencies (p-value 0.25), and combination projects had the fewest modifications (p-value 0.03). Traditional DBB performed worst in schedule growth, modifications, and design deficiencies. Alternative contracting projects had consistently higher DOI scored than DBB, confirming that early interaction positively affected project performance.

Molenaar et al. (1999) expanded on Konchar and Sanvido's (1998) results, considering owner experience, level of design completion, design-builder selection, contract type, and method of award as project variables. The investigators observed 59% of DB projects within 2% of budget and 77% of DB projects within 2% or better of the established schedule on 104 sampled cases.

The thesis by Allen (2001) on 89 Naval facility buildings from the Naval Facilities Engineering Command in 2001 reported 15% less cost growth in DB on average than DBB (vertical DB: 24.6%, horizontal DB: 17.1%). For vertical and horizontal DBB projects, the time growth was 58% and 30% respectively. The DB time growth for vertical and horizontal projects was 3% and -3% respectively. The analysis isolated differing site conditions, owner requested changes, and design errors/omissions as causes for time growth. Award growth for all horizontal DB projects analyzed was -20% while vertical DB, vertical DBB and horizontal DBB award growth were -3%, 3%, and -2% respectively. This study also did not report trends with statistical significance. Allen (2001) recommends a standardized RFP, accelerated NTP issuance, and updated contract information for the best success for DB practice especially on government projects.

Ibbs et al. (2003) also conducted a study of 67 sampled CII global projects. That investigation concluded that DB outperformed DBB in terms of schedule (2.4% less schedule growth) and that time-savings was a "definitive advantage" of using the DB method. However DB did not perform better than DBB in cost growth or productivity, as regression analysis equations used were parallel for both the examined DB and DBB cases and produced mixed results depending on if productivity was measured as a function of cost or schedule. Those conditions made the positive effects in cost or productivity less certain.

Another CII study by Thomas et al. (2002) compared DB and DBB performance impact on 617 projects using National Institute of Standards and Technology (NIST) data compiled by CII. This study used schedule, changes, and rework as the three statistically significant metrics for owner submitted projects, confirming Sanvido's findings of DB's superiority to DBB; however, superior performance for DB was not universal, but depended on which party submitted project data. The metrics in the Thomas (2002) analysis were significantly better for contractor submitted projects only for change performance, and there were no statistically significant differences in any of the observed cost metrics.

The Air Force military construction (MILCON) program was empirically analyzed by Rosner et al. (2009) for DB project performance against traditional DBB project delivery. This study sampled 835 MILCON projects (278 DB, 557 DBB) from 1996 to 2006. The data was examined by six performance metrics (including cost growth, schedule growth, number of modifications per $million), historical performance trends of the two delivery methods, and best delivery method for six defined facility types. The average cost of projects was $6.9 million and the maximum was $87.5 million. DB cost growth performed statistically significant better than DBB (4.52% vs. 6.42%), recording a p-value of 0.006; the schedule growth p-value of 0.293 indicated no statistical difference between DB and DBB. DB also performed better in seven of the nine facility types analyzed. DB also outperformed in Mods/$mill. It should be noted that the projects were not studied on a case-by-case basis due to the data recording methods in the Air Force database. Appropriate information was not tracked to directly compare design and construction phases of DB and DBB projects. Finally, causality was not investigated in this study.

Hale et al. (2009) applied an analysis of variance (ANOVA) to a similar group of 77 building projects (39 DBB and 38 DB), showing 2% less cost growth in DB and 4.5% cost savings. It was noted that the distribution of projects by region was uneven for the two samples, but all metrics except total time, duration per bed, and time growth had equal variances. Cost growth was statistically significant with a p-value of 0.011 and time growth significant at p-value 0.001. The Hale et al. (2009) study showed project duration, fiscal year duration, construction start duration, project duration per bed, fiscal year duration per bed, construction start duration per bed, and time growth metrics were all statistically significant lower for DB than a DBB project.

2.3.2 Transportation Studies

Table 2.3.2: Transportation Study Summary

Summary of Project Performance Comparison for Transportation Projects					
Studies	ACMs	# Projects/ Agenices	Major Findings	Statistical Results	
				Test	p-value
COST GROWTH					
Warne (2005)	D-B vs. D-B-B	60	4% less in D-B	NA	NA
FHWA (2006)	D-B vs. D-B-B	22	3.8% more in D-B	NA	NA
Ellis et al. (2007)	D-B vs. D-B-B	1913	4.9% more in D-B	NA	NA
Shrestha et al. (2007)	D-B vs. D-B-B	15	9.6% less in D-B	F-test	0.03
Shrestha et al. (2011)	D-B vs. D-B-B	22	1.5% more in D-B	ANOVA	0.751
Minchin et al. (2013)	D-B vs. D-B-B	50	24.9% more in D-B	Nonparametric	0.209
TOTAL COST/UNIT COST					
Ellis et al. (1991)	D-B vs. D-B-B	11	11% less in D-B	NA	NA
Ernzen and Schexnayder (2000)	D-B vs. D-B-B	2	15% less in D-B	NA	NA
FHWA (2006)	D-B vs. D-B-B	22	3% less in D-B	NA	NA
SAIC (2002)	D-B vs. D-B-B	11 states	3 of 11 states reported lower cost	NA	NA
NYDOT (2002)	D-B vs. D-B-B	9 agencies	5 of 9 agencies reported lower cost	NA	NA
Molenaar (2003)	D-B vs. D-B-B	1	23% more in D-B	NA	NA
Ernzen et al. (2003)	D-B vs. D-B-B	13	4% less in D-B	NA	NA
SCHEDULE GROWTH					
FHWA (2006)	D-B vs. D-B-B	22	9% less in D-B	NA	NA
Ellis et al. (2007)	D-B vs. D-B-B	1913	9.4% less in D-B	NA	NA
Shrestha et al. (2007)	D-B vs. D-B-B	15	5.3% less in D-B	F-test	0.51
Shrestha et al. (2011)	D-B vs. D-B-B	22	15.4 % more in D-B	t-test	0.17
Minchin et al. (2013)	D-B vs. D-B-B	50	2.8% less in D-B	Nonparametric	0.229
DELIVERY TIME					
Ellis et al. (1991)	D-B vs. D-B-B	11	36% faster in D-B	NA	NA
Warne (2005)	D-B vs. D-B-B	60	100% interviewees agreed that D-B was faster than D-B-B	NA	NA
FHWA (2006)	D-B vs. D-B-B	22	14% less in D-B	NA	NA
SAIC (2002)	D-B vs. D-B-B	11 states	10 of 11 states reported shorter duration	NA	NA
NYDOT (2002)	D-B vs. D-B-B	9 agencies	9 of 9 agencies reported shorter duration	NA	NA
Molenaar (2003)	D-B vs. D-B-B	1	16% faster in D-B	NA	NA
Ernzen et al. (2003)	D-B vs. D-B-B	13	22% faster in D-B	NA	NA

Table 2.3.2 compares the cost and schedule metrics of transportation projects delivered under DBB and DB methods. This study focused exclusively on highway construction projects. A total of 106 US projects from 23 CII member companies were used in a quantitative study by Oberlender and Zeitoun (1993) to identify pre-construction factors that indicate possible cost and schedule growth. The study found that fixed-price projects generally expect fewer changes because of a more well-defined scope, whereas cost-reimbursable jobs are typically awarded prior to design completion. Molenaar and Navarro (2011) used four DB case studies in highway construction to examine key performance indicators. The authors identified six difference performance provinces: cost and schedule, quality, safety, and environmental impact. The following sections summarize the significant findings on the cost and schedule growth performance measures.

Ellis et al. (1991) evaluated 11 DB projects as part of the FDOT DB Pilot program and found DB yielded close to 11% cost savings and 36% faster delivery than DBB. A continued investigation with a larger database by Ellis et al. (2007) analyzed 66 DB projects and 1847 DBB projects. The study results showed DBB cost growth (9.4%) on average was higher than DB projects (4.5%). Ellis et al. (2007) also concluded that for the schedule metric measured, DBB projects were higher in schedule growth (16.5%) than that for DB projects (7.1%). However, the aforementioned studies did not report statistical significance for cost or schedule growth.

Ernzen and Schexnayder (2000) compared two similar highway projects delivered by DBB and DB. After observing 10 construction activities from these projects, the researchers found that the DB sample project outperformed the sample DBB projects by total cost (DB came 10% under budget while DBB came in 5% over the stipulated budget).

The DB Practice Report for the New York Department of Transportation (NYDOT) in 2002 showed that all 9 reporting agencies had shorter project duration with DB, while a similar report for SAIC (2002) also reported 10 out of 11 agencies with shorter DB project duration vs. DBB.

Warne (2005) compared 60 highway projects (21 DB and 39 DBB) ranging from $83 million to $1.3 billion across the U.S. The four main performance indicators chosen isolated for measurement by Warne (2005) were schedule, cost, quality, and owner satisfaction. He found less than 4% cost growth on average for DB projects with 76% of them reported as completed ahead of schedule, along with greater price certainty for DB projects, according to interviewee responses. 100 % of respondents reported the belief that selected projects were built at a faster rate with DB than DBB and with equal or better quality over DBB.

The FHWA conducted a DB Effectiveness Study on 22 sampled cases from the SEP-14 projects within various states (all projects were less than $20 million) to benchmark DB against DBB highway projects in 2006. The study was largely based on survey questionnaires and therefore was almost exclusively qualitative except for the 11 empirically paired project analyses. FHWA (2006) showed 3.8% more cost growth under DB than DBB projects (7.4% vs. 3.6%) and 9% less schedule growth relative to traditional DBB methods (-4.2% vs. 4.8%). These results were based on descriptive statistics only. The

FHWA study also reviewed project evaluation reports from SEP 14, noting that 1) the average of project duration between DBB and DB projects was substantially different (583 days for DB vs. 1,215 days for DBB) and 2) DB projects had less project cost per change order than DBB projects, based on 14 and 10 data points respectively.

The Florida Department of Transportation (FDOT) was one of the first DOTs in the nation to use ACMs in their transportation projects. FDOT started the first documented D-B contracting program in the United States in 1987 and its success encouraged other states to try this innovative contracting approach (Ellis et al. 1991; FHWA 1996). FDOT has conducted research evaluations to accurately and objectively measure the performance of their ACM techniques, most recently in 2007. The DB report by FDOT from 2007 synthesized data from 3130 FDOT construction projects (1160 using ACM's) from 1998 to 2006 to evaluate alternative contracting performance against traditional DBB for cost, time, contractor performance, and value contribution. The work type categories of the sampled projects were selected as: 1) buildings and non-road facilities; 2) Moveable Span Bridges; 3) High Level Bridges; 4) All other Bridges; 5) Resurfacing and Paving; 6) Reconstruction; 7) Technical Projects; 8) Other Projects. FDOT also obtained information on the evaluations of alternative contracting techniques from other DOT agencies. For the qualitative results of the evaluated projects, the award cost of DBB projects was 13.40% less than the official estimates, and the award cost for alternative contracting projects was 11.84% less than official estimates (DB awarded at 3.72% more than the FDOT official estimate). The findings showed alternative contracting projects had 8.04% average cost growth (DB: 4.45% cost growth) compared to 9.36% for DBB. Overall, the cost performance of traditional DBB to alternative contracting was very close: the actual cost of DBB projects were 5.23% less than official estimates and the actual cost of alternative contracting projects was 4.73% less (DB completed at 8.50% more than official estimates). However, the performance among alternative contracting was significantly different.

The differences observed in cost performance also occurred between project type categories. The cost growth on high-level bridge projects was 12.28% with alternative contracting compared to 15.71% for traditional DBB. All other bridge cases had cost growth at 5.73% vs 5.48% for alternative and traditional DBB contracting, respectively. In addition, the alternative contracting projects had superior cost growth performance with buildings, non-road facilities, and technical projects.

While average time growth for traditional DBB projects was 16.47%, the average growth for ACM projects was 4.13%. One significant difference noted in this study was that time growth during construction for alternative contracting was approximately 25% of the time growth of DBB projects. By work type category, all alternative contracting projects analyzed had superior time performance to traditional DBB: other bridges, buildings and non-roads, reconstruction, and technical projects had time-growth approximately 13% less than DBB projects in their categories. Analysis found the choice between ACM and traditional DBB had essentially no effect on contractor performance. In value contributions, ACM's excluding design-build saved 31,645 project days (38 days per project) and $289,600,000 ($347,000 per project). DB projects saved 54,455 days. 34 viable DBB and DB pairs by work-type and size were finalized for the value evaluation.

Statistically, two-sample t- tests showed there was no statistically significant difference in project mean cost (DB: $4,830,495; DBB: $4,684,128) or mean project duration (DB: 294 days; DBB: 284 days) between the DB and traditional DBB projects at the 0.05 level. However, the t-test for the DB and DBB sample did show a significant difference in project delivery duration at 0.05 level; the comparison showed a savings of 19,444 days for the 34 selected DB projects.

The analysis on 22 highway projects (6 DB and 16 DBB) by Shrestha et al. (2011) had DB at 1.5% more cost change for DB, ANOVA statistical tests showing a 0.751 p-value. The same study revealed a rarely observed 15.4% higher DB schedule growth over DBB highway projects (t-test gave a 0.17 p-value). These results contradicted the earlier findings from Shrestha et al. (2007).

The most current highway project comparison is from Minchin et al. (2013), which examined 60 projects between DB and traditional delivery (30 for each method) from the FDOT database. 21 DB and 29 DBB non-outlier projects were statistically analyzed and showed that DBB projects performed significantly better by cost, but not duration. The investigating team under Minchin (2013) used non-parametric tests to verify 24.9% more cost growth on DB (p-value = 0.209) and 2.8% less schedule growth in DBB (p-value = 0.229). It is interesting to note that these results move against many other studies reviewed in the literature. The author justifies the results by stating many analyzed highway projects were completed 15 years ago; at that time DB was still under development (Minchin et al. 2013).

The major transportation sector studies show, overall, higher cost growth trends in DB and lower in DBB, but better performance for DB in schedule growth and delivery time. However, some of the studies did not report statistically significant results or produced trends contradictory to the primary pattern on DB projects and DBB projects for cost performance.

2.4 Chapter Summary

This Chapter presents briefly the background of project delivery methods and their performance metrics. The history of DB program implementation shows that DB performed better to traditional DBB by some metrics, but not other metrics. Concurrently, DB reportedly exists in state DOT programs alongside DBB with no negative documented effects on agency engineer workforces nor substantial reduction to the design/quality control of public agencies. It should be noted that several performance investigations did not show significance in the performance metrics of DB on building or highway projects.

CHAPTER III – POINT OF DEPARTURE AND SCOPE OF STUDY

3.1 Introduction

Although the use of the DB method is steadily increasing in the highway sector, quantitative comparisons of project performance against the traditional DBB system are still limited. In order to extend the body of knowledge on alternative delivery, in particular DB, this thesis uses a comparative analysis to compare performance metric measurement between DB and DBB projects. Further, there is a fundamental need to form greater in-depth observation of highway project cost and schedule trends using a more robust set of empirical data. Chapter 3 identifies the scope of study as well as the main extensions of this thesis from the recent performance comparisons between the traditional project delivery (DBB) and the alternative delivery (DB) methods.

3.2 Point of Departure

This thesis starts from the fact that there is a lack of an empirical comparison of project performance between DBB and DB highway projects. The objective of this study was to investigate this knowledge gap. While previous performance studies on highway projects have compared DBB to DB by exclusively cost and schedule growth metrics, this study utilizes five separate metrics (three in addition to cost and schedule) to form a more comprehensive view of performance trends. Notably, the most recent comparisons have focused on a small sample size of projects for analysis – this thesis has comprised a precedent-setting number of projects and data points from six sampled DOTs, increasing the statistical reliability of the observed trends. The most important attribute to emphasize is that the data examination of the thesis is two-fold: (1) an overall analysis of project data from all six sampled DOTs and (2) a specific analysis breakdown of DBB and DB projects from the states to observe performance metric trends as a function of project size category. A breakdown of project data into a continuous set of bin-sizes has not been attempted in previous investigations.

3.3 Study Domain

The scope of this study is shaped by the data collected and was targeted exclusively toward the completed construction projects in the highway sector. Data was gathered directly from the project databases of the following six DOTs:

- Florida
- Indiana
- Ohio
- Oregon
- North Carolina
- Utah

DB and DBB were the only delivery methods included in the primary data analysis. Further, the sampled database projects were limited to the last 15 years.

3.4 Research Questions

To investigate the aforementioned research objectives, this study aimed at investigating the following research questions:

- How does project performance differ between DB and DBB projects?
- What project size has the greatest impact on a comparison of DBB and DB project performance?

3.5 Chapter Summary

This chapter provides an overview of the knowledge gap, the point of departure for this study, and the primary research questions. Chapter 4 continues with the description of the research methodology and performance metrics.

CHAPTER IV – RESEARCH METHODOLOGY

4.1 Introduction

This chapter discusses the research methodology for this study. The chapter introduces the research framework and explains the purpose of each step within the framework. It provides an explanation of the specifics of the research process and details of the research tasks. The content of this section describes the previous assessment of performance literature, the development of the performance metrics used in this study and a comprehensive definition of terms. The metric development section details how the performance parameters are used as the backbone of the research method.

4.2 Research Framework

Figure 4.1 gives an illustrative guide for the overall methodology employed in this research. This framework was developed at the Stanford Center for Integrated Facility Engineering, and is referred to as the CIFE horseshoe research process. The purpose of the horseshoe-format is to guide researchers through the process of technical investigation that uses a conceptual milestone for each step. The CIFE Research Framework has the following elements: Observed Problem, Intuition, Theoretical Point of Departure, Research Methods, Research Questions, Research Tasks, Validation of Results, Claimed Contributions, and Predicted Impacts.

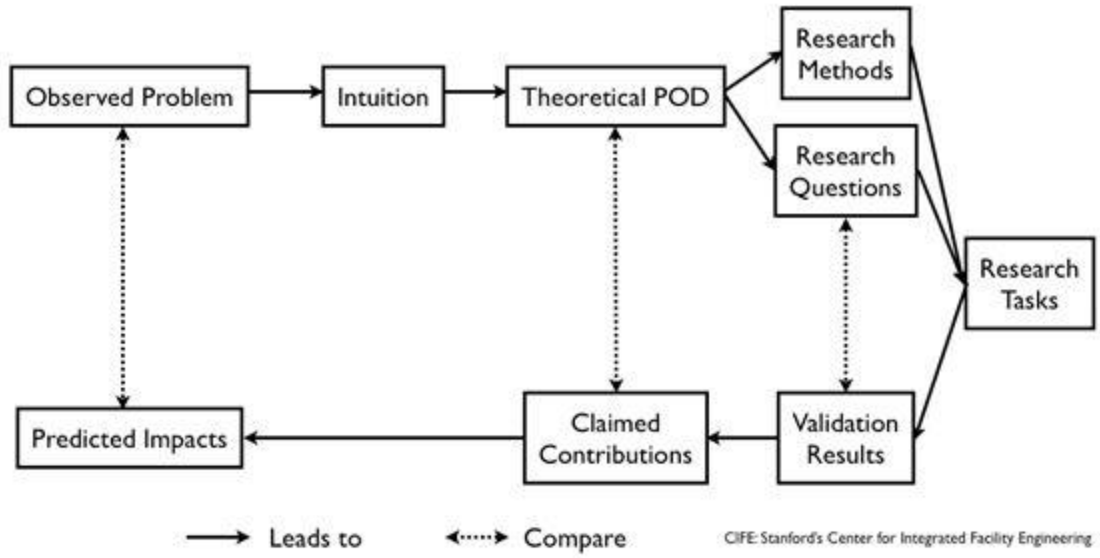


Figure 4.1: Stanford's CIFE Horseshoe Research Framework

Figure 4.2 graphically shows how the CIFE framework was applied to the research problem associated with this study. Each of the topics is discussed further in the proceeding sections.

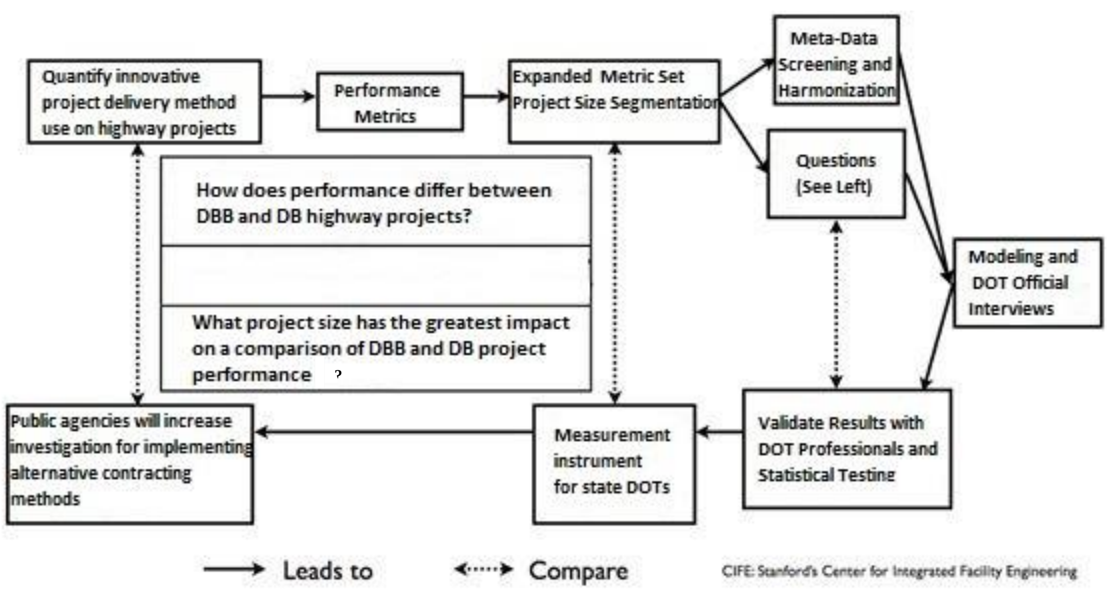


Figure 4.2: Stanford's CIFE Horseshoe Research Framework Applied

4.2.1 Observed Problem

The research was guided by the recent performance investigations on transportation summarized in Chapter 2. One specific factor driving this study was quantifying the cost and schedule effects of applying innovative contracting methods to highway construction projects. Through a comprehensive literature review, it is realized that there is a lack of an empirical comparison of project performance between DBB and DB highway projects.

4.2.2 Intuition

The challenge of confirming the advantage of the DB method over traditional DBB delivery on highway construction projects is determining how to measure cost and schedule performance activity on such work. Many assumptions must be made in comparing construction/design cost for DBB with construction/design cost for DB which cannot be accurately generalized in most cases- each state maintains its own system for determining design and agency components of cost and schedule. The approach used in this research study deals with measuring contract performance (examining construction cost/time for DBB and both design and construction cost/time for DB). The potential solution identified with this study is emulating the performance metric development from previous studies with a new data harmonization technique. This study compares and gathers numerical values from multiple states together when examining performance behavior to produce more reliable metric outputs.

4.2.3 Theoretical Point of Departure

The theoretical point of departure for this study is that there is sufficient empirical data to compare the project performance between DBB and DB delivery methods. On this basis, the author proposed using a comprehensive set of metrics as opposed to the traditional single pairing of cost and schedule, accounting for additional highway project contract variables. The additional metrics used in the group allow for a broadened high order view of the sample populations from each state. The research extensions were also guided by the data sets that were available for further study – the new expanse of sample population levels and size segmentation.

4.2.4 Research Methods

The methodology for this study encompasses four distinct steps: (1) assessment of the literature; (2) developing performance metrics; (3) collecting and mining project data; and (4) performing statistical analysis. Each research phase was dedicated to a specific part of forming the quantitative assessment of both delivery methods. Steps 3 and 4 are presented in detail in Chapter 5 of this thesis. The following sections briefly discuss Steps 1 and 2, research validation, and research contribution and impact.

Step 1: Literature Reviews

Step 1, conducting the literature review, is meant to lay the groundwork for the rest of the study. This phase consists of gaining a high order view on the current state of DB project performance, the knowledge on project delivery comparisons, and project performance metrics. All of these factors were summarized in Chapter 2. Based on the findings from the literature, key variables that need to be analyzed in order to answer the research questions were identified.

As shown in Chapter 2, the findings from the construction literature were summarized to focus on the effectiveness of the traditional DBB and alternative DB delivery system on different sets of highway projects. Unlike the qualities of the data collected for this study, the literature review was not restricted to a specific timeframe. This absence of a time emphasis allowed inclusion of all relevant publications to allow the background of this study to be as comprehensive as possible. Several databases were researched for journal articles, conference proceedings, published books, technical reports, as well as studies completed for national bodies. An extensive list of publications was reviewed, including American Society of Civil Engineering (ASCE) publications such as the *Journal of Construction Engineering and Management* and the *Journal of Management in Engineering*, the *Transportation Research Board (TRB)* and studies conducted by the *CII.*

The variables used in this study are separated into independent or control factors and output or dependent values. The key components that distinguish projects from one another were mainly identified in the literature review. The independent variables, most notably the project delivery system, are characteristics of interest in this thesis that will be tested to determine their effect on the performance metrics. Conversely, the independent variables are components that affect performance but are mainly unwieldy items such as project size, type and even complexity.

Quantitative project performance metrics are dependent variables measured after project completion. The initial list of performance metrics used for this study was based on the factors measured in previous studies, and was later complemented with additional factors to gauge project success.

Step 2: Performance Metric Development

The measurement of construction project performance is an important factor in the project management process. The construction industry has historically used, for its fundamental parameters, measures of change from the original contract's cost and time. These values are usually represented as either a positive or negative percentage of original contract requirements (Gransberg et al. 2003). Clearly the need for performance evaluation for highway projects exists to more systematically and comprehensively reveal if the current implementation of DB as an alternative delivery method has produced improvement over traditional DBB (FDOT 2007). Previous comparative studies, including those discussed in the construction literature review section, included several performance metrics in their analyses. After reviewing the previous studies, it is clear that many of them focus heavily on schedule and cost performance metrics, while largely disregarding any additional metrics. The performance areas identified for this study focused on the following main project concerns: (1) cost; (2) schedule; (3) engineering estimate; (4) construction engineering and inspection (CEI). Each of these performance areas included a specific metric, and was grouped depending on the type of data collected from the six sampled DOTs. The associated metrics are defined as percent change formulas that show the percent change (or growth) value of a certain project characteristic throughout the course of the project. While each project characteristic was designated with at least one metric, the collected data facilitated two metrics for schedule. The metrics were applied iteratively to each listed project in all six state DOT data files to produce a collection of output values. Each metric term will be described in the next section.

4.3.1 Contract Cost Growth

Contract Cost Growth is the percent change from the awarded amount to the successful bidder to the final cost to deliver the project. For DBB, this value is for construction costs only. For DB, this value is inclusive of construction and design costs by the design-builder.

$$\text{Contract Cost Growth } \% = \frac{\text{Final Contract Cost} - \text{Awarded Contract Amount}}{\text{Awarded Contract Amount}} \, x \, 100 \qquad \textbf{(EQ. 1)}$$

The Final Contract Cost is the total cost of installation of all project components after changes and miscellaneous expenses accrued. Contract cost was not expected to include construction engineering inspection (CEI), right-of-way (ROW), or other costs unless part of the original bid.

The Awarded Contract Amount is the amount stipulated by the successful bidding contractor as required to perform the project scope.

4.3.2 Construction Schedule Growth

The collected data revealed that the six DOTs databases recorded project schedule by two primary date milestones: the date of project notice-to-proceed (NTP) issuance and the date of project construction commencement or construction start (CS).

Construction Schedule Growth (NTP) is the percent change from the estimated construction duration of the project to the actual construction duration of the project using the documented date that construction is allowed to commence. This metric is determined based on Equation 2.

$$\text{Const. Schedule Growth (NTP) } \% = \frac{\text{Final Project Duration} - \text{Estimated Contract Duration}}{\text{Estimated Contract Duration}} \; x \; 100$$

(EQ. 2)

The Final Project Duration is measured as the period (in days) from the date notice-to-proceed is received to the date of substantial completion of the work. Final duration takes into account any and all extensions from the estimated project duration. This measurement is determined based on Equation 3.

$$\text{Final Project Duration} = \text{Substantial Completion Date} - \text{Notice To Proceed Date} \qquad \textbf{(EQ. 3)}$$

The Estimated Contract Duration is the period estimated by the public agency required for the completion of the project scope of work. This duration accounts for schedule dates given in the agency request for proposal (RFP). This measurement is determined based on Equation 4.

$$\text{Estimated Contract Duration} = \text{Bid Contract End Date} - \text{Notice To Proceed Date} \qquad \textbf{(EQ. 4)}$$

Construction Schedule Growth (CS) is the percent change from the awarded contract duration of the project to the actual construction duration of the project using the documented date that construction work actually began. For DBB, this value is for construction only. For DB, this value is inclusive of construction and design performed by the design-builder. This metric is determined based on Equation 5.

$$\text{Const. Schedule Growth (CS) \%} = \frac{\text{Final Construction Duration} - \text{Estimated Contruction Duration}}{\text{Estimated Construction Duration}} \; x\,100 \quad \textbf{(EQ. 5)}$$

The Final Construction Duration is measured as the period (in days) from the date that construction work began to the date of substantial completion of the work. Final duration takes into account any and all extensions from the estimated project duration. This measurement is determined based on Equation 6.

$$\text{Final Construction Duration} = \text{Substantial Completion Date} - \text{Construction Start Date} \quad \textbf{(EQ. 6)}$$

The Estimated Construction Duration is taken as the period bid by the contractor or design-builder as necessary to execute and complete the physical building activities for the entire project. This measurement is determined based on Equation 7.

$$\text{Estimated Construction Duration} = \text{Bid Contract End Date} - \text{Construction Start Date} \quad \textbf{(EQ. 7)}$$

4.3.3 Award Growth

In addition to cost and schedule performance measurement, this study also examines the percent change between the initial project engineering estimate for the project cost and the amount awarded to the successful bidding contractor. Project award growth is used to determine a trend of accuracy for internal public agency estimates on highway projects.

Project Award Growth measures the difference between the awarded amount for the project contract and the appraised cost by the engineer of record. This measurement is determined by Equation 8.

$$\text{Project Award Growth} = \frac{\text{Awarded Contract Amount} - \text{Engineering Estimate}}{\text{Engineering Estimate}} \qquad \textbf{(EQ. 8)}$$

4.3.4 CEI Factor

The fifth formulated performance metric indicates the level of expense on construction engineering services between traditional DBB delivery or and DB highway projects. CEI Percent Cost Factor shows the relative percent of cost spent on CEI services. This measurement is determined based on Equation 9.

$$\text{CEI Percent Cost Factor} = \frac{\text{Construction Engineering Inspection Cost}}{\text{Awarded Contract Amount}} \qquad \textbf{(EQ. 9)}$$

Construction Engineering and Inspection Cost is the dollar amount designated for construction engineering expenses such as quality control, specification checks, and performance standards.

The final cost and contract awarded amount in Equations [1], [8] and [9] were easily determined from the databases. The final and estimated durations in Equations [3] and [4] were calculated based on design and construction duration, design-builder procurement time for DB projects, and constructor procurement time and designer procurement time for DBB projects.

4.4 Project Data Overview

The DOT project data mined for this thesis was taken directly from the historical project database of each state agency and was not altered by other intermediate parties. The data is used as a continuous set to produce a set of percentage and graphical trend relationships. The resultant performance metric percentages were relative and did not require inflation adjustment or other corrections. The goal of direct database mining was to keep the project information exclusively numerical and objective in nature. Further, this data was selected from six state DOT databases to create a representative portion of DB and DBB highway projects from the leading states in alternative delivery that was not restricted to one geographical region or work type.

4.5 Use of Data for Performance Measurement

As will be discussed in more detail in Chapter 5, the performance metric values were calculated from the data point values per project directly from the DOT database files. After extensive cleaning of the data for extreme outliers, descriptive analyses (i.e. histogram, boxplot, frequency tables), and harmonization, an aggregate average was taken for all the projects in a given set. The first phase included an aggregate average for the range of DBB and DB projects which were matched in one-to-one pairs. The second phase used an aggregate average for all DBB and DB projects classified in each project size category. The objective is to determine if this given set of metrics can determine systematic differences between the two project delivery methods in a form that would assist the public agency in making the project delivery decision for future projects (Gransberg et al. 2003).

4.6 Validation of Results

In order to validate the results of the research, interviews were conducted with the professionals who were involved with the data preparation and submission. The DOT contacts were chosen because of their familiarity with the project data, the knowledge of the state's specific record keeping practices, and their expertise in the field. This process was designed to verify that the research had included reasonable inputs to the metric formulas and to confirm the proper use of data points in the metric numerical manipulations. In addition, the author organized an intermittent joint conference with all six selected DOT officials presenting a tested application of the performance metrics. Numerical test results were given to the validating contacts to confirm if the data had been properly used and the results reasonable.

The specific questions used to address each of these necessary validations were:

- Do the performance metrics account for all of the input's data points you would use in analyzing a specific contract value?
- What insights do the metrics provide about delivery methods that can influence project phases?
- How would the use of these results change the way you manage project factors that control cost, schedule, etc.?
- How does this approach vary from your current approach in analyzing delivery method efficiency?

The validation process was fundamentally necessary to ensure that the application of metric formulas was accurate and comprehensive for the questions posed. The interviews also established that the metric outputs were useful in addressing the research questions. Finally, the process was used to provide additional interpretation that the results could be utilized in practice where they are currently not being utilized.

4.7 Claimed Contributions

This study contributes to the construction engineering body of knowledge by investigating the performance associated with different delivery systems and contract size. The selected criterion will indicate what and where certain classes of projects may excel with DB use rather than traditional DBB. This study is meant to produce a set of statistically significant relationships between project cost/schedule changes for DB compared against DBB in highway construction. These relationships will help to form a verifiable conclusion about the cost/schedule impacts of DB and DBB approaches currently in place in transportation agencies. The research will inherently provide an additional selection tool for DOT officials to map specific future highway projects to the appropriate delivery method.

4.8 Predicted Impacts

The potential impact of this study provides a basis for researchers and practitioners to further understand project performance associated with different innovative contracting methods. Applying the results of this study will spur more large-scale analysis of projects in the transportation sector on an intra-state basis, possibly with continued data-mining from DOT record systems or other sources. The size segmentation portion of the study will also encourage the investigation of the impact of DB use on a regional basis. The author asserts that the study will create a precedent for analysis based on other specific classification criteria, such as project work type. The findings from this study also allow researchers and practitioners to evaluate and compare project performance under different innovative techniques such as PPP or ID/IQ projects.

4.9 Chapter Summary

Chapter 4 outlined the four-step research method for this study. The section discussed the selection of performance metrics by the critical performance study review, and the process behind their development. Next, the metric equations and the associated terms were defined. The overview of project data, research validation, and research contributions are briefly presented. This chapter concludes by describing the potential impact of the study.

CHAPTER V – DATA COLLECTION AND ANALYSIS

5.1 Introduction

This chapter presents the process of collecting, screening, and analyzing the data. The data used for this study was collected from six state DOTs. First, this chapter briefly discusses the data collection process. Then, the chapter explains the analysis methods used to generate and test the performance metric trends of the project data. Next, all branches of the data collection procedure from collection to cleaning/interpretation to the unique harmonization method are reviewed. After the cleaning process, the data manipulation was performed to obtain comparable pairs of DB and DBB data samples for further analysis. The first analysis section reviews the performance values in the overall level, while the following section discusses the performance analysis by project size classification. This chapter then includes the rigorous statistical analyses to compare the performance metrics between DBB and DB projects.

5.2 Analysis Methods

The methods of analysis for this investigation were two-fold: descriptive and statistical. The descriptive analyses included outlier removal and numerical comparisons of contract cost average and schedule date average for the DBB and DB projects. After the descriptive analyses were conducted to create a final comparable pool of DBB and DB project pairs, the statistical tests were used to show central tendency measures and mean dispersion. Primarily, parametric tests (F-test / T-test / ANOVA) and non-parametric tests (Mann – Whitney U) were conducted for this data.

5.3 Project Data Collection

5.3.1 Data Request Process

Based on a comprehensive literature review and personal contacts the study team requested data from the following states that reported having completed more than 50 DB projects.

- Pennsylvania
- Florida
- North Carolina
- Ohio
- Utah
- Indiana
- Oregon

The six state DOTs were selected because they have completed more than 50 DB projects. Some also have experience with a smaller set of CM/GC projects. The author successfully obtained data on DB and DBB projects from all of these states except Pennsylvania. Each selected state was contacted initially by phone and email with a request to provide completed projects from within the last 10-15 years. We requested these data from the agency in a specific format, which included the following:

1. Project Name/Number
2. Project Delivery Methods (DBB, DB, and CM/GC)
3. Project Cost

- Engineer’s Estimate
- Contract Award Amount
- Final Cost
- Construction Engineering and Inspection Cost
- Final Design Cost

4. Project Duration

- Date Advertised
- Award Date
- Construction Start Date (Notice to Proceed)
- Bid Contract End Date
- Final Contract End Date (Substantial Completion)

5. Change/Extra Work Data

- Number of Change/Extra Work Orders
- Change Order Amounts

Due to the amount of data and level of detail being requested, as well as the volunteer nature of the response, data collection began in February of 2014 and was not completed until November 2014. Each DOT contact returned a project file composed from their database with as many data points as readily available within the requested timeframe. Table 5.1 summarizes the data collection and status.

Table 5.1: Data Collection Status

Agency	Position/Office	Status
Florida DOT	State Construction Systems Engineer	Received ~5000 projects
Indiana DOT	Construction Cost Manager / Division of Contract Administration	Received ~2,700 projects
North Carolina DOT	State Estimating Engineer	Received ~70 projects
Ohio DOT	Analyst, Office of Estimating	Received ~7,300 projects
Oregon DOT	Manager / Office of Planning and Letting	Received ~1,700 Projects
Utah DOT	Project Development Business Systems Team Manager	Received ~1,100 projects

Cost and schedule data points related to project design (i.e. external consultant design costs, design milestone dates) were not available or accurate in the majority of the sampled DOT databases and thus were not reported. Table 5.2 describes the project identification information provided from each DOT. Tables 5.3 and 5.4 detail the cost and schedule data points respectively returned from each of the six state DOTs.

Table 5.2: Project Identifiers

State DOT	Contract ID	Contract Type	Delivery Method	Project Title	Project Description	Project Work Type
Florida DOT	X	X	X	X	X	X
Indiana DOT	X	X	X	X	X	X
Ohio DOT	X	X	X	X	X	NA
Oregon DOT	X	X	X	X	X	X
North Carolina DOT	X	X	X	X	X	NA
Utah DOT	X	X	X	X	X	X

Table 5.3: Available Project Cost Data

	Project Size Grouping	Contract Bid Amount	Final Cost	CEI Amount	Change Order Amount	Engineer's Estimate
Florida DOT	X	X	X	NA	X	X
Indiana DOT	X	X	X	X	X	X
Ohio DOT	X	X	X	X	X	X
Oregon DOT	X	X	X	X	X	X
North Carolina DOT	X	X	X	X	X	X
Utah DOT	X	X	X	X	X	X

X – Data point directly available or calculated
NA – Data point not available

For cost data points, all six DOTs reported a value for 1) project size category; 2) contract bid amount; 3) project final cost; 4) change order amount; and 5) project engineering estimate. For the requested cost data point of construction engineering inspection (CEI) cost, all selected state DOTs except for Florida confirmed an equivalent value to report from their records.

Table 5.4: Available Project Schedule Data

	Original Bid Days	Bid Contract Start Date	Construction Start Date (Work Beginning Date)	Bid Contract End Date (Estimated Completion Date)	Date of Ad.	Date of Contract Letting	Date of Contract Award	Notice to Proceed Issued	Substantial Work Complete Date	Date of Final Acc.
Florida DOT	X	X	X	X	X	X	X	X	X	X
Indiana DOT	X	X	NA	X	NA	NA	X	X	X	X
Ohio DOT	X	X	X	X	X	X	X	X	X	NA
Oregon DOT	X	X	X	X	X	NA	X	X	X	NA
North Carolina DOT	X	X	X	X	X	X	X	NA	X	NA
Utah DOT	X	X	X	X	X	X	X	X	X	X

X – Data point initially available
NA – Data point not available

In the corresponding summary transcript of schedule data points, Florida and Utah DOTs reported all data points previously listed as readily available. Indiana DOT did not have construction start date, date of advertisement, or date of contract letting in their database. The Ohio DOT had all data points except for date of final acceptance on record. Oregon DOT database reported all data points except date of contract letting and date of final acceptance. Date of final acceptance and date of notice-to-proceed were the only schedule data points not available from North Carolina DOT. In total, the study received more than 17,500 projects. However, upon initial data collection, the fields relating to cost and schedule were somewhat inconsistent across the six state DOTs due to the attributes of each state DOT's contract record system. This inconsistency presented a significant obstacle to analyze and compare project performance. To overcome this challenge, the author systematically analyzed and mined a comparable data field from each state's project database. Each state was individually contacted to ensure that the values in the database were understood. Additionally, the author participated an on-line meeting with all the states to review the data and preliminary results. The following sections discuss the data cleaning and harmonization processes in detail.

5.3.2 Data Cleaning and Interpretation

Since each DOT maintains their data in a slightly different format, the study needed to confirm a precise definition for each field in the data provided. This step conceptualized what each field should include and exclude for showing contract cost growth, schedule growth, etc. For cost fields, the author asserted that "final contract cost" includes pay items per bid, overruns/underruns, supplemental agreements, liquidated damages (L/D's) and incentives/disincentives. Contract cost was not expected to include construction engineering inspection (CEI), right-of-way (ROW), or other costs unless part of the original bid. Contract cost growth takes into account the construction costs for DBB projects while considering design and construction costs for DB projects. Similarly, the investigator composed definitions for the schedule data points ("actual" vs. "bid" construction start, "substantially complete", and "final" vs. "bid" contract start and end dates). For example, when combining the data from different states, the date for *contract award* must not be confused with the date for *notice to proceed*.

After putting the data into one common format, the author had to set each field title as it appeared in the reported data equivalent to the most likely data point term requested. The ambiguous data fields were isolated in the original data file to bring forward for interpretation confirmation later on in one-on-one phone discussions with each DOT contact. Appendix A provides the results of data clarification in detail. It should be noted that any and all data metric equation terms with an equivalent data column not provided were also identified. In the proceeding step, the author transformed the terms with unclear information into a summary list of data clarification questions by-state to send to each state official. During the intervening period waiting for responses from the DOT contacts, the study refined one set of metrics equations for all the DOTs and then created a key equating their column headings to the terms in the metric formulas. The author used this formula term key in the conference and follow up phone calls to confirm that the data field assumed for each term in the performance metric equations for each state was accurate. The final output of the data interpretation process was a finalized set of clarifications for each DOT official to adjust and return missing data fields. Appendix B provides a result of the one-on-one data clarification and verification with each DOT. It is noted that in the supplemental phase of data collection, all six DOT contacts returned revised project files with all missing data points required to complete the performance metrics calculations.

5.3.3 Data Harmonization

To facilitate data harmonization, the study provided for a joint conference call with all six DOT contacts. The goal was to show preliminary results of the performance metrics for the full project population sizes reported for each delivery method, using the returned data points. The participants were shown the purpose of data collection and analysis to compare project performance. The author also established the overall differences between the DOTs in the qualitative nature of their DBB and DB projects – for example, DB projects being low-bid or best value; scheduling projects by a period of days vs. a set of dates; etc. The final part of the conference involved discussing the initial trends for cost and schedule performance. At the conclusion of the conference call the interpretation of each state's project data was confirmed. In step 3, the author conducted follow-up phone interviews to each DOT contact individually. The one-on-one discussion assisted in understanding each state's own definition of all data points returned. The performance metric definitions were additionally shown to the DOT officials, intent on using their perspectives for the best fields to reach the desired metric performance value. The most common differences between states were the figures included/excluded in the "Final Contract Cost" value as well as the meaning of "Notice-to-Proceed", "Bid Contract Start", and "Substantially Complete" dates for construction. The researchers used the data file review with the DOT contacts to map with and adjust the prepared metric formulas accordingly.

5.4 Population Matching for Overall Project Performance Comparison

A primary challenge in the data analysis dealt with selecting a comparable sample of DBB and DB highway projects. Statistically, the study needed to compare two samples with similar attributes. For example, to compare project performance between DBB and DB delivery methods, the ideal scenario dictates obtaining two samples with control variables that might include project type, locations, size, time, cost and other characteristics. However, the data available to the investigators did not allow for controlling for all of these variables. However, the data did allow control, or normalization of, the sample for both project cost and start date. These control variables will create a first-of-a-kind analysis for delivery methods in the highway sector.

After receiving the harmonized data sets, the author identified all projects with missing data points in any of the cost or schedule fields needed for the defined performance metrics. Any project with a missing value in relevance to cost or schedule was ruled as an incomplete project case and the entire project was eliminated from further analysis. We created clean versions of each project file for analysis, omitting these incomplete cases for every instance. Table 5.5 shows initial reported data from all six state DOTs. Table 5.6 shows the results of missing project case removal.

Table 5.5: Summary of Initial Project Data

State DOT	Total projects	# of DBB projects	# of DB projects	# of CM/GC projects
Indiana	2762	2728	34	0
Oregon	543	528	15	0
Utah	1167	1074	36	57
Ohio	7315	6844	77	0
North Carolina	74	41	33	0
Florida	5000	4592	408	0

An average of 20-30 % of projects were removed in five state DOT files for DBB. 15-20% of projects were removed in two state DOT files for DB.

Table 5.6: Summary of Projects without Missing Data Points

State DOT	Total projects	# of DBB projects	# of DB projects	# of CM/GC projects
Indiana	2377	2350	27	0
Oregon	335	325	10	0
Utah	941	874	29	38
Ohio	6906	6829	77	0
North Carolina	74	41	33	0
Florida	4181	3811	370	0

To obtain a comparable sample of DBB and DB projects, the study used a number of descriptive analyses (i.e., histogram, box plots, and frequency tables) to identify outliers and determine an appropriate bin size. Because the total number of DB projects is significantly smaller than DBB projects, the author randomly selected DBB projects from the sample based on the characteristics of the DB projects. Four rounds of manipulation were conducted: Round 1 – missing data point removal; Round 2 – outlier removal; Round 3 – project down sampling by outlier removal method; Round 4 – project down sampling by bin-sampling method. The missing data point removal in Round 1 involved deleting project cases with incomplete cost or schedule data point information. The missing data that were deleted minimized any risk of mathematically skewing the aggregate percent averages calculated for each metric in the final project sample pools. The author focused on the projects with extreme percentage values resulting from the performance metric equations in Round 2. This outlier removal followed Round 1, and any metric growth percentages above +150% and below -150% for cost, schedule, award, or CEI factor were designated by the author as extreme outliers that would additionally skew the aggregate average results and thus also removed. Within Round 3, also referred to as Trial 1 of population matching, the author paired DBB and DB projects using similar bid amount ranges. The author disregarded extremely large bid amounts from DBB or DB in Round 3. The author revised the project matching method in Round 4 by using a bin-sampling method. Round 4 of manipulation repeated the matching of the DBB and DB sample pools using a one-to-one pairing criterion of bid amount and year of project construction start.

5.4.1 Trial 1

The first attempt at data matching used a descriptive statistical approach to clean outlier projects from the DB and DBB populations. The author considered contract award amount as the measurement to map comparable projects. For example, FDOT projects less than $1 million in contract award amount were removed for both DB and then DBB populations. Outlier removal continued after calculating averages for all 5 metrics in all six state DOT project sample groups. Emphasis was given to cost growth and schedule growth #1 and schedule growth #2. In round 3 of data manipulation, population down-sampling, the number of remaining DB projects was used as the controlling factor to match to an equal number of randomly sampled DBB projects. It is noted that since only Utah DOT provided CM/GC project data, this study does not consider CM/GC data for the further analysis. Table 5.7 summarizes the comparable pairs of DBB and DB projects from the Trial 1.

Table 5.7: Comparable Pairs of DBB and DB Projects – Trial 1

State DOT	# of DBB projects	# of DB projects
Indiana	27	27
Oregon	8	8
Utah	23	23
Ohio	44	44
North Carolina	10	10
Florida	182	182

The author initially executed a project mean comparison for DBB and DB project down-sampled populations within each state. The mean contract award amount and mean date of construction commencement were calculated for each state's DBB and DB project group. The goal of this step was to select a comparable pair of DBB and DBB projects. Table 5.8 shows the typical descriptive statistical results (i.e., mean, range, min and max) for construction cost and schedule based on the construction start date across six DOTs.

TABLE 5.8: Mean Comparison of DOT Projects – Trial 1

DOT	DBB Mean Cost	DBB Mean Schedule Commence	DB Mean Cost	DB Mean Schedule Commence	DBB Range	DB Range
FLORIDA n_{DBB} = 182 n_{DB} = 182	$6,180,595	9/22/2007	$13,655,944	9/12/2007	MIN = $1,066,630 MAX = $70,745,007	MIN = $1,010,842 MAX = $196,268,800
INDIANA n_{DBB} = 27 n_{DB} = 27	$2,284,956	8/25/2007	$5,019,474	8/30/2009	MIN = $89,628 MAX = $19,293,875	MIN = $326,688 MAX = $58,527,877
OHIO n_{DBB} = 44 n_{DB} = 44	$6,716,452	11/15/2008	$3,745,613	4/2/2009	MIN = $535,045 MAX = $91,314,514	MIN = $523,825 MAX = $23,444,848
OREGON n_{DBB} = 8 n_{DB} = 8	$5,442,861	6/27/2010	$45,098,429	1/24/2007	MIN = $319,130 MAX = $11,421,019	MIN = $619,000 MAX = $129,900,000
NORTH CAROLINA n_{DBB} = 10 n_{DB} = 10	$26,028,961	12/1/2007	$52,071,558	5/14/2005	MIN = $633,137 MAX = $116,470,217	MIN = $4,037,624 MAX = $192,040,143
UTAH n_{DBB} = 23 n_{DB} = 23	$2,230,922	9/14/2010	$81,000,336	8/13/2009	MIN = $538,595 MAX = $91,314,514	MIN = $339,283 MAX = $1,098,426,245

One can observe from Table 5.8 that there is still a wide range in terms of mean cost between the two samples across these six DOTs. For example, the mean cost of DB projects in FDOT is more than double the mean cost of DBB projects. To mitigate this large difference and obtain a comparable pair, we conducted the Trial 2 data sampling.

5.4.2 Trial 2

To obtain the most similar projects with regard to the project size and construction start date, the author used an alternative bin-sampling method to match DBB with DB projects. In this process, projects from the DB population were categorized by contract award amount and construction start date, emulating a project mean comparison. Comparable projects were targeted within approximately +/- 15% of contract award cost and +/- one years of construction commencement date. Next comparable DBB projects were randomly sampled on a one-by-one basis from the entire DBB highway project pool using the mentioned cost and time criteria.

As shown in Table 5.6, after removing missing data points, approximately 15,000 projects were obtained. It is noted that these projects vary greatly in terms of cost and start date. Table 5.9 summarizes the contract award amount of these 15,000 projects in six state DOTs. Table 5.10 indicates the project schedule based on the construction start-working dates associated with DBB and DB projects. The range of cost and time of these 15,000 projects vary greatly. It should also be noted that the DB values include cost and time for design, but the DBB values do not include any cost or time for design.

Table 5.9: Summary of Contract Awarded Amount Data

State DOT	DBB Contract Amt.		DB Contract Amt.	
	Min ($)	Max ($)	Min ($)	Max ($)
Indiana	$7,400	$45,922,865	$133,305	$58,527,877
Oregon	$621,121	$52,052,648	$619,000	$129,900,000
Utah	$15,980	$99,681,923	$147,998	$1,098,426,245
Ohio	$9,650	$219,996,000	$95,000	$23,444,848
North Carolina	$553,500	$116,470,112	$2,462,594	$192,040,143
Florida	$4,000	$149,898,506	$24,447	$430,487,941

Table 5.10: Summary of Initial Construction Schedule Data

State DOT	DBB Construction Schedule		DB Construction Schedule	
	Min (date)	Max (date)	Min (date)	Max (date)
Indiana	1/28/2007	2/28/2014	4/16/2008	9/22/2010
Oregon	4/7/2004	3/18/2014	6/3/2002	9/7/2011
Utah	6/3/2004	6/2/2014	3/15/2005	3/5/2014
Ohio	2/25/2002	4/9/2014	11/18/2002	7/8/2013
North Carolina	12/31/2001	5/27/2013	12/3/2001	5/31/2011
Florida	4/14/1995	4/9/2014	8/17/2000	7/26/2013

Table 5.11 presents a result of the revised comparable pairs of D-B-B and D-B projects in terms of project cost and schedule criteria.

Table 5.11: Comparable Pairs of DBB and DB Projects – Trial 2

State DOT	# of DBB projects	# of DB projects
Indiana	20	20
Oregon	7	7
Utah	21	21
Ohio	44	44
North Carolina	10	10
Florida	141	141

Table 5.12 summarizes in detail mean cost, cost range, mean schedule, and schedule range for these revised two samples: DBB and DB projects. One can observe form Table 5.12 that the mean cost these two samples is less than 10%, and the mean schedule of these two samples is less than a year. As a result, it is reasonable to conclude that the two samples are suitable for further analysis. The results of statistical analysis are presented in Chapter 6.

Table 5.12: Descriptive Results of Cost and Schedule for DBB and DB Projects

State DOT	DBB				DB			
	Mean Cost	Cost Range	Mean Schedule	Schedule Range	Mean Cost	Cost Range	Mean Schedule	Schedule Range
Indiana ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =20)	$5,173,875	min= $142,644 max = $45,922,865	5/6/2009	min=8/8/2007 max = 7/12/2011	$6,075,144	min= $133,305 max = $58,527,877	8/19/2009	min= 4/16/2008 max = 9/22/2010
Oregon ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =7)	$28,759,004	min= $539,370 max = $52,052,648	1/26/2009	min=11/23/2005 max = 5/11/2011	$30,009,491	min= $619,000 max = $45,900,000	5/14/2007	min= 3/26/2004 max = 8/2/2011
Utah ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =21)	$25,271,540	min= $356,417 max = $96,336,372	2/17/2009	min=12/6/2004 max = 8/9/2013	$30,969,452	min= $331,656 max = $172,100,000	8/17/2009	min= 9/10/2006 max = 3/1/2013
Ohio ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =44)	$3,653,304	min= $537,048 max = $19,855,219	9/22/2008	min= 6/4/2002 max = 8/12/2013	$4,081,816	min= $523,825 max = $23,444,848	10/30/2008	min= 11/18/2002 max = 5/28/2013
North Carolina ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =10)	$48,803,894	min= $3,765,430 max = $116,470,217	7/6/2006	min=10/28/2002 max = 4/2/2012	$52,071,558	min= $4,037,624 max = $192,040,143	5/14/2005	min= 10/6/2003 max = 9/2/2008
Florida ($n_{D\text{-}B} = n_{D\text{-}B\text{-}B}$ =141)	$9,850,327	min= $1,078,899 max = $149,898,506	10/13/2007	min= 10/11/1998 max = 9/5/2013	$9,827,449	min= $1,110,942 max = $148,661,735	8/18/2007	min= 9/5/2000 max = 7/26/2013

5.5 Population Matching for Performance Comparison based on Project Size

The project size analysis of this study contains several applications to the performance study of DBB and DB highway projects. In the first application, the size segmentation of this data provides an introductory exploration into which scale of highway project experiences the most cost or schedule change. Along with this concept, size analysis can indicate if certain project scope levels cause the cost or schedule growth trends to fluctuate from a primary direction or tendency. The first application will aid DOT officials assessing project efficiency to select which project costs or realms of project schedule are the causation of change from the initial contract requirements. On a more direct level, the segmentation of project data by contract size becomes an independent verification of the comprehensive metric trend analysis conducted in Section 5.4 of this study.

5.5.1 Metric Outputs by Size Class

For the size category analyses, this study focused on the full range of DBB and DB projects reported from the each state DOT. While the project pairings for the overall analysis described in Section 5.4 were based on specific cost and schedule criteria, the size class tests accounted for all applicable projects under each size bin. This method allowed the author to increase the viable number of DB projects to be used in comparison with DBB under each level.

To compare the project performance delivered under DBB and DB delivery methods, the author divided these 10,327 DBB and 452 DB projects into six levels in terms of project size. These six levels include the projects with the contract award amount ranging from under $2 million to over $50 million. Table 5.13 and 5.14 summarize these six levels along with the sample size (n) associated with DBB and DB projects. The intent of this classification was to ensure that the results from the project performance comparison are based on similar sizes and substantial for statistical analysis.

Table 5.13: Classification of DB Projects by Contract Size Level

	N_{DB}	N_{DB}	N_{DB}	N_{DB}	N_{DB}	N_{DB}
DOT	Under $2M	$2M-$5M	$5M-$10M	$10M-$20M	$20M-$50M	Over $50M
Florida	174	61	32	20	26	10
Ohio	41	8	9	3	2	0
Utah	6	5	5	3	3	6
Oregon	1	0	0	0	6	3
North Carolina	0	1	2	0	4	3
Indiana	14	1	1	1	1	0
Σ_{DB}	**236**	**76**	**49**	**27**	**42**	**22**

Table 5.14: Classification of DBB Projects by Contract Size Level

	N_{DBB}	N_{DBB}	N_{DBB}	N_{DBB}	N_{DBB}	N_{DBB}
DOT	Under $2M	$2M-$5M	$5M-$10M	$10M-$20M	$20M-$50M	Over $50M
Florida	2338	738	221	91	44	14
Ohio	5066	634	175	77	54	24
Utah	426	101	37	22	4	4
Oregon	145	49	20	14	2	1
North Carolina	0	1	2	0	3	2
Indiana	14	1	1	1	1	0
Σ_{DBB}	**7989**	**1524**	**456**	**205**	**108**	**45**

Table 5.14 shows that the sample size of DBB projects is much larger than that of DB projects. To satisfy a random assumption of statistical analysis presented below, the authors randomly selected DBB projects based on the number of DB project available associated with each level. For example, in level 1 (project size less than $2 million), the author randomly selected 236 DBB projects from a research sample of 7989 projects.

5.6 Statistical Analyses

Based on the cleaned data, the author tested all assumptions required for comparing the mean values between two DB and DBB project samples. . The null hypothesis for these tests is that the means of the DB and DBB samples were equal ($\mu_{D\text{-}B\text{-}B} = \mu_{D\text{-}B}$).To do so, we checked the normality assumption of the refined data. The author used Anderson-Darling test statistic for a sample size less than 25 and skewness and kurtosis indices for a sample size larger 25. If the p-value for these tests was less than 0.05 (95% confidence), it was concluded that the sample is not normally distributed. If the p-value for these tests was larger than 0.05, it was concluded that the sample is normally distributed.

Second, for those samples that were normally distributed, the author used the F-test statistic to test the variances between two DB and DBB project samples. Similarly, if the p-value for these tests was less than 0.05 (95% confidence), it was concluded that the variances of these two samples were not equal. If the p-value for these tests was larger than 0.05, it was concluded that the variances of these two samples were equal at 95% confidence.

Finally, the author conducted either a t-test statistic or a nonparametric test statistic to test the mean of two DB and DBB project samples. If the two project samples are normally distributed and equal variance, a t-test was conducted. Otherwise, a Mann-Whitney U test, a nonparametric test, was conducted.

5.7 Chapter Summary

This chapter discussed the analysis methods used to evaluate the formulated performance metrics. First the full project data collection process described the way the data points were mined, interpreted, and interrelated from the six sampled DOTs. The section continued with the iterative descriptive analysis performed to create comparable sample populations between DBB and DB in the overall and size level stages. Next the performance results were shown for both analysis stages. Finally the statistical analysis process detailed which tests were used to validate the metric results found. The next chapter discusses the main findings of the performance trends.

CHAPTER VI – FINDINGS

6.1 Introduction

This chapter presents the analysis results of the DBB and DB project data. The performance trends for all the exploratory metrics are summarized associated with the individual state data, combined data, and project size data. The significant relationships that can be drawn between DBB and DB from the trend behavior, particularly in terms of cost and schedule growth, are also discussed.

6.2 Individual State Results

Table 6.1 shows the results of contract cost growth between the DBB and DB projects in each of the six state DOTs. The results are similar to those in the combined projects. In five of the six states, the average contract cost growth of the DB projects is higher than the DBB projects. The one exception is Oregon in which the DB projects have less cost growth. However, only six pairs of projects are included for Oregon and the difference is not statistically significant. Utah is the only state in which there is statistically significant evidence to suggest that cost growth of DB is higher than that of DBB.

Table 6.1: Contract Cost Growth (%) by State

State DOTs	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Indiana ($n_{DBB} = n_{DB} = 20$)	1.1%	1.3%	0.291	0.000	0.012	0.898
Oregon ($n_{DBB} = n_{DB} = 7$)	8.9%	6.3%	0.214	0.214	0.518	0.307
Utah ($n_{DBB} = n_{DB} = 21$)	4.9%	10.6%	0.308	0.544	0.044	0.019*
Ohio ($n_{DBB} = n_{DB} = 44$)	1.8%	2.6%	>.10	<0.02	0.001	0.608
North Carolina ($n_{DBB} = n_{DB} = 10$)	8.6%	8.9%	0.376	0.376	0.469	0.933
Florida ($n_{DBB} = n_{DB} = 141$)	2.0%	2.1%	<0.02	<0.02	NA	0.569

(*): Statistically significant at the 95% confidence

Table 6.2 shows the results of construction schedule growth based on the NTP date between DBB and DB delivery methods. The North Carolina DOT could not provide the NTP dates required for the calculation. The findings agree with the overall project pools that show a statistically significant difference in the construction schedule growth metric. On average the construction schedule growth based on the NTP date of DB projects is lower than that of DBB projects throughout the five DOTs. Table 6.2 indicates that these results are statistically significant at the 90% and 95% confidence level, for Florida and Oregon respectively. It is notable that the result for Florida is based on a larger sample.

Table 6.2: Construction Schedule Growth based on NTP Date (%) by State

State DOTs	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Indiana ($n_{DBB} = n_{DB} = 20$)	15.9%	10.4%	0.532	0.566	0.146	0.320
Oregon ($n_{DBB} = n_{DB} = 7$)	39.2%	30.0%	0.670	0.531	0.985	0.089**
Utah ($n_{DBB} = n_{DB} = 21$)	16.9%	16.6%	0.011	0.884	0.898	0.972
Ohio ($n_{DBB} = n_{DB} = 44$)	14.4%	10.8%	>.10	>.10	0.014	0.469
North Carolina ($n_{DBB} = n_{DB} = 10$)	--	--	NA	NA	NA	NA
Florida ($n_{DBB} = n_{DB} = 141$)	19.4%	12.9%	0.000	0.000	NA	0.000*

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Table 6.3 shows the results of the construction schedule growth based on the CS date between the DBB and DB projects. The Indiana DOT could not provide the data required for the calculation. As expected from the combined data pool and the schedule growth based on the NTP, the average growth of DB projects is lower than DBB projects across all five DOTs. Similar to Table 6.2, Table 6.3 shows that the results are statistically significant at the 90% and 95% confidence level - for Florida and Oregon respectively.

Table 6.3: Construction Schedule Growth based on CS Date (%) by State

State DOTs	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Indiana ($n_{DBB} = n_{DB} = 20$)	--	---	NA	NA	NA	NA
Oregon ($n_{DBB} = n_{DB} = 7$)	41.3%	29.4%	0.483	0.561	0.758	0.056**
Utah ($n_{DBB} = n_{DB} = 21$)	21.8%	16.4%	0.013	0.635	0.337	0.597
Ohio ($n_{DBB} = n_{DB} = 44$)	21.0%	18.7%	>.10	>.10	0.036	0.759
North Carolina ($n_{DBB} = n_{DB} = 10$)	14.0%	4.5%	0.542	0.451	0.059	0.162
Florida ($n_{DBB} = n_{DB} = 141$)	24.4%	14.5%	0.000	0.000	NA	0.000*

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Table 6.4 summarizes the results of award growth between the DBB and DB projects. There is no consistent trend in the project award growth. For example, the project award growth of DB projects is lower than DBB projects in Indiana and Ohio. However, the project award growth of DB projects is higher in Oregon, Utah, Florida and North Carolina. Since the project award growth for all six DB projects in Oregon is 0%, no statistical tests were performed. While the combined state results show a statistically significant difference, there is no evidence to infer a statically significant difference in DB and DBB project award growth for any individual state. As previously stated, the DB projects vary in the way that they were procured (e.g., low bid, best value and bid-to-cost). This fact likely contributes to the erratic results and makes them difficult to interpret. Analysis of the further data may shed light on the issue of award growth on DB projects.

Table 6.4: Project Award Growth (%) by State

State DOTs	DBB mean	DB mean	Normality Test DBB	Normality Test DB	F-test/ Levene's test	t-test/ Nonparametric
Indiana ($n_{DBB} = n_{DB} = 20$)	-21.0%	-30.1%	0.438	0.387	0.062	0.198
Oregon ($n_{DBB} = n_{DB} = 7$)	-7.3%	0.0%	0.770	NA	NA	NA
Utah ($n_{DBB} = n_{DB} = 21$)	-12.9%	-9.6%	0.100	0.879	0.377	0.649
Ohio ($n_{DBB} = n_{DB} = 44$)	-6.5%	-6.6%	>.10	<0.02	p = 0.424	0.978
North Carolina ($n_{DBB} = n_{DB} = 10$)	-1.8%	1.5%	0.063	0.063	0.09	0.684
Florida ($n_{DBB} = n_{DB} = 122$)	-0.08%	-0.05%	> 0.1	>0.1	0.007	0.335

Table 6.5 shows the results of the CEI cost factors between DBB and DB projects. The Florida DOT could not provide the data required to calculate the CEI cost factor. The Indiana DOT could not provide data for DB required for the CEI cost; therefore no statistical tests were performed. One can observe from Table 6.5 that the CEI cost factors for DB projects in Oregon, Utah and Ohio are lower than DBB projects and are statistically significant at the 95% confidence level. The CEI cost factor for DB projects in North Carolina DOT is higher than that of DBB projects, but not statistically significant. While this trend seems to be encouraging for DB performance, there is no way to know the overall CEI project costs. The CEI costs that were included in the contract price by the contractor or design-builder were not available.

Table 6.5: CEI Cost Factor (%) by State

State DOTs	DBB mean	DB mean	Normality Test DBB	Normality Test DB	F-test/ Levene's test	t-test/ Nonparametric
Indiana ($n_{DBB} = n_{DB} = 20$)	--	--	NA	NA	NA	NA
Oregon ($n_{DBB} = n_{DB} = 7$)	12.9%	4.8%	0.216	0.707	0.002	0.011*
Utah ($n_{DBB} = n_{DB} = 21$)	10.4%	5.0%	0.006	0.712	0.011	0.003*
Ohio ($n_{DBB} = n_{DB} = 44$)	8.0%	5.3%	>.10	<0.02	0	0.004*
North Carolina ($n_{DBB} = n_{DB} = 10$)	7.6%	7.7%	0.077	0.020	0.006	0.961
Florida ($n_{DBB} = n_{DB} = 141$)	--	--	NA	NA	NA	NA

(*): Statistically significant at the 95% confidence

6.3 Combined Data Results

The results of the combined data from six DOTs are documented in Table 6.6.

Table 6.6 Comparison of Project Performance between DBB and DB Projects

Performance Metric	DBB mean	DB mean	Normality Test DBB	Normality Test DB	F-test	t-test/ Nonparametric
Cost Growth	2.5%	2.7%	0.104	>.10	0.347	0.588
Schedule Growth #1 – NTP	17.4%	12.0%	0.486	<.02	0.030	0.000*
Schedule Growth #2 – CS	20.1%	13.3%	0.001	<.02	NA	0.001*
Award Growth	-8.6%	-7.5%	0.054	.05-.02	NA	0.075**
CEI Cost Factor	7.2%	4.3%	0.006	<.02	NA	0.000*

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

At the highest level, the DB projects in Table 6.6 have significantly less schedule growth with no significant difference in cost growth. The DBB projects perform slightly better than

DB in terms of cost growth, but this difference is not statistically significant. The DB projects outperform the DBB in both NTP and CS schedule growth metrics and these results are statistically significant. As discussed later in this section, these schedule results are similar across all states. The DBB projects perform better in award growth but the DB projects perform better in the construction engineering and inspection (CEI) cost factor. While the award growth and CEI cost factor results are statically significant, these results must be interpreted carefully as discussed in the paragraphs that follow.

For all results relating to cost in Table 6.6, one should note that cost and schedule values for DB projects include both design and construction costs while DBB projects include construction costs only. Unfortunately, the state DOT construction databases did not allow for the subtraction of design costs on DB projects or the addition of design costs to DBB projects.

The DBB projects in Table 6.6 were awarded at an average of 8.6% less than the engineer's estimate and the DB projects were awarded at an average of 7.5% less. The difference between these two values was statistically significant. However, it should be noted that the DB projects in the data pool contain low-bid, best-value and bid-to-cost procurement types. It could be the bid-to-cost projects that are driving the statistical significance of this. By design, bid-to-cost projects have an award growth of 0%. Unfortunately, the states did not record the procurement type, so no further analysis is available.

Table 6.6 also reports the CEI factors, which are significantly lower on the DB projects. It should be noted, however, that the CEI values are for agency costs only. Data were not available for CEI costs that the contractor or design-builder included in their contract price. Therefore the value of this CEI information is fairly limited.

6.4 Project Size Analysis Results

Table 6.7 shows the mean values of cost growth for sampled DBB projects in each contract size level. It is noteworthy that the cost growth for DBB projects consistently increases as the contract size range is increased from under $2M to $10M and $20M to over $50M. With the exception of under $2M and $2M - $5M projects, DBB has higher average cost growth than the DB projects at all remaining levels. The cost growth value at $10M - $20M and is statistically significant at 95% confidence. In addition, the cost growth at the $20M - $50M range is statistically significant at 90% confidence.

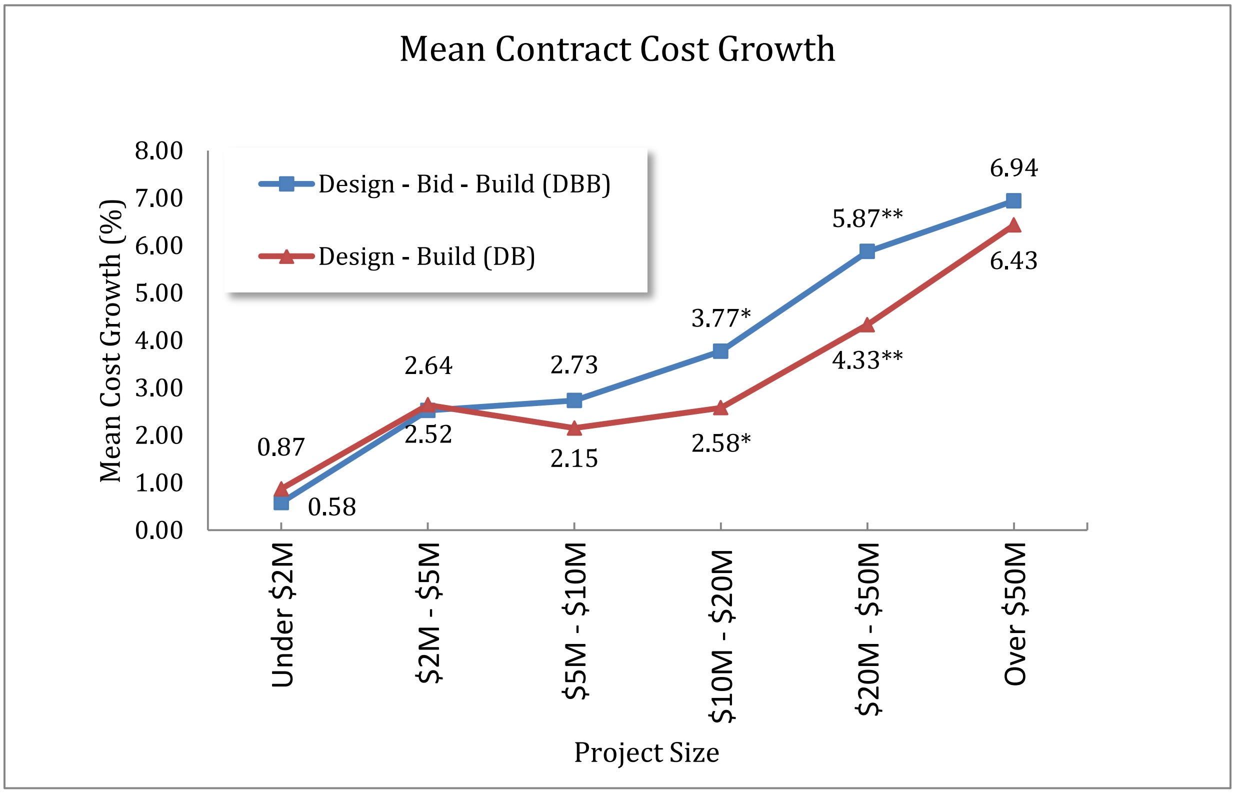
Table 6.7: Cost Growth (%) by Contract Size Level

Contract Size Category	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Under $2M ($n_{DBB}$ = n_{DB} = 188)	0.58%	0.87%	0.083	0.264	0.001	0.357
$2M - $5M ($n_{DBB}$ = n_{DB} = 66)	2.52%	2.64%	0.002	0.000	NA	0.763
$5M - $10M ($n_{DBB}$ = n_{DB} = 47)	2.73%	2.15%	0.178	0.002	0.549	0.216
$10M - $20M ($n_{DBB}$ = n_{DB} = 21)	3.77%	2.58%	0.045	0.031	NA	0.049*
$20M - $50M ($n_{DBB}$ = n_{DB} = 38)	5.87%	4.33%	0.003	0.000	NA	0.080**
Over $50M ($n_{DBB}$ = n_{DB} = 19)	6.94%	5.93%	0.000	0.133	0.755	0.637

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

The size-categorized DB projects cost growth analysis results are also shown in Table 6.7. For the range of $10M - $20M, the cost growth is statistically lower than that of projects at

95% confidence. For the range of $20M - $50M, the cost growth of DB projects statistically lower than that of DBB projects at 90% confidence. Figure 6.1 illustrates the mean cost growth resultant trends for DBB and DB in the size level analysis.



(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.1: Mean Contract Cost Growth – DBB and DB

Figure 6.1 shows that the cost growth for DBB begins lower than DB for the lower size ranges under $2M and $2M - $5M. At the $5M - $10M size range a crossover point occurs, where the DB projects average less cost growth than DBB from $10M through $50M. While the DBB cost growth mean trend experiences a steeper change between $10M - $20M and $20M - $50M, the DB cost growth has a more gradual increase through $50M projects.

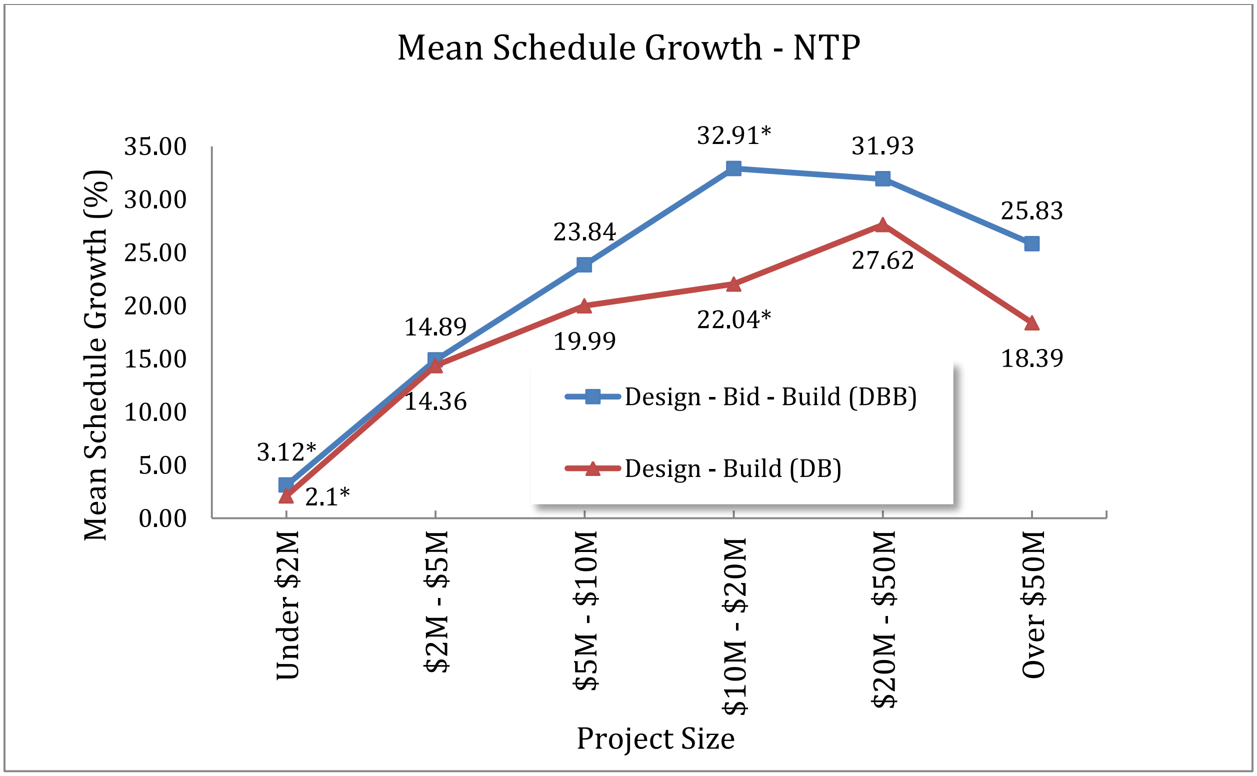
Schedule growth by NTP date for the sampled DBB projects is detailed by contract size in Table 6.8. The schedule growth (NTP) of DB projects was statistically lower than that of DBB projects at the 95% confidence level for size range under $2M and $10M - $20M. The DBB mean schedule growths (NTP) show higher values for DBB projects through all contract size levels.

Table 6.8: Schedule Growth based on NTP Date (%) by Contract Size Level

Contract Size Category	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Under $2M ($n_{DBB}$ = n_{DB} = 188)	3.12%	2.10%	0.031	0.038	NA	0.004*
$2M - $5M ($n_{DBB}$ = n_{DB} = 66)	14.89%	14.36%	0.000	0.000	NA	0.839
$5M - $10M ($n_{DBB}$ = n_{DB} = 47)	23.84%	19.99%	0.046	0.244	0.598	0.398
$10M - $20M ($n_{DBB}$ = n_{DB} = 21)	32.91%	22.04%	0.122	0.467	0.003	0.004*
$20M - $50M ($n_{DBB}$ = n_{DB} = 38)	31.93%	27.62%	0.015	0.005	NA	0.526
Over $50M ($n_{DBB}$ = n_{DB} = 19)	25.83%	18.39%	0.012	0.293	0.837	0.426

(*): Statistically significant at the 95% confidence

The mean value behavior shows schedule growth (NTP) increasing up to projects at $10M and increasing between $20M projects and $50M projects (Figure 6.2).



(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.2: Mean Schedule Growth (NTP) – DBB and DB

Figure 6.2 shows the mean schedule growth by NTP date trends for DBB and DB in the size level analysis. One can observe that DB projects hold a consistently lower schedule growth mean value through all project size levels. It should be noted that the schedule growth difference between the DB and DBB methods increases by a large margin at $10M-$20M. Schedule growth throughout the larger size ranges for DBB decreases as the schedule growth for DB shows fluctuation between increasing and decreasing growth values on projects from $10M to over $50M.

Table 6.9 shows the mean value and statistical testing results for schedule growth based on project construction start date. One can observe from Table 6.9 that the schedule growth

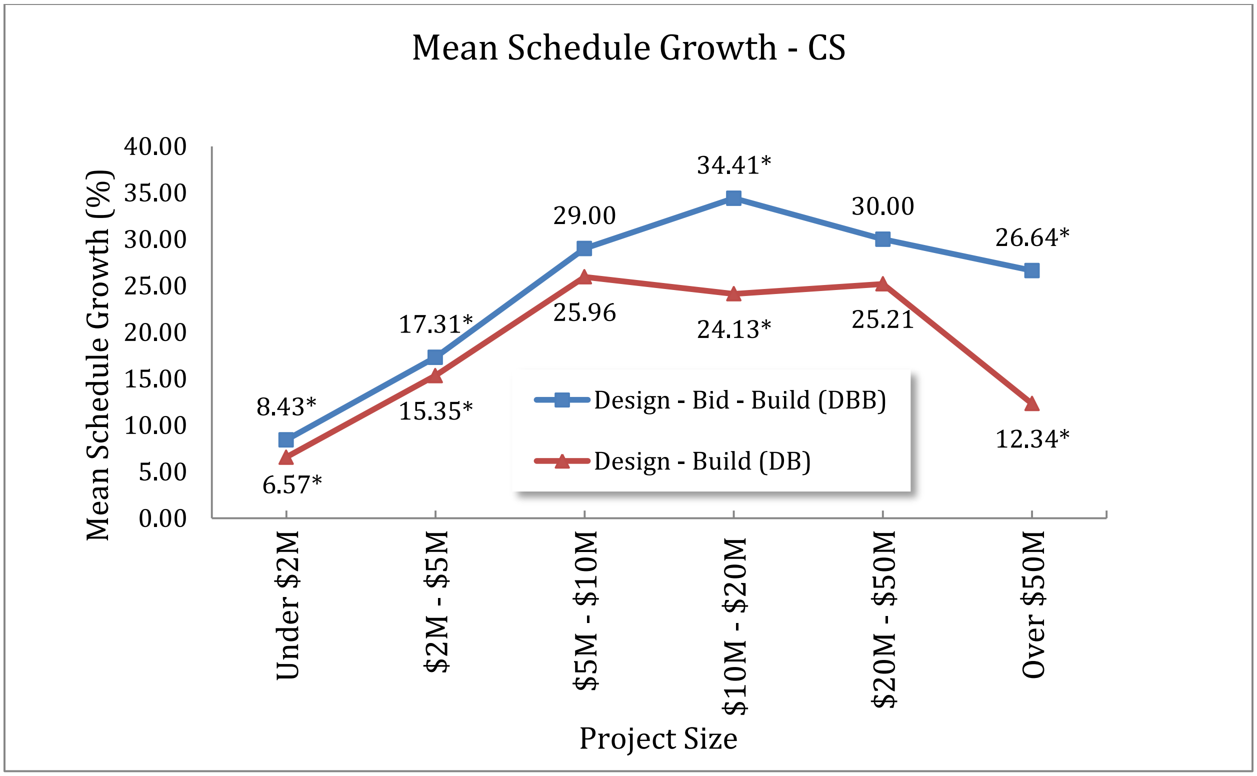
(CS) of DB projects are significantly lower than that of DBB projects at the 95% confidence level for the following ranges: under \$2M, \$2M - \$5M, \$10M - \$20M, and over \$50M. The mean schedule growth (CS) for sampled DB projects is lower than mean schedule growth (CS) for DBB projects in all size categories.

Table 6.9: Schedule Growth based on CS Date (%) by Contract Size Level

Contract Size Category	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Under \$2M (n_{DBB} = n_{DB} = 188)	8.43%	6.57%	0.022	0.245	0.133	0.041*
\$2M - \$5M (n_{DBB} = n_{DB} = 66)	17.31%	15.35%	0.003	0.001	NA	0.024*
\$5M - \$10M (n_{DBB} = n_{DB} = 47)	29.00%	25.96%	0.002	0.005	NA	0.481
\$10M - \$20M (n_{DBB} = n_{DB} = 21)	34.41%	24.13%	0.101	0.200	0.002	0.019*
\$20M - \$50M (n_{DBB} = n_{DB} = 38)	30.00%	25.21%	0.009	0.030	NA	0.640
Over \$50M (n_{DBB} = n_{DB} = 19)	26.64%	12.34%	0.020	0.510	0.094	0.036*

(*): Statistically significant at the 95% confidence

Figure 6.3 illustrates the mean schedule growth by construction start date between DBB and DB projects.



(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.3: Mean Schedule Growth (CS) – DBB and DB

Figure 6.3 shows similar behavior to the metric trends for schedule growth by NTP. DB projects hold a consistently lower schedule growth mean value through all project size levels. The schedule growth difference between the DB and DBB methods increases sharply at $10M-$20M. Schedule growth throughout the larger size ranges for DBB shows less change than the accelerated change on the DB projects from $10M to $50M.

Table 6.10 describes the mean values of award growth for DBB projects. The statistical test results show for a size of $5M - $10M, the award growth of DBB projects is statistically lower than that of DB projects at 90% confidence. For a size of $20M - $50M, the award growth of DBB projects is statistically lower than that of DB projects at 95% confidence.

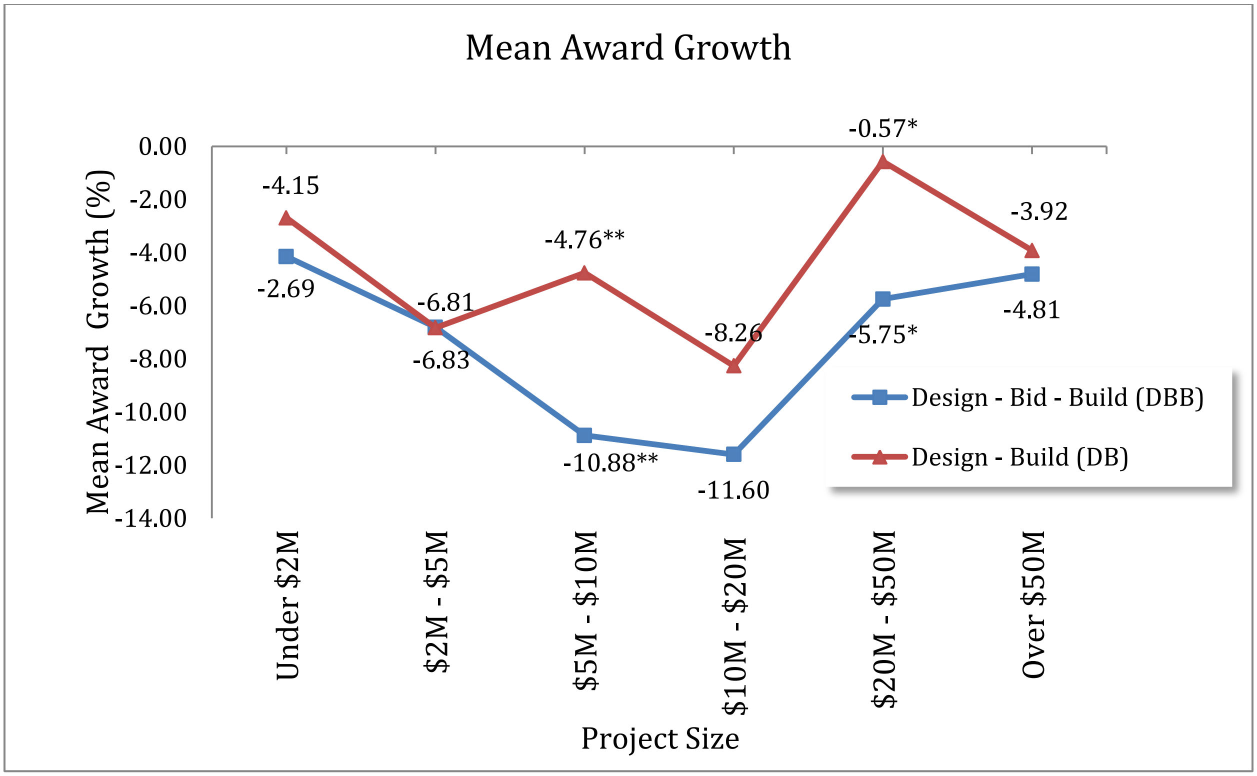
The award growth behavior for DBB projects decreases in value (more negative) into the $10M - $20M ranges and then increases through the larger contract size bins.

Table 6.10: Award Growth (%) by Contract Size Level

Contract Size Category	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Under $2M ($n_{DBB}$ = n_{DB} = 188)	-4.15%	-2.69%	0.069	0.427	0.003	0.280
$2M - $5M ($n_{DBB}$ = n_{DB} = 66)	-6.81%	-6.83%	0.569	0.000	0.529	0.862
$5M - $10M ($n_{DBB}$ = n_{DB} = 47)	-10.88%	-4.76%	0.187	0.010	0.055	0.065**
$10M - $20M ($n_{DBB}$ = n_{DB} = 21)	-11.60%	-8.26%	0.479	0.010	0.571	0.442
$20M - $50M ($n_{DBB}$ = n_{DB} = 38)	-5.75%	-0.57%	0.017	0.007	NA	0.041*
Over $50M ($n_{DBB}$ = n_{DB} = 19)	-4.81%	-3.92%	0.213	0.200	0.085	0.767

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

The award growth behavior shows constant negative values. One can also observe from Table 6.10 that although the award growth means of DBB projects for sizes of under $2M, $2M - $5M, $10M - $20M, and over $50M are lower than that of DB projects, these differences are not significant. Figure 6.4 shows the graphical trend of award growth for the DB and DBB projects.



(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.4: Mean Award Growth – DBB and DB

Figure 6.4 indicates that DBB projects start negative at the under $2M range and continue increasing in negative value until projects at $20M and then move to less negative award growth. DB projects also maintain negative award growth through all project size ranges, but showed more fluctuation. It should be noted that DB begins with more negative award growth than DB, however at $2M - $5M the methods show virtually the same award growth mean. The greatest difference between award growth means between DB and DBB occurs at $5M - $10M.

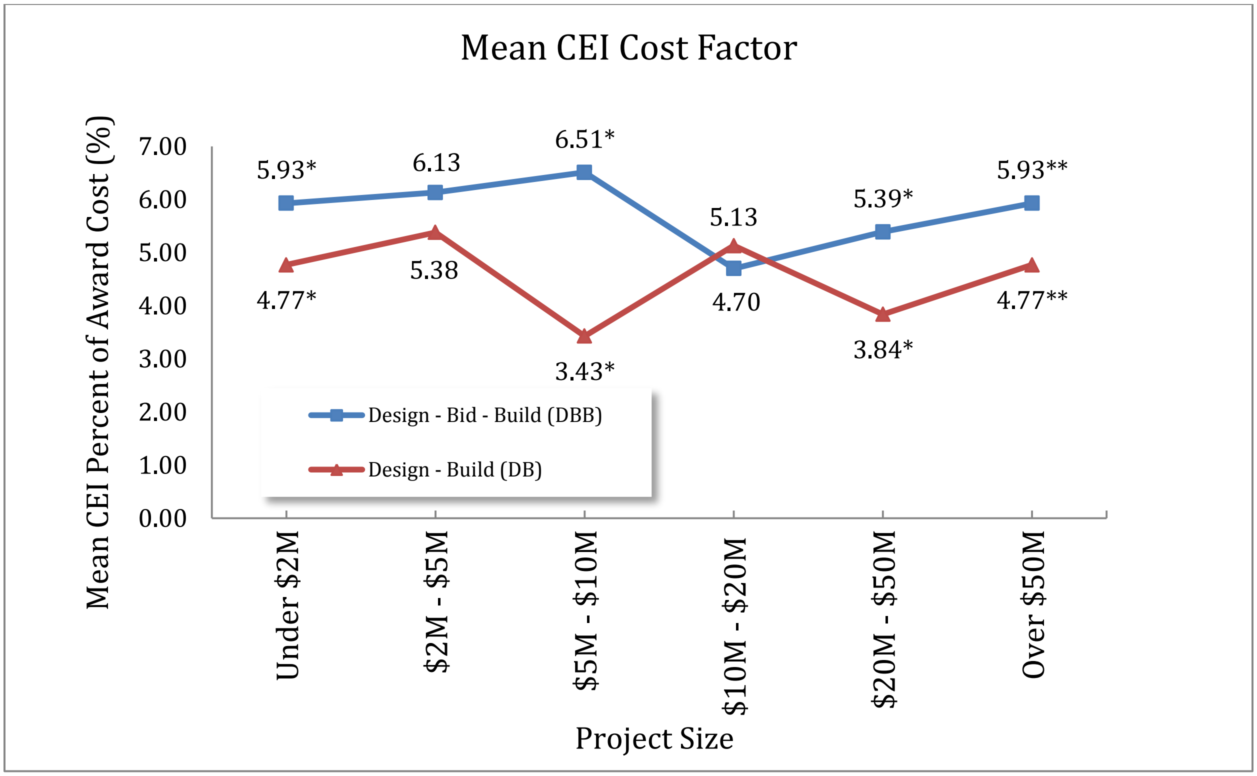
The CEI cost factor means for DBB and DB projects are presented in Table 6.11. This table shows the CEI cost factor of DBB projects are statistically higher than that of DB projects at the 95% confidence level for the following sizes: under \$2M, \$5M - \$10M, and \$20M - \$50M. Further, the CEI cost factor of DBB projects are statistically higher than that of DB projects at the 90% confidence level for the project size over \$50M.

Table 6.11: CEI Cost Factor (%) by Contract Size Level

Contract Size Category	DBB mean	DB mean	Normality Test		F-test/ Levene's test	t-test/ Nonparametric
			DBB	DB		
Under \$2M (n_{DBB} = n_{DB} = 64)	9.01%	6.65%	0.00	0.001	NA	0.001*
\$2M - \$5M (n_{DBB} = n_{DB} = 15)	6.13%	5.38%	0.303	0.345	0.049	0.499
\$5M - \$10M (n_{DBB} = n_{DB} = 16)	6.51%	3.43%	0.230	0.615	0.070	0.002*
\$10M - \$20M (n_{DBB} = n_{DB} = 6)	4.70%	5.13%	0.368	0.134	0.582	0.767
\$20M - \$50M (n_{DBB} = n_{DB} = 14)	5.39%	3.84%	0.031	0.054	0.124	0.049*
Over \$50M (n_{DBB} = n_{DB} = 12)	5.93%	4.77%	0.021	0.007	NA	0.100**

(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.5 shows the mean CEI cost factor values for DBB and DB projects.



(*): Statistically significant at the 95% confidence
(**): Statistically significant at the 90% confidence

Figure 6.5: Mean CEI Cost Factor – DBB and DB

Figure 6.5 indicates that DB projects start with lower CEI percent of award costs up to $10M. At $10M - $20M a brief crossover point occurs where DBB projects decrease in CEI cost factor between $5M - $10M and $10M - $20M and then steadily increase through $50M. DB projects alternate decreasing to increasing to decreasing. The greatest difference between CEI means between DB and DBB occurs at $5M - $10M.

6.5 Chapter Summary

This chapter summarized the performance trends for the overall and size analyses of the DBB and DB project data. Next the performance results were shown for both analysis stages. Each method's metric results were discussed individually, and then the correlations between the overall analysis and size analysis for delivery method performance in the DB and DBB delivery on highway projects were drawn. This section also incorporated the results of statistical tests on the metrics to validate the performance conclusions made for this study. The final chapter discusses the conclusions and recommendations to be made from the data and results in this study.

CHAPTER VII – CONCLUSIONS

7.1 Introduction

Chapter 7 concludes this thesis with the implications of the findings on metric trends for construction contract performance between the alternative DB and traditional DBB delivery methods on highway projects. This section also discusses the research at the summary level. The chapter further addresses the inherent challenges of this study, the research impact, and areas of further research within the topic of quantitative measurement of project delivery methods.

7.2 Conclusion

The content presented in this thesis comprised a research study measuring construction contract performance of highway projects between two project delivery methods: the traditional DBB and alternative DB system. The study collected data from state DOT databases based on alternative delivery experience and volume of recorded projects. This research was based on quantitative measurement of cost or time growth by performance metric equations and compared aggregate mean averages of the project data pools for each metric parameter (cost, schedule, award, and CEI). The comparison was performed for DBB and DB projects both between the sampled states and between sizes of highway projects. The analysis methods included outlier removal, one-to-one bin sampling by contract amount and project date of construction start, and establishing comparable samples in DBB and DB and using several rounds of analyses. The statistical analysis included parametric and non-parametric tests.

The results from this study show that there is a trend in cost and schedule performance by state using DB and DBB delivery. Specifically, DB showed higher cost growth than DBB in all six states. The marginal difference indicates that DB performs almost as well as DBB by cost growth, although the statistical tests revealed that DB cost performance is most likely on a project-by-project basis between state DOTs at this point. The schedule comparison among six states showed DB outperformed DBB by both NTP and CS dates. Although statistical tests support these trends across the states, the author recommends more iterative analysis between state agency project data for confirmation. For award growth, DBB showed consistently more negative mean values than DB. The award growth result indicates that DBB projects awarded below the project engineering estimate are lower than DB projects. Since procurement methods were not accounted for in this analysis, the trends in contract award growth need adjustment in further analysis to take into account the impact of different contract types such as low-bid, bid-to-cost, and others. The CEI factor produced higher mean values for DBB among all applicable states, but this relationship does not prove a definite trend for DBB relative to DB with the absence of external CEI costs in sampled highway projects.

With regards to the project size, the results of this study also show the following trends of the cost and schedule performance between DB and traditional DBB projects. For a highway project with the cost from \$10M to \$50M, the results show DB has a chance to provide better cost performance (less cost growth) than DBB. However for a project with the cost less than $5M, the results indicated that DBB may yield less cost growth than DB. Additionally, DB outperforms DBB in schedule growth by both NTP date and construction start date. It is noted that although the results indicated that DB does decrease schedule growth relative to DBB delivery in both NTP and construction start dates, the schedule growth reduction by construction start date is greater on average. Thus, we can assert that DB reduces schedule in project phases associated with construction at a greater rate than schedule related to overall project duration phases.

The results of this study showed that DBB possesses more negative award growth than DB. This means that more DBB highway projects are awarded on average below the engineering estimate than DB projects in the same size ranges. It is important to note that this study does not consider the impact of procedures and award methods in the comparison process. Finally the CEI cost factor by size category showed higher mean values for DBB than DB, suggesting that traditional delivery results in higher CEI service expenditures allocated from contract award amount per projects. More investigation on sample projects with all CEI costs (agency + external) should be conducted to validate this relationship.

7.3 Research Contributions

This thesis by way of collective data analysis between a group of state DOTs provides a useful benchmarking point for alternative DB delivery method performance in terms of cost and schedule. The direct-mining approach improves the validity of the performance trends for reference by other state agencies looking to expand the implementation of DB with primary cost and schedule concerns on future highway projects. It is expected that this study will encourage current DOTs implementing alternative delivery to continue investigation of its use for less frequent levels of work. State DOT officials and analysts retain the ability to map these results with their own internal performance records and use these results as a decision aid in the future to allocate resources to DB implementation in the most successful contract ranges as appropriate. In addition, state DOTs contemplating introduction of alternative delivery methods into their construction programs will possess a more assured probability of success beginning a method such as DB following the results of this research.

7.4 Limitations and Future Research

Although this study collected a great amount of data from six DOTs, more data is needed to verify and validate the project performance between DBB and DB projects. In addition, as stated in previous sections, select state DOTs did not have certain data points available in their agency database for project schedule milestone dates (i.e. North Carolina, NTP) CEI costs (Florida) or procurement types for their reported projects. The missing data points reflect the difficulty in comparing project data between different states due to the separate agency practices in contract award, project scheduling, and procurement methods. This condition was the fundamental reason for the deflated interpretation value of the award growth and CEI cost comparisons in particular. In addition, the reported project cost and schedule data points reflected only the construction cost and time for DBB contrasted to both design and construction cost/time for alternative DB. No design times or costs were given by any DOT as a reference to calculate complete project cost and schedule duration for traditional delivery. Thus, the performance metrics developed for this research were limited to comparing relative contract performance of the project content inclusive in DBB to the project content inclusive for DB. Next, this study focused on only four performance metric areas, including cost growth, schedule growth, award growth, and CEI factor. Future research may investigate other metrics such as construction speed or construction quality.

As stated previously, the subject of quantitative performance research on alternative project delivery in the highway sector contains a limited number of empirically driven studies in the field as of yet. In order to validate the level of impact of alternative delivery systems on cost, schedule, and other select project parameters, more comparison of individual state agency practices and measurement at the project management level is recommended. Some of the topics for future research include:

- Increasing the sample projects for a similar bin size per state. While this study used all available projects for a respective size, regardless of state, larger state-specific bin population sizes will enhance the comparison of project performance results between DB and DBB.
- Performing case studies to verify and validate the finding from this study. As mentioned before, there are a number of factor impacting the project performance. To understand how these factor impact DBB and DB projects, more refined data need to be collected.
- Investigating the impact of certain work types on highway DBB or DB project performance. Future research may need to compare performance metrics between DBB and DB projects with regard to different types of work (e.g., new construction or reconstruction).

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APPENDIX A - Data Clarification Transcripts

INDIANA DOT

Cost Data Points
1 - STIP Amount: The majority of states have been able to provide the STIP amounts for the projects. Would it be possible to obtain the STIP amounts for the projects?

Schedule Data Points
2 - “CNDT LET” Date:
What does CNDT stand for?
Is this equivalent to the date the project was advertised?
3 – “Construction Start” Date:
Do you have a recorded start date for construction work and/or planned start date for construction?
4 – “SCHD_COMP” Date:
.........Is this the scheduled completion date for the entire contract or the construction phase?
5 – “FINAL ACCEPTANCE” Date:
Our original question was not clear. Can you provide a separate date for “Substantial Completion” and a se
......................If not, does Final Acceptance relate to Substantial Completion or Contract Close?

OREGON DOT

Schedule Data Points
1 – “NTP” and “F-Note”:
You did have two separate dates for notice to proceed and the actual start of construction?
2 – “3rd Note / T – Note”:
Our original question was not clear. Can you provide a separate date for “Substantial Completion” and a second for “Contract Close”?
If not, does 3rd Note/T-Note relate to Substantial Completion or Contract Close?

OHIO DOT

Cost Data Points
1 – “STIP” Amount:
Do you have a STIP amount or budget amount per project in your records?
2 – “PE-Labor.. / RW-Labor / CO-Labor / OTH-Labor”:
Can you clarify what these acronyms stand for in type of labor? Are these amounts accounted for in the “Final Cost”, “Engineer’s Estimate”, or other already reported cost data columns?

Schedule Data Points
1 – "NTP" Date:
You mentioned that this was not usually recorded. Do you have a date you would say is close to a notice to proceed that is common for all your reported projects?
2 – "Final Contract End" Date:
Our original question was not clear. Can you provide a separate date for "Substantial Completion" and a second for "Contract Close"?
If not, does Final Contract End relate to Substantial Completion or Contract Close?
3 – What does "Adjusted Completion" Date refer to?
4 – What does "Original Completion Date" refer to?

NORTH CAROLINA DOT

Cost Data Points
1 – "Estimate to Date": Does this value mean the same thing as the final cost?

Schedule Data Points
1 – "NTP" Date:
Do you have a value that is close to a notice to proceed?
Our original question was not clear. Can you provide a separate date for "Substantial Completion" and a second for "Contract Close"?
If not, does Final Acceptance related to Substantial Completion or Contract Close?

2 – Is the final acceptance date equivalent to your actual contract end date?

FLORIDA DOT

Cost Data Points
1 – Do you have CEI project cost values in your records?
2 – Do you have recorded the number of change orders per project to coincide with the provided change order amount?

Schedule Data Points
1 – "EXEC" Date:
Does this date refer to the actual contract start date?

3 – "EST_COMP_DATE":
Our original question was not clear. Can you provide a separate date for "Substantial Completion" and a second for "Contract Close"?
If not, does Final Acceptance related to Substantial Completion or Contract Close?

APPENDIX B - One–on-One Data Clarifications and Results

INDIANA DOT

- **Investigator:** Verify/modify definition and values for substantial completion date.
- **INDOT Official:** Provide a construction start date for sample projects or confirm that they are not available.
- **INDOT Official:** Verify whether Indiana tracks contract bid days against actual days or whether Indiana only tracks bid dates against actual dates.

Project qualitative issues disclosed by agency

  - Only 5-10 price and time contracts per year
  - Schedule tracked by date
  - D-B projects are best value

Tables B2-1 an B2-2 summarize the verification of the cost and schedule data for Indiana DOT.

Table B2-1. Project Cost Data Verification – Indiana DOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Liquidated Damages
Not Provided	ESTIMATE	AWARD	CURRENT	CONST_ENG	INCENTIVE (DISINCENTIVE)	LIQ DAMAGES

Table B2-2. Project Schedule Data Verification – Indiana DOT

Date Advertised	Award Date	Notice to Proceed	Construction Start	Bid Contract End Date	Final End Date (or Substantially Complete)
CNDTLET	AWD	NTP	Not Provided	SCHD_COMP	FINAL ACCEPTANCE

OREGON DOT

- **ODOT Official:** Provide actual change order amounts. Please include number of changes if available.

- **ODOT Official:** Verify whether Oregon tracks contract bid days against actual days or whether Indiana only tracks bid dates against actual dates.

Project qualitative issues disclosed by agency:

  - Very small number of time-based contracts
  - Schedule tracked by dates partially and days partially
  - D-B projects are best value

Tables B2-3 and B2-4 summarize the verification of the cost and schedule data for Oregon DOT.

Table B2-3. Project Cost Data Verification – Oregon DOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Liquidated Damages
STIP Apprvd Cost	Not Provided	Contractor's Bid	Contractor Paid	Eng Paid to Date	Not Provided	Not Provided

Table B2-4. Project Schedule Data Verification – Oregon DOT

Date Advertised	Award Date	Notice to Proceed	Construction Start	Bid Contract End Date	Final End Date (or Substantially Complete)
Advertised	Award	NTP	F Note	S Note	T Note

<u>OHIO DOT</u>

- **Investigator:** Verify the new data file sent with unfinished projects removed.

- **Investigator:** Need to discuss with official what should be removed from the "Final Cost" to match our definition; Final Cost official reported is inclusive of everything during the construction phase. The research team is trying to compare bid contract costs to completed final contract costs. We believe that the final contract cost will include pay items per bid, overruns/underruns, supplemental agreements, liquidated damages and/or incentives. We do not expect that the final cost would include CEI, ROW or other costs unless they were part of the original bid cost.

- **OHDOT:** Verify whether Ohio tracks contract bid <u>days</u> against actual days or whether Indiana only tracks bid <u>dates</u> against actual dates.

  Project qualitative issues disclosed by agency:

  - Very small number of time-based contracts
  - Schedule tracked by dates
  - D-B projects are low-bid
  - The "Final Cost" reported was inclusive of everything during the construction phase

Ohio DOT Official's Clarifications:

1. The cost analyst reporting the OHDOT data reviewed the performance metric equations discussed and specified a sum of column values per project for "Final Cost" – "Awarded Amount"+ "Net Change Orders" + "Incentives/Disincentives"+ "Liquidated Damages"
2. The CEI value amount was specified as 'Internal CEI Expense" + "External CEI Labor"

Tables B2-5 an B2-6 summarize the verification of the cost and schedule data for Ohio DOT.

Table B2-5. Project Cost Data Verification – Ohio DOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Liquidated Damages
Not Provided	Engineer's Estimate	Original Contract Amount ($)	Original Contract Amount + I/D's + L/D's+ Net Change Order	C-O Exp + C-O Labor	Net Incentives Disincentives	Liquidated Damages

Table B2-6. Project Schedule Data Verification – Ohio DOT

Date Advertised	Award Date	Notice to Proceed	Construction Start	Bid Contract End Date	Final End Date (or Substantially Complete)
Advertising Date	Date of Award	Not Provided	Construction Work Began	Original Completion Date	Substantial Work Complete

UTAH DOT

- **UDOT Official:** Check with secondary associate to determine if there is any item that needs to be removed from the "Final Cost" amount.

- **Investigator:** Analysis for schedule growth needs to be changed for **days** not **dates**; Utah's contracts track total days. A factor may need to be added to these days to make them comparable with the dates from the other states.

  Project qualitative issues disclosed by agency:

  - All reported projects are price + time
  - Schedule tracked by days
  - D-B projects are best value
  - The "Final Cost" reported was inclusive of everything during the construction phase

Tables B2-7 an B2-8 summarize the verification of the cost and schedule data for Utah DOT.

Table B2-7. Project Cost Data Verification – Utah DOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Liquidated Damages
STIP_AMOUNT	ENGINEERS _ESTIMATE	CONTRACT_ AWARD_ AMOUNT	FINAL_COST	CONSTRUCTION _ ENGINEERING	INCENTIVES	LIQUIDATED_ DAMAGES

Table B2-8 Project Schedule Data Verification – Utah DOT

Date Advertised	Award Date	Notice to Proceed	Construction Start	Bid Contract End Date	Final End Date (or Substantially Complete)
DATE_ADVERTISED	AWARD_DATE	NOTICE_TO_ PROCEED	CONSTRUCTION_ START_DATE	BID_CONTRACT_ END_DATE	SUBSTANTIALLY_ COMPLETE_DATE

NORTH CAROLINA DOT

- **NCDOT Official:** Locate D-B-B projects other than those with time-based contracts (only time-based were provided). These need only have the minimum amount of information that is readily available from the database.
- **Investigator:** Down-sample D-B-B projects from official so that they can use the shorter list to get further project information from construction group (i.e. CEI costs which are not typically included in their contracts).
- **NCDOT Official:** Sending supplemental agreement amounts that are included in the "Final Cost".
- **NCDOT Official:** Obtain NTP dates for sample projects.

Project qualitative issues disclosed by agency:

- All reported projects were time-based contracts
- Schedule tracked by dates
- D-B projects are best value
- Reported projects had L/D's on every contract
- CEI included in the final cost on reported project- needed to be removed

NCDOT Official's Clarifications:

1. NCDOT's state estimating engineer reported that the initial "Final Cost" value did not include supplemental agreements as per our team's definition; these agreement amounts were added to the project file at this point.
2. Substantial completion dates were also added by the NCDOT contact per project.
3. Not all NCDOT projects are bid to substantial completion, so a limited number of projects were returned with substantial completion dates.
4. Notice-To-Proceed dates were not tracked in the NCDOT system; this negated an accurate calculation of the construction schedule growth with respect to notice-to-proceed

Tables B2-9 an B2-10 summarize the verification of the cost and schedule data for NC DOT.

Table B2-9. Project Cost Data Verification – NC DOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Liquidated Damages
STIP Amount (Most Current)	Engineer's Estimate	Contract Award Amount	Final Cost	Const Engineering and Inspection Cost	Incentives Earned (Bonuses)	Liquidated Damages Assessed

Table B2-10. Project Schedule Data Verification – NC DOT

Date Advertised	Award Date	Notice to Proceed	Constructio n Start	Bid Contract End Date	Final End Date (or Substantially Complete)
Letting Date	Award Date	Not Provided	Construction Start Date	Bid Contract End Date	Acceptance Date

FLORIDA DOT

- **Investigator:** Call/email to verify schedule dates being used for NTP, Bid Contract End, Construction Start, and Substantial Completion in Schedule Growth formulas.

- **FDOT Official:** Verify Final Acceptance Date is the only date readily accessible or if he can get a substantial completion date.

- **FDOT Official:** Verify whether Florida tracks contract bid days against actual days the project took to complete.

- **FDOT Official:** Verify if FDOT has separate CEI costs available for sample projects.

  Project qualitative issues disclosed by agency:

  - Schedule tracked by dates
  - D-B projects are best value

FDOT Official's Clarifications:

1. The state estimating engineer overseeing the FDOT reported data reviewed the discussed performance metric equations and altered the file column value used for "Final Cost" per our definition.
2. CEI amounts are allocated and let in project bundles- not on a project-by-project basis; this negated a one-by-one project calculation for CEI percent cost factor metric.

Tables B2-11 and B2-12 summarize the verification of the cost and schedule data for FDOT.

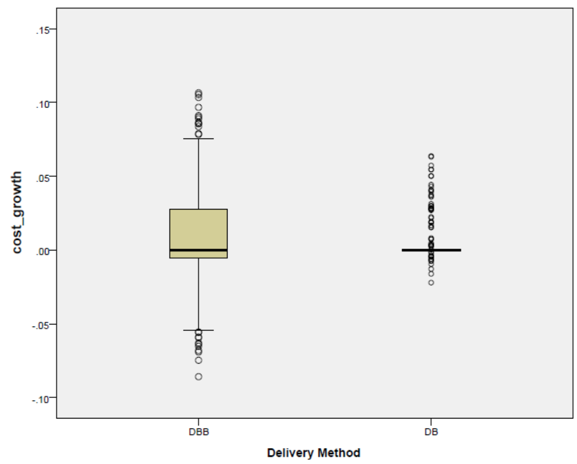
Table B2-11. Project Cost Data Verification – FDOT

STIP Amount	Engineer's Estimate	Contract Award Amount	Final Cost	CEI Cost	Incentives	Change Order Amount
wpa_amt	Engineers Estimate	Amount of BID	Curr_Amnt	Not Provided	Not Provided	Change Order Amnt

Table B2-12. Project Schedule Data Verification – FDOT

Date Advertised	Award Date	Notice to Proceed	Construction Start	Bid Contract End Date	Final End Date (or Substantially Complete)
let_date	AWD	NTPD_date	WKBG_date	EST_COMP_ DATE	Date of Final Acceptance

APPENDIX C – DATA BOXPLOTS: SIZE SEGMENTATION



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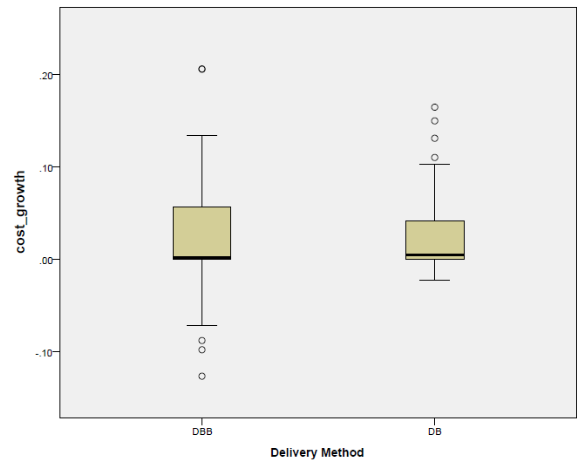

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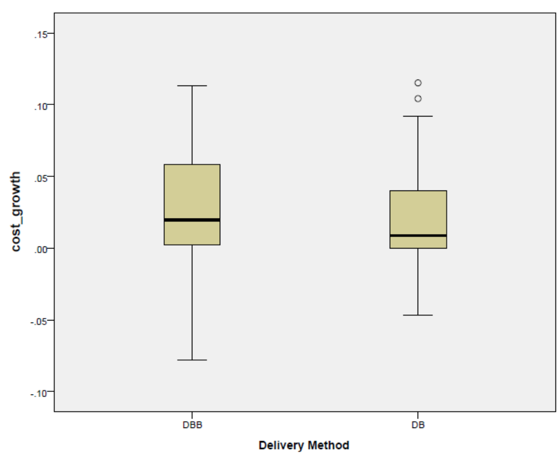

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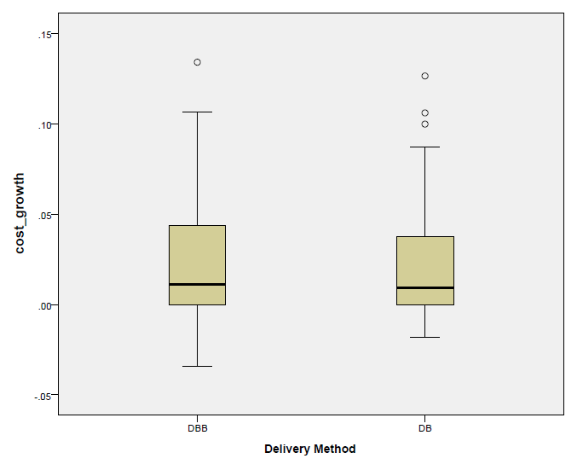

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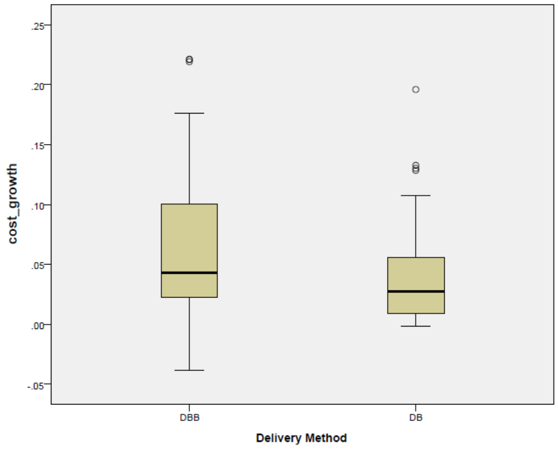
C.1 - COST GROWTH



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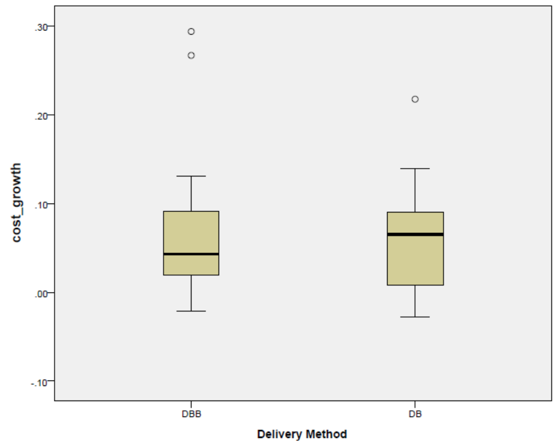
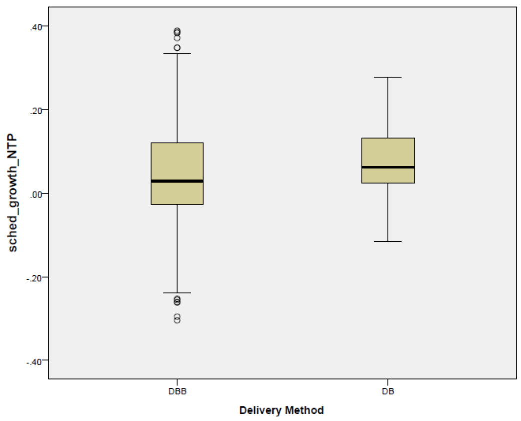


OVER $50M

C.1 - COST GROWTH



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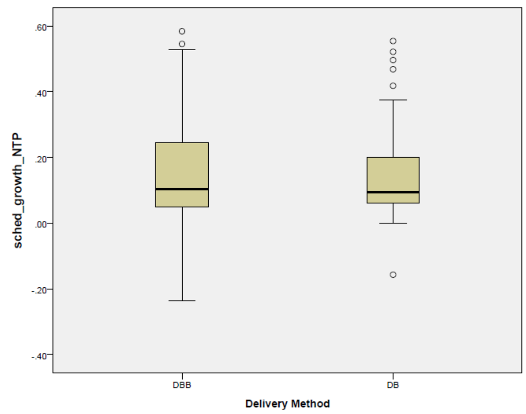

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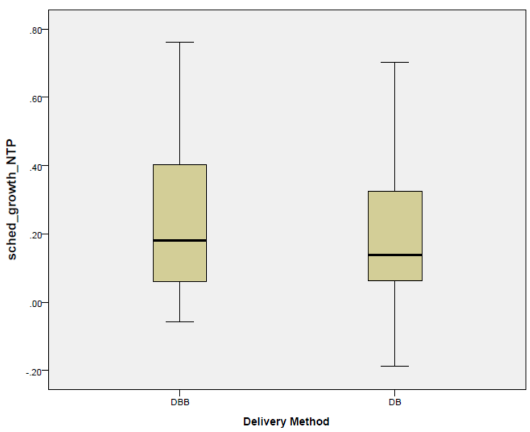

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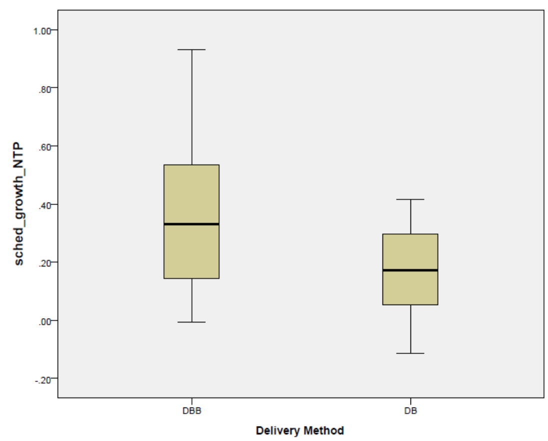
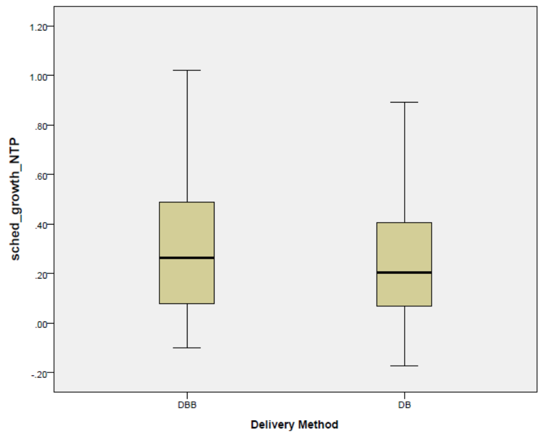


$10M - $20M

C.2 - SCHEDULE GROWTH – NTP



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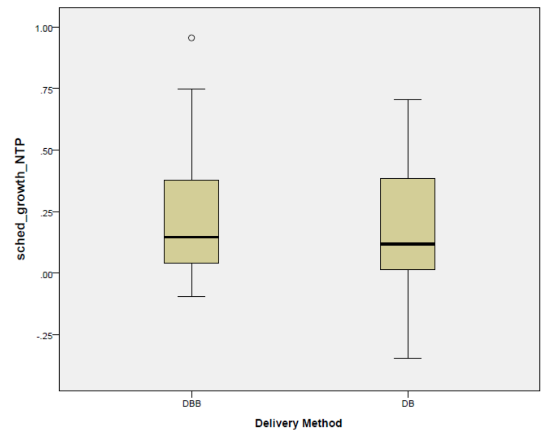
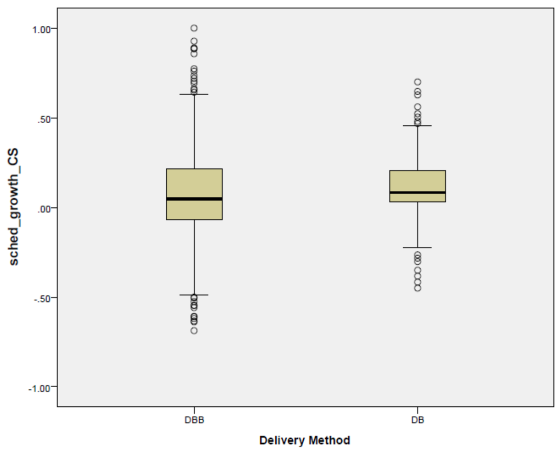


OVER $50M

C.2 - SCHEDULE GROWTH – NTP



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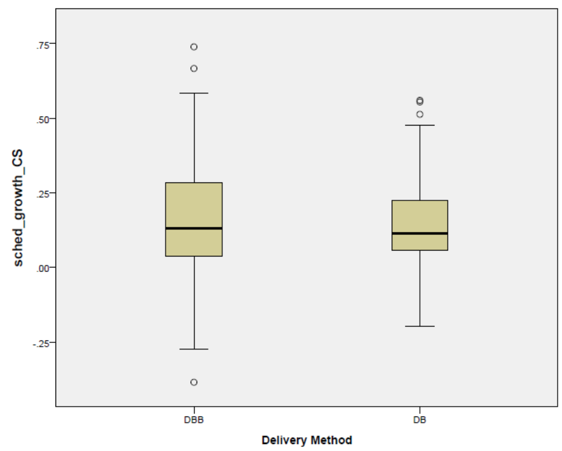

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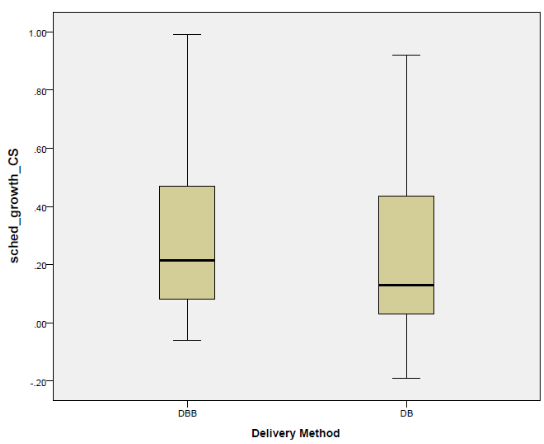

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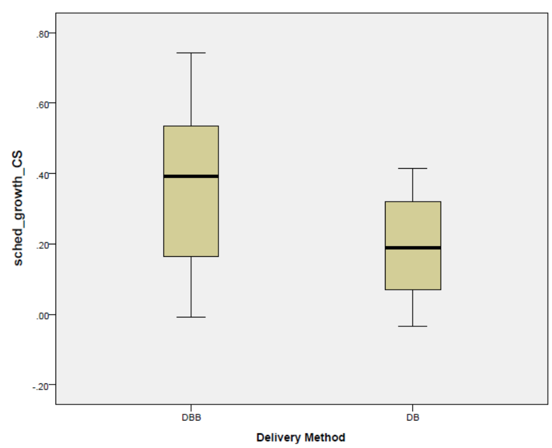
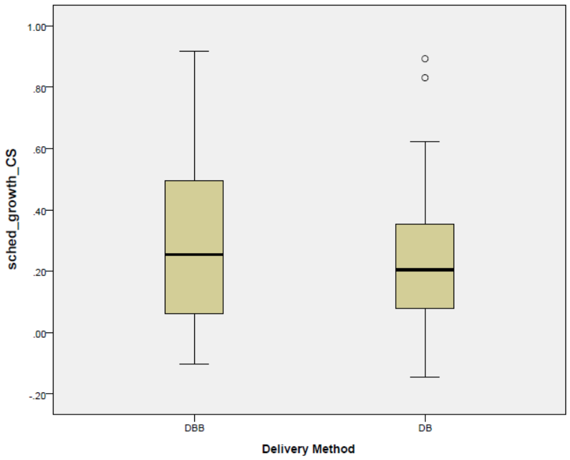


$10M - $20M

C.3 - SCHEDULE GROWTH – CS



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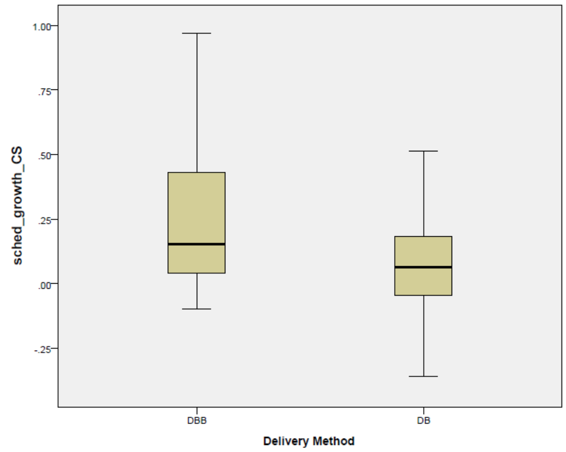

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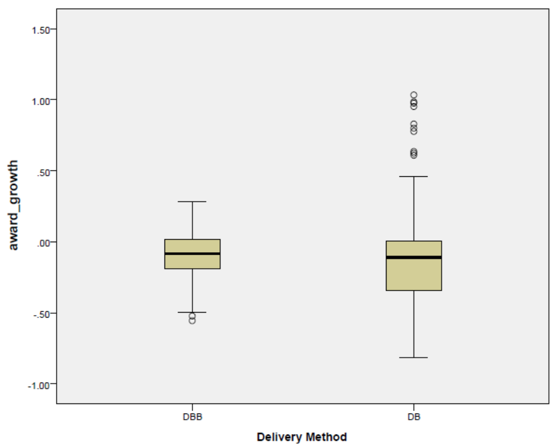
C.3 - SCHEDULE GROWTH – CS



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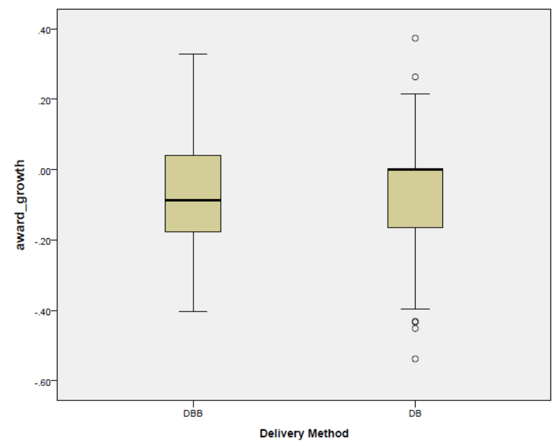

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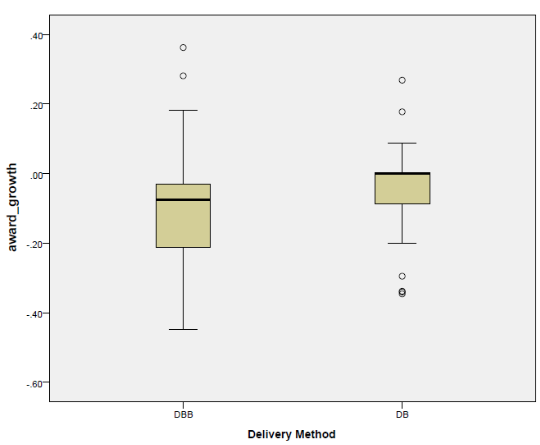

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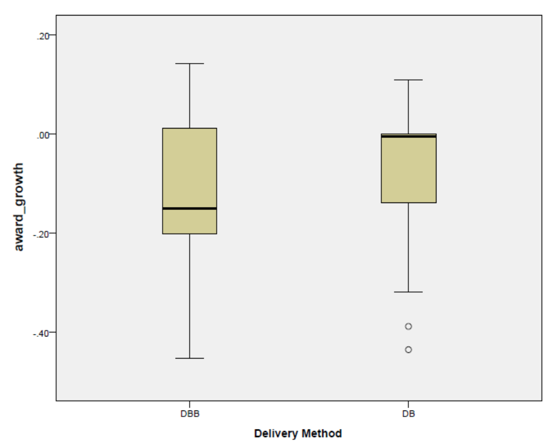
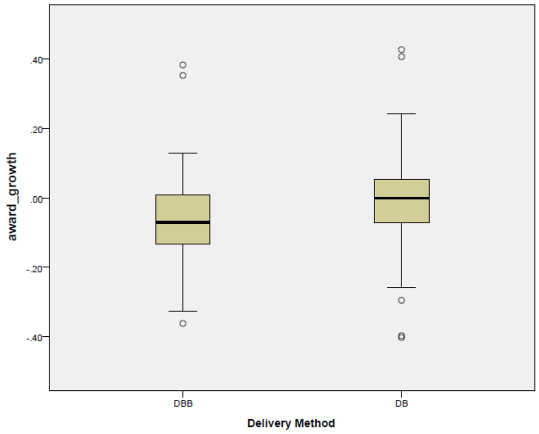


$10M - $20M

C.4 - AWARD GROWTH



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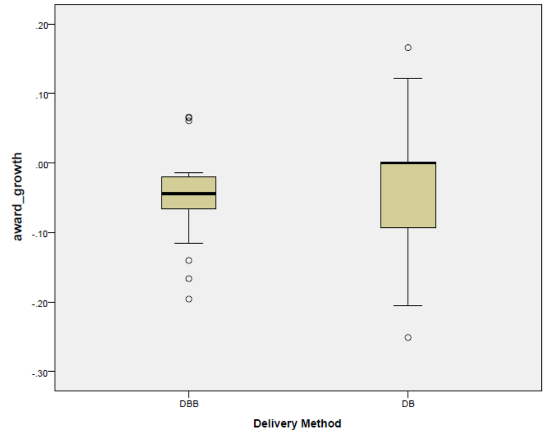
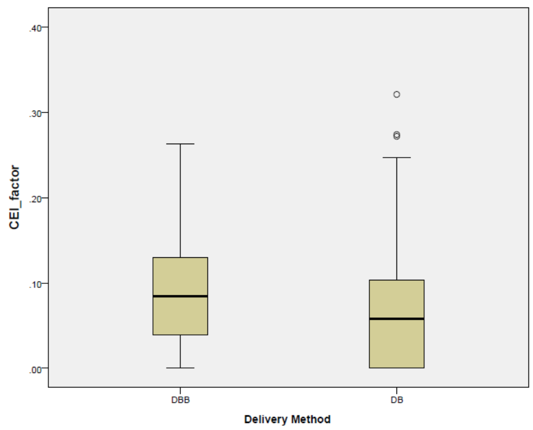
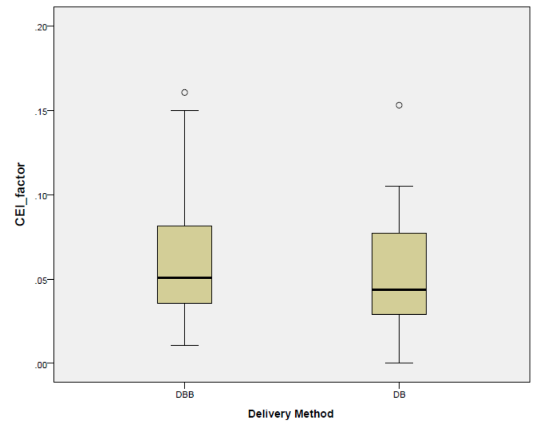


OVER $50M

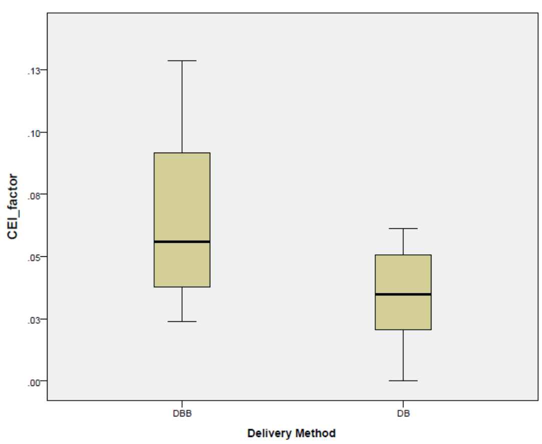
C.4 - AWARD GROWTH



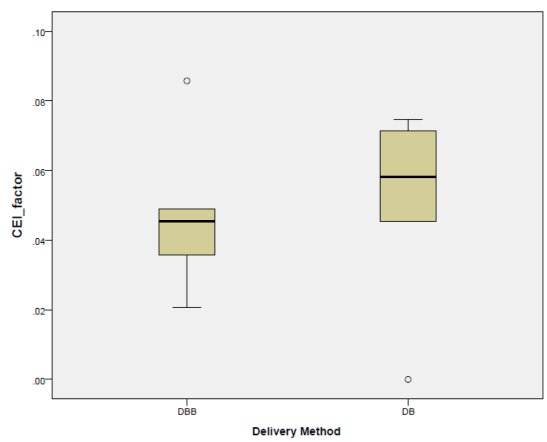
UNDER $2M



$2M - $5M

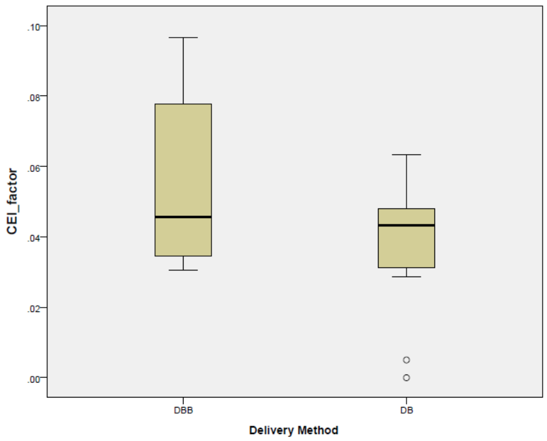


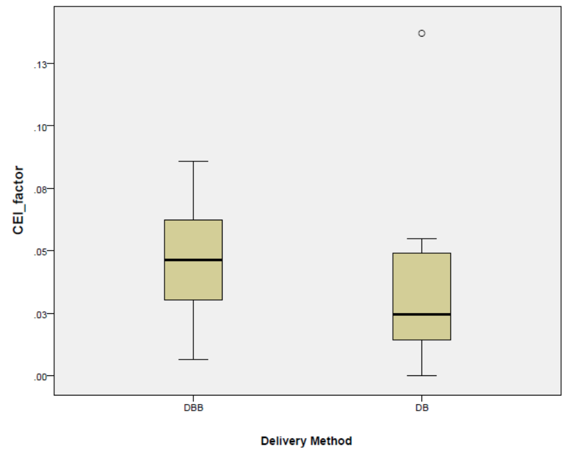
$5M - $10M



$10M - $20M

C.5 - CEI COST FACTOR





$20M - $50M

OVER $50M

C.5 - CEI COST FACTOR