

EVALUATION OF DESIGN BUILD PROJECT DELIVERY IN
THE PERFORMANCE OF
BRIDGE CONSTRUCTION PROJECTS

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

(Civil and Environmental Engineering)

at the

UNIVERSITY OF WISCONSIN-MADISON

2014

Acknowledgements

First and foremost, thank you to the gigantic network of Schiebers, Brakebushes, and Robinsons who call me one of their own. You will never know the magnitude of the impact that your love and support have had on my life. You have given me the foundation to know who I am and the confidence to chase my dreams. Thank you also to my extended family in the Lake Farm City Group at the Vine Church. You have provided me a home in Madison that constantly surrounds me with love and challenges me to grow and think outside of myself. Without you, my time in Madison would not have been the same.

Thank you to all of the wonderful graduate students that I have had the privilege of studying alongside over the last two years. Your intelligence and dedication have challenged me to grow as a student and your friendship has enriched my graduate school experience.

An overwhelming amount of thanks is due to Dr. Awad Hanna. Without his confidence and affirmation I would not have had the opportunity to return to this wonderful University to pursue a Masters degree. His guidance through the research process has undoubtedly transformed me into a more thorough student and a better engineer. I would also like to thank Mr. Gary Whited and the Construction Support and Materials Center. Without the funding provided by the Center this thesis would never even have begun. Mr. Whited's patient instruction in all things transportation has been infinitely eye-opening in the exploration of this new world and his honest support has continually been an encouragement. Additionally, I would like to thank Dr. Jeffrey Russell for being willing to sit on my committee and for his encouragement many years ago in advising a young undergrad to take a second look at the University's Construction Engineering and Management program. Thank you also to Dr. Murray Clayton for his patient guidance in the statistical process.

Thank you to all of the transportation agencies and individuals that contributed to the data collection process in the form of phone calls, emails, and most of all in the contribution of hard data for analysis. This project would be impossible without the willing contributions of your time, experience, and knowledge.

Finally, and most of all, thank you to the One who gave His life for mine, who loves me beyond what I could ask or imagine. This work is dedicated to You alone.

Abstract

Since the early 1990s, state transportation agencies in the United States have been attempting to improve the transportation construction process through the use of innovative project delivery systems. These systems, which define the relationship between different contracting parties and the timing of their involvement in that relationship, have been shown to have significant impacts on the outcomes of vertical construction projects. Design build has been one of the most common innovative project delivery systems to be utilized transportation construction. Bridges are one of the most significant aspects of the United States transportation system, and the current state of bridges in the U.S. is considered by the American Society of Civil Engineers (ASCE) to be deficient. Given this, major bridge construction projects will continue to be a regular occurrence for state transportation agencies in the United States. Anecdotal accounts and analysis of case studies have led to speculation that design build could be well suited for the delivery of such bridge projects. Little research has been completed to quantitatively analyze the effect that design build delivery has on transportation construction. This study investigated the impact that design build has on performance outcomes in five different categories, including construction cost, construction schedule, change management, quality, and legal implications. This research found that bridge projects delivered by design build show significantly less construction schedule growth than those delivered by design bid build. Additionally, this research analyzed the qualitative and quantitative characteristics of bridge projects, termed project inputs for this research. This research found that bridge projects delivered by design build had a significantly higher degree of flexibility in their scope and a significantly lower degree of design completed at their time of award. It was also found that the specification sets utilized for design build projects were composed of a significantly higher degree of performance specifications, and thus a lower degree of prescriptive specification. Surprisingly, there was no difference in the level of schedule urgency demonstrated by be delivered by design build and those delivered by design bid build.

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Chapter 1

Introduction

1.1 Background

In the Architecture, Engineering, and Construction (AEC) industry, the project delivery system defines the relationship between different contracting parties and the timing of their involvement in that relationship (Hanna 2010). Since 1990, state transportation agencies in the United States have explored the delivery of transportation construction projects through innovative project delivery systems that break the mold of the traditional design bid build; chief among these innovative methods has been design build (FHWA 2006). In the vertical construction industry, design build has been shown to have many superior qualities to traditional project delivery, including increased schedule reliability and, in some cases, cost reliability or savings (Gransberg and Molenaar 2003; Hale et al. 2009; Konchar and Sanvido 1998). Due to inherent differences in the drivers and magnitude of transportation design, it is understood that in comparison to vertical construction, transportation construction may hold lower potential for cost-related benefits to be realized by the use of design build. Conversely, those same differences could create greater potential for the realization of schedule related benefits, like the reduction of schedule growth, by the use of design build (Gransberg 2003).

One area of transportation construction in the United States that appears to be fit for the use of design build delivery system is bridge construction, which lends itself to innovation in design and construction. Bridges are a vital piece of the United States transportation system. In 2007, travel over bridges accounted for 45 percent of the vehicle miles traveled over the entire National Highway System, even though bridges make up only 4.1 percent of the total length of the system (Oberstar 2007). Construction on bridges throughout the United States is imminent as the current state of bridges in the United States demands reconstruction efforts in the near future. It is estimated that it would be necessary to invest an annual sum of \$20.5 billion every year until 2028 in new bridge construction and rehabilitation and reconstruction of existing bridges to eliminate the deficiency and capacity problems facing bridges in

the United States (ASCE 2013). Furthermore, the direct and indirect costs of social impacts – for example traffic detours that result from the loss of a bridge during construction – can exceed the actual cost of the structure itself, especially in large urban centers where economic impact is seen in commercial and industrial activities (FHWA 2013). Design build could be a vital resource in delivering bridge construction projects efficiently and reducing the social and economic impact of such projects on its user.

Vast research has been done concerning the definition of various project delivery systems and the process, means, and methods of executing design build in transportation construction, but research concerning the efficacy of design build in transportation construction has been quite limited. To date, no research has been conducted concerning the effect of project delivery system on the project performance outcomes in terms of cost, schedule, and quality of bridge projects or which bridges project are optimal for delivery by design build. This research investigates the effects of project delivery system on performance outcomes of bridge construction projects delivered by state transportation agencies. Additionally, the project delivery system selection process utilized by state transportation agencies will be analyzed and discussed in relation to the projects analyzed by this research. Recommendations based on those analyses will be made that with the goal of improving the selection of project delivery system on bridge projects specifically, in Wisconsin and throughout the greater United States.

1.1 Problem Statement

Design build could hold great potential to solve challenges that are currently experienced in the transportation construction industry with traditional project delivery. According to Miller et al. (2000) no single project delivery system (PDS) can be thought of as the only solution to all project delivery struggles, as multiple delivery systems have, at times, been shown to outperform others. The goal of PDS research is not to accomplish the impossible goal of identifying the elusive “perfect PDS,” but rather to increase the body of knowledge available to owners in their pursuit to identify the right PDS for each project they undertake (Molenaar and Songer 1998; Oyetunji and Anderson 2006). There has been no research involving the subset of the transportation industry dedicated to bridge construction. This research project will seek to

fill the gap in the research in order to support more informed PDS decision making regarding the bridge construction projects.

1.2 Research Questions

This research focuses on answering the following questions:

1. In what ways does the use of the design build project delivery system in bridge construction projects contribute to the success of the project for its owners in terms of cost, schedule, change management, quality, and legal outcomes?
2. Is there a difference between the project context or classification of bridge construction projects currently being delivered by design build or design bid build?

1.3 Methodology

This research project was conducted in two phases. Phase one involved informal and formal data collection and phase two included data analysis. This section will discuss each step of these phases.

1.3.1 Phase 1

Phase one of this research included research and information gathering in the forms of a literature review and survey development, an informal pilot study, and formal data collection using a data collection survey tool.

1.3.1.1 Literature Review and Survey Development

A literature review was conducted with three main objectives: to identify a working definition of PDS for this research, to establish an understanding of the current state of DB in transportation construction, and to identify criteria to be measured by the study's data collection survey tool. The following section of this paper primarily focuses on the last objective mentioned, the identification of data collection criteria. The definition of PDS adopted for this research will be in line with Hanna (2010), where PDS was concluded to be the system which defines the relationship between different contracting parties and the

timing of their involvement in that relationship. Chapter 2 of this paper discusses in further detail the research results regarding the current state of DB in the transportation industry.

The identification of data collection criteria began with analysis of the 2006 FHWA Design-Build Effectiveness Study. This study compared the use of DBB with DB for projects in United States early in the country's adoption of the PDS in transportation construction under the ratification of SEP-14 legislation. The FHWA report analyzed the biggest dataset to date of such a study, which included 14 DB and 14 DBB project profiles. Although there are some limitations of this study, as discussed in Chapter 2, the study was a groundbreaking effort for such an analysis concerning transportation construction. Included in the Appendix of this study's publication was the data collection survey used to collect project profiles for the study. The FHWA data collection survey provided a transportation-specific focus that served as a foundation for the development of this research's own data collection survey.

The second data collection tool that provided deep insight into PDS data collection was the comprehensive data collection survey tool developed at the University of Wisconsin-Madison for PDS research in the vertical construction industry. This survey, which was reviewed by the UW-Madison Survey Center, has been used in the collection of over 250 construction project profiles and was utilized to collect data for the groundbreaking IPD research recently published by the University of Wisconsin-Madison (El Asmar et al. 2013)(Olsen 2013). Although the UW-Madison data collection survey included many criterion specific to the vertical construction industry that were not applicable to this research, much of the survey was focused on the construction industry in general and was easily adaptable to the transportation construction industry. The intensive, detail-oriented focus of the UW-Madison survey on specific, quantitative, and qualitative data concerning a broad range of PDS topics was invaluable to this research.

1.3.1.2 Expert Review

After the initial draft of the data collection survey tool, an expert review was conducted with four DOT officials that held DB coordination positions for their respective state or DOT region. Each DOT official was provided a copy of the original draft of the data collection survey tool prior to an individual

phone interview. During that interview, officials first shared their own experience with DB in transportation construction and answered questions regarding the procedures and practices involved in their state’s adoption of DB. After this brief introduction, the majority of each interview involved reviewing each question of the data collection survey tool. During this time, interviewees commented on the questions being asked, the phrasing of questions, and the responses or types of responses requested.

The valuable insights gathered from the expert review were integrated into the final draft of data collection survey tool utilized for this research, seen in Appendix B. The final data collection survey tool consisted of four sections, detailed below in Table 1.3-A. Each section consisted of eight to nine questions, some which included multiple parts.

Table 1.3-A: Summary of the Sections Utilized by the Data Collection Survey

Data Collection Survey Structure	
Section 1	Respondent Information and Project Characteristics
Section 2	Project Delivery Approach
Section 3	Project Performance
Section 4	Quality and Other Performance Metrics

1.3.1.3 Formal Data Collection

The data collection survey tool was distributed in the form of an online survey through Qualtrics Survey Software to state level transportation officials holding various positions, which included DB coordinators, innovative contracting directors, state engineers, and project managers, among others. As every state transportation agency (STA) is unique in its organization and coordination of construction, the research team attempted to identify officials at each state transportation office best equipped to respond to the data collection survey. Such officials were primarily identified through STA websites, guided in part by the DBIA membership directory and various FHWA membership lists. Each official was requested to complete, or oversee the completion of, two submissions of the data collection survey, one submission for a project completed by DB and one for a project delivered by DBB. State officials at 43 different STAs were contacted for participation in this research. After a two-month data collection period, individual follow-up calls and emails were pursued with individuals that had begun the survey, but had not completed

it. Additionally, follow-up was pursued with officials from states know to more commonly utilize DB. In total, the data collection period spanned about seven months from September 2013 to April 2014. In total, 18 surveys were submitted by 10 STAs, accounting for a response rate of 23 percent. One of the 18 surveys submitted was omitted from the data analysis due the fact that the profiled project had not been completed at the time of the survey.

1.3.2 Phase 2

Phase two included an initial periphery analysis of the data followed by in-depth, univariate statistical analysis. The initial analysis stage was utilized to review the data for conformance to the research scope and to identify holes in the data submitted – specifically to identify unanswered or incomplete sections of the data collections tool. When possible, contact was made with the respective survey respondent and the missing data was entered into the database. Project metrics were separated into two distinct groups: performance outcomes and project inputs. The univariate analysis stage included formal hypothesis testing using two-tailed t-tests and Mann-Whitney-Wilcoxon tests. The procedure utilized for this stage of the research is detailed further in Chapter 3 of this thesis.

1.4 Thesis Organization

The first chapter of this thesis establishes the purpose of this research by identifying its contributions to the body of knowledge and provides an overview of the methodology utilized in the completion of this research. Chapter 2 outlines the literature review that establishes a deep understanding of the current state of design build in the transportation industry and identifies gaps in the literature to be addressed by this research. Chapter 3 offers a detailed assessment of the methodology utilized in the statistical analysis of the data, including the identification of variable and performance metrics, the selection of the hypothesis testing methods, the establishment of the scope of data, and an overview of the dataset. Chapter 4 contains the statistical analysis and interpretation of the performance outcomes. Chapter 5 contains the statistical analysis and interpretation of the project input metrics. Chapter 6 includes a summary of the study findings, research conclusions and potential limitation, and opportunities for future research.

Chapter 2

Literature Review

2.1 Motivation to Conduct Research

Up to the 1980s, construction in the United States generally followed a long, established pattern of delivering construction projects through a system known as design bid build (DBB). Over the last 30 years other alternative project delivery systems (PDSs) have been developed off of the DBB model. This exploration has caused many in the academic community to investigate the tangible benefits gained through the use of alternative PDSs. Konchar and Sanvido studied a diverse sampling of public and private vertical construction projects and found that in comparison to design bid build and construction management at risk, design build (DB) achieved significantly improved cost and schedule advantages (1998). In a study that included both vertical and horizontal construction projects, Molenaar et al. found that owners involved in DB projects experienced a high level of overall project satisfaction and that a majority of projects studied were delivered within two percent of the established budget and/or two percent of the established schedule (1999). Hale et al. found that cost growth and all schedule-related metrics of DB were significantly superior to the construction of similar living quarters delivered by DBB when considering a dataset that included the construction of Navy living quarters (2009). Project delivery system research showed that design build holds great promise in a variety of diverse variety of applications.

In 1990, the Federal Highway Administration established the Special Experimental Project Number 14 (SEP-14), which enabled state transportation agencies to test and evaluate a variety of alternative project contracting methods; chief among these methods was design build (DB) (FHWA 2006). This groundbreaking piece of legislation encouraged state transportation agencies to join the trend of project delivery system exploration and experimentation already prominent at that time in the private construction industry (Konchar and Sanvido 1998). Given that as public entities have many more barriers to entry to consider when moving away from traditional low bid design bid build (DBB), there has been a significant amount of research dedicated to the process of implementing DB in the public sector and investigating the risks associated with such implementation (Gransberg and Molenaar 2003; Tran and Molenaar 2013). Such

research has found that the team approach encouraged by design build in public projects helped “to defuse the historically adversarially ‘charged’ construction environment” which, the author posited, could allow for a greater optimization of project, design, schedule, and quality (FHWA 2006).

Unlike the vertical construction industry, little research has been done concerning the significant advantages that DB delivers in various facets of the transportation construction industry. Currently the body of knowledge is lacking regarding specialized facets of the transportation construction industry, most notably within the bridge construction industry.

2.2 The Construction Project Delivery System

2.2.1 Definition of the Project Delivery System

Before there can be any discussion or comparison of project delivery systems (PDSs) the scope through which the discussion is framed must be clearly defined. As the concept seems somewhat abstract, many attempts have been made to formally define PDS. The definition that will be used to define the scope of this research construes project delivery system as “the system that defines the relationship between different contracting parties and the timing of involvement in that relationship” (Hanna 2010). Similar to the Hanna definition, Oyetunji and Anderson expanded the definition of PDS beyond scope and compensation to include project phasing with the following interpretation: “Project delivery system defines the sequence of project phases, parties involved in the project, and implicitly assigned roles and responsibilities to project parties” (Oyetunji and Anderson 2006). The Associated General Contractors of America defined PDS as “the comprehensive process of assigning the contractual responsibilities for designing and constructing a project” (AGC 2004). Thomsen published a similar, role-oriented definition of PDS that stated the “project delivery process is the sequence of defining responsibility, scope, and compensation” (Cho et al. 2010).

2.2.2 Evolution of the Project Delivery System

Until the turn of the 20th century, nearly all construction projects were delivered by the same PDS known as the Master Builder delivery system. In this PDS, a single person – the master builder – served as the sole designer, engineer, and contractor throughout the entire project delivery process (Konchar and Sanvido 1998). Responsible for many ancient world marvels and Renaissance icons, master builders were revered for their creativity, knowledge, and vision (Flavell 2011). However, the Master Builder delivery system met its inevitable demise as advances in construction technologies and increasing design sophistication far exceeded the capacity that would allow an individual person to assume responsibility for all project decision making (Flavell 2011). Due to the increase in project complexity, the construction world saw the dawn of more specialized engineering, design, and construction services. Eventually, this definition of roles led to the development of more PDSs beyond the master builder system (Konchar and Sanvido 1998).

The first PDS to break the convention of master builder project delivery was design bid build (DBB). This system is still widely used today; however, it is not without its flaws. DBB, known also as traditional project delivery, is characterized by an owner entering into separate contracts with design and construction entities with their engagements occurring in sequential phases that have minimal, if any, overlap (Miller et al. 2000). The design phase of the project may be completed in-house by the project's owner or will be contracted out by the owner to a separate design entity architect/engineer (AE) to complete construction documents. Often in public transportation projects, the design is completed through the former procedure. Upon completion of these documents, the owner will then allow construction contractors to submit bids based on the design that they present. The owner will award the construction contract to the contracting firm that submitted the lowest responsible bid (Miller et al. 2000). While the contract and compensation structure for AEs in DBB can vary, the contractor will be retained by a lump sum in the amount of the bid award. Because DBB parties are engaged in sequential phases, there is little information sharing or interaction of design and construction parties during project phases. This lack of collaboration between project parties, especially during the design phase, has been shown to result in inefficient designs

and frequent errors and disputes between project parties (Konchar and Sanvido 1998). DBB's sequential engagement of parties reduces the possibility of constructability analysis during the design phase and does not allow construction to begin before 100 percent of the design is complete. This also eliminates prominent opportunities to decrease the schedule duration of many projects. It has also been observed that DBB fails to align the interests of all project stakeholders. For example, it seems that bidders have the tendency to submit artificially low bids in some cases to receive contracts with the plans to inflate the price of inevitable changes orders, ultimately coming at the expense of the owner (Gransberg 2013). Opportunities to improve stakeholder alignment and collaboration present in traditional project delivery led the construction industry to seek out alternative project delivery systems and methods to overcome them.

One of the first methods utilized to combat the construction industry's growing dissatisfaction with DBB was the adoption of a construction manager (CM) role throughout entire construction projects, from initial planning and design stages through project completion. CMs were introduced to the U.S. construction industry around 1980 with the goal of increasing design constructability and decreasing schedule durations. Eventually this method became so popular that a new PDS, construction management at risk (CMR), was born (Konchar and Sanvido 1998). The contractual relationships present in CMR are similar to those in DBB in that the owner will contract with two parties, the AE and the CM. However, the timing of engagement of these two parties in CMR is different than that in DBB. In CMR, the owner will engage the CM at almost the same time as the AE, rather than waiting for the completion of the design phase. The compensation package of the CM entity that most often accompanies CMR delivery is the Guaranteed Maximum Price (GMP) structure. In the GMP structure, the CM is responsible for any project costs, excluding change orders, that exceed the GMP established at the contract award (Minchin Jr. et al. 2007). Recently, another CM oriented PDS has become popular, particularly in transportation construction, called Construction Manager-General Contractor (CMGC). CMGC is very similar to CMR except that the CM will also act as the project GC, self-performing some construction work rather than solely managing subcontractor work (Gransberg 2013). In both CMR and CMGC, the early engagement of the CM allows for increased collaboration between stakeholders throughout the design and construction phases, earlier

engagement of key subcontractors, and the overlap of the design and construction phases (Minchin Jr. et al. 2007). The inclusion of CMs in U.S. construction inspired one of the first PDSs that pushed the construction industry towards increased collaboration between project stakeholders with the goal of increasing design constructability and decreasing project conflicts and duration.

Design build (DB) also gained popularity as an alternative PDS in America along with CMR throughout the late 1980s and 1990s (Konchar and Sanvido 1998). DB strays from traditional project delivery by replacing the multiple individual contracts that an owner enters into with separate AE and contracting firms with a single contract entered into with a DB entity (McManamy 2004). This DB entity could be an independent design builder firm that offers both design and construction services in-house or may be a joint venture between an AE firm and a contracting firm. Since the AE and construction parties are both members of the same entity in DB, both parties enter the process at the same time, at the beginning of the project. This allows for increased integration of and collaboration between the design and construction phases and, potentially, great reduction in project duration (Yates 1995). Additionally, with both the design and construction services being provided by the same entity, DB aligns the interests of design and construction stakeholders much more than in CMR or DBB where design and construction services are kept separate. Although there is some flexibility in the compensation structure in DB, generally DB contracts will be awarded on a lump sum basis similar to DBB. However, the methods for awarding contracts can often vary from the DBB low bid structure. Due to the variability that is typically present between designs submitted by DB entities in their bid packages, bid evaluation in DB is much more complicated than in DBB where all construction contractors are bidding from the same set of completed construction documents (Palaneeswaran and Kumaraswamy 2000). This concept of bid evaluation in DB is a complex matter that will be explored later in this chapter. Perhaps the greatest potential advantage of DB over traditional project delivery is that a single source of contact and responsibility is established when the owner enters into a contract with only one party. DB's single point of responsibility reduces the owner's administrative tasks, as the owner is only burdened with contract administration and payment responsibilities for one party, and it can also potentially minimize legal entanglements by reducing the

AE/contractor tension and liability disputes. Similarly, the previously mentioned collaboration between design and construction phases has potential to reduce the number of project change orders and increase the probability that the project will be completed on time and under budget. Conversely, this single source of responsibility also has potential to reduce the checks and balances generally present in project administration as the AE entity shifts from acting as an owner's representative to a partner with the construction entity (Yates 1995). The single source of responsibility model sets DB apart from traditional project delivery and holds great potential for cost and time savings in project delivery with increased collaboration and alignment of project stakeholders.

While innovative PDS methods all have the potential to improve certain aspects of traditional project delivery, no single PDS can be thought of as a perfect solution to all project delivery struggles. Even traditional DBB project delivery, although not without its own challenges, is still a viable delivery method in many settings (Miller et al. 2000). Miller et al. suggest that there is a fundamental shift in ideology required in the construction industry, especially the public sector, toward a project delivery approach that includes a structured planning phase that considers all delivery methods every time a new project is started. To support this end, the goal of PDS research in actuality should not be to accomplish the impossible goal of identifying the elusive "perfect PDS," but rather to increase the body of knowledge available to owners in their pursuit to identify the right PDS for each project they undertake (Molenaar and Songer 1998; Oyetunji and Anderson 2006). Because the focus of this paper is specifically contributing to this body of knowledge with the goal of assisting public transportation owners in DB project selection, the remainder of the chapter, and the paper as a whole, will be dedicated to the status of DB in transportation construction.

2.3 Design Build in Transportation Construction

2.3.1 The Rise of Design Build in Transportation

The adoption of design build in transportation construction, and the greater public sector, has been slower than in the rest of the construction industry as the public sector continues to deliver projects primarily by DBB. Miller et al. posited that the public sector's overwhelming focus on DBB has led the industry to

focus disproportionately on up-front project costs and miss opportunities to take advantage of the potential design innovations put forth by DB that could offer greater value in transportation projects and ultimately offer the greatest long-term benefit to the public. However, the current planning and procurement strategies of most public agencies in the U.S. are primarily tailored towards DBB delivery for many reasons, not the least of which is its long-standing tradition in federal public works projects dating back to World War II (Miller et al. 2000). Many public owners consider DBB the most consistent way to ensure accountability to constituents, as DBB is perhaps the most straightforward PDS. As such, it is much easier for local and federal governments to maintain a competitive and transparent bid environment while avoiding the perception of corruption in the project award process due to DBB's straightforward low price bid evaluation process (El Asmar et al. 2010; Miller et al. 2000).

2.3.2 Design Build Project Award Processes

Multiple studies have investigated the bid award process utilized by public sector owners as they attempt to maintain a competitive and transparent environment in which to award DB projects. In research concerning DB projects in both the public and private sector, Palaneeswaran and Kumaraswamy (2000) classified DB bid evaluation processes into two categories: single-stage and two-stage contractor selection. In this classification system, single-stage evaluation included many different bid evaluation strategies, ranging from classic low-bid selection to highly complex forms of value-based analyses utilizing complex formulas to determine value delivered by various bids. Two-stage contractor selection in this system involves two stages: the first being some kind of firm-based short-listing or prequalification process that bidders had to complete before being allowed to submit project-based proposals, and the second being an analysis of separate technical and cost proposal analysis, similar to a complex single-stage bid evaluation. The authors found that a multi-stage selection process that considered value criteria beyond cost to be the project award method most able to capture the innovation and cost benefits of DB, while also noting that low-bid evaluation could be the adequate award method for straightforward and easily-defined projects.

Gransberg and Senadheera (1999) conducted research similar to Palaneeswaran and Kumaraswamy in an effort to classify the design build contract award methods being utilized in transportation construction. Gransberg and Senadheera divided the contract award methods into three categories: low bid, adjusted score, and best value. Low-bid selection, as the name implies, was defined as the same procedure seen in classic DBB. In this procedure, the contract is awarded to the lowest responsive bidder. Adjusted score was assessed based on the submittal of separate technical and price proposals. In this procedure, the technical proposals are evaluated and given a score out of 100; the price proposals are then divided by the technical score, resulting in an adjusted score. The contract is awarded to the lowest adjusted score. Similarly, best value selection also involved the assessment of separate technical and price proposals. This selection differs from adjusted score in that the technical and price proposals are assessed together based on a predetermined weighting scheme, in which price is one category in conjunction with numerous qualitative categories, resulting in a weight score for each project. This difference in weighted score between the lowest bidder and the next-lowest bidder is then considered in comparison to the percent difference of total cost. If this result in a justifiable increment, the test is repeated between that bidder and the next lowest bidder until the difference is not justified. When that instance is encountered, the contract is awarded.

El Wardani et al. (2006) went further in DB procurement research, studying and classifying procurement systems used and investigating the differences in project results seen between these methods. The research team categorized DB project award methods using four different categories of award method: sole source selection, qualifications-based selection, best value selection, and low-bid selection. Each of these methods identified by El Wardani et al. could have been considered a single-stage selection process as categorized by Palaneeswaran and Kumaraswamy. El Wardani et al. also noted that all four could also be paired with a second stage of pre-qualification as well. The research team found that sole source and qualifications-based selection are often primarily based on pre-established relationships and involve extensive amounts of negotiation. Due to this fact, the team found that these methods are used very little in the public sector. Best value selection was defined by El Wardani et al. as a bid evaluation system that examined proposals based on technical aspects of the proposal together with the associated cost of the

project, generally through the use of a weighted criteria evaluation method. Low-bid selection in this research was defined slightly differently than in Gransberg and Senarheera as bid selection that is based primarily on cost-related items. In addition to classic low-bid situations, bid evaluation methods in which cost criteria represented greater than 90 percent of the value measurement were also considered to be low-bid. El Wardani et al. noted that this bid method is characterized by a high level of design completion at the time of procurement in order to more easily facilitate competitive selection. This study found projects procured by low-bid methods had a higher average cost growth than all other procurement methods studied, while also maintaining the lowest unit cost (cost per square foot) and the fastest delivery speed (square feet per month). Best value procurement showed to have nearly the lowest cost growth and the lowest schedule growth of all of the methods studied, and experienced the highest unit cost of the four methods.

2.3.3 Design Build Legislation

Despite the fairness that these evaluations methods strive to accomplish in the bid award process, concerns regarding public competition and transparency have proven to be difficult hurdles for federal and state legislations to overcome in their adoption of DB. In recent years, some progress has been made toward overcoming hurdles to the public adoption of DB. In 1990, the Federal Highway Administration (FHWA) was largely responsible for the incorporation of design build delivery into transportation construction with the introduction of Special Experimental Project Number 14 (SEP-14). This initiative established contracting provisions that enabled state DOTs to test and evaluate a variety of alternative project delivery systems with a large emphasis on DB. As part of this initiative, the FHWA proposed over 300 projects to be delivered with DB by transportation agencies in 32 states, the District of Columbia, and the Virgin Islands (FHWA 2006). After the successful execution of many of these proposed projects, the FHWA extended the reach of SEP-14 with the issuance of the design build Contracting Rule in December 2002. This final ruling reconfigured many of the temporary contracting provisions of SEP-14 beyond experimental projects to a more permanent status, making the use of DB on federally funded transportation projects much less complex and more accessible (CTC & Associates LLC 2003). Despite this focused effort to investigate and incorporate DB into transportation construction legislation at the federal level, individual

states must also make way in their own legislation for the use of DB in transportation construction (DBIA 2012). At this point in time, some states have opened legislative doors for the use of DB in transportation construction with no restrictions while legislation in other states allows for the use of DB on a limited basis or with approval by government entities. In a very small number of states, there is no legislation regarding the use of DB in transportation construction or the practice is expressly forbidden (Tran and Molenaar 2013). Although DB still is not completely accessible to all public owners as a means of project delivery, there has been great progress made towards the adoption of DB at the federal and state level.

2.3.4 Transportation Construction Performance Metrics

Gransberg (2003) stated that one of the most pressing needs regarding the adoption of DB in transportation construction is the production of reliable project performance metrics. The production of these metrics enables the objective evaluation of transportation projects delivered by different PDSs, including DB or DBB, allowing DOTs to make better decisions when considering project delivery systems. This section will summarize the progress that has been made to date in the production and study of these metrics. See Table 2.3-A for a summary of the metrics considered in each study.

Table 2.3-A: Performance Metrics Considered in Recent Literature

Year	Author	Schedule Growth	Project Delivery Speed	Construction Speed	Total Cost Growth ⁺⁺	Cost per Lane-Mile	Number of Change Orders	Cost of Change Orders	Owner Satisfaction	Quality	Number of Claims	Cost of Claims
2005	Warne											
2006	FHWA											
2007	Shrestha et al.											
2012	Shrestha et al.											

Cell highlighting indicates which variables were actually tested in a given study.

⁺⁺ As explained in the body of this paper, each of the studies considered here defined cost growth with slight variations.

Most factors measured in the studies described in this section were consistent between studies in terms of measurement method and calculation with the exception of the cost growth categories. Each of the mentioned studies used derivations of four primary descriptions for cost growth, which included cost growth, total growth, contract growth, and award growth. Between some studies, the calculation for this growth was the same, but the naming convention differed. For others, the naming convention was the same, but the calculation method differed. Table 2.3-B summarizes the naming conventions and calculation technique used for each of the studies.

Table 2.3-B: Cost Growth Metrics Utilized in Transportation Literature

	<u>Award Amount – Estimate</u> Estimate	<u>Total Cost – Award Amount</u> Award Amount	<u>Total Cost – Estimate</u> Estimate
FHWA	Award Growth	Contract Growth	Total Growth
Shrestha 2007	-----	-----	Cost Growth
Shrestha 2012	Contract Award Growth	Total Cost Growth	-----

In 2005, Warne et al. published a report investigating the effectiveness of DB in highway construction through the analysis of a group of 21 DB projects completed in the United States. This study compared the performance of these DB projects with generalizations observed in the construction industry of DBB projects. This study did not, however, make direct comparisons with statistical significance testing between performance metrics of DBB and DB projects. This study considered DB effectiveness in four different areas: schedule, cost growth, quality, and owner satisfaction. In terms of schedule considerations, a majority of projects (76 percent) included in this data finished ahead of their original schedule. Owners of all of the projects were asked to compare how the use of DBB could have changed the outcome of the project. All owners that considered the comparison to be applicable stated that the choice of DBB as the PDS would have resulted in a project duration longer than that of the DB delivery. Cost growth in this study was defined as the percentage of change between then total design and construction costs and the contract award amount. This study reported an aggregate cost growth of four percent for all DB projects included in the dataset. In this study, owners also estimated that the average cost growth of their DBB project as five to ten percent. This study reported that there was no difference in quality observed in DB projects. Although all owners reported that they were satisfied with their DB project, this factor was not considered in the scope of the comparison to DBB.

As a requirement of the previously mentioned SEP-14 initiative, the FHWA (2006) published the first study exclusively dedicated to the evaluation of DB in transportation project delivery. This study evaluated the effectiveness of DB's use throughout SEP-14 both on an entire DOT program and on an individual project basis. The project level evaluation of this study was performed with two different sets of project data: one that considered all 69 completed DB project surveys with the goal of investigating current procedural practices being used in DB (eg. bid selection practices and project selection), and one that considered the outcomes of a 17-project subset of the DB projects in comparison with 11 similar DBB projects also collected for this study. For the project comparison aspect of this study, the performance metrics utilized were similar to those that had been published in previous, non-transportation-specific PDS literature. These metrics included schedule growth, cost growth, cost per change order, and number and

cost of claims. This study measured three different kinds of cost growth referred to as award growth, contract growth, and total growth. Award growth was defined as the percentage of change between then contract award amount and the original DOT estimate for the project. Contract growth was defined in a similar fashion as cost growth in Warne et al. as the percentage of change between then total design and construction costs and the contract award amount. Finally, total growth was defined as the percentage of change between the total design and construction costs and the original DOT estimate for the project. Although significance testing was not performed on this data, the results were more favorable for DB than DBB in the areas of schedule growth, number of change orders per project, number of claims per project, and cost of individual claims when the means of the metrics were compared. It should be noted that this is the only study to consider any claim-focused metrics like number and cost of claims.

Shrestha et al. (2007) also contributed to this effort with the establishment of transportation-specific performance metrics. This study established two new, transportation-specific metrics – actual cost per lane-mile and project delivery speed – which were measured in days per lane-mile and considered total design and construction duration divided by the total lane-miles of highway included in the project. Additionally, three metrics similar to those measured in previous PDS literature were also included in this study: cost growth, schedule growth, and change order cost factor. Cost growth is defined in this study as the percentage of change between the total design and construction costs and the original DOT estimate for the project. Change order cost factor was defined as the total cost of change orders as a percentage of total project cost. Due to the lack of available information in regard to the DBB projects in the areas of cost per lane-mile and project delivery speed, statistical comparison analysis was not performed for these metrics and the DB data for these metrics was not compared with DBB. This study found that DB outperformed DBB in the area of cost growth and showed little difference in the means of the other metrics (Shrestha et al. 2007).

Shrestha et al. continued this research effort with a publication in 2012, very similar to the 2007 publication, which compared five transportation projects delivered by DB with 16 projects delivered by DBB in seven performance metrics. This study established one new transportation specific metric –

construction speed – which is similar to the project delivery speed metric in the previous study – but only considered the duration of the construction phase of the project. This study also considered six other metrics similar to those included the previous literature: actual cost per lane-mile, cost per change order, contract award growth, total cost growth, project delivery speed, and total schedule growth. In this study, contract award growth is similar to the award growth definition in the FHWA study and was defined as the percentage of change between the contract award amount and the original DOT estimate for the project. Additionally, total cost growth was similar to definition of contract growth in the FHWA study and was defined as the percentage of change between then total design and construction costs and the contract award amount. For a summary the Shrestha et al. found that DB significantly outperformed DBB in the areas of project delivery speed and construction speed. Although not statistically significant, the means of all other performance metrics considered by this study were more favorable for DBB projects than DB projects. Table 2.3-C summarizes which metrics in each of the mentioned studies showed DB to be more effective in project delivery than DBB.

Table 2.3-C: Summary of Favorable DB Findings in Recent Literature.

Year	Author	Metrics Favorable to DB	Schedule Growth	Project Delivery Speed	Construction Speed	Total Cost Growth	Cost per Lane-Mile	Number of Change Orders	Cost of Change Orders	Customer Satisfaction	Quality	Number of Claims	Cost of Claims
2005	Warne		+			+							
2006	FHWA		+					+				+	+
2007	Shrestha et al.					*							
2012	Shrestha et al.		*	*									

⁺ Indicates that statistical significance testing was not performed in these studies and projects performed by DB showed favorable, but not necessarily statistically significant, results in comparison with DBB.

^{*} Indicates that statistical significance testing was performed in these studies and DB was shown to statistically outperforms DBB in these metrics

Chapter 3

Methodology and Data Organization

3.1 Statistical Testing Methods

Statistical testing methods utilized in this research were guided primarily by the precedents set in previous PDS research and secondarily by the characteristics of the data being analyzed. Given the research questions guiding this study, statistical methods that detect differences between dataset categories were utilized for analysis. Specifically, categories were determined by independent dataset variables, and differences between the means of various dependent variables were tested. The categories of independent variables tested in this research are projects delivered by DB and those delivered by DBB. Historically, the standard two sample t-test has been predominantly used in PDS research for such statistical analysis (Molenaar and Songer 1998) (Konchar and Sanvido 1998) (Shrestha 2012). The two sample t-test is a method of hypothesis testing. For such testing, a null hypothesis is established and the data is tested against its opposite alternative hypothesis. For example, the null hypothesis, “There is no difference in the construction schedule growth of DB and DBB projects,” is tested against the alternative hypothesis, “There is a difference in the construction schedule growth of DB and DBB projects.” The results of a hypothesis test completed by the t-test is the t test statistic, which correlates to a p-value. Tests that return a p-value of less than 0.05 are considered to offer statistically significant evidence against the null hypothesis, worded as strong evidence against the hypothesis for this research. The value of 0.05 has long been established as an indicator of statistical significance and is readily accepted by the research community (Draper and Smith 1966) (Molenaar and Songer 1998). The terms “there was no statistical significance found,” or “the null hypothesis was not rejected,” will be used interchangeably throughout this research to indicate a hypothesis test that resulted in a p-value that exceeded 0.05. For this research, tests that return a p-value that approaches the 0.05 threshold, between 0.05 and 0.1, will be noted to offer weak evidence against the null hypothesis, indicating a possible weak connection between PDS and the factor being tested (Draper and Smith 1966). Hypotheses, test statistics, and p-values will be clearly communicated in Chapter 4 for each test completed.

One assumption of the two-sample t-test is that the variances of the two samples being tested are equal. For the research, Levene's test was used to determine variance equality. When Levene's test resulted in a p-value less than 0.05, Welch's t-test was used in place of the two-sample t-test. Welch's test does not require variance equality as a necessary assumption, but is essentially identical to the two-sample t-test in all other aspects. An additional assumption of both the two-sample and Welch's t-test is that both the population and sample being tested are distributed normally. Normality for each sample being tested was determined using standard Q-Q plots. To determine if samples conformed to the normality assumptions, the sample's Q-Q plots were visually inspected for a general linearity of the data, as is the standard practice. In cases where the sample showed a Q-Q plot that did not conform to a general linear shape or if the Q-Q plots appeared to be skewed, the sample's normality was found to be in question. In this case, an alternative hypothesis test was utilized. The Mann-Whitey-Wilcoxon (MWW) is a non-parametric test that considers null and alternative hypotheses similar to the aforementioned t-tests, but due to its non-parametric nature, the MWW test has an advantage when samples have a peaked or skewed distribution (Winter and Dodou 2012). Normality of the samples was tested by visual inspection of Q-Q plots. In cases where the data appeared to conform to the normality assumption, analysis was completed using the traditional t-test. In cases where this assumption was in question, the MWW test was utilized.

3.2 Variables and Metrics

In order utilize the aforementioned statistical testing methods, the collected data were organized by independent and dependent variables. Independent variables define the groups tested against various null hypotheses through the t-test methodology. In this case, dependent variables are those factors which are tested to detect the efficacy of DB. The definition of both groups is discussed throughout this section.

3.2.1 Independent Variables

Variable assignment throughout this research was guided by the research questions discussed in Chapter 1. The research questions asked what, if any, differences are observed between the outcomes and inputs of construction project delivered by different project delivery systems (PDS), specifically design

build (DB) and design bid build (DBB). For this reason, PDS was treated as the independent variable throughout the entire research process. During the data collection process, profiles were only sought for projects delivered by DB or DBB.

3.2.2 Dependent Variables

Dependent variables measured by the data collection tool were identified during the literature review stage of this research. These variables were categorized in two different groups that will be referred to as project inputs and performance outcomes. Project inputs are project traits that characterize the nature of the project. Essentially, they are project traits that could have been identified during the bid phase of the project before any construction was completed, like technical complexity or specification composition. Performance outcomes are traits that measure some aspect of the performance of the construction process, like construction schedule growth, or of the performance of the project as a whole upon completion of the construction, like cost growth. Generally, project inputs were measured in Sections 1 and 2 of the data collection survey tool, and performance outcomes were measured in Sections 3 and 4 of the data collection survey tool, though some project inputs were included in Sections 3 and 4 when appropriate. Table 3.2-A below summarizes the categories into which the dependent variables are divided.

Table 3.2-A: Categories of Dependent Variables

Project Inputs	Project Type
	Bid Context
	Design Completion
Performance Outcomes	Cost
	Schedule
	Change Management
	Quality
	Legal

It should be noted that throughout this, thesis boxplots will be used to communicate the distribution of dependent variables. As shown in Figure 3.2-A, the boxplots will be organized by the independent variable on the horizontal axis. In all cases throughout this thesis, the independent variables on the horizontal axis will be organized by project delivery system (PDS): design build (DB) and design bid build (DBB). The vertical axis shows the distribution of the dependent variable. In this case, the vertical axis is labeled AG, representing award growth. The box shown for each distribution encompasses the interquartile range (IQR), which can be described as the “middle 50 percent” of the data. The values in the IQR lay between the 25th and 75th percentiles of the variables distribution. The tails that sit outside the box represent the first and last quartiles, the values in the 0th to 25th percentiles and the values in the 75th to 100th percentiles. The line shown in the boxes represent the data’s median, or the 50th percentile. In some cases, the data are distributed in such a way that the boxplot will not conform as easily to the classic boxplot distribution, as is the case for the DBB plot in Figure 3.2-A. In this case, the extreme low value is shown alone without a tail extending down from the box so that it is clear to the observer that only one observation sits in the lower quartile of the distribution.

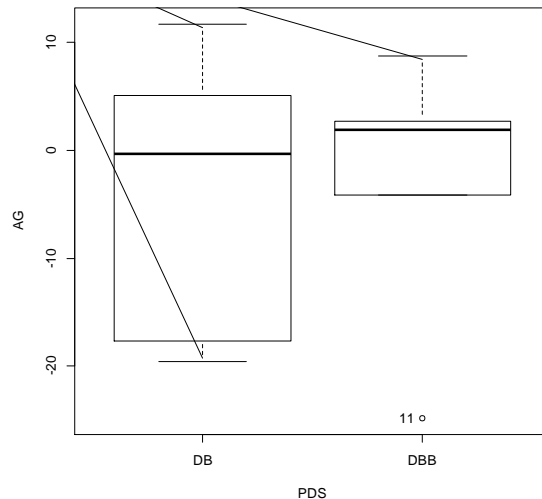


Figure 3.2-A: Sample Boxplot

3.3 Scope of Research

The scope of data for this research was established with consideration to the scope and size of a low bid design build project completed by the Wisconsin Department of Transportation (WisDOT) in 2012

known as the Milwaukee Lift Bridge Project. This project served as a major driver and funding source of this research, with the ultimate goal being that this thesis would serve as a resource that would allow WisDOT to view the Lift Bridge project in the context of the greater transportation construction industry. As such, a scope of research was selected to include projects that would be considered similar to the Milwaukee Lift Bridge project by the industry at large. The Milwaukee Lift Bridge Project was a rehabilitation and reconstruction project completed in the urban Milwaukee town center. It was delivered by Low Bid Design Build and the initial estimate of the construction and engineering costs combined was reported to be about \$26 million. The scope of this research was established to include transportation construction projects completed in the United States by state transportation agencies. Submitted projects were to be defined primarily as bridge projects. Projects were to be completed by DB or DBB within five years of the data collection period and finished after January 1, 2008. The original scope of project size was constrained to include projects with a combination of construction and engineering costs of totaling more than \$25 million and not in excess of \$200 million. As will be discussed later in this section, this scope was expanded to include projects with a combined construction and engineering cost between \$5 million and \$400 million.

As previously discussed, observation of Q-Q plots were used in conjunction with box plots throughout analysis to detect when extreme observations were present within an individual metric of the dataset. All of the projects included in the dataset are within the research data scope in terms of date of completion, size, cost, and nature of construction. Thus, the individual attributes of any of the projects in the dataset are relevant to the analysis of individual metrics. Understanding this, data points that appear to be outliers by observation of plots of individual metrics merit inclusion into the data set. That being said, in some instances there was concern that certain extreme observations held heavy influence over the analysis results. In these cases, analysis was performed both with the entire dataset and with the offending point removed from the data set. In such cases, both results are communicated.

3.4 Overview of Dataset

Prior to performing statistical analysis, periphery analysis of the data was conducted to ensure that the characteristics of the dataset were consistent and within the established scope. The dataset consisted of 18 projects.

The dataset was divided fairly evenly between the two delivery systems investigated in this research with 47 percent design bid build projects and 53 percent design build projects, as shown in Figure 3.4-A below.

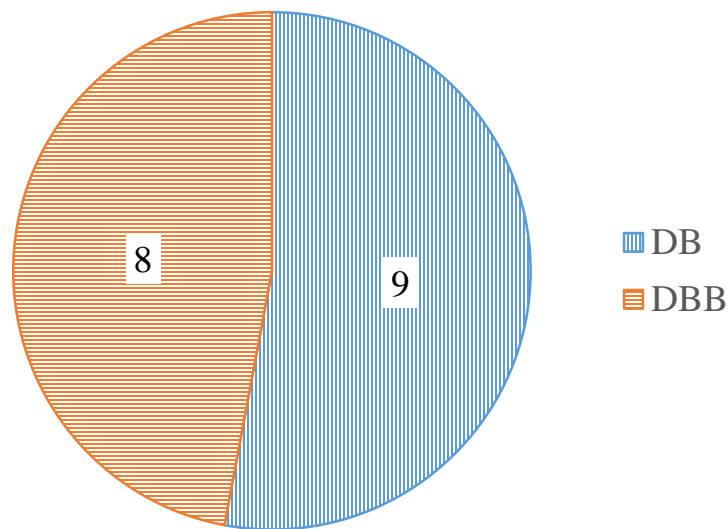


Figure 3.4-A: Distribution of Dataset by PDS

All projects submitted were within the required scope of being defined primarily as bridge projects. Individually, projects that included one, two, or five bridges each accounted for 83 percent of the dataset. The distribution of the number of bridges of each project for the entire dataset is shown in Figure 3.4-B.

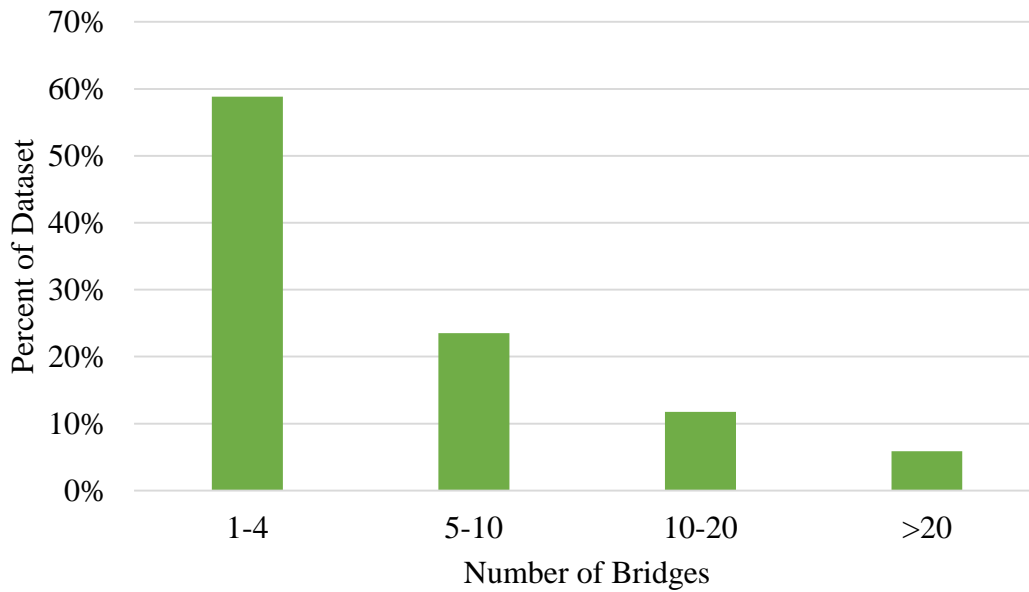


Figure 3.4-B: Distribution of Dataset by Number of Bridges

During the periphery data analysis phase, it came to the attention of the research team that 47 percent of the projects submitted for this research project were outside of the construction and engineering total cost constraint that had been established for the scope despite clear instruction of the scope in the data collection survey. The research team recognized that continuing the research with a dataset any smaller than the number of projects originally submitted could be detrimental to the data analysis effort, while an expansion of the scope to include a range of cost values that allowed for all the inclusion of the submitted data would not be detrimental to the research effort or hinder the analysis in anyway. Due to this, it was the decision of the research team to expand the scope of the research to include the projects that sat outside of the original scope rather than exclude some of the data. This range, which originally was set at a total construction and engineering cost ranging from \$25 million to \$200 million was adjusted to \$5 million to \$400 Million. The distribution of construction and engineering costs within the dataset is shown in Figure 3.4-C.

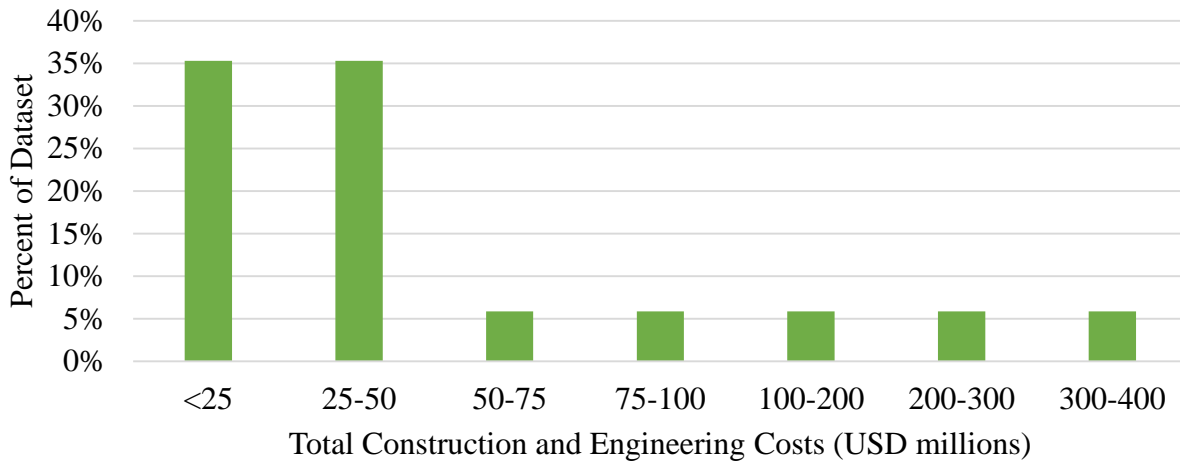


Figure 3.4-C: Distribution of Construction and Engineering Costs

The majority of projects included in the dataset were constructed on stretches of road less than 10 miles long. 38 percent of projects were constructed on stretches of roadways that spanned less than one lane-mile. The distribution of length of all roadways included in the dataset is shown in Figure 3.4-D.

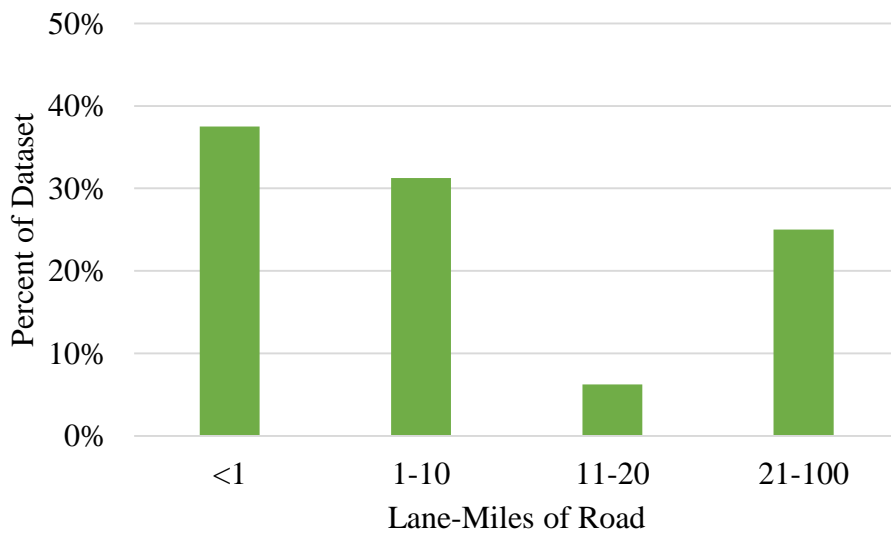


Figure 3.4-D: Distribution of Project Roadway Length

A majority of projects included in the dataset were completed in the urban context. Only 26 percent of projects were completed in the rural context, as shown in Figure 3.4-E.

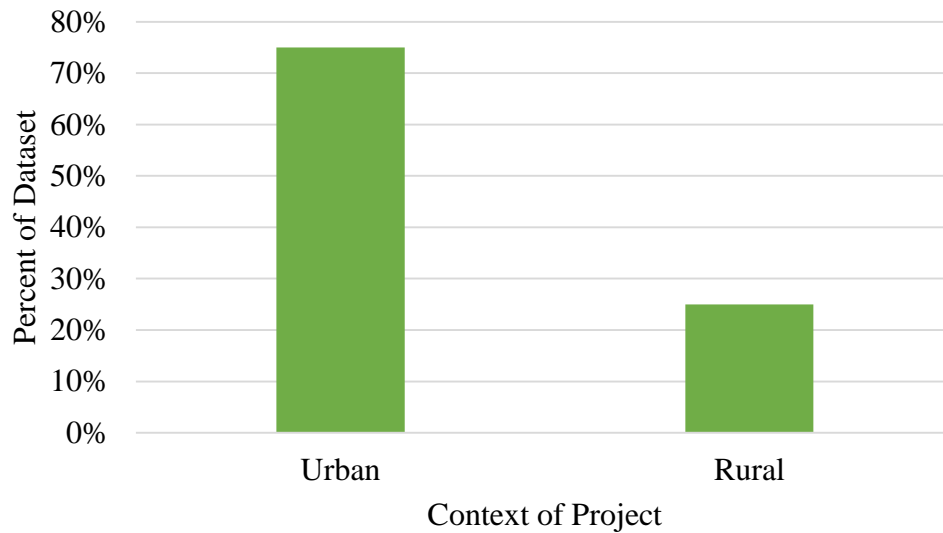


Figure 3.4-E: Distribution of Project Context

There was a fairly even distribution of projects in regards to the nature of projects being constructed, as illustrated in Figure 3.4-F with 50 percent of the projects being new construction or expansion and 44 percent of projects being rehabilitation or reconstruction of current roadway. The projects that account for the 6 percent categorized as “Other” construction generally included both new construction and rehabilitation within a single project.

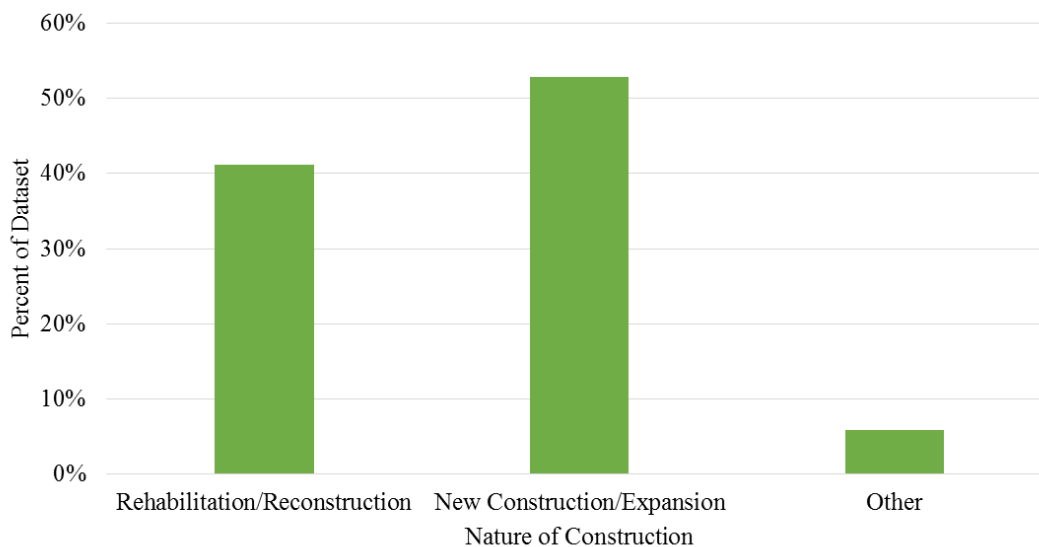


Figure 3.4-F: Distribution of Nature of Construction

Project data was solicited from 44 state transportation agencies. A total of 10 state agencies responded contributed project data to this research, with five agencies contributing data for one DB and a DBB project and four agencies contributing data only for DB projects. Outside of the five agencies that contributed two projects to the dataset, Wisconsin Department of Transportation contributed two DBB projects in addition to the single DB and DBB project requested. The map shown in Figure 3.4-G depicts this graphically, with states that contributed both a DB and DBB projects to the dataset shown in stripes and states that contributed only a DB project shown in gray. Wisconsin is depicted in black.



Figure 3.4-G: Map of Contributors to Dataset.

Chapter 4

Analysis of Performance Outcomes

4.1 Performance Outcomes Analysis

This chapter details the results of the statistical testing of the performance outcomes. The interpretation of this analysis will seek to answer the first research question of this study: “In what ways does the use of the design build project delivery system in bridge construction projects contribute to the success of the project for its owners?” Statistical testing procedures were discussed in-depth in Chapter 3. This chapter will present metric-specific inputs and outputs of each hypothesis test conducted. For all performance areas, a table summarizing statistic inputs and test results is included at the end of the section. For all performance outcomes, both the t-test and MWW were completed, and the prevailing test for each outcome is highlighted in the table. Table 4.1-A: Description of Performance Outcomes offers a summary of the performance outcomes that were tested in this research, as well as the numerical ranges of each of the outcomes.

Table 4.1-A: Description of Performance Outcomes

Outcome Category	Performance Outcome	Units	Range			
			DB		DBB	
Construction Cost*	Award Growth	% Estimate	-19.55	11.73	-24.83	8.77
	Contract Growth	% Contract	-7.72	7.63	-5.90	1.80
	Total Growth	% Estimate	-19.55	20.25	-29.27	8.77
Construction Schedule	Construction Schedule Growth	% Planned Const. Duration	-13.14	11.37	-2.41	132.54
	Burn Rate	\$ / Day	5,741	296,655	5,943	165,940
Change Management ⁺	Number of Change Orders	Total Number	1	123	7	140
	Absolute CO Cost	% of Total Cost	-1.68	50.63	-6.27	11.29
	Cost per CO	\$ / CO	548	218,904	-199,137	100,000
	Resubmittals	Total Number	0	1,000	0	1,000
Quality	Spec Conformance	Scale (1-5)	4	5	2	5
	Provision Compliance	Scale (1-5)	3	4	3	5
	Construction Quality	Scale (1-5)	4	5	2	5
	DOT Satisfaction	Scale (1-5)	4	5	2	5
Legal	Deficiency Issues	Total Number	0	1,175	0	200
	Litigation Cases	Total Number	0	2	0	0
	Claims	Total Number	0	5	0	85
	Claims (Dollar Value)	\$	0	2,000,000	0	3,500,000

* Negative values in Construction Cost outcomes indicate a final cost less than the bid value or engineer’s estimate.
 + Negative values in the Change Management outcomes indicate that the aggregate cost of change orders was subtractive to the project.

4.2 Construction Cost Outcomes

Three different cost outcomes were tested in the course of this research: award growth, contract growth, and total growth. These terms follow the precedents set in the 2006 FHWA design build publication. Some form of each outcomes has been tested in recent transportation construction PDS research, though often with slightly different naming conventions. All three metrics capture cost growth attributed to different stages of the project as a percentage of either the awarded contract or the original estimate. To reduce confusion caused by the subtleties of the naming convention, Table 4.2-A outlines the cost metric naming convention, the cost metrics calculation and the precedents for each in previous research.

Table 4.2-A: Cost Metric Summary

	<u>Award Amount – Estimate</u> Estimate	<u>Total Cost – Award Amount</u> Award Amount	<u>Total Cost – Estimate</u> Estimate
FHWA 2006	Award Growth	Contract Growth	Total Growth
Shrestha 2007	-----	-----	Cost Growth
Shrestha 2012	Contract Award Growth	Total Cost Growth	-----
Cost growth terminology utilized in this thesis matches the terminology utilized by FHWA 2006.			

For all construction cost outcomes, a negative sign preceding the percentage of growth indicates a negative cost growth in that category. In other words, when a cost outcome is found to be negative, the end stage value being considered by that metric is less than the earlier stage metric considered by the outcome. For example, an award growth value of -4.15 percent indicates that a project’s award amount was 4.15 percent less than the estimate amount. Similarly, a contract growth of -0.6 percent indicates a total cost that was 0.6 percent less than the awarded contract value.

The award growth metric measures the amount by which the awarded contract exceeds the original estimate and is communicated as a percentage of the estimate. A negative award growth metric indicates that the value of the contract awarded is below the original engineer’s estimate. For this metric, five of nine DB projects and five of eight DBB projects submitted adequate information to calculate the award growth. The comparative boxplot in Figure 4.2-A shows that the DB projects have a lower median award growth than the DBB projects. The means of the two categories are less variable than the medians, with DB sitting at -4.15 percent and DBB sitting at -3.11 percent. Visual inspection of the Q-Q plots showed the data to be in conformance with the t-test normality assumption, and Levene’s Test for Homogeneity of Variance showed that there was no significant difference in variance of the two groups with a p-value of 0.58. Given these facts, the means were compared using the two-sample t-test against the null hypothesis: “There is no difference in the mean award growth of DB and DBB projects.” The t-test resulted in a p-value of 0.91, indicating no significant difference between the two groups.

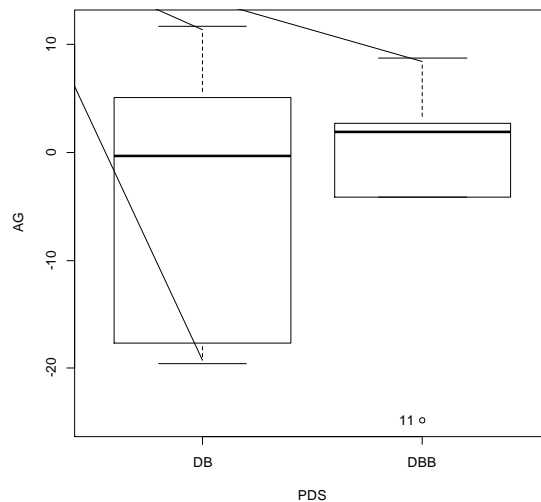


Figure 4.2-A: Comparative Boxplot of Award Growth Metric

Contract growth measures the proportion by which the final construction cost exceeds the awarded contract, as a percentage of the original contract. A negative award growth indicates that the total construction costs were lower than the value of the awarded contract. Five of the nine DB projects and six of the eight DBB projects submitted adequate information to calculate the contract growth metric. From the comparative boxplot shown in Figure 4.2-B, it is evident that the medians of the two categories are quite

close. The means of the DB and DBB projects respectively are 1.12 percent and -0.6 percent. Levene’s test resulted in a p-value of 0.14 indicating no significant difference in variance and Q-Q plots of each group indicated general conformance to the linearity assumption. Means of the groups were compared using the two-sample t-test with the null hypothesis: “There is no difference in the mean contract growth of DB and DBB projects.” The null hypothesis was not rejected with a p-value of 0.5417.

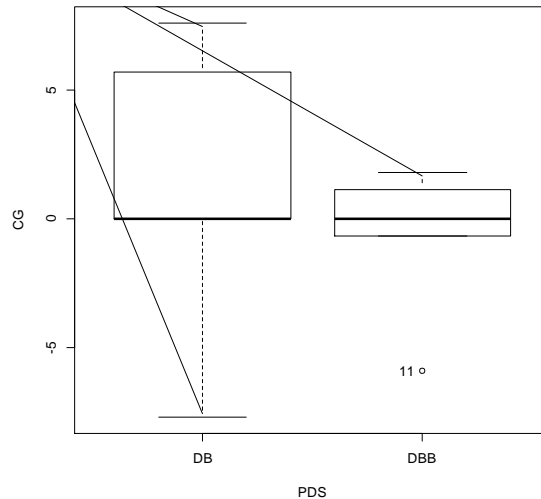


Figure 4.2-B: Comparative Boxplot of Contract Growth.

Total growth communicates the difference between the final total cost of construction and the engineer’s original estimate as a percentage of the original estimate. A negative value indicates the final projects costs were lower than the original estimate. Of the projects submitted, seven of nine DB projects and five of eight DBB projects provided adequate information to calculate total growth. The comparative boxplot in Table 4.2-C: Summary of Cost Outcomes Excluding the Extreme Observation shows that there is nearly a 10 percent gap between the medians of the two samples. The means of the samples are much closer with a DB mean of -3.91 percent and a DBB mean of -3.92 percent. Visual inspection of the Q-Q plots of the DB and DBB groups showed the data to generally conform to the normality assumption, and Levene’s test resulted in a p-value of 0.71, indicating no significant difference in variance. The two-sample t-test conducted against the null hypothesis, “There is no difference in the mean total growth of DB and DBB projects.,” resulted in a p-value of 0.99, indicating no significant difference in the means of the two groups.

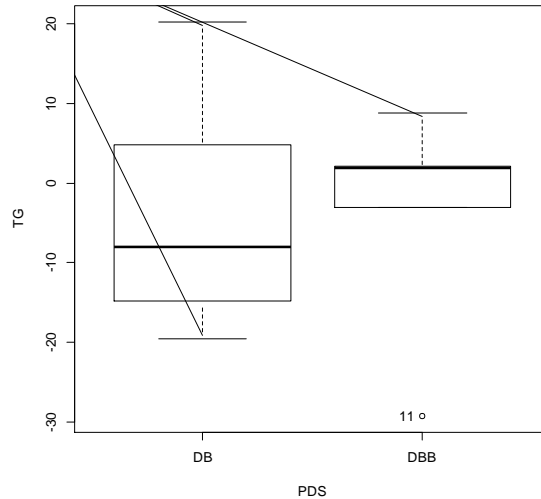


Figure 4.2-C: Comparative Boxplot of Total Growth

A summary of all of the cost outcomes is shown in Table 4.2-C.

Table 4.2-B: Summary of Cost Outcome Statistics

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Award Growth	13.90	12.97	-4.14	-3.11	0.91	1.00
Contract Growth	6.00	2.74	1.12	-0.60	0.54	0.52
Total Growth	14.39	14.78	-3.91	-3.92	0.99	1.00

* Indicates statistically significant result at the $\alpha \leq 0.05$ level.

As is evident from the boxplots of each performance outcome, there is one DBB project that appears to be an extremely low value in comparison to rest of the dataset. It is the opinion of this researcher that is data point cannot rightly be described as an outlier as the project represented by the data point is fully within the original data scope of this research. However, as the data point in question is extreme in cost metrics, there is some interest in knowing the results of the statistical tests without the influence of that point. Table 4.2-C shown below summarizes the statistical results without this project included in the dataset.

Table 4.2-C: Summary of Cost Outcomes Excluding the Extreme Observation

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Award Growth	13.90	5.28	-4.14	2.32	0.38	0.73
Contract Growth	6.00	0.99	1.12	0.456	0.82	0.67
Total Growth	14.39	4.85	-3.91	2.42	0.32	0.53

*Indicates statistically significant result at the $\alpha \leq 0.05$ level.

These results reinforce some of the previous transportation construction PDS publications preceding this research. Similar to this research, Shrestha (2012) found no significant difference between DB and DBB using two-sample t-test analysis in the areas of award growth and contract growth. In the 2006 FHWA study, which included no statistical means testing, larger gaps were seen in all cost growth metrics. For all three metrics in this study, the mean of the DBB project was lower than the DB projects.

4.3 Construction Schedule Outcomes

It has been the opinion of the research community that due to the nature of transportation construction projects, DB holds the most promise over DBB for the transportation construction industry in potential schedule improvement (Gransberg 2003). PDS research in transportation construction has also generally agreed with this assertion, showing that DOT project managers believe that delivering transportation construction projects by DB could consistently reduce project delivery time in comparison to delivery by DBB (FHWA 2006).

Construction schedule growth is defined in this research as the difference in the actual construction schedule duration and the planned schedule duration as a percentage of the planned schedule duration. This research defined the beginning of construction as the date that the notice to proceed was issued and defined the construction end as the date that substantial completion was reached. Five of nine DB and five of eight DBB projects submitted data adequate to calculate construction schedule growth. As shown in the comparative boxplot in Figure 4.3-A, the median of the DB projects sits much lower than the median of the DBB projects. Similarly, the mean of the DB projects is -0.22 percent and the mean of the DBB projects is 56.10 percent. Visual inspection of Q-Q plots of the data groups showed the data conformed to the normality assumption and Levene's Test resulted in p-value of 0.08, indicating that there was not a significant difference in the means of the sample groups. The two-sample t-test conducted against the null hypothesis, "There is no difference in between the construction schedule growth of DB and DBB projects," resulted in a p-value of 0.04 causing the null hypothesis to be rejected. Therefore, based on the reduction of schedule

growth, it can be concluded that the choice of DB as the PDS in bridge construction projects has a desirable effect on the construction project schedule.

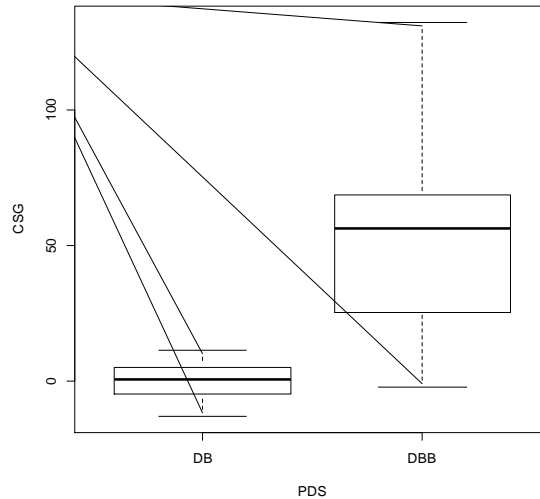


Figure 4.3-A: Comparative Boxplot of Construction Schedule Growth

It should be noted that an assumption inherent in the Construction Schedule Growth metric is that the planned construction schedule is appropriate for the level of work required by the project. Projects that do not meet this assumption, for example a project with a constrained schedule imposed by an external force, may appear to have a falsely high or low Construction Schedule Growth. This research did not attempt to measure or test for compliance with this assumption.

Previous research studies concerning PDSs in transportation construction have considered construction speed in addition to construction schedule growth using the metric lane-miles per day or days per lane-mile (Shrestha 2012; Shrestha et al. 2007). Similar research in the vertical construction industry has utilized square feet per day to measure burn rate (El Asmar et al. 2013). Due to the variability seen in the proportion of lane-miles of road and square feet of bridge deck making up a complete project between projects in the dataset, neither of these units adequately captured the burn rate of the dataset. For this reason, the measurement of burn rate in the dollars per day was chosen as a metric for this research instead of construction speed. The comparative boxplot in Figure 4.3-B shows the distribution of the burn rate metric for the DB and DBB groups. Given the total dataset, eight of nine DB project and eight of eight DBB projects submitted data adequate to calculate the burn rate. The mean of the DB sample group was found

to be \$101,774/day and the mean of the DBB group was found to be \$46,681/day. Visual inspection of the Q-Q plots showed the data did not violate the normality assumption. Levene’s test resulted in a p-value of

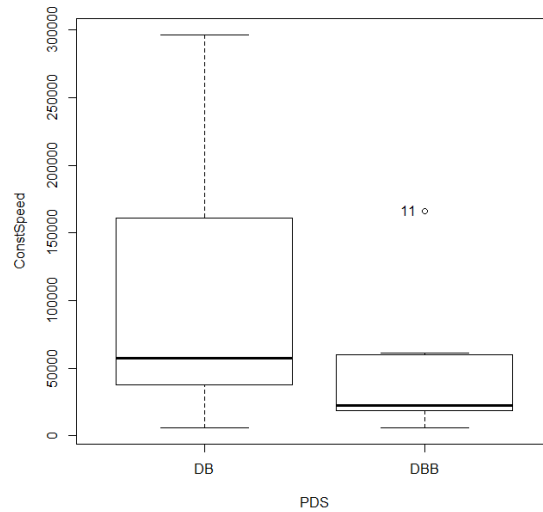


Figure 4.3-B: Comparative Boxplot of Burn Rate

0.10 indicating that the variances of the groups were not significantly different. The two-sample t-test was conducted against the null hypothesis: “There is no difference in the mean of the burn rate of DB and DBB projects.” The t-test resulted in a p-value of 0.20, indicating no significant evidence against the null hypothesis.

The results of the schedule outcomes offer some confirmation that had previously been obscure in the area of construction schedule growth. Burn rate has not previously been studied in published transportation construction research, and, thus, cannot be compared to any previous findings. The results of both schedule outcomes are summarized in Table 4.3-A. The conclusion that DB reduces the construction schedule growth agrees with widely held perceptions within the transportation community that DB has the most potential in transportation construction to improve schedule related metrics (FHWA 2006; Gransberg 2003). Previous research has been somewhat inconclusive in confirming this perception. Shrestha et al. (2007) showed the mean of construction schedule growth to be lower for DB projects than for DBB projects, while Shrestha (2012) showed the mean of DBB projects to be lower than DB projects.

Table 4.3-A: Summary of Schedule Outcomes

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Construction Schedule Growth	9.37	50.91	-0.22	56.10	0.041*	0.056
Construction Delivery Speed	102,765	52,149	101,774	46,681	0.19	0.23
*Indicates statistically significant result at the $\alpha \leq 0.05$ level.						

4.4 Change Management Outcomes

Change management outcomes primarily investigated the effects of PDS on project change orders and the related category of resubmittals. Intuitively, potential for reduction is often drawn between the use of innovative contracting methods like DB and the reduction of change orders due to the closer relationship between the design and construction entities of the project. No significant difference has been seen in change related metrics in previous transportation construction research (Shrestha 2012; Shrestha et al. 2007).

The number of change orders has not previously been investigated as a change management outcome in transportation construction research. Both sample groups in the dataset had a highly variable distribution, with the standard deviation being nearly equal to the mean for both sample group. This variability is evident in the boxplots shown in Figure 4.4-A. The mean of the DB group was found to be 46.33 change orders for projects in the DB group and 42.50 for projects in the DBB group. The distribution of both groups led to the determination of the MWW test as the prevailing test for this Outcome. Testing against the null hypothesis, “There is no difference between the number of change orders on DB and DBB projects,” resulted in a p-value of 0.75, indicating no significant difference between the two groups.

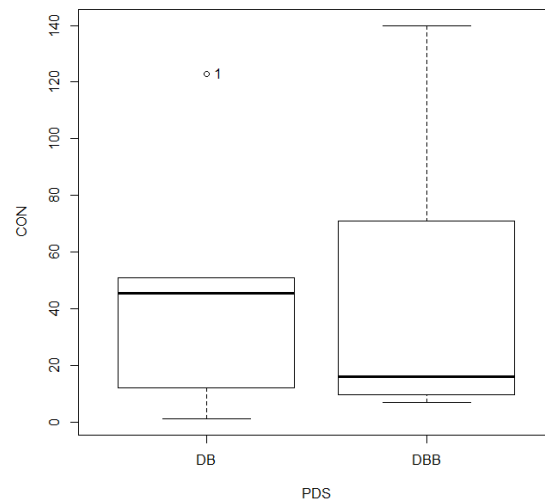


Figure 4.4-A: Boxplots of Number of Change Orders Outcome

Cost per change order, as is implied by the outcome name, was calculated by dividing the total cost of all change orders by the total number of change orders encountered for each project. Similar to number of change orders, this outcome was also seen to be highly variable with both sample groups having a standard deviation over \$90,000. This result is, however, not entirely surprising, as this outcome was also studied by Shrestha (2012) and both sample groups in that study had standard deviations of over \$140,000, nearly equal to the means of both groups in that study. The means of the DB and DBB groups in the dataset of this study were found to be \$93,263 and -\$6,311 respectively. The distribution of both groups is shown in Figure 4.4-B. The distributions of both sample groups appeared to be skewed upon observation of the groups' Q-Q plots, so the MWW test was chosen as the prevailing test for cost per change order. The data were tested against the null hypothesis: "There is no difference between the cost per change order of DB and DBB projects." Testing resulted in a null hypothesis of 0.10, indicating that there is weak evidence against this null hypothesis. This result disagrees with former conclusions about cost per change order published in Shrestha et al. (2007) and Shrestha (2012), which found no evidence that PDS affected cost per change order. It is notable to recognize that the same project that appeared to be an extreme observation for the previously mentioned Cost Outcomes is similarly an extreme negative observation for the category of cost per change order around -\$200,000. Examining the project represented by this data point more carefully, it was reported that nearly the majority of the changes, 50% as reported by the survey respondent were due to deletions in scope. This project is the only DBB project that reports such a high percentage of change orders due to scope deletion in scope. The mean of the DBB group when this point is removed from the data set is increased to \$25,826. When the MWW test is completed comparing the DB group to the

DBB group without the extreme value, the p-value is 0.18, which indicates no significant difference in the Cost per Change order between the two delivery systems.

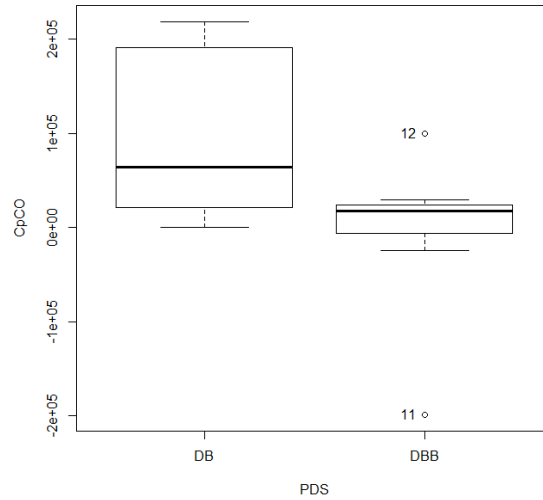


Figure 4.4-B: Boxplots of Cost per CO Outcome

Resubmittals were defined for this research as samples, shop drawings, product data, etc. Previously, a connection between this performance outcome and PDS has been unpublished. This outcome was adapted for use in transportation construction from previous PDS research done concerning the vertical construction industry at the University of Wisconsin (El Asmar et al. 2013; Olsen 2013). Generally, projects in both groups of this dataset reported a low number of resubmittals; however, one project in each group reported 1,000 resubmittals. The distribution of the dataset is shown in the strip charts in Figure 4.4-C. Due to the skewed nature of the resubmittals outcome, the MWW test was chosen as the prevailing test. The dataset was tested against the null hypothesis: “There is no different in the number of resubmittals on DB and DBB projects.” This test calculated p-value of 0.34, leading to the conclusion that PDS does not affect the number of resubmittals on a project. All change management outcome are summarized in Table 4.4-A.

Table 4.4-A provides a summary of all change management performance outcomes.

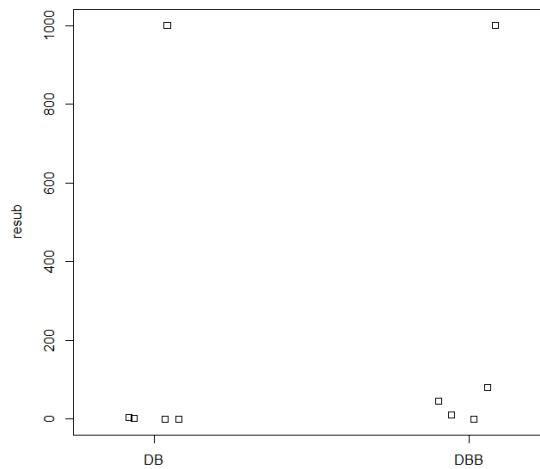


Figure 4.4-C: Strip Chart of Resubmittal Outcome

All change management outcome are summarized in Table 4.4-A.

Table 4.4-A: Summary of Change Management Outcomes

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Number of COs	42.89	49.36	46.33	42.50	0.88	0.75
Cost per CO	93,547	92,812	93,263	-6,311	0.08	0.10 ⁺
Cost per CO (Without Extreme Observation)	93,547	40,757	93,263	25,826	0.15	0.18
Resubmittals	446.66	433.27	201	227	0.93	0.34

* Indicates statistically significant result at the $\alpha \leq 0.05$ level.

⁺ Indicates a result with $\alpha \leq 0.1$, defined in this research as weak evidence against the null hypothesis.

4.5 Quality Outcomes

Quality outcomes attempted to capture suitability of construction completed from the perspective of the respective project owners, all of which are state transportation agencies. All quality outcomes were measured on a five-point Likert Scale. Survey respondents were asked to rate their satisfaction with the various quality outcomes by choosing a single answer from the Likert scale: very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied. In the analysis of the quality outcomes, very dissatisfied was coded with a value of 1, dissatisfied was coded with a value of 2, and all points continued accordingly with very satisfied coded with a value of 5. At least one sample group for each of the quality outcomes appeared to

be skewed or peaked based on visual inspection of Q-Q plots. The MWW test was used for all hypothesis testing, due to its increased power with such distributions (Winter and Dodou 2012).

The four quality outcomes measured in this study included satisfaction with the following four factors: conformance with standards/specifications, compliance with warranty provisions, overall construction quality, and overall DOT satisfaction with performance outcomes. For each quality outcome, the mean of responses for both groups was at least 3, indicating at least a neutral average satisfaction, with the mean falling below 4 – or a satisfied response – on only two occasions: once for the DB group in the compliance with warranty outcome and once in the DBB group in the overall construction quality metric. The distributions of all Quality Metrics are shown in the strip charts in Figure 4.5-A. Additionally, strip

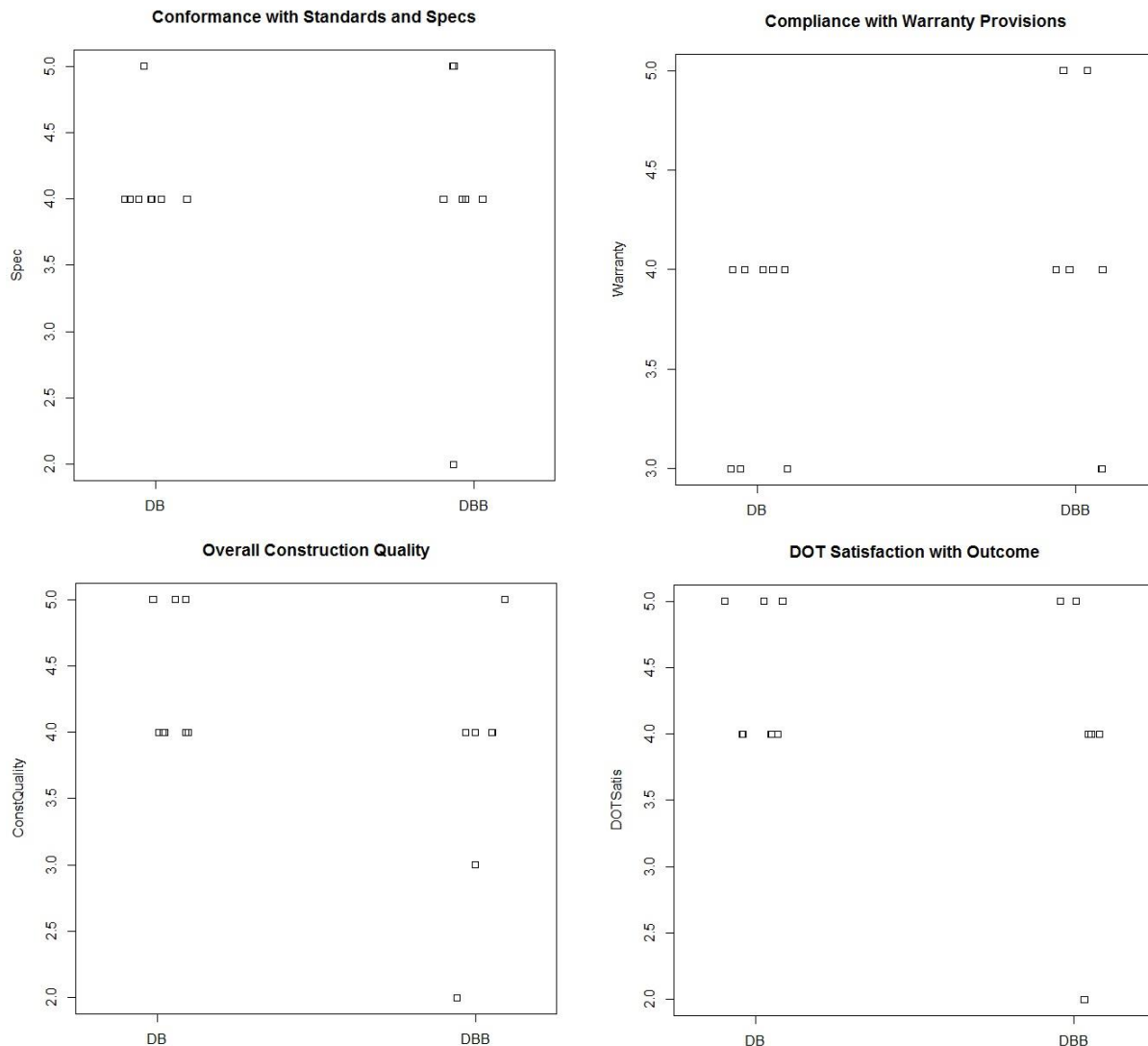


Figure 4.5-A: Quality Outcome Strip Charts

charts, rather than boxplots, are used in this section to visually communicate the distribution of the data. Due to the skewed nature of the data, strip charts are much clearer. All quality outcomes were tested against the null hypothesis, “There is no difference between the mean of the quality outcome from the owner’s perspective in DB projects and DBB projects,” using the MWW tests. The means of each sample group for each quality outcome and the p-values of each of the MWW tests are shown in Table 4.5-A below. There was no significant difference found between the DB and DBB project for any of the projects outcomes.

Table 4.5-A: Summary of Quality Outcomes

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Conformance with Standards/Specs	0.35	1.00	4.125	4.00	0.75	0.94
Compliance with Warranty Provisions	0.52	0.82	3.63	4.00	0.30	0.37
Overall Construction Quality	0.52	0.96	4.38	3.71	0.11	0.15
Overall DOT Satisfaction with Outcome	0.52	1.10	4.38	4.00	0.41	0.66

* Indicates statistically significant result at the $\alpha \leq 0.05$ level.

Previous studies concerning PDS in transportation construction have published results attempting to measure differences in quality between DB and DBB. Given that no quality outcomes showed a significant difference between the means of the DB and DBB groups, it can be asserted that the choice of PDS in bridge construction projects does not affect the quality of the project from the owner’s perspective.

4.6 Legal Outcomes

Legal outcomes are closely related to the quality outcomes as defined by this research. Both categories of outcomes are post-construction oriented metrics that attempt to capture the suitability of construction completed from the perspective of the respective project owners. The legal outcomes differ from the quality outcomes in that the legal outcomes reach beyond simple levels of satisfaction or dissatisfaction with a certain project aspect and are instead categorized as some kind of jurisdictional violation or a major quality issue that has significant legal or financial implications.

Visual inspection of the Q-Q plots of each of the legal outcomes distributions revealed that most, if not all, of the sample distributions were skewed towards the low end, with a few extreme observations at the high end. Due to this skewed nature of the data, the MWW test was the prevailing test for all legal outcomes (Winter and Dodou 2012). For reasons similar to those discussed in the previous section, strip charts will be used in this section to illustrate the metric distributions.

Deficiency issues were defined in this research as: “Issues arising from a field inspection/report, A/E, jurisdiction/code, etc. or issues requiring correction before substantial completion.” This definition for deficiency issues was adopted from previous PDS research done at the University of Wisconsin concerning the implications of PDS choice in vertical construction (Olsen 2013). The strip chart in Figure 4.6-A shows that both groups exhibited a similar low distribution of deficiency issues with one extreme observation in the DB category. The mean of the DB projects was 288 issues while the mean of the DBB group was 48 issues. The data were tested against the null hypothesis, “There is no difference in the mean of deficiency issues between DB and DBB,” using the MWW test. The test resulted in a p-value of 0.33, which offered no evidence against the null hypothesis.

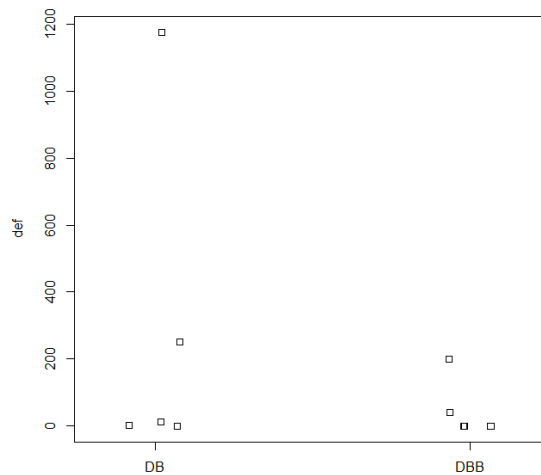


Figure 4.6-A: Strip Chart of Deficiency Issues Metric

Litigation cases were the most serious, in terms of legal implications, of the legal outcomes measured in this study. Litigation cases were reported to be present in only one of the projects in the dataset, as shown in the strip chart in Figure 4.6-C. This distribution resulted in a mean of 0.25 litigation cases for the DB sample group and a mean of 0 for the DBB sample group. The data were tested using the MWW test against the null hypothesis: “There is no difference in the mean of the number of litigation cases between projects delivered by DB and those delivered by DBB.” The p-value of this test was found to be 0.53, indicating no significant difference between the two groups.

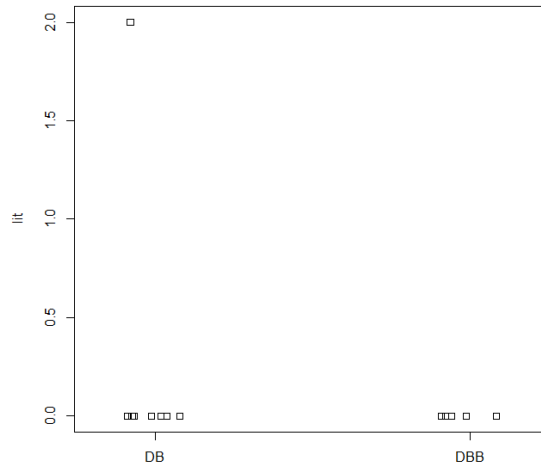


Figure 4.6-C: Strip Chart of Litigation Cases Metric

No previous research has attempted to measure a difference in the effect of PDS in the legal outcomes of transportation construction projects. Given the low number of issues reported for all legal outcomes and the fact that no legal outcomes were found to show a significant difference between the DB and DBB sample groups, it can be concluded that legal outcomes are generally project-specific and are not affected by the choice of PDS in bridge construction projects. The summary of the legal outcomes metrics is shown in Table 4.6-A.

Table 4.6-A: Summary of Legal Outcomes Metrics

Performance Outcome	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Deficiency Issues	507.08	86.72	288	48	0.35	0.33
Number of Claims	1.81	31.69	0.88	14.00	0.32	0.71
\$ Value of Claims	702,928	1,428,868	262,500	583,335	0.59	0.81
Litigation Cases	0.71	0.00	0.25	0.00	0.35	0.53

*Indicates statistically significant result at the $\alpha \leq 0.05$ level.

4.7 Conclusions

A summary of all performance outcomes is shown in Table 4.7-A. One performance outcome was found to show a significant difference when considered on the basis of PDS. Construction schedule growth was found to be significantly lower in the DB sample group of this research than in the DBB sample group. This finding is generally consistent with Shrestha (2012) which found DB to be advantageous over DBB in other schedule related outcomes, though not in schedule growth specifically.

Table 4.7-A: Summary of Performance Outcomes Test Results

Performance Area	Performance Outcome	Units	p-values	
			t-test	MWW test
Construction Cost	Award Growth	% Estimate	0.91	1.00
	Contract Growth	% Contract	0.54	0.52
	Total Growth	% Estimate	0.99	1.00
Construction Schedule	Construction Schedule Growth	% Planned Const. Duration	0.041*	0.056
	Burn Rate	\$ / Day	0.19	0.23
Change Management	Number of Changer Orders	Total Number	0.88	0.75
	Cost per CO	\$ / CO	0.08	0.10 ⁺
	Resubmittals	Total Number	0.93	0.34
Quality	Spec Conformance	Scale (1-5)	0.75	0.94
	Provision Compliance	Scale (1-5)	0.30	0.37
	Construction Quality	Scale (1-5)	0.11	0.15
	DOT Satisfaction	Scale (1-5)	0.41	0.66
Legal	Deficiency Issues	Total Number	0.35	0.33
	Litigation Cases	Total Number	0.32	0.71
	Claims	Total Number	0.59	0.81
	Claims (Dollar Value)	\$	0.35	0.53

* Indicates statistically significant result at the $\alpha \leq 0.05$ level.

⁺ Indicates a result with $\alpha \leq 0.1$, defined in this research as weak evidence against the null hypothesis.

Chapter 5

Analysis of Project Inputs

5.1 Project Input Analysis

This chapter presents the results of statistical testing of quantitative project inputs and discusses trends observed in the qualitative Project Inputs. This analysis will speak to answering the second research questions presented in Chapter 1: “Is there a difference between the project context or classification of bridge construction projects currently being delivered by the design build or design bid build?” Project inputs investigated by this research were predominantly identified through previous publications that investigated the suitability of certain projects for delivery by DB, most notably Molenaar and Songer (1998) and FHWA (2006). Testing procedures utilized for the statistical analysis will be briefly presented for each input; a more in-depth discussion of analysis methods is presented in Chapter 3. Similar to the analysis presentation in the previous chapter, the t-test and MWW test were both completed for every project input and the prevailing test for each input is discussed in the body of the analysis and documented in the summary tables for each outcome category. Table 5.1-A presents a summary of the project inputs that will be discussed in this chapter.

Table 5.1-A: Description of Project Inputs

Input Category	Project Input	Units (if applicable)	Range			
			DB		DBB	
Project Type	Technical Complexity	Scale (1-7)	3	7	3	7
	Schedule Urgency	Scale (1-7)	4	7	4	7
	Scope Flexibility	Scale (1-7)	4	7	2	5
	Utility Relocation	Scale (1-7)	3	7	3	7
Bid Context	Specification Composition	% Prescriptive Spec	10	100	20	100
	Bid Evaluation	Qualitative				
	Pre-Bid Communication	Binary (Y/N)				
Design Completion	Pre-Award Design Completion	% Complete	15	70	95	100
	Pre-Award NEPA Completion	% Complete	95	100	0	100
	Pre-Award Permitting Completion	% Complete	0	100	0	100
	Pre-Award ROW Completion	% Complete	0	100	0	100

5.2 Project Type Inputs

Project type inputs encapsulate major defining characteristics of the projects included in this research data set. Three of the four project type inputs measured in this research were included survey utilized in the 2006 FHWA survey of DB projects. The fourth, amount of utility relocation, was added for this research. Questions regarding all project type inputs placed the project being profiled in comparison to the typical project undertaken by the project's respective state transportation agency. For all project type inputs, 100 percent of both the DB and DBB projects submitted information adequate to be included in the analysis. Following the format utilized in the FHWA survey, answers were measured on a seven-point Likert scale which included in the following responses: much less, less, somewhat less, the same, somewhat more, more, and much more. For statistical analysis, the answers were coded with numbers 1 through 7, much less being coded equal to 1, less being coded equal to 2, which continued consistently to much more being coded equal to 7.

Project technical complexity was defined as the degree of technical/engineering complexity in comparison to the average project seen by the DOT undertaking the project. As shown in the comparative boxplot in Figure 5.2-A, both the DB and DBB group had similar distributions. The mean of the DB group was found to be 5.0, which correlates to the answer somewhat more. A mean of 5.5 was calculated for the DBB group, which sits just between the somewhat more and more descriptors. It should be noted that it was a requirement of all projects submitted in this research to meet the data scope requirements, which, in the case of this research, required all projects to be bridge projects. In general, it can be expected that most bridge projects would be more complex than the average project undertaken by most transportation agencies. Analysis of the Q-Q plot showed both distributions to be fairly normal, so the t-test was used as the prevailing test over the MWW test. A p-value of 0.97 was calculated by Levene's test, signifying a difference in variability between the two groups. The two-sample t-test was used for analysis and tested against the null hypothesis: "There is no difference between the relative level of technical complexity in projects delivered by DB and those delivered by DBB." The t-test returned a p-value of 0.47, indicating no

significant difference between the complexity of projects delivered by DB and those delivered by DBB. This result can be considered in view of Molenaar and Songer (1998), which found that, contrary to prominent thinking at the time, DB delivery to be well-suited for use on technically complex projects.

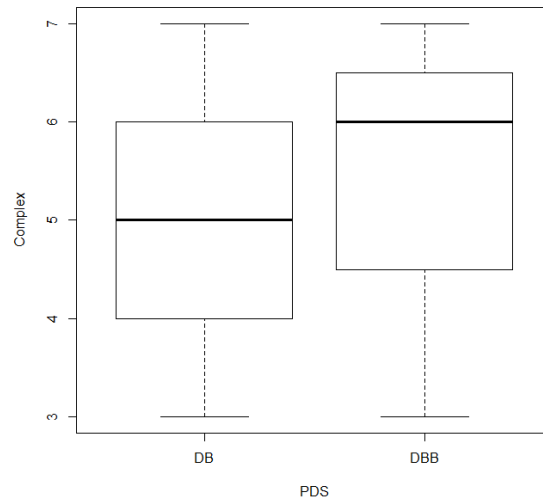


Figure 5.2-A: Boxplot of Technical Complexity

The degree of schedule urgency of each project was also measured as a project input. The distribution of this input was slightly more diverse than that observed for technical complexity, with the DB group exhibiting an almost bi-nodal distribution, as shown in the strip chart in Figure 5.2-B. For this reason, the MWW test was chosen as the prevailing test for this Input. The mean of the DB group was found to be 5.55 and a mean of 5.38 was calculated for the DBB group. Both sit between the responses worded in the data collection as somewhat more and more. The MWW test, performed against the hypothesis “There is no difference in the relative schedule urgency of projects delivered by DB and those delivered by DBB,” resulted in a p-value of 0.76 indicating that there is no difference in the schedule urgency of the two groups. This result is somewhat surprising, as it has long been ventured that DB could hold greatest potential for advantage in the area of schedule control and reduction (Gransberg 2003). Additionally, anecdotal and statistical data have also confirmed that DB does hold advantages over DBB in schedule-driven projects (Drennon and Higgins 1997; Molenaar and Songer 1998). Given the conclusion regarding construction schedule growth discussed in the previous chapter, it appears that there may be an underutilization of DB

delivery on projects that are the most apt to benefit from DB – that is, projects with a higher than average degree of schedule urgency.

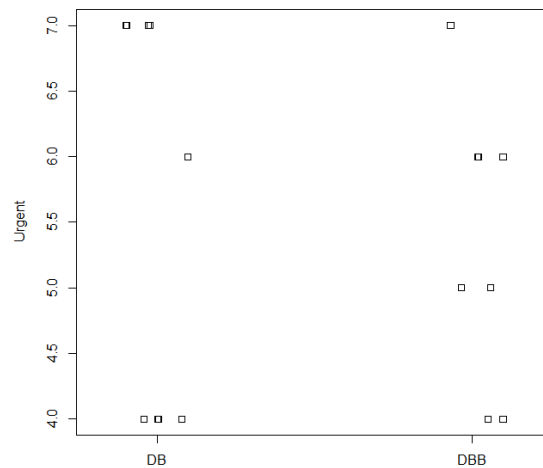


Figure 5.2-B: Strip Chart of Schedule Urgency Input

Flexibility of project scope was the final project type input adapted from the FHWA 2006 study utilized in this research. As shown in the strip chart in Figure 5.2-C, the DB sample group was found to have a slightly skewed distribution. This skewedness was also observed in the Q-Q plot, so the MWW test was chosen as the prevailing test. The mean of the DB group was calculated to be 4.88 and DBB was found to have a mean of 3.5. The ranges of both groups were notably different, with the DB group ranging from 3-7, while the DBB group ranged from 2-5. The MWW test was conducted against the null hypothesis: “There is no difference in the relative scope flexibility of projects delivered by DB and those delivered by DBB.” The MWW test resulted in a p-value of 0.04, indicating evidence against the null hypothesis. This result, which can be interpreted as DB projects having a significantly higher degree of relative scope flexibility than DBB projects, is somewhat to be expected, as DB projects must inherently include some scope flexibility in order to allow for the design entity to design the project after award.

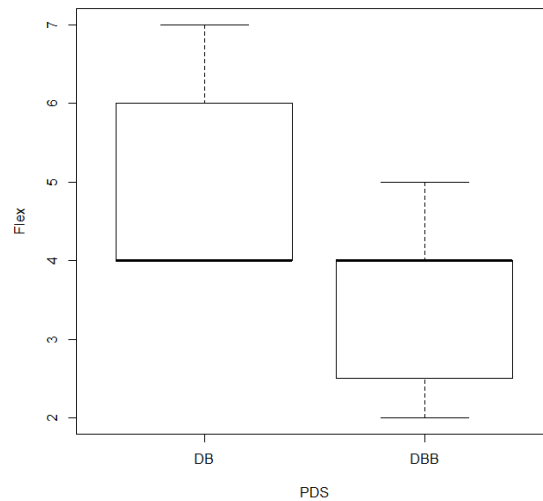


Figure 5.2-D: Boxplot of Scope Flexibility Input

The amount of utility work/relocation has not been previously studied in published work concerning the inputs regarding DB projects in transportation construction. As is evident in boxplots shown in Figure 5.2-D, both the DB group and DBB group had similar distributions for this project type input. The mean of the DB group was found to be 5.00, which correlates to the answer somewhat more, and the mean of the DBB group was found to be 4.63, which sits between the same and somewhat more. Visual inspection the Q-Q plot showed that both distributions were fairly normal and Levene’s test resulted in a p-value of 0.5316, so the two-sample t-test was chosen as the prevailing test. The t-test was conducted under the null hypothesis: “There is no difference in the relative amount of utility work/relocation between DB and DBB projects.” The t-test resulted in a p-value of 0.57, indicating no significant difference in the relative amount of utility relocation between the two sample groups.

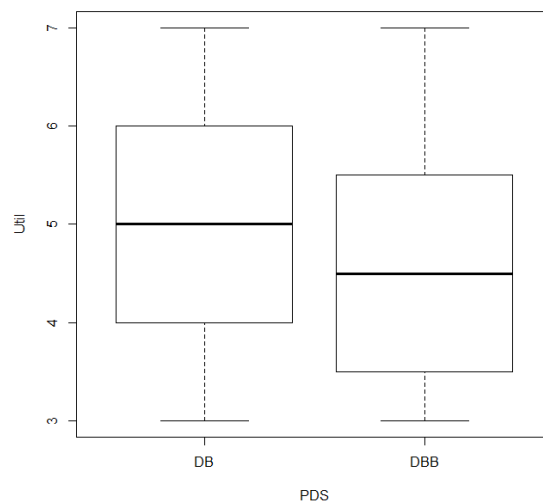


Figure 5.2-C: Boxplots of Utility Relocation Input

Analysis of the project type inputs revealed one input, scope flexibility, for which there was a significant difference between the DB and DBB sample groups. It was somewhat surprising to discover that the only schedule-related project type input, schedule urgency, was found to show no significant difference between the two sample groups. A summary of all of the project type input metrics is shown below in Table 5.2-A.

Table 5.2-A: Summary of Project Type Inputs

Project Type Input	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Technical Complexity	1.41	1.41	5.00	5.50	0.47	0.49
Schedule Urgency	1.51	1.06	5.56	5.38	0.78	0.76
Scope Flexibility	1.17	1.07	4.89	3.50	0.02	0.04*
Utility Work/Relocation	1.22	1.41	5.00	4.63	0.57	0.55

* Indicates statistically significant result at the $\alpha \leq 0.05$ level.

5.3 Bid Context Inputs

Bid context inputs include inputs that define the characteristics of the project award process. By their nature, these inputs are closely inter-connected to each other and often are seen as being dramatically impacted by project type inputs (Miller et al. 2000). Despite this, some research has found that public agencies select bid context inputs more often based on their prior experience with these inputs, choosing to pursue familiar context over those previously unexperienced by the agency (Lædre et al. 2006). This section will investigate the contrast of bid context inputs between the DB and DBB sample groups and discuss trends seen in the qualitative inputs in regard to prominent research.

5.3.1 Specification Composition

Multiple researchers have noted that as state transportation agencies continue to build familiarity with DB, delivery their propensity toward the acceptance of performance specifications also increases (Xia et al. 2011). Additionally, it has been noted that the flexibility offered by performance specifications over traditional prescriptive specifications make specifications with a higher degree of performance based requirements better suited for DB project delivery (Molenaar et al. 1999). Understanding that performance specifications allow for greater innovation and can offer greater opportunities for contractors, some state

transportation agencies in the U.S. are shifting to predominantly performance based specs for all project delivery methods, even DBB (MoDOT n.d.). During the pilot survey stage of this research, one respondent in a state DB coordinator position at a state DOT office stated that they expected to see a much more prominent shift across all state transportation agencies in the U.S. toward a greater use of performance specifications. In 2006, the FHWA found that state transportation agencies were utilizing prescriptive and performance specs with about the same frequency in both DB and DBB projects (FHWA 2006).

The specification composition input is defined as the proportion of the specification that is made up of prescriptive, traditional specifications. Respondents of the data collection survey were asked to specify what proportion of the profiled project's specification set was made up of prescriptive or performance specs. The total of the two was set to equal 100 percent. As seen in Figure 5.3-A below, distribution of the data groups follows the generally expected pattern, with more DB projects utilizing a lower percentage of prescriptive specs. It should be noted that all but one DBB project reported that the project specification set was comprised of at least 75 percent prescriptive specification, while there was a single extreme low value in the DBB data group, reported to be 20 percent. This data point appears at first glance as an outlier that should be excluded from the specification composition analysis. Upon closer inspection, this point was found to be an accurate observation from a project completed by a state transportation agency that has been extremely progressive in their adoption of performance specifications for all projects undertaken by that agency. Given this, it is reasonable to see this data point as the beginning of what is expected to become a more prominent trend in the U.S. construction transportation industry, and, thus, within the scope of data for this input. Simultaneously, it could be argued that the adoption of a specification set comprised of such a low percentage of prescriptive specifications for a DBB project is still

an anomaly among U.S. state transportation agencies, and this point represents an outlier to the input. As both arguments hold valid weight, testing under both scenarios is detailed in the following paragraph.

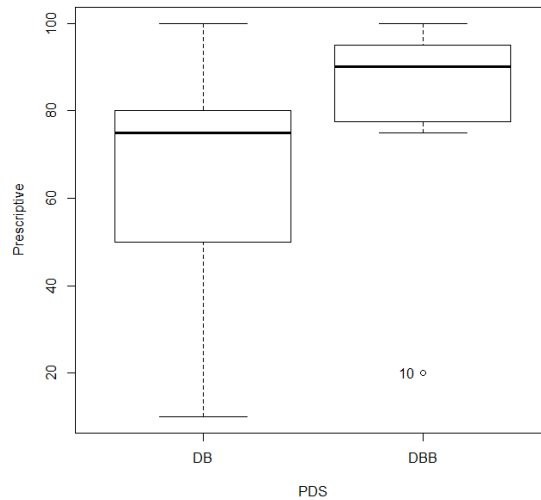


Figure 5.3-A: Boxplots of Specification Composition Input

Considering the dataset with the extreme value, the mean of the DB group was found to be 58.89 percent and the mean of the DBB group was found to be 80.63 percent. Additionally, 44 percent of the DB projects utilized a specification set comprised of 50 percent or fewer prescriptive specifications, with only one project reporting the use of 100 percent prescriptive specifications. Without the extreme value, the mean of the DBB group increases to 89.29 percent. For both cases, the distributions of the data appeared to be non-normal upon analysis of the Q-Q plots, so the MWW test was as the prevailing test for the input. Both cases were tested against the null hypothesis: “There is no difference in the specification composition of DB and DBB projects.” Testing of the full dataset resulted in a p-value of 0.07, and testing of the dataset without the extreme value resulted in a p-value of 0.02. These results, summarized in

Bid Context Inputs	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Specification Composition (With Extreme Value)	31.70	25.97	58.89	80.63	0.15	0.07 ⁺
Specification Composition (Excluding Extreme Value)	31.70	9.32	58.89	89.29	0.02	0.02 [*]

* Indicates statistically significant result at the $\alpha = 0.05$ level.
⁺ Indicates a result with $\alpha \leq 0.1$, defined in this research as weak evidence against the null hypothesis.

Table 5.3-A, suggest that when compared with traditional DBB, there is a significant difference in the specification composition of DB projects. This trend may be changing, as a p-value of 0.07 returned by the full data set suggests only weak evidence against the null hypothesis.

Table 5.3-A: Summary of Bid Context Inputs

Bid Context Inputs	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Specification Composition (With Extreme Value)	31.70	25.97	58.89	80.63	0.15	0.07 ⁺
Specification Composition (Excluding Extreme Value)	31.70	9.32	58.89	89.29	0.02	0.02 [*]
[*] Indicates statistically significant result at the $\alpha = 0.05$ level. ⁺ Indicates a result with $\alpha \leq 0.1$, defined in this research as weak evidence against the null hypothesis.						

5.3.2 Bid Evaluation

As the use of DB in the transportation industry has continued to rise, the methods of bid evaluation and contract award have also continued to evolve. Many stakeholders prefer the low-bid bid evaluation method that has been prominent in traditional DBB delivery since its inception due to its outward appearance of fairness and public transparency. However, simple low-bid evaluation has been found to be difficult to utilize well in DB, as it has little room for regard of design differences between DB bid packages (Molenaar et al. 1999). That is not to say that low-bid evaluation has no place in DB bid evaluation; Gransberg and Senadheera (1999) found it to be a prominent evaluation method, along with two other methods identified as adjusted score and best value evaluation. Understanding this, studies have consistently found that the bid evaluation method utilized to award DB project contracts are crucial to the success of DB projects and are most effective when chosen on based on each individual project's characteristics (Gransberg and Senadheera 1999; Miller et al. 2000; Xia et al. 2013).

Table 5.3-B: Description of Bid Evaluation Methods

Evaluation Method	Description
Low Bid*	Projects awarded to the lowest responsible bidder solely based on price.
Adjusted Bid*	Separate technical and price proposals are submitted; the technical proposals are evaluated and given a score out of 100. The price proposals are then divided by the technical score, resulting in an adjusted score. The contract is awarded to the lowest adjusted score.
Weighted Criteria*	Separate technical and price proposals are submitted; the technical proposal is scored in various criteria, each with a previously determined weight. The price proposal is also assigned a weight. Criteria scores and the price are each multiplied by their respective weights. The highest cumulative score is awarded the bid.
Quantitative Cost-Technical Trade-Off +	Separate technical and price proposals are submitted. A total project score is determined using individual evaluation scores in weighted categories. The bids are sorted from low to high price, and the percent incremental difference between bids is then calculated. The lowest price bid will be awarded if its incremental difference between it and the technical score of the next-lowest bid exceeds the incremental difference of the prices. If it does not, the same procedure is attempted on the second lowest bid until this criterion is met.
Fixed Cost-Technical +	Only a technical proposal is submitted. Evaluation is 100 percent technical and all bids come in at the same, fixed price, specified in the RFP by the DOT.
* Definitions adapted from Gransberg and Senadheera 1999	
+ Definitions adapted from FHWA 2006	

Evaluation methods utilized by the DB and DBB projects in the dataset were vastly different. Respondents to the data collection survey were asked to identify which evaluation method was utilized to award project contracts from a list of five evaluation methods found to be prominent in the transportation construction industry – outlined in Table 5.3-B – with the option to write in an evaluation method that differs from any of those included. Analysis of the data set showed that no evaluation method was utilized prominently over the others to evaluate project bids in the DB sample group, suggesting that bid evaluation methods vary greatly on a project-by-project basis. As is shown in Figure 5.3-B, every evaluation method was used in at least 11 percent of the projects, with three categories being used to evaluate 22 percent of the DB projects each. Figure 5.3-B also shows no variation was found in the DBB sample group, in which low bid was utilized as the bid evaluation method for 100 percent of the projects in the DBB sample group.

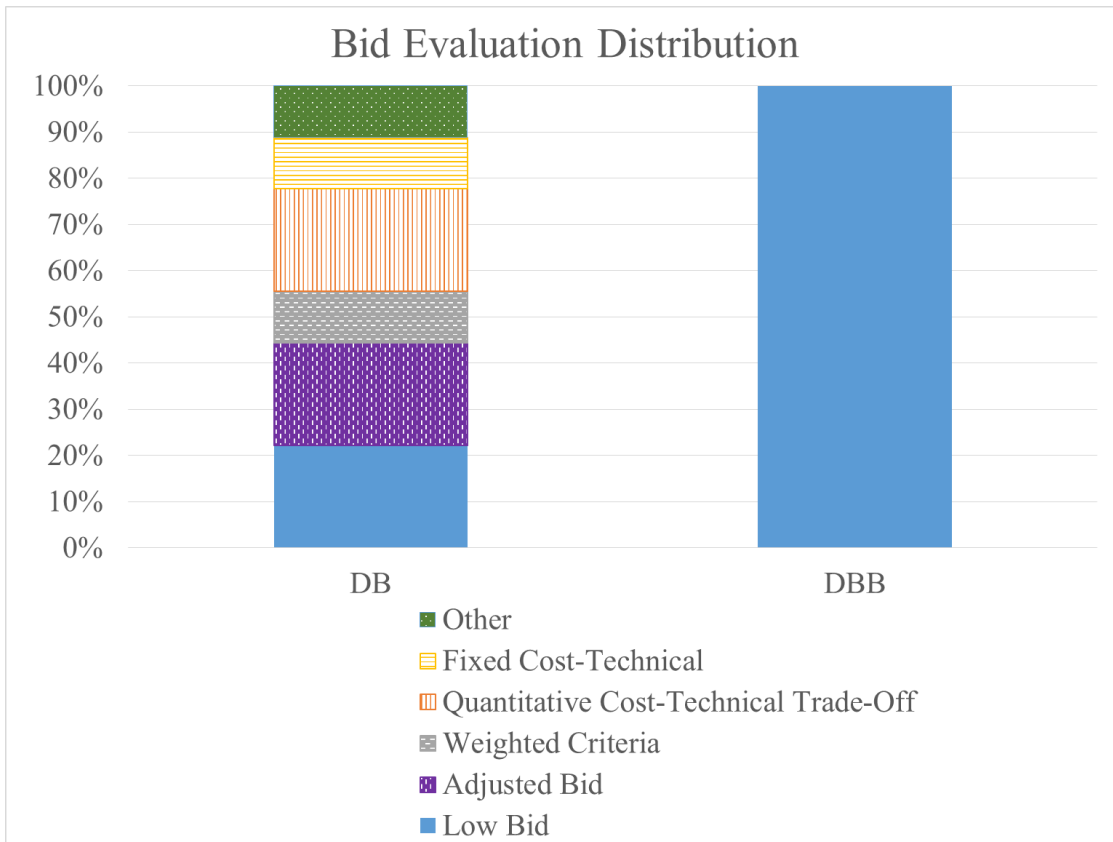


Figure 5.3-B: Distribution of Bid Evaluation Techniques

5.3.3 Pre-Bid Communication

During the pilot survey phase of this research, one DB coordinator identified the single most important aspect of his company's DB program as the culture of continued communication between the state transportation agency and local contractors participating or considering participation in the DB program. Among other efforts, this communication took the form of pre-bid meetings before the bid package due date on every DB project executed. For this reason, pre-bid communication with contractors was measured by this research. Research participants were asked whether a pre-bid conference or meeting was held for prospective bidders on the project being profiled; if respondents answered yes to that question, they were also asked to respond to whether the meeting was mandatory for bidders. Figure 5.3-C below shows the distribution of responses for this question. Pre-bid communication was much more common for DB projects than for DBB projects. Pre-bid conferences were held prior to the bid package deadline for 89 percent of DB projects and only held for 28 percent of the DBB projects. It is interesting to note that for both sample groups, half of the projects that held pre-bid conferences categorized them as mandatory.

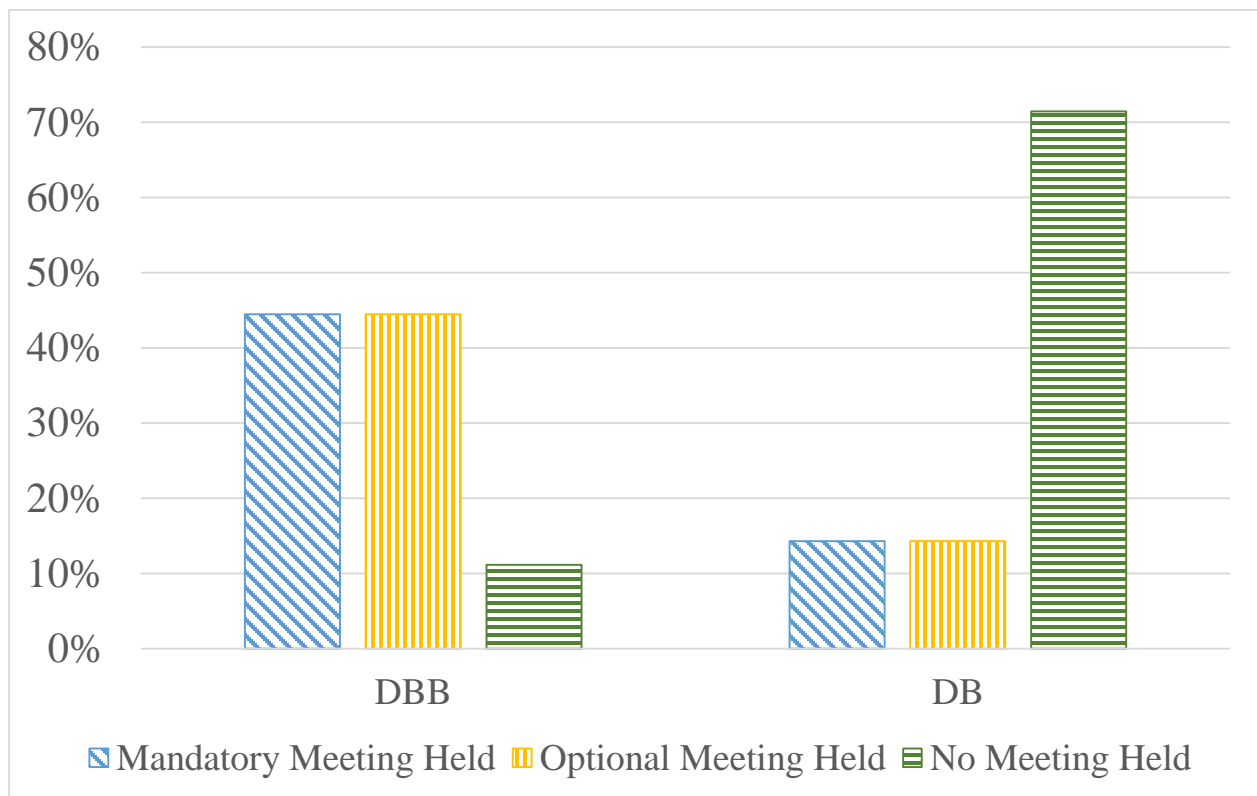


Figure 5.3-C: Distribution of Pre-Bid Communication Input

5.4 Detail Completion Inputs

This section will discuss four different areas of detail completion that generally need to be completed prior to construction or early in the construction process of transportation construction projects: construction design, NEPA clearance, permit acquisition, and ROW acquisition. NEPA clearance includes environmental clearances like environmental assessments or impact statements, which are customarily required for public transportation projects. Permit acquisitions include permits like water or air quality, noise levels, or locally required permits. ROW (right-of-way) acquisitions include the private land parcel acquisitions required for the project. This research investigated the actual percentage of each of the mentioned tasks completed prior to the contract award for both DB and DBB projects. Additionally, research participants were asked to provide their opinion of the optimal percentage of detail completion of each of the tasks that should be completed prior to contract award for a DB project. This section will include results and conclusions concerning both the percentage observed in the data set and the optimal percentage.

5.4.1 Design Completion

As was expected, analysis of the project datasets revealed a stark difference between DB and DBB in the percentage of design completed prior to award. As is evident in the boxplots shown in Figure 5.4-A, only one project delivered by DBB had less than 100 percent design complete at project award, while there was a much wider range of design completion when considering the DB projects. Figure 5.4-A also shows the distribution of the optimal design complete prior to contract award, according to the opinion of the survey respondents. The mean of the DB sample group design completion was calculated to be 37.5 percent while the DBB sample group mean was calculated to be 99.38 percent. The mean of the optimal design completion in the opinion of the respondents was found to be 31.67 percent. Visual inspection of the Q-Q plots of both distributions revealed the populations to be non-normal, so the MWW test was utilized. Testing against the null hypothesis, “There is no difference between design completion at contract of DB and DBB projects,” returned a p-value of 0.00097, indicating a significant difference between the amount of design completion prior to award between DB and DBB. Similar testing was done between the DB

sample group and the optimal design completion group. A p-value of 0.47 was found when the DB sample group was tested against the optimal design group. This result indicates that there is not a significant difference between the level of design complete of the DB projects in the dataset and the optimal level of design complete for DB projects prior to contract award.

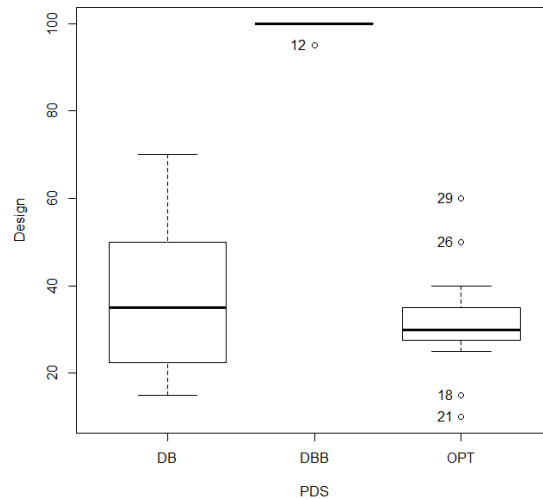


Figure 5.4-A: Boxplots of Design Completion

Optimal level of design completion prior to contract award has been a prominent topic of research in recent years. In a 2006 publication, the FHWA recommended that no more than 30 percent of design be completed prior to the execution of a DB contract for transportation construction projects. This recommendation was based on analysis of a large sampling of DB transportation construction projects which found the average design completion prior to contract award of the DB subset sample group to be 37 percent, with 78 percent of the projects in the sample group having 30 percent or less design completion at the time of the contract award (FHWA 2006). One study that included a wide range of project across sector and project types found the level of completion prior to release of the request for proposal (RFP) to be significantly associated with project type, project size, contractor selection method and contract type. In this study, it was found that a majority – 87.5 percent – of heavy civil and highway projects have 30 percent or less design complete prior to the release of the RFP (Xia et al. 2011). The results of this research are close to the optimal levels of design completion in these publications, with the average of the DB projects

in the dataset being 37.5 percent and the respondents’ optimal percentage of design completion being 31.67 percent. Additionally, 50 percent of the DB projects in the dataset had design completion amounts less than or equal to 50 percent prior to contract award, with 75 percent of respondents considering 30 percent or less design completion at contract award to be optimal.

5.4.2 NEPA Clearance

Less variability was seen in all categories when considering the percentage of NEPA Clearances completed before contract award. As shown in the box plots in Figure 5.4-B, NEPA completion for both the DB and DBB groups was concentrated around 100 percent completion. The means of the NEPA clearances completed prior to contract award were calculated as follows: DB – 99.38 percent, DBB – 84.29 percent, and Optimal – 92.14 percent. Distributions of all three groups were found to be non-normal based on visual observation of the distributions Q-Q plots; thus, the MWW test was used for hypothesis testing. The sample data were tested against the null hypothesis: “There is no difference in NEPA clearance prior to contract award between DB and DBB projects.” This test resulted in a p-value of 0.41, indicating no difference between the two sample groups.

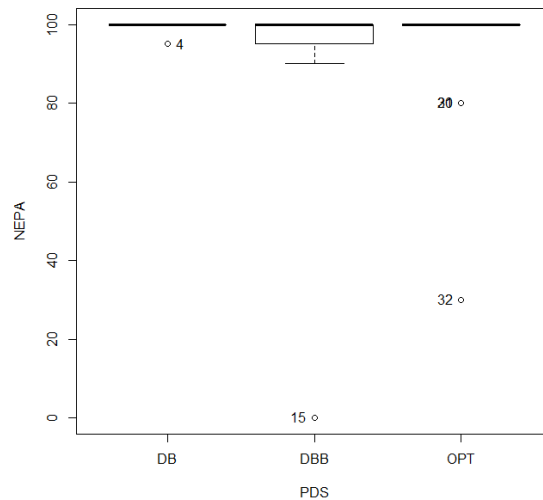


Figure 5.4-B: Boxplots of NEPA Clearance Prior to Contract Award

These results are as expected due to legislation and statutes surrounding NEPA clearances and transportation construction projects. In the 2002 Design-Build Contracting Final Rule, which outlined regulations under which design-build contracting could be applied within the Federal-Aid Highway

Program, 100 percent of NEPA clearance was required to be completed prior to the release of any DB project RFP. The 2005 SAFE Transportation Equity Act, which offered provisions to the 2002 Rule, amended the NEPA stance somewhat by allowing RFPs to be issued prior to NEPA completion. This statute still required 100 percent NEPA completion prior to the contractor continuing with the final design or construction (FHWA 2006). In that study, the aggregate group of DB projects studied had an average of 99 percent NEPA clearance completed prior to contract award. This research reflects that state DB programs, regardless of involvement with federal aid on a particular project, are generally in accordance with the federal standard. Additionally, though there were a small number of respondents that stated that the optimal percentage of NEPA completion prior to contract award was less than 100 percent – 79 percent – of respondents stated that it was optimal to have 100 percent of NEPA clearances completed prior to contract award.

5.4.3 Permit and ROW Acquisition

Permit clearance and ROW acquisitions are similar in relation to project design and completion and have been shown to be similar in completion consideration prior to DB contract award. Unlike NEPA clearance, neither category was included federal legislation surrounding DB in transportation construction. In the 2006 FHWA study, the average of both metrics in the aggregate group of DB data was found to be quite close, with the ROW acquisition average found to be 89 percent and the permit clearance average found to be 83 percent. For both inputs, the average DBB percentage complete prior to contract award was 100 percent (FHWA 2006).

Both the permit and ROW inputs were found to have similar distributions across sample groups. The boxplots for both inputs are shown in Figure 5.4-C. Visual inspection the sample groups' Q-Q plots showed the sample distributions to be skewed; the MWW test was chosen as the prevailing test for both inputs. The means of the ROW acquisition input were found to be 74.29 percent for the DB group and 82.14 percent for the DBB group. Similar means were found in the permit clearance input, with the DB mean being 66.25 percent and the DBB mean being 84.29 percent. Testing for both groups was done against the null hypothesis: "There is no difference between the percent completion of (the detail input) of DB and DBB projects." The p-values found for the ROW and permit inputs were 0.58 and 0.39 respectively, indicating no significant difference between the DB and DBB sample groups.

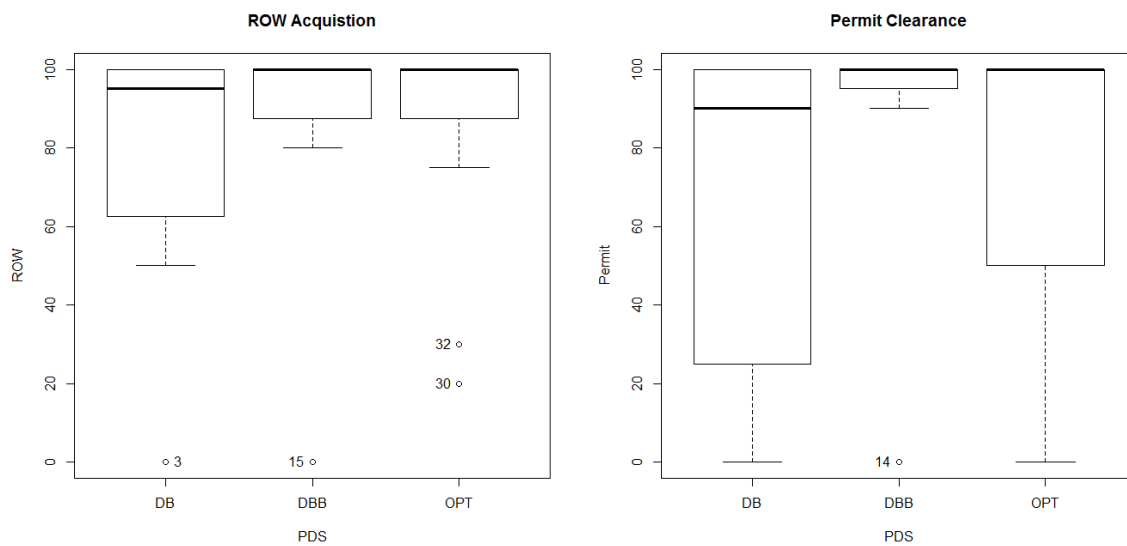


Figure 5.4-C: Boxplots of ROW Acquisition and Permit Clearance

The averages of both the ROW acquisitions and permit clearance inputs in both sample groups show an interesting trend when considered in view of the 2006 FHWA study. Recall in the FHWA study that the averages of the DB project's ROW acquisition and permit clearance prior to contract award were 89 percent and 83 percent, respectively. For both inputs, the average of aggregate DBB data was 100 percent complete before award. The data presented in this study shows that, since the publication of that research, the percent complete of both inputs in both the DB and DBB groups has been reduced by a level between 15 percent and 18 percent. This suggests that for projects delivered by DB and DBB in transportation construction, projects are being awarded with a lower average completion percentage than was previously

observed in 2006. This trend is notable and could warrant further research. Results of all detail completion inputs are shown in Table 5.4-A.

Table 5.4-A: Summary of Detail Completion Input Results

Detail Completion Input	Standard Deviation		Mean		p-value	
	DB	DBB	DB	DBB	t-test	MWW test
Design Complete	18.90	1.89	37.50	9.29	0.000032	0.00098*
NEPA Clearance	1.77	37.35	99.38	84.29	0.33	0.40
Permit Clearance	44.38	37.35	66.25	84.29	0.41	0.39
ROW Acquisition	37.69	36.95	74.29	82.14	0.70	0.58

* Indicates statistically significant result at the $\alpha = 0.05$ level.

5.5 Conclusion

Analysis of project inputs confirmed that the bridge construction dataset studied in this research conforms to the general expectations of the current transportation construction industry and revealed some surprising assumptions. Analysis of the project type inputs showed the only project type input that is significantly different between the DB and DBB sample groups is the project scope flexibility. Surprisingly, schedule urgency yielded no significant difference between the two sample groups. Analysis of the bid context inputs revealed, as perhaps expected, that the use of performance specifications is significantly more common in DB projects than in DBB projects. However, due to current trends in the construction industry, this gap may not continue to persist. Detail completion input analysis found that the significant difference seen in the amount of pre-award design did not carry over to other detail aspects.

Table 5.5-A: Summary of Quantitative Project Inputs

Performance Area	Project Input	Units	p-values	
			t-test	MWW test
Project Type	Technical Complexity	Scale (1-7)	0.47	0.49
	Schedule Urgency	Scale (1-7)	0.78	0.76
	Scope Flexibility	Scale (1-7)	0.02	0.04*
	Utility Work/Relocation	Scale (1-7)	0.57	0.55
Bid Context	Specification Composition (With Extreme Value)	% Prescriptive Spec	0.15	0.07 ⁺
	Specification Composition (Excluding Extreme Value)	% Prescriptive Spec	0.02	0.02*
Detail Completion	Design Complete	% Complete	0.000032	0.00098*
	NEPA Clearance	% Complete	0.33	0.40
	Permit Clearance	% Complete	0.41	0.39
	ROW Acquisition	% Complete	0.70	0.58
<p>*Indicates statistically significant result at the $\alpha \leq 0.05$ level. ⁺Indicates a result with $\alpha \leq 0.1$, defined in this research as weak evidence against the null hypothesis.</p>				

Chapter 6

Conclusion

6.1 Summary of Results

This research has answered the questions asked at the beginning of this report and contributes the following to the transportation construction industry's body of knowledge:

- The performance of bridge construction projects was evaluated across 17 different performance outcomes, each comparing the performance on those projects delivered by DB and those delivered by DBB. There was found to be a statistically significant difference in one performance outcome, construction schedule growth, in which DB projects were shown to outperform DBB in terms of schedule growth.
- The projects delivered by DB and DBB were evaluated across nine quantitative and two qualitative project inputs. There were found to be three inputs that showed a statistically significant difference between DB and DBB projects: scope flexibility, specification composition, and pre-award design completion.

This research will give the public transportation construction industry a deeper understanding of the effect of PDS on the outcomes of bridge construction, and will support this community in PDS selection for future bridge projects. Miller et al. (2000) suggests that there is a fundamental shift in ideology required in the construction industry, especially the public sector, towards a project delivery approach that includes a structured planning phase that considers all delivery. The outcome and input research provided in this report will support the public sector in the process of identifying projects for delivery by DB.

6.1 Research Limitations

This research analyzed performance outcomes and project inputs of bridge projects from the perspective of state transportation agencies that acted as the owners of the respective projects. The viewpoint and information provided by other project stakeholders may differ from this perspective; this research is applicable only from the perspective of state transportation agencies acting as owners of bridge construction projects. The dataset included bridge construction projects with a final construction and engineering cost ranging from \$5 million to \$400 million and may be applicable to a certain range of values outside that cost spectrum. The dataset includes projects delivered in a several diverse U.S. states, but no perspectives from states that have no experience with the use of DB project delivery.

6.2 Future Research Opportunities

The results of this research project have revealed that PDS research opportunities continue to exist in the transportation construction industry. Research similar to this study with a variable, closely focused scope of projects would provide beneficial decision-making information to state transportation agency decision-makers in their choice of PDS on a project-by-project basis. No research regarding PDS and transportation construction has been conducted from the perspective of any stakeholder outside of state and federal transportation agencies. Gaining insight into the effect of project delivery system on the partners that work closely with transportation agencies to deliver construction projects could prove to be extremely valuable in improving the project delivery process and could allow for continued improvement in the relationships maintained between public and private sector partners.

6.3 Closing Remarks

As a student in construction engineering and management, this research has served an important purpose in providing me with a unique perspective into the current state of the construction industry and allowed me to contribute, even in a small way, to the future of the industry. Obviously no single technology will be responsible for shaping the entire future of the construction industry. However, the potential for

innovation through project delivery systems has been eye-opening through the course of this research. Information gleaned through conversations and interactions with industry professionals proved not only to be vital resources to this research, but were also rewarding experiences that will continue to shape my own professional life. Although construction is an industry that is known historically for its adversarial environment and slowness to adapt, the innovation and forward thinking that I have seen in the industry through this research are quite encouraging to me as I enter into the field as a professional.

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Appendix B – Data Collection Survey

Appendix C – Sample R Code

Appendix D – Quantitative Data Summary