The Dissertation Committee for Pramen Prasad Shrestha Certifies that this is the approved version of the following dissertation:

PERFORMANCE BENCHMARKING OF LARGE HIGHWAY PROJECTS

Committee:

James T. O'Connor, Co-Supervisor

G. Edward Gibson, Jr., Co-Supervisor

Gary D. Borich

Stephen R. Thomas

Zhanmin Zhang

PERFORMANCE BENCHMARKING OF LARGE HIGHWAY PROJECTS

by

Pramen Prasad Shrestha, B.Sc., M.Sc.

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Dedication

To my wife, Arunjali Shrestha, and my daughter, Kajol Shrestha, for their love and support throughout my Ph.D. study and dissertation writing. To my parents, Shreebatsa Prasad Shrestha and Sumati Shrestha, my brothers, Ramen Prasad Shrestha and Umen Prasad Shrestha and their families, as well as to my sisters, Reema Shrestha and Reena Shrestha and their families. They all gave me the inspiration and support I needed to pursue further study and to gain more knowledge.

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PERFORMANCE BENCHMARKING OF LARGE HIGHWAY PROJECTS

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Pramen Prasad Shrestha, Ph.D.
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Supervisors: James T. O'Connor and G. Edward Gibson, Jr.

This dissertation compares and analyzes the relationship of design-build (DB) and design-bid-build (DBB) project delivery methods with performance metrics of large highway projects. Project performance is measured in terms of cost, schedule, safety, change orders, and quality on these two types of highway projects. The performance benchmarking methodology used here is derived from work done on a Texas Department of Transportation (TX DOT) study of the State Highway (SH) 130 Project. Because SH 130 is the first DB highway project in Texas and is being built under a new contractual concept called the Comprehensive Development Agreement (CDA), this dissertation establishes a framework for evaluating the performance of large DB highway projects.

The CDA approach is an innovative form of the DB project delivery method that allows the contractor to simultaneously undertake right-of-way acquisition, utility adjustment, design, and construction activities. Because this approach is being used for the first time on a state highway project in Texas, it is beneficial to track highway project performance in order to assess whether this project delivery method is a better alternative for building high priority highways.

The main objective of this dissertation is thus to compare the performance of large recent DB highway projects (in the context of SH 130) with similar on-going in-state DBB highway projects. The research hypothesis is to determine whether there is a statistical difference in mean performance between DB and DBB highway projects. For large, recently built DB highway projects (Federal Highway Administration, Special Experimental Project Number 14 & Cost > US $ 100 million) and four of the largest, most recently built in-state DBB highway projects are identified for comparison purposes. This dissertation provides a detailed methodology to collect data and gives the results of performance benchmarking of these large DB and DBB highway projects. It also investigates associations or relationships between project characteristics (input variables) and project performance (output variables) of large highway projects.

While previous analyses of DB and DBB methods have included a wide range of construction projects as varied as buildings and industrial facilities, this dissertation isolates the analysis of these two delivery approaches for large highway projects. It also helps to develop a method to collect data for benchmarking of large highway projects. This research should help TX DOT choose the appropriate delivery method for large future highway projects.

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Chapter One: Introduction

1.1 Overview

For generations, highway projects in the United States have been delivered with the traditional design-bid-build (DBB) project delivery method. In 1990, the Federal Highway Administration introduced Special Experimental Project Number 14 (SEP-14) to encourage state agencies to use more efficient alternative methods for delivering projects. As of 2002, about 140 SEP-14 projects worth $5.5 billion have been built using the design-build (DB) delivery method (FHWA, 2006). While the use of the DB method for highway projects has increased noticeably in the last decade, attempts to compare project performance for DB as versus DBB have been limited to comparisons among small projects. Therefore, this research seeks to compare performance of large highway projects built under these two delivery methods and identify project characteristics that have association with their performance.

A project delivery method is a process of designing and constructing any facility. It is a method for owners/clients "to deliver and finance constructed facilities" (Miller 1999, P 669). A typical way of constructing a facility is first to design a facility and then construct it in accordance with its detailed design. According to Loulakis and Huffman, 2000, a project delivery method is "a process by which the components of design, construction – including the roles and responsibilities, sequence of activities, cost of materials, labor etc – are combined to deliver a project."

In the construction industry, different kinds of project delivery methods have been used. Some of them are a combination of methods. A traditional way of designing first and then constructing a facility according to the completed detail design is called design-bid-build (DBB). Recently there have been several innovations in project delivery method. Some of the project delivery methods used today includes:

- Construction Manager (CM)
- Construction Manager @ Risk (CM @ Risk)
- Design-Build (DB)
- Design-Build-Operate-Maintenance (DBOM)
- Design-Build-Finance-Operate (DBFO) / Concession

In DBB, owners procure, design and construct separately, or sometimes owners perform design in-house. In this type of project delivery method, construction can not start until detailed design is complete.

In CM, the owners give construction management responsibility to a construction manager. CM @ Risk is a modified version of CM, in which the construction manager shares profit and loss of the project (Gibson and Waleskwi, 2001).

In the DB project delivery method, owners award design and construction services to a design-build contractor. The owner allocates risks associated with schedule and cost growth to the contractor. In this method, construction of facilities can start before detail design is complete. In DBOM, owners award design, construction, operation, and maintenance services to a single contractor. Similarly, in DBFO, owners award design, construction, finance, and operation services to a single contractor.

1.2 TEXAS DESIGN BUILD HIGHWAY PROJECT OVERVIEW

Interstate Highway 35 (IH-35) is the only major north-south transportation corridor through Central Texas, and the recent rapid urbanization of this area, especially around Austin, has increased traffic congestion. To relieve this traffic congestion, the Texas Department of Transportation (TX DOT) has started constructing a commuter and

North American Free Trade Agreement (NAFTA) corridor alternative to IH-35 with a system of new toll roads called the Central Texas Turnpike Project (CTTP) to meet the demands of NAFTA.

The first phase of the three-part CTTP includes the following:

- State Highway 130 (SH 130): Georgetown to US 183 South (approximately 49 miles)
- State Highway 45 North (SH 45 N): RM 620 to SH 130 (approximately 13 miles)
- Loop 1: FM 734 (Parmer Lane) to SH 45 North (approximately 3.5 miles)

As an element of the CTTP, SH 130 is the state's first highway to be constructed under a Comprehensive Development Agreement (CDA). Under this CDA, an innovative DB project delivery method was used allowing the Developer to simultaneously undertake right-of-way (ROW) acquisition, utility adjustment, design, and construction.

The length of SH 130 is 49 miles, extending from IH-35 north of Georgetown southward to US 183 southeast of Austin, and passing through Williamson and Travis Counties. SH 130 will be a four-lane toll road with major interchanges at IH-35, US 79, SH 45 N, US 290, SH 71, and US 183. Construction of SH 130 started in the fall of 2003 and is expected to be completed by December 2007. The total estimated cost of this project is $1.5 billion, including $300 million for ROW acquisition (O'Connor et. al., 2005).

Under the terms of this CDA, TX DOT has an optional maintenance agreement for SH 130 with the Developer. The organizational structure of this project is significantly different from traditional design-bid-build (DBB) projects. In this CDA, TX DOT hired a Program Manager (PM), HDR Engineering, Inc., as an extension of its staff.

The Developer, Lone Star Infrastructure (LSI), is responsible for designing and building the SH 130 highway project. LSI, then, works under the supervision of TXDOT and the PM. Figures 1.1 and 1.2 show the organizational structure of traditional DBB and SH 130 DB project delivery methods (Design Build Institute of America, 2005).

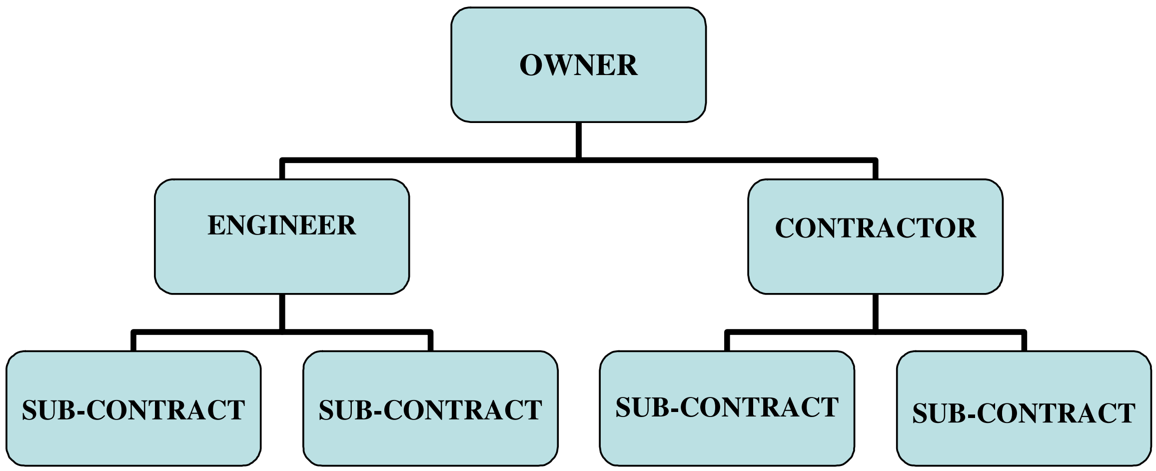


Figure 1.1: Typical Organizational Structure of DBB Project

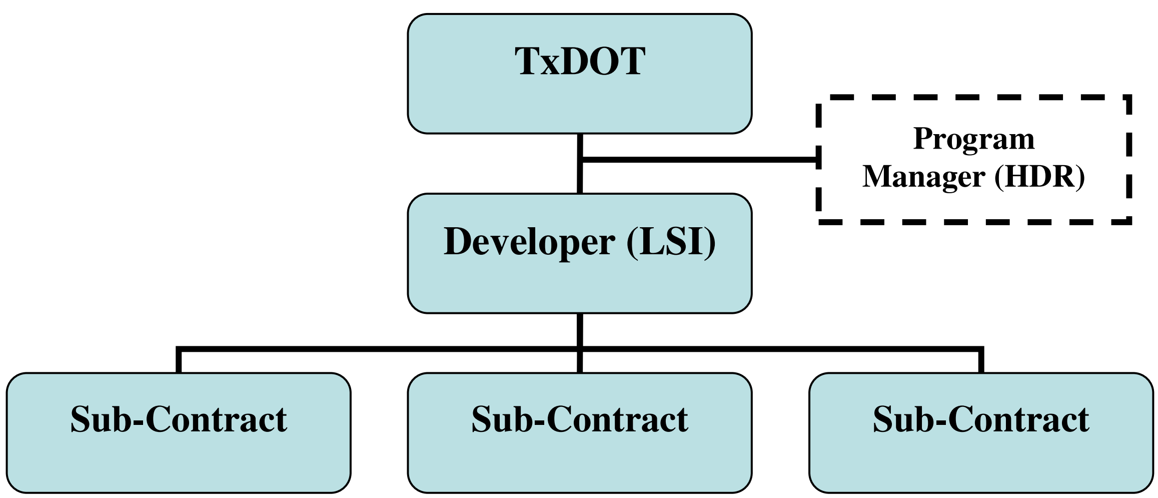


Figure 1.2: Typical Organizational Structure of DB SH 130 Project

Under this CDA, TXDOT is also constructing State Highway 45 South East (SH 45 SE) and State Highway 183A (SH 183A) using the DB project delivery method. However, State Highway 45 North (SH 45N) and Loop 1, which are parts of CTTP, are being built under a traditional DBB method.

Highway projects have different phases, including feasibility study, planning, road schematic, detail design, construction, operation, and periodic maintenance phases. The procurement system of each project phase is different in traditional DBB and DB models. Figure 1.3 shows the services covered by these two types of delivery methods in highway projects (Koppinen and Lahdenpera, 2004).

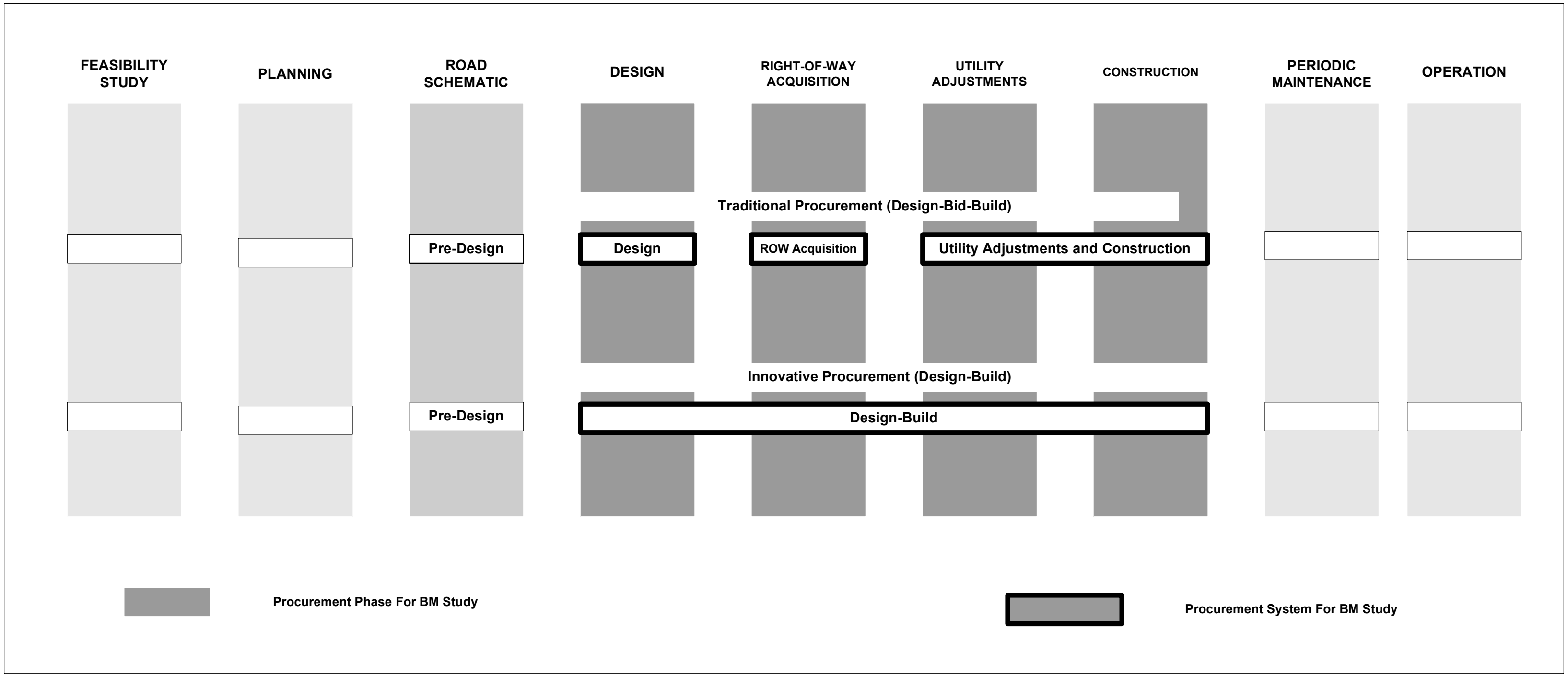


Figure 1.3: Different services covered by DB and DBB

1.3 Problem Statement

Transportation authorities in the United States are trying to find the best project delivery method that improves the quality, cost and timeliness of large highway projects. The cost effectiveness, project delivery time reduction and quality improvement are very important in large highway project, because it saves tax payers' money.

The Texas Department of Transportation has used DBB as its primary project delivery method for designing and constructing highways. However, after the House Bill 3588 was passed in the legislature in May 2003, allowing use of CDA, TX DOT started construction of SH 130, SH 45 SE and SH 183 A under the DB project delivery method.

Because of the extensive use of DB method in highway projects, it is desirable to compare the performance of DB with DBB; so that DOTs will be able to assess which delivery method should be used to improve the performance of large highway projects.

1.4 Research Need and Motive

This research helps to measure the impact of DB and DBB project delivery methods on large (>$100M) highway project performance. This study is also performed to develop a scheme to collect data for benchmarking of large highway projects built under DB and DBB project delivery methods. It also helps to identify the benefits of DB projects versus DBB projects and the variables associated with large highway project performance.

The main motives of performance benchmarking of these two project delivery methods are to:

- Develop a comprehensive method to collect data for benchmarking large (>$100M) highway projects

- Assess whether the DB process is more beneficial than traditional DBB
- Determine what improvements should be made in this process to achieve better cost, schedule, and quality performance
- Find out whether the DB process should be widely used for building high priority highways.
- Determine the input variables that have an association with large highway project performance.

1.5 RESEARCH OBJECTIVES

The main objectives of this research are to:

1. Develop an approach to benchmark large highway construction projects
2. Compare statistically the input and output variables (performance) of large DB and DBB highway projects in terms of cost, schedule, safety, change orders, and quality
3. Calculate the association between input and output variables.

1.6 HYPOTHESIS STATEMENTS

There were three research hypotheses. The first research hypothesis is: A credible method can be developed to capture and compare input variables and performance metrics for large highway projects.

The second research hypothesis is: The mean cost, schedule, safety, change orders and quality performance of large DB highway projects are different and superior to large DBB highway projects.

The third research hypothesis is: There is an association between the input and output variables of large DB and DBB highway projects.

1.7 Research Scope Limitations

The scope of this research is limited to:

1. Developing benchmarking methodology
2. Identifying input and output variables (performances)
3. Making statistical conclusions of the effects of DB and DBB project delivery methods on large highway project performance by using descriptive statistics

The limitations of this research are:

1. The cost of DB and DBB projects are greater than $100 million.
2. Performance benchmarking of DB projects reflects the performance of only four FHWA SEP 14 highway projects.
3. The current dataset does not include international projects.
4. A limited number of in-state DBB and out-of-state DB projects were selected for benchmarking.
5. Benchmarking of large highway projects include only design and construction phases.

1.8 Organization of Dissertation

Subsequent to this chapter, the dissertation is structured as follows. Chapter two presents the literature review performed to develop a benchmarking methodology for this research. Chapter three lays out the research methodology. Chapter four describes the development of input and output study variables for benchmarking. Chapter five shows the descriptive statistics of input variables of DB and DBB highway projects. Chapter six shows the descriptive statistics of output variables of DB and DBB highway projects. Chapter seven outlines the input-output variables associations of large highway projects. Chapter eight draws conclusions and recommendations of this research.

Chapter Two: Literature Review

2.1 Benchmarking History and Purpose

Benchmarking started in the early 1980s when Xerox developed a program to establish the performance goals for all of their performed tasks in order to have better quality products (Camp, 1989). They called this the "benchmarking" of their company. Today, it is desirable for all companies to benchmark their performance in order to know how well they are performing in comparison with other companies. Benchmarking is the process that compares one's performance against the industry's best performance. Every business, whether it deals with construction, production, or customer services, requires some process of self-evaluation because this process can determine process deficiencies in a company, the first step in advancing performance.

Benchmarking is, now, carried out in most of the projects and companies to identify how their performance is in comparison to best industry performance. It also helps to identify the best practices which results in the better project performance. Currently, benchmarking is widely used in construction of industrial projects.

2.2 DB and DBB Project Delivery Methods

In spite of the general American view of the DBB method as traditional, the DB method was used well before DBB in other countries around the world. Even before the building of the Parthenon in Athens, people designing and constructing buildings were called master builders. During the Renaissance, the famous master builders were Abbe Suger and Filippo Brunelleschi (Beard et al., 2001). Design and construction were first separated after the Industrial Revolution in the late eighteenth century, because complex new manufacturing processes required specialized design expertise. The DBB method allowed project designers to express their intent through plans and specification without requiring them to stay on site.

During the post-WWII construction boom, owners in the United States wanted more coordination between the designer and constructor to complete projects on time and within budget. This requirement precipitated the re-emergence of the DB project delivery method. The DB project delivery method is now widely used in the private sector. Its use in the public sector to construct buildings, bridges, and highways is increasing. Since 1994, when the federal highway administration (FHWA) introduced Special Experimental Projects No.14 (SEP-14), bridges and highways have increasingly been built with DB method.

2.3 CII BENCHMARKING PROCESS

The Construction Industry Institute (CII) is a leading organization in the benchmarking of capital facility projects (CII, Benchmarking and Metrics, 2005). Its Benchmarking & Metrics Program was established to fulfill two goals:

- Providing quantitative information to member companies on the benefits of using CII-endorsed best practices on overall project performance.
- Assisting member companies in statistical measurements that can improve capital project effectiveness.

The CII Benchmarking & Metrics Program has developed project performance and practices-use metrics with which to compare construction industry projects. The performance metrics are related to project cost, schedule, changes, rework, safety and productivity. The practice-use metrics are related to front end planning, organization, change management, constructability, and zero accidents.

Because some of the performance metrics for owners are different from those for contractors, CII has developed two sets of questionnaires to allow owners and contractors to collect and submit data. The submission of the data is on a voluntary basis. The CII questionnaires are divided into the following sections (CII, 2006):

- Project General Information
- Project Performance
- Practices Used
- Construction Productivity Metrics
- Engineering Productivity Metrics
- Closeout.

CII benchmarks its member companies' projects without sharing their voluntarily-submitted data with any other organizations (CII, 2006). Each year, CII produces findings from submitted data for its member companies. Most of the member companies are related to industrial projects. The CII benchmarking database contains over 1560 projects worth more than $72 billion. Most of them are industrial projects and only a few are highway projects. It has produced several reports regarding benchmarking and metrics, most of which concentrate on the performance of the projects compared against industry best practices used. A recent report regarding benchmarking and metrics value of best practices was published on 2003-2004. This report summarizes the potential benefits of best practice use in industrial and building projects (CII, 2003).

Recently, CII has taken an initiative to develop an industry-specific metrics for assessing the performance of different industries. Processes vary by industry, so any metrics must be attuned to each process. The pharmaceutical industry expends a considerable amount of resources in startup due to strict requirements for installation, operational, and process qualifications. In addition to this, the cost of process equipment influences total installed cost (TIC) and tends to distort TIC / process equipment cost metrics. Special metrics developed for the pharmaceutical industry make it possible to measure performance for these projects in terms of cost, schedule, etc. (CII, 2007).

CII has also started developing specific metrics related to productivity. It has developed an owner version of a productivity questionnaire to collect data. In this questionnaire productivity is categorized as engineering and construction productivity. The questionnaire includes productivity measures and other descriptive data required to perform meaningful productivity analysis. In this questionnaire, both engineering productivity- and construction productivity-related questions are organized by the categories shown below.

- Concrete
- Structural Steel
- Electrical
- Piping
- Instrumentation
- Equipment
- Insulation

CII uses two approaches to measuring engineering productivity. The first approach, called “direct measure” uses work-hours and quantities to produce ratios of inputs to outputs. The second approach, developed by Project Team 192, uses selected quantities and reported discipline work-hours to establish discipline level metrics from predictive equations. Both systems are in validation and CII is using both approaches to produce productivity metrics until sufficient data are available to assess a preferred method (CII, 2007).

CII measures construction productivity metrics by calculating the ratio of actual work-hours to quantities of work item completed. The actual work-hours include only direct work hours and rework hours.

2.4 Other Benchmarking Processes

Independent Project Analysis (IPA) Inc. is one of the leading private companies to benchmark capital projects. It has a database of about 4200 projects. It compares the company's performance with the industry's best performance. It also conduct seminar on benchmarking. "The overall objective of an IPA benchmarking is to understand the effectiveness of the practices and procedures employed by your company in planning, defining, engineering, constructing, and starting up capital projects" (IPA, 2006). IPA generally focuses on benchmarking industrial and environmental projects.

There is a considerable body of literature regarding benchmarking; one report summarized the benchmarking process as follows (Hamilton, 2003):

1. Involve and get support of top management
2. Establish what to benchmark
3. Determine what and how to measure
4. Identify comparable external and internal organizations and processes
5. Prepare a data collection plan
6. Collect data
7. Use quantitative measures to identify best performance
8. Compare one's own performance with the industry best performance
9. Identify the root causes of any performance gap
10. Prepare an action plan for improvement

11. Get support from top management level to implement the action plan
12. Implement the action plan
13. Monitor the plan.

In 1993, with the introduction of the Government Performance and Results Act (GPRA), the United States government required all agencies to quantify performance of all federal programs (Brunso and Siddiqi, 2003). Therefore, the Corps performed a study to evaluate project delivery of environmental restoration programs by using benchmarks and metrics. This research study evaluated the ability of one of these federally-funded environmental restoration programs to deliver projects: the Environmental Management Program (EMP). To benchmark this project, researchers selected some common performance metrics (e.g., cost growth, schedule growth, planning, and design phase cost factors, etc.) developed by Construction Industry Institute (CII). The researchers also subjectively evaluated whether the design goals had been met. They also addressed the customer's concern over operation and maintenance (O & M) costs by calculating actual O & M cost divided by estimated O & M cost. From these metrics they found that the Corps had made improvement in delivering EMP projects because the cost and schedule growth of these projects were found to be under control.

In 1995, James Odeck investigated the statistical relationship between actual and estimated costs of road construction in Norway using data over the years 1992-1995. He analyzed the data of about 620 road construction projects totaling 519 million Norwegian kroners to benchmark the cost growth of highway projects. The projects that were examined are those that were carried out by the Norwegian Public Roads Administration (NPRA), and not through the bidding process. The main finding of this research is: the mean cost overrun (difference between estimated and actual costs) of highway projects is 7.9 percent ranging from -59 percent to +183 percent. It is also found out the cost overrun occurs mostly in the small projects rather than in large projects. Other factors influencing the size of cost overruns include completion time of the projects and the regions where projects are situated (Odeck, 2004).

In his Ph. D. dissertation in University of Texas at Austin, David R. Shields (2002) developed an index for scoring the success of the construction phase of projects with the help of CII benchmarking data. Owners and contractors can benchmark their construction performance with the help of this index. This study concluded that the index may be used to internally and externally benchmark the company's construction phase success on their industrial construction projects (Shields, 2002).

In 1990, Sanvido et al. identified Critical Success Factors (CSF) for construction on building projects. Researchers analyzed qualitative data from 16 building projects to develop numerical scores. This research identified seven CSFs that must be given special and continual attention to bring about high project construction performance (Sanvido et. al., 1992). These critical success factors are: facility team, contracts, experience, optimization information, resources, product information, and performance information.

In 1990, CII and the U.S. Navy sponsored a demonstration research study which was focused on project performance and benchmarking for a Navy Maintenance Facility being built in Portsmouth, VA (O'Connor et. al., 1995). The researchers quantified the project performance impact from the Navy's implementation of six CII best practices: project objective setting, project scope definition, design effectiveness, constructability, and materials management.

2.5 BENCHMARKING OF PROJECT DELIVERY METHODS

In 1997, Molenaar, Songer and Barash performed a study to find out the performance of public sector DB projects. The data for this study was collected from 104 building, heavy highway, and industrial projects. Researchers selected budget, schedule, administrative burden, and owner satisfaction as main performance index to evaluate success of DB projects. They found that 59 percent of projects were 2 percent or better of the budget established when design-builder was hired. It was also found that 77 percent of projects were 2 percent or better of the schedule established when design-builder was hired (Molenaar et al., 1997).

Research was done in 1998 by Mark Konchar and Victor Sanvido regarding the benchmarking of federal project delivery systems. The researchers benchmarked construction management-at-risk, DB, and DBB project delivery methods. They compared the cost, schedule, and quality metrics of 351 building projects being built under these three project delivery methods. Results of the research showed that the median unit cost for DB projects was $80 per square feet; whereas the median unit cost for DBB projects was $120 per square feet. The median cost growth for DB was 2.17 percent and for DBB was 4.83 percent. The cost analysis showed that the unit cost for DB was 6.1 percent lower than DBB projects. Similarly, results of univariate schedule showed that median value of schedule growth for DB was 0 percent and for DBB was 4.4 percent. The median values of construction speed for DB and DBB projects were 9,000 and 5,100 square feet per month respectively. The construction speed analysis showed that the construction speed for DB projects was 12 percent faster than that for DBB projects. The median delivery speed for DB projects was 6,800 square feet per month, whereas for DBB projects, it was 3,250 square feet per month. Comparatively, the delivery speed for DB projects was 33.5 percent faster than that for DBB projects. From their research, they concluded that DB project delivery achieved significantly improved cost and schedule advantages. It also produced equal and sometimes more desirable quality performance than construction management-at-risk and DBB projects (Konchar and Sanvido, 1998).

In his Master thesis completed at University of Texas at Austin, Darren R. Hale (2005) did the statistical analysis of cost and schedule performance of a homogenous sample of DB and DBB United States Navy Bachelor Enlisted Quarters constructed under the Military Construction program. He made the statistical conclusions by analyzing 38 DBB and 37 DB projects built from fiscal years 1995 to 2004 (Hale, 2005).

The main findings of this study are:

- Schedule performance metrics e.g. actual project duration, actual construction duration, project duration per bed, construction duration per bed, and schedule growth for DB were less than that for DBB and were statistically significant at alpha level .05.
- Cost performance metrics e.g. cost per bed and cost growth for DB were less than that for DBB, but only the cost growth was statistically significant at alpha level .05.

The Construction Industry Institute (CII) is a leading organization in the benchmarking of capital facility projects (CII, Benchmarking and Metrics, 2005). It's Benchmarking and Metrics Program has developed project performance and practices-use metrics with which to compare construction industry projects. The performance metrics are related to project cost, schedule, change, rework, safety, and productivity performance. The practice-use metrics are related to pre-planning, organization, change management, constructability, and zero accidents.

Recently, research was done by CII to measure the impacts of the DB and DBB delivery systems on project performance. The sample size of DB and DBB projects were 210 and 407 respectively. These projects were classified as Industrial, which included both heavy and light industrial projects, and buildings. Analysis was based on data submitted voluntarily by CII member companies to its Benchmarking and Metrics Program. Some of the findings of this research are (CII and NIST, 2002):

- On average, DB projects were about four times larger than DBB projects in terms of project cost.
- Public sector projects made less use of the DB project delivery system than private sector projects.
- Overall, owner-submitted DB projects outperformed DBB projects in cost, schedule, changes, rework, and practice use. However, statistically significant differences were found only for schedule, changes, rework, and practice use.

2.6 BENCHMARKING OF HIGHWAY PROJECTS

In 2003, Booz Allen Hamilton carried out research for the National Cooperative Highway Research Program to develop a primer and a guide on customer-driven benchmarking of maintenance activities (of highway projects). Because maintenance of a highway is often related to the road user's satisfaction, the researchers developed customer-oriented maintenance performance metrics. The findings of this study suggest that it is necessary for maintenance organizations to focus more on customer-oriented measures such as smoothness of roads, legibility of signs at night, sight distance at intersections, attractiveness of roadsides, and the speed at which ice and snow melts on pavement (Hamilton, 2003). The researchers used the following "outputs" for measures of accomplishments: linear feet of ditches cleaned, number of bags of litter collected, and acres of grass mowed. He used as "inputs" resources used in maintenance activities such as labor, material, equipment, and financial cost.

Recently, Thomas R. Warne of Tom Warne & Associates, LLC prepared a report regarding performance assessment of DB contracting for highway projects (Warne, 2005). The author studied twenty-one DB highway projects across the country ranging in size from $83 million to $1.3 billion. The main goal of this research was to ascertain the performance characteristics of DB highway projects. These performance characteristics will allow owners to assess the effectiveness of the DB project delivery process.

The researcher gathered a significant amount of information about each of the twenty-one DB highway projects and analyzed it. The analysis was summarized in two sections, Design-Build Performance and Design-Build Process. The comparison between DB and DBB projects was done by asking hypothetical questions to project managers regarding their project performance. The main findings in the DB performance section are (Warne, 2005):

- Seventy-six percent of the DB projects were finished ahead of schedule.
- One hundred percent of these selected projects were built faster with the DB approach than they would have been with the DBB approach.
- DB offers greater price certainty and reduced cost growth than DBB.
- One hundred percent of the owners were happy with DB approach and would use it again.

In January 2006, FHWA published the report on DB effectiveness study (FHWA 2006). The main objectives of this study were:

- Assess the effect of design-build contracting on project quality, cost and timeliness
- Recommend appropriate design level for the design-build procurement
- Assess impact of design-build contracting on small business

In 2006, FHWA published a report to evaluate the effectiveness of the SEP-14 program. To obtain data for this study, FHWA researchers asked state transportation agencies to fill out an online survey on pairs of SEP-14 DB and DBB projects of similar size within their states. At the end of data collection, complete data had been obtained on 11 pairs of DBB and DB projects. The cost of each of these DB and DBB projects was less than $20 million. The final FHWA report presents only a comparison of descriptive statistics and does not perform any statistical analyses. The main findings of this study were:

- The average schedule growth for DB projects was equal to -4.2 percent as against 4.8 percent for DBB projects.
- The average cost growth for DB projects was equal to 7.2 percent as against 3.6 percent found for DBB projects.
- The average number of change orders for DB projects was equal to 16 while 22 were found for DBB projects. However, the average cost of change orders was equal to $85,000 for DB projects compared to $47,000 for DBB projects.

2.7 GAPS ON LITERATURE AND SUMMARY

Most of the previous studies of DB and DBB project delivery methods on project performance included building projects (vertical construction) or industrial projects with varied project costs. Research has found that DB project delivery method is more effective in big and complex projects (Kocher and Sanvido, 1998). Previous studies on comparing these two project delivery methods on highway projects (horizontal construction) were limited to project cost less than $20 million. No absolute metrics e.g. cost per lane mile, delivery duration per lane mile, etc. were used in comparison.

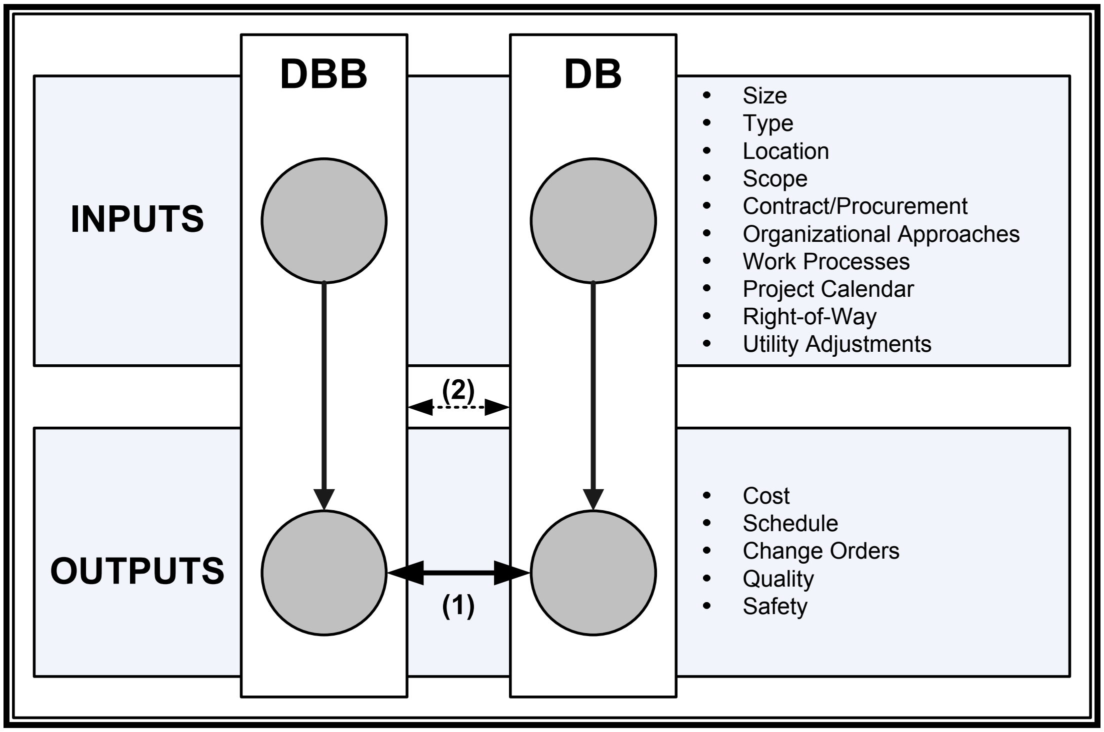
Researchers had not performed statistical comparison for large (cost greater than $100 million) DB and DBB highway projects.

Chapter Three: Research Methodology

3.1 Model for Performance Benchmarking Analysis

The performance (i.e. output) of any project depends upon the type and amount of inputs applied on that project. For this benchmarking study of comparing DB against DBB highway projects, the association of inputs versus outputs will be assessed. The projects will be selected both from out-of-state and in-state (Texas). From out-of-state, only DB projects will be selected. From in-state, both DB and DBB projects will be considered. The model for benchmarking of DB against DBB highway projects is depicted in Figure 3.1.

The construction industry mostly benchmarks projects by comparing their output variables of the projects without considering the effect of input variables. This benchmarking process is shown by solid line marked as 1. However, this research compared output variables by considering the association with input variables. This benchmarking process is shown by the dotted line marked as 2. To find input variables that have association on output variables, the descriptive statistics of output variables were used. To conduct comprehensive benchmarking of DB against DBB highway projects, these input variables must be analyzed in order to have "apple-to-apple" comparison of DB and DBB projects. These input variables are related to the project characteristics of these projects. Similarly, output variables are related to cost, schedule, change orders, safety and quality performance.



Legend:
(1) Output variables comparison without considering association with input variables
(2) Output variables comparison considering association with input variables

Figure 3.1: Model for Benchmarking

3.2 RESEARCH METHODOLOGY

This chapter will discuss the methodology used to conduct this research. Figure 3.2 gives the flow chart outlining the methodology steps.

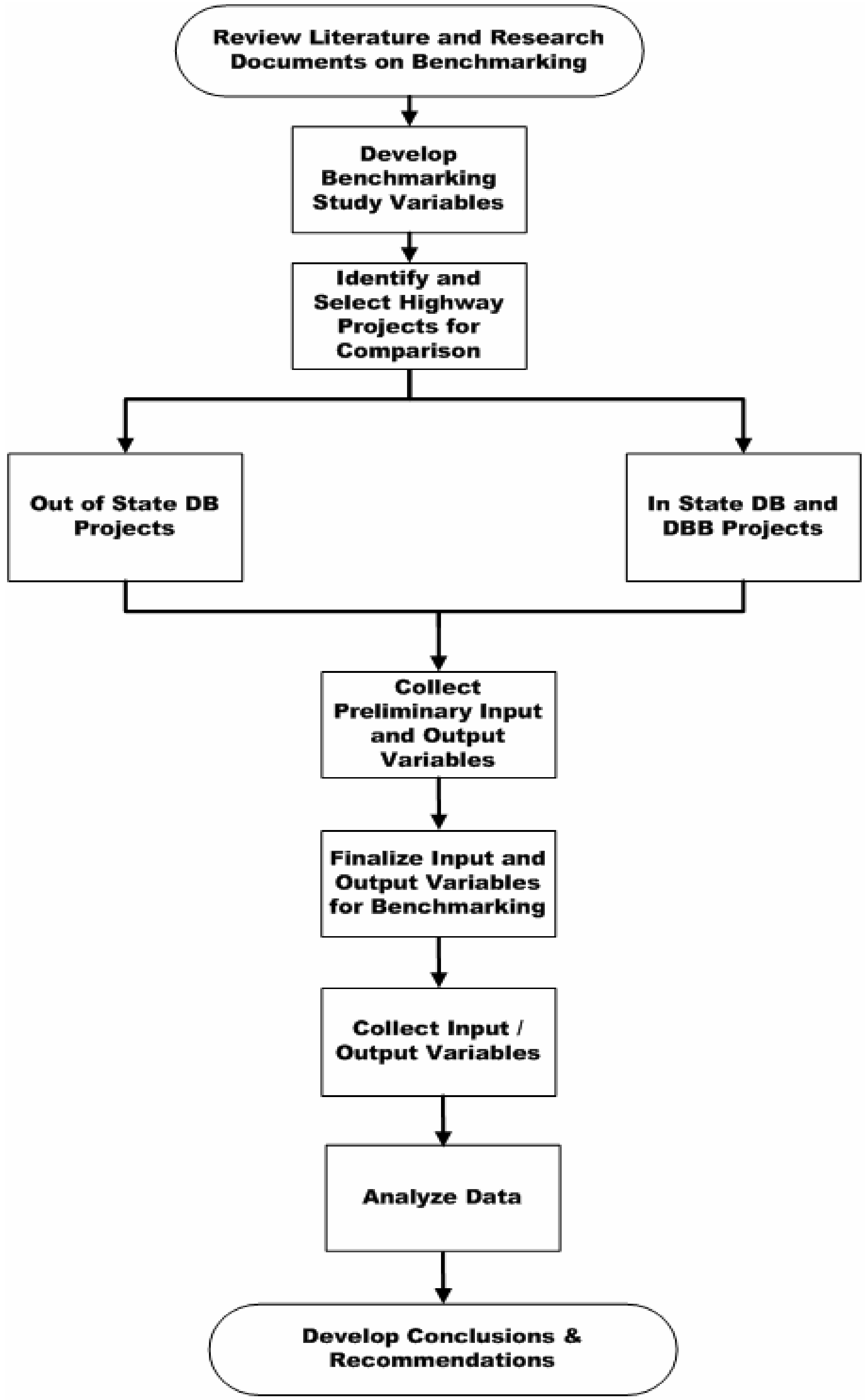


Figure 3.2: Research Methodology

3.2.1 Review Literature

The literature review was carried out to find established benchmarking methodology and other researches done in benchmarking for DB against DBB project delivery methods.

3.2.2 Develop Benchmarking Study Variables

After the literature review, the input and output variables affecting project performance were identified. The input variables are categorized according to the work item areas and the output variables are associated with cost, schedule, change orders, safety, and quality.

3.2.3 Select Highway Project Samples

The DB and DBB highway project samples were selected using some basic criteria. The selection was crucial in order to have comprehensive and reasonable benchmarking of these project delivery methods. The selection methodology and criteria is described below.

Selection of In-state Highway Projects

For comparison purposes, both DB and DBB highway projects were selected from ongoing highway projects being built in Texas. Ultimately, the largest (>$100M) ongoing DBB projects were selected for the comparison. The basic criteria used to select in-state highway projects were:

1. The projects should involve construction of a considerable amount of roadway.

2. The construction completion time of the projects should be after 2000 and should not go beyond end of 2006.
3. The design and construction cost of the projects should exceed $ 100 million.
4. The DBB projects should be constructed in the state of Texas.

Using the above criteria, the selected in-state DBB highway projects were:

1. High Five Project – Construction of 5 level interchange, Dallas
2. Corridor Program of Katy Freeway Project – Reconstruction of IH 10 including the interchange on IH 610, Houston
3. Corridor Program of SH 45N, Austin and

The corridor programs of Katy Freeway and SH 45N project have respectively one and two completed contracts that have more than $100 million contract cost. Each contract was treated as a sample project for data collection and analysis. Therefore, 4 DBB project contracts were selected for this study. For the DB projects, researchers selected highways under construction in the state of Texas: SH 130 and US 183A currently being built in Texas. But both of the projects are under construction, therefore the complete data could not be collected.

Selection of Out-of-state Highway Projects

Benchmarking of a highway project is useful if the project is benchmarked against similar projects. Therefore for the benchmarking of DBB projects in the state of Texas, it was necessary to select comparable DB highway projects. However, there were only two DB projects built in Texas that met the criteria, so researchers identified various out-of state Federal Highway Administration DB highway projects approved under Special Experimental Projects No. 14 (SEP-14) as December 31, 2002, which would be possible candidates for the benchmarking of DB against DBB.

The initial criteria for the selection of out-of-state DB highway projects were as follows:

1. The projects should involve construction of a considerable amount of roadway.
2. The highway projects are to be selected from FHWA SEP-14 projects only.
3. The construction completion time of the projects should be after 2000 and should not go beyond the end of 2006.
4. The design and construction cost of the projects should exceed $ 50 million.
5. The projects should be domestic projects.

After the initial screening of the DB projects from the FHWA, SEP-14 list, there were 26 out-of-state DB highway projects remaining for the final selection (FHWA, 2005). The detailed list of these highway projects is given in Appendix A.

The second stage of selection was done considering the following criteria:

1. The project design and construction cost should exceed $100 million.
2. The projects should be completed before the end of 2006.
3. There is enough information available for the projects being selected.

After the second screening, there were 8 projects left for comparison. They were:

1. US 60 Design-Build Project, Arizona (US 60 DB Project, 2005)
2. Transportation Expansion Project, Colorado (TREX Project, 2005)
3. Route 3, Massachusetts (Route 3 Construction, 2005)
4. US 70 Hondo Valley Project, New Mexico (US 70 Hondo Valley Project, 2005)
5. Bays Parkways, South Carolina (South Carolina DOT, 2005)
6. Conway Bypass, South Carolina (South Carolina DOT, 2005)
7. I-15, Utah (FHWA, 2005)

8. Route 288, Virginia (Route 288, 2005).

A selection method was developed to choose five highly similar projects to the SH 130 project out of the eight projects for the closest comparison. SH 130 was chosen as the base project for DB, because it is the largest DB project built in Texas and researchers intended to compare large DB and DBB projects in this study. For this study, sixteen initial project characteristics were identified in order to make the final selection. These characteristics were formulated from gathered data from these projects' websites. Then importance weights of high (H), medium (M) and low (L) were assigned for each of these characteristics relative to its importance in the selection criteria. The project characteristics data summary of these projects along with the SH 130 project is given in Table 3.1.

After this weighting process was complete, a comprehensive scoring legend was developed to assign scores to these projects relative to the SH 130 project. The scoring criteria are then drawn from the scoring legend. The detailed scoring legend for each of these project characteristics is shown in Table 3.2. The relative scores of these projects for each of the characteristics were determined by using the scoring criteria. These scores are depicted in Table 3.3. The total weighted scores and rankings of the highway projects under considerations are shown in Table 3.4.

Table 3.1: Selecting Out-Of-State DB Highway Projects for Benchmarking

No.	Project Characteristics	WT.	US 60 DB Project, AZ	TREX, CO	Route 3, MA	US-70 Hondo Valley, NM	Bays Parkway, SC	Conway Bypass, SC	I-15, UT	Route 288, VA	SH-130, TX
1	Project Location (State)	H(3)	AZ	CO	MA	NM	SC	SC	UT	VA	TX
2	Project Cost (> $ 100 Million)	H(3)	184	795*	385	129	232	387	1590	236	1500
3	Project Duration (Months)	H(3)	26	60	42	38	30	36	54	31	48
4	Toll Road (T) or Non-Toll Road (NT)	M(2)	NT	NT	NT	NT	NT	NT	NT	NT	T
5	Project Funding (Public P, Public Private PP, Private PR)	L(1)	P	P	P	P	PP	PP	P	PP	P
6	Type of Construction - New (N) / Rehab (RH) / Reconstruct (RC)	H(3)	RC	RH	RC	RC	N	N	RC	N	N
7	Project Completed or Ongoing	H(3)	C	O	C	O	C	C	C	C	O
8	Total Length of Highway to be Constructed (Miles)	M(2)	13	17	21	38	20	28.5	39	17.5	49
9	Online Website Available (Y/N)	H(3)	Y	Y	Y	Y	N	N	Y	Y	Y
10	Newsletter Available on Internet (Y/N)	H(3)	Y	Y	Y	Y	N	N	N	Y	Y
11	Contract with Maintenance Option (Y/N)	L(1)	N	N	Y	N	N	N	Y	N	Y
12	No. of Design Build Contractors Involved	L(1)	2	2	1	3	1	1	3	3	3
13	Pavement Type (Concrete / Asphalt)	M(2)	A	A	A	A	A	A	C	A	C
14	Dirt Work Involved (Excavation / Embankment Filling), Y / N	L(1)	Y	Y	Y	Y	Y	Y	Y	Y	Y
15	Bridge Construction Involved (No.)	M(2)	6	22	47	7	29	31	130	25	111
16	Contract Selection Method	L(1)	BV	BV	BV	BV	BV	BV	BV	BV	BV

* Estimated Cost for Highway Only

	Score
Low	1
Medium	2
High	3

Table 3.2: Legend for Scoring Out-Of-State DB Highway Projects for Benchmarking

No.	Project Characteristics	Legend for Scoring
1	Project Location (State)	South West Region = 1, South Region = 0.80, Central Region = 0.60, West Region = 0.40, NE & MW Region = 0.20
2	Project Cost (> $ 100 Million)	= Project Cost / SH 130 Project Cost, Maximum Value =1
3	Project Duration (Months)	= Project Duration / SH 130 Project Duration, Maximum Value =1
4	Toll Road (T) or Non-Toll Road (NT)	= 1, if Toll Road, otherwise 0.
5	Project Funding (Public P, Public Private PP, Private PR)	= 1, if Public (P) Funding, otherwise 0.
6	Type of Construction - New (N) / Rehab (RH) / Reconstruct (RC)	= 1, if New Construction, otherwise 0.
7	Project Completed or Ongoing	= 1, if Project Completion till 2005 Spring, otherwise 0.
8	Total Length of Highway to be Constructed (Miles)	= Project Length / SH 130 Project Length, Maximum Value =1.
9	Online Website Available (Y / N)	= 1, if Yes, otherwise 0.
10	Newsletter Available on Internet (Y / N)	= 1, if Newsletter Available on Internet, otherwise 0.
11	Contract with Maintenance Option (Y / N)	= 1, if Contract with Maintenance Option, otherwise 0.
12	No. of Design Build Contractors Involved (Joint Venture / Single)	= 1, if Joint Venture, otherwise 0.
13	Pavement Type (Concrete / Asphalt)	= 1, if Concrete Pavement, otherwise 0.
14	Dirt Work Involved (Excavation / Embankment Filling), Y / N	= 1, if Dirt Work Involved, otherwise 0.
15	Bridge Construction Involved (No.)	= Total No. of Bridges / Total No. of Bridges in SH 130 Project, Maximum Value = 1.
16	Contract Selection Method	= 1, if Best Value Selection, otherwise 0.

Table 3.3: Relative Scores of Out-Of-State DB Highway Projects for Benchmarking

No.	Project Characteristics	WT.	US 60 DB Project, AZ	TREX, CO	Route 3, MA	US-70 Hondo Valley, NM	Bays Parkway, SC	Conway Bypass, SC	I-15, UT	Route 288, VA	SH-130, TX
1	Project Location (State)	8.82	1.00	0.60	0.20	1.00	0.80	0.80	0.40	0.80	1.00
2	Project Cost (> $ 100 Million)	8.82	0.12	0.53	0.26	0.09	0.15	0.26	1.00	0.16	1.00
3	Project Duration (Months)	8.82	0.54	1.00	0.88	0.79	0.63	0.75	1.00	0.65	1.00
4	Toll Road (T) or Non-Toll Road (NT)	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
5	Project Funding (Public P, Public Private PP, Private PR)	2.94	1.00	1.00	1.00	1.00	0.00	0.00	1.00	0.00	1.00
6	Type of Construction - New (N) / Rehab (RH) / Reconstruct (RC)	8.82	0.00	0.00	0.00	0.00	1.00	1.00	0.00	1.00	1.00
7	Project Completed or Ongoing	8.82	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	Total Length of Highway to be Constructed (Miles)	5.88	0.27	0.35	0.43	0.78	0.41	0.58	0.80	0.36	1.00
9	Online Website Available (Y / N)	8.82	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00
10	Newsletter Available on Internet (Y / N)	8.82	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00
11	Contract with Maintenance Option (Y / N)	2.94	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00
12	No. of Design Build Contractors Involved	2.94	1.00	1.00	0.00	1.00	0.00	0.00	1.00	1.00	1.00
13	Pavement Type (Concrete / Asphalt)	5.88	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
14	Dirt Work Involved (Excavation / Embankment Filling), Y / N	2.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	Bridge Construction Involved (No.)	5.88	0.05	0.20	0.42	0.06	0.26	0.28	1.00	0.23	1.00
16	Contract Selection Method	2.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 3.4: Total Weighted Scores of Out-Of-State DB Highway Projects for Benchmarking

No.	Project Characteristics	WT.	US 60 DB Project, AZ	TREX, CO	Route 3, MA	US-70 Hondo Valley, NM	Bays Parkway, SC	Conway Bypass, SC	I-15, UT	Route 288, VA	SH-130, TX
1	Project Location (State)	8.82	8.82	5.29	1.76	8.82	7.06	7.06	3.53	7.06	8.82
2	Project Cost (> $ 100 Million)	8.82	1.08	4.68	2.26	0.76	1.36	2.28	8.82	1.39	8.82
3	Project Duration (Months)	8.82	4.78	8.82	7.72	6.99	5.51	6.62	8.82	5.70	8.82
4	Toll Road (T) or Non-Toll Road (NT)	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88
5	Project Funding (Public P, Public Private PP, Private PR)	2.94	0.03	0.03	0.03	0.03	0.00	0.00	0.03	0.00	2.94
6	Type of Construction - New (N) / Rehab (RH) / Reconstruct (RC)	8.82	0.00	0.00	0.00	0.00	8.82	8.82	0.00	8.82	8.82
7	Project Completed or Ongoing	8.82	8.82	0.00	8.82	8.82	8.82	8.82	8.82	8.82	8.82
8	Total Length of Highway to be Constructed (Miles)	5.88	1.56	2.04	2.52	4.56	2.40	3.42	4.68	2.10	5.88
9	Online Website Available (Y / N)	8.82	8.82	8.82	8.82	8.82	0.00	0.00	8.82	8.82	8.82
10	Newsletter Available on Internet (Y / N)	8.82	8.82	8.82	8.82	8.82	0.00	0.00	0.00	8.82	8.82
11	Contract with Maintenance Option (Y / N)	2.94	0.00	0.00	2.94	0.00	0.00	0.00	2.94	0.00	2.94
12	No. of Design Build Contractors Involved	2.94	2.94	2.94	0.00	2.94	0.00	0.00	2.94	2.94	2.94
13	Pavement Type (Concrete / Asphalt)	5.88	0.00	0.00	0.00	0.00	0.00	0.00	5.88	0.00	5.88
14	Dirt Work Involved (Excavation / Embankment Filling), Y / N	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94
15	Bridge Construction Involved (No.)	5.88	0.32	1.17	2.49	0.37	1.54	1.64	5.88	1.32	5.88
16	Contract Selection Method	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94
			52	**49**	**52**	**57**	**41**	**45**	**67**	**62**	**100**
	RANK		**4**	**6**	**4**	**3**	**8**	**7**	**1**	**2**	

The out-of-state DB projects selected for comparison are:

1. I-15 Project, Utah
2. Route 288 Project, Virginia
3. US 70 Hondo Valley Project, New Mexico
4. US 60 DB Project, Arizona
5. Route 3 North Project, Massachusetts

The complete data of Route 3 North Project could not be collected because the project is still active. Therefore, 4 DB projects data were analyzed in this study.

3.2.4 Collect Preliminary Input and Output Data

The input and output variables were first collected by using a questionnaire. In the first phase of data collection, questionnaires were sent to those projects which were completed (Appendix B.1). The owner project manager of each of these selected projects was contacted for the collection of input and output variables. In this phase, all the projects which were already completed were targeted for data collection. In the second phase of data collection, the questionnaire was divided into pre-completion and post-completion sections to collect the data for on-going projects. The pre-completion questionnaire consisted of questions regarding the initial data of the projects (Appendix B.2). The post-completion questionnaire consisted of questions regarding the project completion data (Appendix B.3). Most of the in-state highway projects were under construction when the data collection was started.

3.2.5 Finalize Input and Output Variables for Benchmarking

After the data were collected from the completed projects, the researchers finalized the input and output variables to be used in benchmarking of DB against DBB highway projects. These variables were selected and sent to the Texas Department of Transportation (TXDOT) for verification. After comments were received from TXDOT, the input and output variables were finalized.

3.2.6 Collect Input and Output Data

Once the input and output variables were finalized, the collection of these data were started. The pre-completion questionnaires were sent to under-construction highway projects. As the projects completed, the post-completion questionnaires were sent to the corresponding projects to get the final data. A two-phase data collection procedure was used to collect the under-construction projects data. However, some of the project contracts were still under construction and their data were not included in the final analysis. Four DB and four DBB highway project contracts post-completion data were collected and analyzed.

3.2.7 Analyze Data

Eight project contracts were included in the final input and output variables comparison. Forty-seven input variables were analyzed using descriptive statistics. The cost, schedule, change orders, safety, and quality-related output variables were analyzed in this study. A descriptive statistics was used to determine whether the mean performance of DB and DBB are different from each other. An input and output variables' association was determined comparing descriptive statistics of output variables.

3.3 FRAMEWORK FOR COMPARISON

The final framework for benchmarking DB against DBB project is depicted in Figure 3.3.

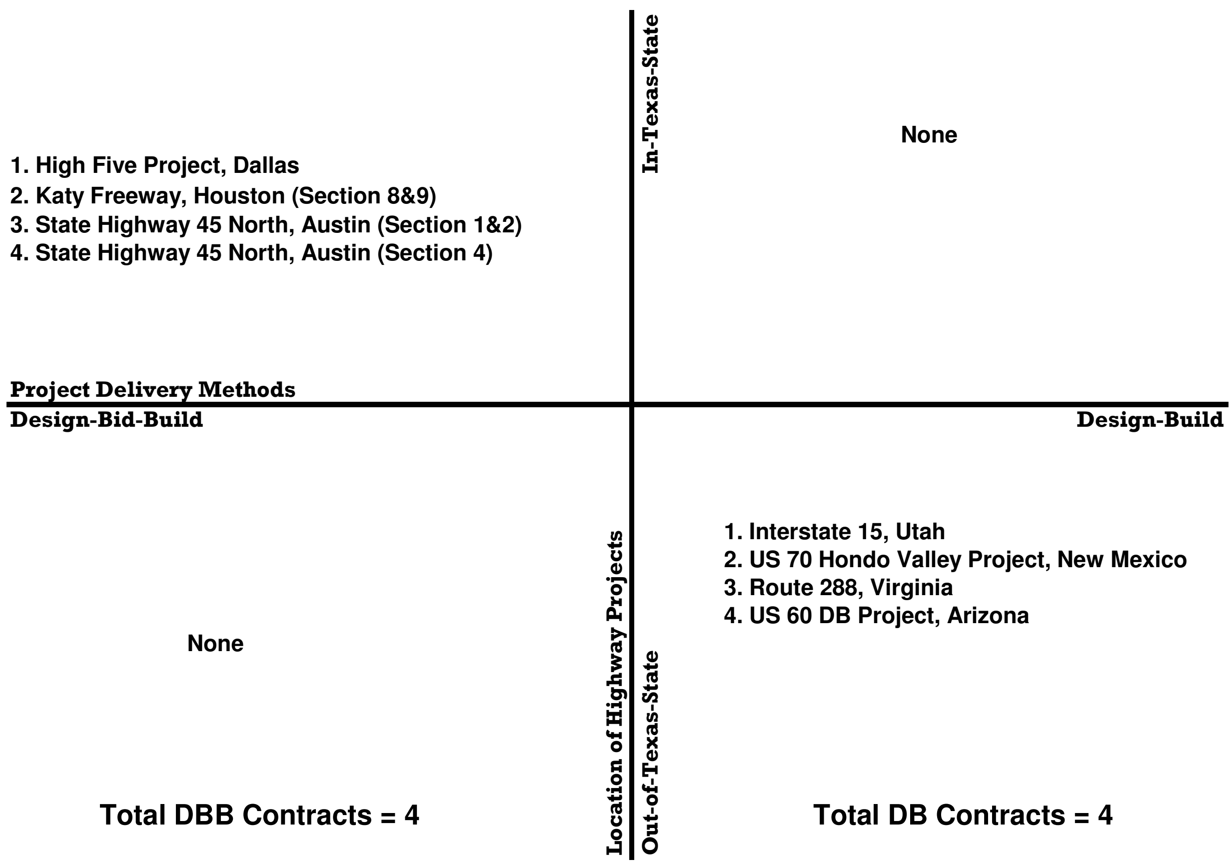


Figure 3.3: Framework for Comparisons

3.4 TEST STATISTICS

The statistical analysis of this research was done by using only descriptive statistics. There were altogether five DB highway projects excluding the SH 130 project, because the data of SH 130 could not be collected despite repeated efforts by the researchers. The complete data of Route 3 North Project could not be collected. Therefore, researchers were able to collect four DB and four DBB highway contract data. Table 3.5 shows the sample contract projects with their total design and construction cost.

Table 3.5: Description of Data Sample with Total Design and Construction Cost

Project Name	Project Delivery Method	Total Design and Construction Cost
High Five Project	**DBB**	301,000,000
Katy Freeway Project (Section 8&9)	**DBB**	232,000,000
SH 45 N Project (Section 1&2)	**DBB**	146,000,000
SH 45 N Project (Section 4)	**DBB**	188,000,000
Route 288 Project	**DB**	240,000,000
US 70 Project	**DB**	165,000,000
US 60 DB Project	**DB**	208,000,000
Interstate 15 Project	**DB**	1,150,000,000

Data analysis of output and input variables comparison was performed using descriptive statistics Input-output association analysis was also conducted by using descriptive statistics.

3.5 Data Collection

The data for this research was collected by questionnaires, phone interviews and internet searches related to these projects. A follow-up phone interview was carried out for each of these projects to verify the data received from the questionnaires.

One of the objectives of this research is to develop a credible method for data collection to benchmark large highway projects. Therefore, a considerable amount of efforts were expended to develop a questionnaire that captures all the data of large highway projects. The questionnaire was prepared to capture the input variables that might have associations with the output variables of large highway projects. Detailed output variables (performance metrics) were also collected from this questionnaire. Two questionnaires were developed: one for DB highway projects and the other for DBB highway projects. The questionnaire was divided into four sections: Project General Information; Project Characteristics; Project Performance; and Stakeholders' Success. Project General Information consists of the name of the project, location, starting and ending points, year of project start and information of the person providing data. Project characteristics consist of input variables under consideration for this research such as length of road, contract provision, ROW issues, etc. Project performance was related to cost, schedule, change order, safety and quality. Project stakeholder's success was related to owner's rating of quality of the project work. The questionnaires used for this research are given in Appendix B.

3.6 DATA ANALYSIS

The data analysis was performed by using Statistical Package for Social Science (SPSS) software. The difference of means of output variables for DB and DBB projects was determined by comparing their mean and median. The association between input and output variable was determined by the help of the descriptive statistics of output variables.

The data were analyzed and presented in various graphs and box plots. Descriptive statistics of input variables are presented in bar charts. The output variables data are also shown in the bar charts. The comparison of output variables of DB and DBB projects are depicted by box plots and bar charts. Box plots in Statistical Package for Social Science (SPSS) software show the range and the quartile of the data, and possibly some outliers. The central portion, or the box, consists of 50 percentages of the data, from the first quartile (25^{th} percentile) to the third quartile (75^{th} percentile). This range is also called the inter-quartile range (IQR). The median is drawn as a thick horizontal line in the box. The end points of the box plot represent the last data point that falls within the 1.5 IQR. Data which lies outside this 1.5 IQR range are called outliers. A sample box plot is shown in Figure 3.4.

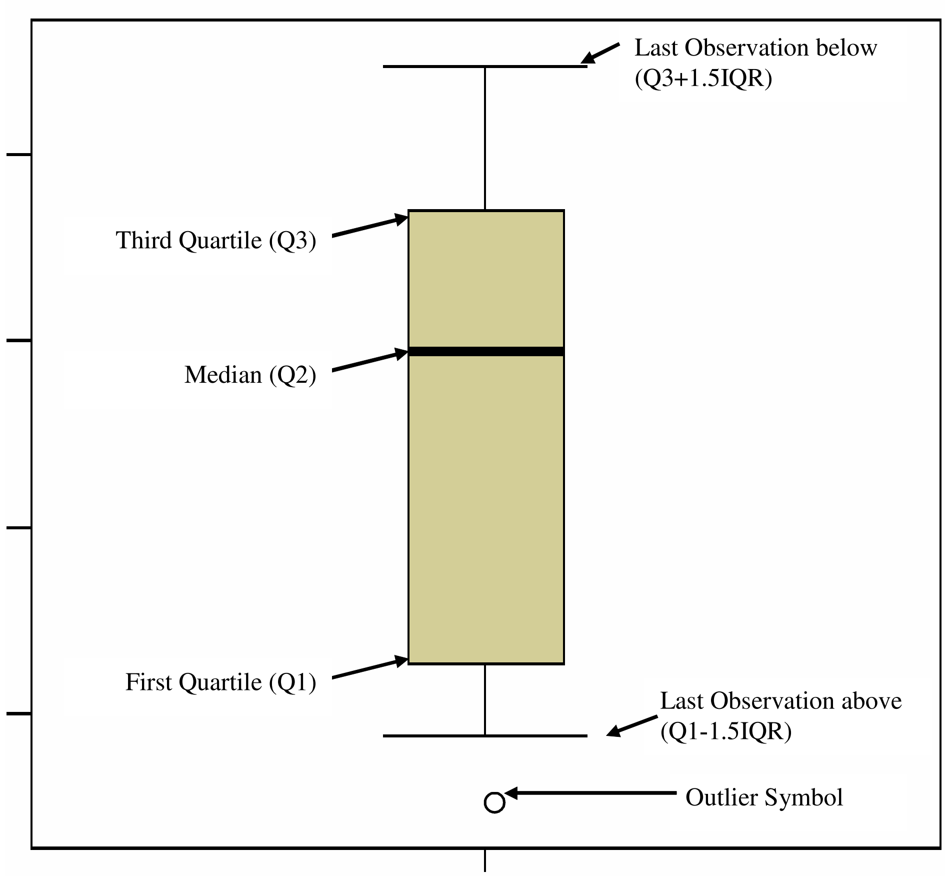


Figure 3.4: Sample Box Plot

3.7 LIMITATIONS AND BIASES

This research is conducted with a limited sample size due to the fact that large highway projects built under the DB project delivery method are few. Similarly, large DBB highway projects are also limited in number. DOTs usually build highway projects with smaller contracts. Due to the nature of the work and the public's money involved in the construction of highways, the contract is generally awarded with the low bid price. Therefore the projects have generally been divided into smaller packages to give opportunities for more contractors to bid on them. Large projects costing more than $100 million are rarely built by DOTs until recently, therefore it was difficult to increase the sample size of this research. The limitations of this research are as follows.

The findings from this study are limited to projects costing more than $100 million and completed after 2000. The DBB projects were selected from Texas whereas the DB projects were selected from out-of-state. The output variables were calculated for the design and construction phase of the project.

The researchers did not conduct an inferential statistical test on this sample due to the smaller sample size. In inferential statistics, there are some underlying assumptions that attend the use of F- tests for any samples (Borich, 2006). These assumptions are:

1. The dependent variables should be interval or ratio-scaled.
2. Independent random samples are selected from the population.
3. The population distributions of response variables for all the groups are normal.
4. The variances of the population distribution for all the groups are equal.

The first assumption was found to hold true in this sample. However, regarding the second assumption, the sample projects were not selected randomly from the population. Since the research was done only on large projects costing over $100 million, the small size of this population lessened the researcher's ability to select the sample randomly from the true population.

The population distribution for output variables should be normal. Because the sample size for this study is small, the tests for normality could not be performed. The Central Limit Theorem states that "if the shape of the distribution of scores in the population is unknown, as sample size increases the sampling distribution of means will tend toward normality and have a mean that equals the mean of the population" (Borich, 2006). The number of samples needed to have normal distribution is about 30. In this study, the sample size is nowhere near this number, so this assumption of normal distribution cannot be satisfied.

The fourth assumptions of homogeneity of variance must also be satisfied to conduct inferential statistics. Levene's Test is used to test whether the samples have equal variances. Equal variance across samples is called homogeneity of variance. This test was conducted on the output study variables of the sample. Table 3.6 shows the result of this test.

Table 3.6: Test Results of Homogeneity of Variances

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Total Cost Growth	.322	1	6	.591
Adjusted Cost / LM	.664	1	6	.446
Total Schedule Growth	2.058	1	6	.201
Delivery Duration / LM	2.152	1	6	.193
Fatality Rate	.040	1	6	.848
Change Cost Factor	1.364	1	6	.287
Quality Rating	1.000	1	6	.356

The test result shows that no output variables had a Levene statistic that was significant at alpha level .10. Therefore, the homogeneity of variance assumption did not hold true for this sample. Thus, the research data was not analyzed using inferential statistics and only descriptive statistics were used to analyze the data.

Chapter Four: Input and Output Study Variables

4.1 Input Study Variables

The input variables for benchmarking were divided into subcategories according to highway construction work areas. These variables were selected by considering their impact on project performance. These input parameters were updated and reviewed during the Project Monitoring Committee meeting with TXDOT in March 3, 2005. They were adjusted according to the availability of data during the data collection phase. The inputs are related to the following area of the projects.

- Size, type of work and location
- Project scope
- Contract provision
- Organizational approaches
- Work processes
- Project calendar
- Environmental
- Right-of-way
- Utility adjustments
- Owner staffing

The detail breakdown of inputs is given as follows.

4.1.1 Size, Type of Work and Location-Related Input Variables

These input variables identify the size, type, nature and location of the highway projects. They are “Design and Construction Cost,” “Design and Construction Duration,” "Project Nature," "Location," and "Construction under Traffic." Table 4.1 shows the definition and profile of input variables under this category.

Table 4.1: Project Size, Type and Location-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Design and Construction Cost	$ MM	Quantitative	Yes	Owner	During Project
2. Design and Construction Duration	Days	Quantitative	Yes	Owner	During Project
3. Project Nature (New/Reconstruction)	-	Qualitative	Yes	Owner	During Project
4. Location (Urban / Rural)	-	Qualitative	Yes	Owner	During Project
5. Construction under Traffic (Y / N)	-	Qualitative	Yes	Owner	During Project

Definition of Terms:

"Design and Construction Cost": The completion design and construction cost of a highway project.

"Design and Construction Duration": The completion design and construction duration of a highway project.

"Project Nature": The type of highway project, e.g. New Construction or Reconstruction.

New Construction: Work done on a highway that is built as a grass root project.

Highway Reconstruction: The dismantlement and reconstruction of an existing highway.

"Location": A highway project located at, e.g. Urban or Rural

Urban: A project located inside a metropolitan area.

Rural: A project located outside a metropolitan area.

"Construction under Traffic": The highway project constructed interfacing traffic.

4.1.2 Project Scope-Related Input Variables

The input variables describing project scope are "Highway Length in Lane Mile," "Number of Bridges," "Number of Interchanges," and "Pavement Types." A detailed description and definition of these input variables is shown in Table 4.2.

Table 4.2: Project Scope-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Highway Length in Lane Miles	Miles	Quantitative	Yes	Owner	During Project
2. Number of Bridges	No.	Quantitative	Yes	Owner	During Project
3. Number of Interchanges	No.	Quantitative	Yes	Owner	During Project
4. Pavement Types	-	Qualitative	Yes	Owner	During Project

Definition of Terms:
"Highway Length in Lane Miles": A total length of a highway measured in lane miles.
"Number of Bridges": A total number of bridges built in a highway project.
"Number of Interchanges": A total number of interchanges built in a highway project.
Interchange: A road junction that utilizes grade separation and one or more ramps to permit traffic on at least one road to pass through the junction without crossing any other traffic stream.
"Pavement Types": A type of pavement built in a highway, e.g. concrete or asphalt.

4.1.3 Contract Provision-Related Input Variables

The contract provision-related input variables are "Project Delivery Methods," "Contract Award Methods," "Previous DB Experience," "Percentage of Design Complete," "Liquidated Damage Provision," "Schedule Performance Bonus," "Lane Rental Provision," and "Types of Specification." The detailed description and the definition of the terms are given in Table 4.3.

Table 4.3: Contract Provision-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Project Delivery Methods	-	Qualitative	Yes	Owner	During Project
2. Contract Award Methods	-	Qualitative	Yes	Owner	During Project
3. Previous DB Experience	-	Qualitative	Yes	Owner	During Project
4. % of Design Complete	%	Quantitative	Yes	Owner	During Project
5. Liquidated Damage Provision	-	Qualitative	Yes	Owner	During Project
6. Schedule Performance Bonus	-	Qualitative	Yes	Owner	During Project
7. Lane Rental Provision	-	Qualitative	Yes	Owner	During Project
8.Types of Specification (Performance / Blend)	-	Qualitative	Yes	Owner	During Project

Definition of Terms:

"Project Delivery Methods": The type of method delivering a project (e.g., DBB, DB, CDA, or CM at Risk, etc.)

"Contract Award Methods": The process by which the contract is awarded to the contractor (e.g., best value, or low bid, or A+B bidding, etc.)

"Previous DB Experience"; The Owner's previous experience in building DB highway projects.

"Percentage of Design Complete": A total percentage of design complete at the time of contract award.

"Liquidated Damage Provision": An amount agreed upon in advance between contractual parties as reasonable reparation for damages incurred to one in the event of a breach of the contract by the other.

"Schedule Performance Bonus': An amount stipulated in the contract the owner will pay if the project is completed on the schedule time.

"Lane Rental Provision": An amount per hour per lane that the contractor will pay if an existing lane is closed during the construction of a highway project.

"Types of Specification": A type of specification used for construction of a highway, e.g. prescriptive, performance or blend.

4.1.4 Organizational Approaches-Related Input Variables

The input variables related to organizational approaches are "Partnering Consultant Involved," "Frequency of Partnering Sessions," "Level of Environmental

Assessment," "Level of ROW Assessment," "Number of Design Sub-contractors," "Number of Construction Sub-contractors," "Co-location," "Change Management," "Value Engineering," and "Constructability." The detailed description of input variables related to organization approaches is given in Table 4.4.A and the definitions used are given in Table 4.4.B.

Table 4.4.A: Organizational Approach-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Partnering Consultant	-	Qualitative	Yes	Owner	During Project
2. Frequency Partnering Sessions	No./Y	Quantitative	Yes	Owner	During Project
3. Level of Environ. Assess.	-	Qualitative	Yes	Owner	During Project
4. Level of ROW Assess.	-	Qualitative	Yes	Owner	During Project
5. No. of Design Sub-contractors	No.	Quantitative	Yes	Contractor	During Project
6. No. of Constr. Sub-contractors	No.	Quantitative	Yes	Owner	During Project
7. Co-location	-	Qualitative	Yes	Owner	During Project
8. Change Management	-	Qualitative	Yes	Owner	During Project
9. Value Engineering	-	Qualitative	Yes	Owner	During Project
10. Constructability	-	Qualitative	Yes	Owner	During Project

Table 4.4.B: Definitions of Organizational Approach-Related Input Variables

<u>Definition of Terms:</u>
"Partnering Consultant": A consultant hired to improve communication between owner and contractors and avoid disputes.
"Frequency of Partnering Sessions": A number of times owner and contractors meet every year for partnering session.
"Level of Environmental Assessment": The process of assessing environmental-related issues in a highway project during pre-project planning.
"Level of Right-of-Way Assessment": The process of assessing Right-of-way-related issues in a highway project during pre-project planning.
"Number of Design Sub-contractors": A total number of design sub-contractors involved during design of a highway project.
"Number of Construction Sub-contractors"": A total number of construction sub-contractors involved during construction of a highway project.
"Co-location": A project environment wherein all the project parties, e.g., owner, contractor, and designer, are located in the same building.
"Change Management": The process of incorporating a balance changed culture, one that involves recognition, planning, and evaluation of project changes in an organization to effectively managed project changes (CII 2005).
"Value Engineering": Any engineering practice that enhances cost, time, safety, quality, etc. of a project and aids project teams in meeting their clients' expectations, goals, and project objectives (CII 2005).
"Constructability": The effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives with the best possible time and accuracy, at the most cost effective levels (CII 2005).

4.1.5 Work Processes-Related Input Variables

The work processes-related input variables are use of "Latest Construction Technology" and "Web Portal." Table 4.5 depicts the detailed description of these input variables

Table 4.5: Work Process-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Latest Construction Technology	-	Qualitative	Yes	Owner	During Project
2. Web Portal	-	Qualitative	Yes	Owner	During Project

Definition of Terms:

"Latest Construction Technology": Use of any type of technology on the construction site to improve the quality and reduce project cost and duration.

"Web Portal": The Internet web site of the project used to inform people and report the progress of the project.

4.1.6 Project Calendar-Related Input Variables

The project calendar-related input variables are "Designer Work-hours per Day," "Designer Work Days per Week," "Contractor Work-hours per Day," "Contractor Work Days per Week," and "Contractor Work Shifts." Table 4.6 shows the detailed description of the input variables used during data analysis.

Table 4.6: Project Calendar-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Designer Work-hours per Day	Hours	Quantitative	Yes	Contractor	During Project
2. Designer Work Days per Week	Days	Quantitative	Yes	Contractor	During Project
3. Contractor Work-hours per Day	Hours	Quantitative	Yes	Owner	During Project
4. Contractor Work Days per Week	Days	Quantitative	Yes	Owner	During Project
5. Work Shift (Single / Multiple)	No.	Quantitative	Yes	Owner	During Project

Definition of Terms:
"Designer Work-hours per Day": The number of hours that designers work per day on the project.
"Designer Work Days per Day": The number of days that designers work per week on the project.
"Contractor Work-hours per Day": The number of hours that contractors work per day on the project.
"Contractor Work Days per Week": The number of days that designers work per week on the project.
"Construction Work Shift": The number of shifts that construction staffs work on the project.

4.1.7 Environmental Issue-Related Input Variables

The input variables related to environmental issues are presence of "Contaminated Soil," "Contaminated Ground Water," "Endangered Species," Historical Sites," "Wetlands," "Asbestos," "Wildlife Refugee," and "Archeological Sites." Table 4.7 shows the detailed description of input variables related to environmental issue.

Table 4.7: Environment-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. Contaminated Soil	-	Quantitative	Yes	Owner	During Project
2. Contaminated Groundwater	-	Qualitative	Yes	Owner	During Project
3. Endangered Species	-	Qualitative	Yes	Owner	During Project
4. Historical Sites	-	Qualitative	Yes	Owner	During Project
5. Wetlands	-	Qualitative	Yes	Owner	During Project
6. Asbestos	-	Qualitative	Yes	Owner	During Project
7. Wild Life Refugee	-	Qualitative	Yes	Owner	During Project
8. Archeological Sites	-	Qualitative	Yes	Owner	During Project

Definition of Terms:

"Contaminated Soil": Soil contamination is either solid or liquid hazardous substances mixed with the naturally occurring soil (USEPA, 2007)

"Contaminated Groundwater": Groundwater contamination occurs when hazardous substances come into contact and dissolve in the water that has soaked into the soil.

"Endangered Species": Endangered species are plants and animals that are so rare they are in danger of becoming extinct. Species become endangered because of changes to the earth that are caused either by nature or by human activity. Under the Endangered Species Act of 1973, Congress provided for the conservation of endangered species and their habitats (USEPA, 2007).

"Historical Sites": The sites where pieces of history have been preserved.

"Wetlands": Areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (USEPA, 2007).

"Asbestos": The building materials, paper products, plastics, and other products.

"Wild Life Refugee": Wildlife refers to all non-domesticated plants, animals, and other organisms.

"Archeological Sites": Archeology sites are related to human remains or other historical sites that can delay construction.

4.1.8 Right-of-Way Acquisition-Related Input Variables

The input variables identified for right-of-way acquisition are: "Number of Right-of-Way Parcels," "Number of Right-of-Way Parcels Acquired through Condemnation," and “Right-of-Way Delays.” Table 4.8 shows detailed description of input variables related to right-of-way acquisition.

Table 4.8: Right-of-Way-Related Input Variables Profile

Name of Variables	Units	Type	Availability	Source	Timing of Data Collection
1. No. of ROW Parcels	No.	Quantitative	Yes	Owner	During Project
2. No. of Parcels Acquired by Condemnation	No.	Quantitative	Yes	Owner	During Project
3. ROW Delays	-	Qualitative	Yes	Owner	During Project

Definition of Terms:

“Number of ROW Parcels”: Parcels of land to be acquired from private landowners for the construction of a highway project.

‘Number of Parcels Acquired by Condemnation”: Parcels of land acquired through condemnation.

Condemnation: The process of taking private property for public use through the power of eminent domain. When private property is taken by the government, the owner is entitled to receive just compensation.

“ROW Delays”: The delays caused by right-of-way acquisition.

4.1.9 Utility Adjustments-Related Input Variables

A single input variable related to utility adjustments considered is: “Number of Utilities Adjustments.” It is a total number of utilities adjusted during construction of a highway.

4.1.10 Owner Staffing-Related Input Variables

The input variables related to owner staffing is “Program Manager Involved.” Program manager is an engineering consultant hired to work as the extension of an owner.

4.2 Output Study Variables

The output variables describe project performance. These are subdivided according to cost, schedule, change orders, safety, and quality. These output variables (performance metrics) are quantitative except for a quality metric, which is a subjective judgment. Most of the output variables (performance metrics) related to cost, schedule, safety, and change orders, used in this benchmarking study were also used in previous benchmarking evaluations of construction projects by CII.

The output variables were adjusted according to data available during the data collection phase. The detailed description of the output variables considered in benchmarking of the DB and DBB highway projects follow.

4.2.1 Cost-Related Output Variables

The output variables related to cost include "Total Cost Growth" and "Adjusted Cost per Lane Mile" of a highway. "Total Cost Growth" is the percent difference between final completed design and construction cost and estimated design and construction cost. Since the design and construction of DBB projects are executed separately by two different contractors, the cost associated with these phases is added together to calculate cost-related performance variables. However, the design and construction cost of DB project is combined because both phases are executed by a single design-build contractor.

"Total Cost Growth" is a measure of the cost growth for design and construction phases of a highway project. The cost includes only design and construction, excluding cost of right-of-way acquisition. This variable indicates how much change in cost occurs in between the estimation and the completion of the highway. The formula to calculate this variable is:

"Total Cost Growth" (%)

$$= \frac{\text{Total Design \& Construction Cost} - \text{Estimated Design \& Construction Cost}}{\text{Estimated Design \& Construction Cost}}$$

One of the absolute cost performance metrics researchers compared was "Adjusted Cost per Lane Mile." This output variable is a measure of an absolute cost of a highway. It shows the total cost of design and construction of a highway per lane mile. The following formula is used to calculate adjusted cost per lane mile of highway

"Adjusted Cost per Lane Mile" ($/LM)

$$= \frac{\text{Total Adjusted Design \& Construction Cost}}{\text{Total Length in Lane Mile}}$$

The adjusted total cost excludes the cost of right-of-way acquisition. The cost of highway for DB and DBB projects was adjusted according to its year of completion and location. The Engineering News-Record Construction Cost Index was used to calculate the rate of inflation and change in cost due to location. The completion date of projects selected in this study ranges from 2001 to 2007. The recent project completed was in 2007; therefore, all total highway project costs were adjusted to 2007 costs. All DBB projects were from the state of Texas; therefore all DB projects were adjusted to Texas. The highway cost was adjusted for inflation by multiplying the total highway cost by the 2007 annual average then dividing by the respective year's annual average (Table 4.9). Similarly, for location adjustment, the total adjusted highway cost was obtained by multiplying the total highway cost by the Texas index and dividing by the corresponding location index (Table 4.10).

Table 4.9: Construction Index from Engineering News Record

Year	Index	Mutiplication Factor
2001	6318	1.25
2002	6578	1.20
2003	6781	1.16
2004	7308	1.08
2005	7646	1.03
2006	7691	1.02
2007	7879	1.00

Table 4.10: Location Index from Engineering News Record

Project Location	City Reference	Index	Mutiplication Factor
Arizona	Denver	5588	0.85
New Mexico	Denver	5588	0.85
Utah	Denver	5588	0.85
Virginia	Cincinati	7590	0.62
Texas	Dallas	4726	1.00

Table 4.11 shows the profile of "Total Cost Growth" and "Adjusted Cost per Lane Mile."

Table 4.11: Project Cost-Related Output Variables Profile

Name of Variables	Units	Attributes Measured	Metric Type	Formula	Availa -bility	Source
1. Total Design & Const. Cost (TDCC)	$	Project Cost	Absolute	None	Yes	Owner
2. Estimated Design and Construction Cost (EDCC)	$	Project Cost	Absolute	None	Yes	Owner
3. Total Design Cost (TDC)	$	Design Cost	Absolute	None	Yes	Owner
4. Estimated Design Cost (EDC)	$	Design Cost	Absolute	None	Yes	Owner
5. Estimated Construction Cost (ECC)	$	Constr. Cost	Absolute	None	Yes	Owner
6. Total Construction Cost (TCC)	$	Constr. Cost	Absolute	None	Yes	Owner
7. Total Cost Growth (TCG)	$	Project Cost Predictability	Relative	$\frac{TDCC - EDCC}{EDCC}$	Yes	Calculate
8. Adjusted Total Design and Construction Cost (ATDCC)	$	Adjusted Cost	Relative	TDCC x Cost Index	Yes	Calculate
9. Adjusted Cost per Lane Mile (ACPLM)	$/LM	Highway Cost Predictability	Absolute	$\frac{ATDCC}{TLM}$	Yes	Calculate

TLM – Total Lane Mile

<u>Definition of Terms</u>

Total Design and Construction Cost (TDCC): The total cost of design and construction excluding cost of right-of-way to construct the highway project.

Estimated Design and Construction Cost (EDCC): The owner's budget at the time of a highway project construction authorization.

Total Design Cost (TDC): The actual cost incurred for designing a highway project.

Estimated Design Cost (EDC): The owner's budget for design of a highway project.

Total Construction Cost (TCC): The actual construction cost of a highway project.

Estimated Construction Cost (ECC): The owner's budget for the construction of a highway project.

Adjusted Total Design and Construction Cost (ATDCC): The total cost of highway project adjusted to base cost of 2007 using Engineering News Record cost index.

4.2.2 Schedule-Related Output Variables

Schedule is an important measure of project performance. Project performance can be assessed by quantifying whether the project is completed on time or not. The schedule-related output variables used in this study include “Total Schedule Growth” and “Delivery Duration per Lane Mile” of a highway. Since the design and construction of DBB project are executed separately by two different contractors, the duration associated with these phases is added together to calculate schedule-related output variables. However, the design and construction duration of DB project is combined because both of these phases are executed by a single design-build contractor.

“Total Schedule Growth” is a performance metric used frequently by the construction industry. This variable is a measure of total project schedule performance during design and construction phase. “Total Schedule Growth” is the difference between actual and estimated design and construction duration, expressed in a percentage of estimated duration. The duration excludes environmental clearance duration. The formula for this variable is:

“Total Schedule Growth” (%)

$$= \frac{\text{Total Design \& Constr. Duration} - \text{Estimated Design \& Constr. Duration}}{\text{Estimated Design \& Construction Duration}}$$

An absolute design and construction duration variable for DB and DBB projects is measured by calculating the design and construction “Delivery Duration per Lane Mile” of a highway. This output variable determines the exact duration taken by the contractor to design and construct the highway. This duration does not include pre-project planning, contract procurement and environmental clearance duration. Only the duration which has been assigned to the designer and contractor is included. The “Delivery Duration per Lane Mile” of a highway is calculated by the following formula.

"Delivery Duration per Lane Mile" (Days/LM)

$$= \frac{\text{Total Design \& Construction Duration}}{\text{Total Length in Lane Mile}}$$

Table 4.12 shows the output variables profile and definition of terms used for schedule-related output variables.

Table 4.12: Project Schedule-Related Output Variables Profile

Name of Variables	Units	Attributes Measured	Metric Type	Formula	Availa -bility	Source
1. Total Design and Construction Duration (TDCD)	Days	Project Schedule	Absolute	None	Yes	Owner
2. Estimated Design and Construction Duration (EDCD)	Days	Design Schedule	Absolute	None	Yes	Owner
3. Total Design Duration (TDD)	Days	Design Schedule	Absolute	None	Yes	Owner
4. Estimated Design Duration (EDD)	Days	Construc. Schedule	Absolute	None	Yes	Owner
5. Total Construction Duration (TCD)	Days	Construc. Schedule	Absolute	None	Yes	Owner
6. Estimated Construc. Duration (ECD)	Days	Project Schedule	Absolute	None	Yes	Owner
7. Total Schedule Growth	%	Predictability	Relative	$\frac{TDCD - EDCD}{EDCD}$	Yes	Calculate
8. Delivery Duration Per Lane Mile (DDLM)	Day/LM	Delivery Speed Predictability	Relative	$\frac{TDCD}{TLM}$	Yes	Calculate

TLM – Total Lane Miles

Definition of Terms

Total Design and Construction Duration (TDCD): The total duration from the beginning of detail design to turnover to owner (CII 2005).

Estimated Design and Construction Duration (EDCD): The predicted duration at the time of authorization of a highway project (CII 2005).

Total Design Duration (TDD): The actual total duration to complete the detailed design of a highway project.

Estimated Design Duration (EDD): The owner's predicted duration to complete the detail design of a highway project.

Total Construction Duration (TCD): The actual duration to complete construction of a highway project.

Estimated Construction Duration (ECD): The owner's predicted duration to complete construction of a highway project.

4.2.3 Change Order-Related Output Variable

Change orders frequently occur in construction projects. Change orders can originate either from the owner's scope change or from design error. Change orders caused delays in the project due to labor productivity loss. Frequent changes in a project can have a negative impact on the schedule and cost of the project, therefore, the measure of change orders is considered a performance measurement. In this study, the change order-related output variables used is "Change Cost Factor." The "Change Cost Factor" is calculated from the following formula:

$$\text{“Change Cost Factor” (\%)} = \frac{\text{Total Change Order Cost}}{\text{Total Design and Construction Cost}}$$

Table 4.13 shows the detailed description of the "Change Cost Factor" variable.

Table 4.13: Project Change Order-Related Output Variables Profile

Name of Variables	Units	Attributes Measured	Metric Type	Formula	Availa-bility	Source
1. Total Number of Change Orders (TNCO)	No.	Project Change Order	Absolute	None	Yes	Owner
2. Number of Design Change Orders (NDCO)	No.	Project Design Change Order	Absolute	None	Yes	Owner
3. Number of Construction Change	$	Project Construc.	Absolute	None	Yes	Owner
Orders (NCCO)		Change Order	Absolute	None	Yes	Owner
4. Total Cost of Change Orders (TCCO)	$	Project C-O Cost	Absolute	None	Yes	Owner
5. Total Cost of Design Change Orders (TCDCO)	$	Project Design Change Order Cost	Absolute	None	Yes	Owner
6. Total Cost of Construction Change Orders (TCCCO)	$	Project Construc. C-O Cost	Absoulte	None	Yes	Owner
7. Change Cost Factor	%	Project C-O Cost Predictability	Relative	$\frac{TCCO}{TDCC}$	Yes	Calculate

TDCC – Total Design and Construction Cost

Definition of Terms

Total Number of Change Orders (TNCO): The total number of written order issued by the Owner to the Developer delineating any changes in the requirements of the Contract Documents.

Number of Design Change Orders (NDCO): The total number of change order associated with the design changes.

Number of Construction Change Orders (NCCO): The total number of change orders associated with the construction changes.

Total Cost of Change Orders (TCCO): The total cost associated with change orders.

Total Cost of Design Change Orders (TCDCO): The total cost of change orders associated with design.

Total Cost of Construction Change Orders (TCCCO): The total cost of change orders associated with construction.

4.2.4 Safety-Related Output Variable

Safety of the construction project is very important. In addition to better cost, schedule and quality performance, the project should be completed without any incidents. In this study, researchers collected data related to safety to compare the DB and DBB project safety performance. For this purpose, researchers used the "Fatality Rate" as a measure of safety for the projects. It is defined by the CII as:

$$\text{"Fatality Rate"} = \frac{\text{Total Number of Fatalities x 200,000,000 Hours}}{\text{Total Construction Work Hours}}$$

This output variable is a measure of the number of fatalities per 100,000 full time workers per year in the construction site.

4.2.5 Quality-Related Output Variable

Quality is an important aspect of project construction. A construction project should be built with good quality. But it is very difficult to rate the quality of highway construction. In this study, researchers measured subjectively "Quality Rating" of DB and DBB projects by asking the owners to rate the project quality on a scale of 1 to 4, 1 being bad and 4 being excellent.

4.3 Summary of Input and Output Study Variables

The input and output study variables of large highway projects presented in this chapter were identified during this study. The review of literature and DOT's specification yielded input variables that are believed to have an association with output variables. The total number of input variables considered in the analysis of this study is forty-seven. The total number of output variables used in this study for comparison is eight. "Adjusted Cost per Lane Mile" and "Delivery Duration per Lane Mile" output variables are used for the first time to compare large DB and DBB highway projects. The next two chapters present detailed findings related to these study variables.

Chapter Five: Descriptive Statistics of Input Variables

5.1 Size, Type of Work and Location

As discussed previously, the cost for each of the projects selected for benchmarking was more than $100 million. Four out-of-state DB projects and four in-state DBB projects data could be collected. The resulting sample size for input and output variables analysis was eight. The total design and construction cost of these eight projects is $2.6 billion. The raw data of input variables are shown in Appendix C.

From analysis of project cost data, it was found that the average "Design and Construction Cost" of the DB and the DBB contracts were $441 million and $217 million respectively. Therefore, the average cost of DB contracts was higher than DBB contracts for this sample. The average cost of the entire sample was $329 million. The data analysis shows that the median cost of DB and DBB was similar. Figure 5.1 and Figure 5.2 show the average and median "Design and Construction Cost" of the DB, DBB, and total sample set.

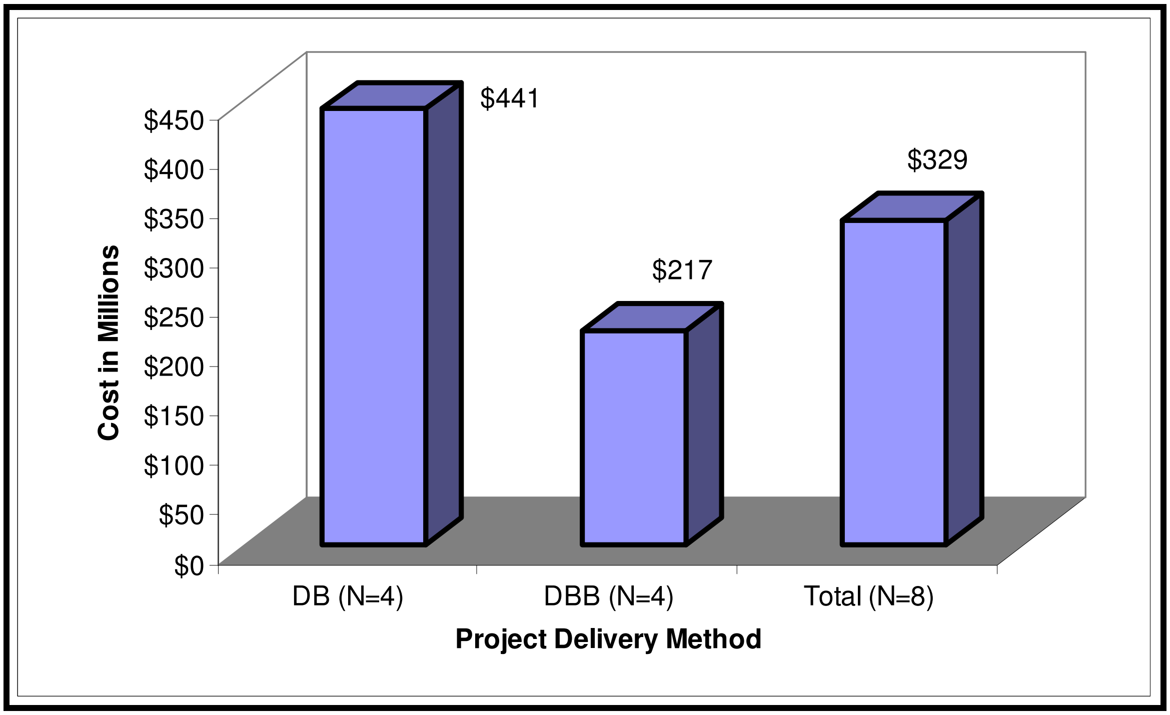


Figure 5.1: Average Design and Construction Cost by Project Delivery Method

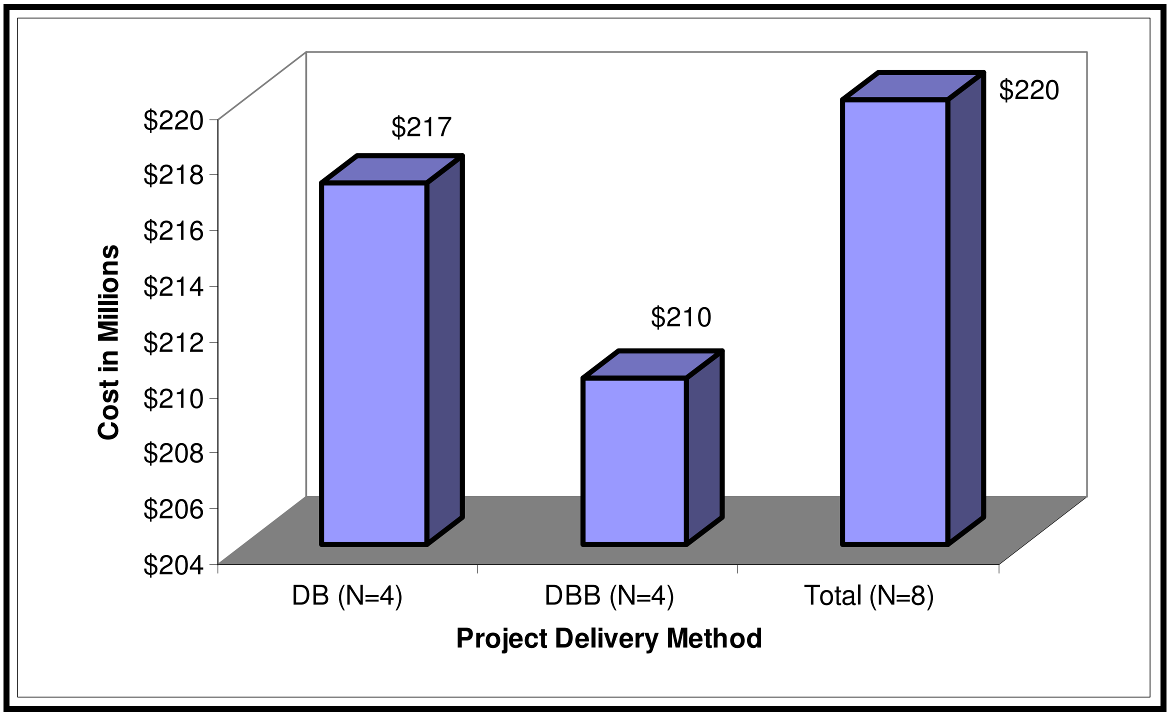


Figure 5.2: Median Design and Construction Cost by Project Delivery Method

The average "Design and Construction Duration" for DB and DBB highway contracts were 963 and 1663 working days respectively. The analysis shows that despite DB projects being higher in cost, they had less design and construction duration in comparison to the DBB projects. The data sample shows that the average "Design and Construction Duration" for the entire sample was 1313 working days. Figure 5.3 shows the average "Design and Construction Duration" by project delivery methods.

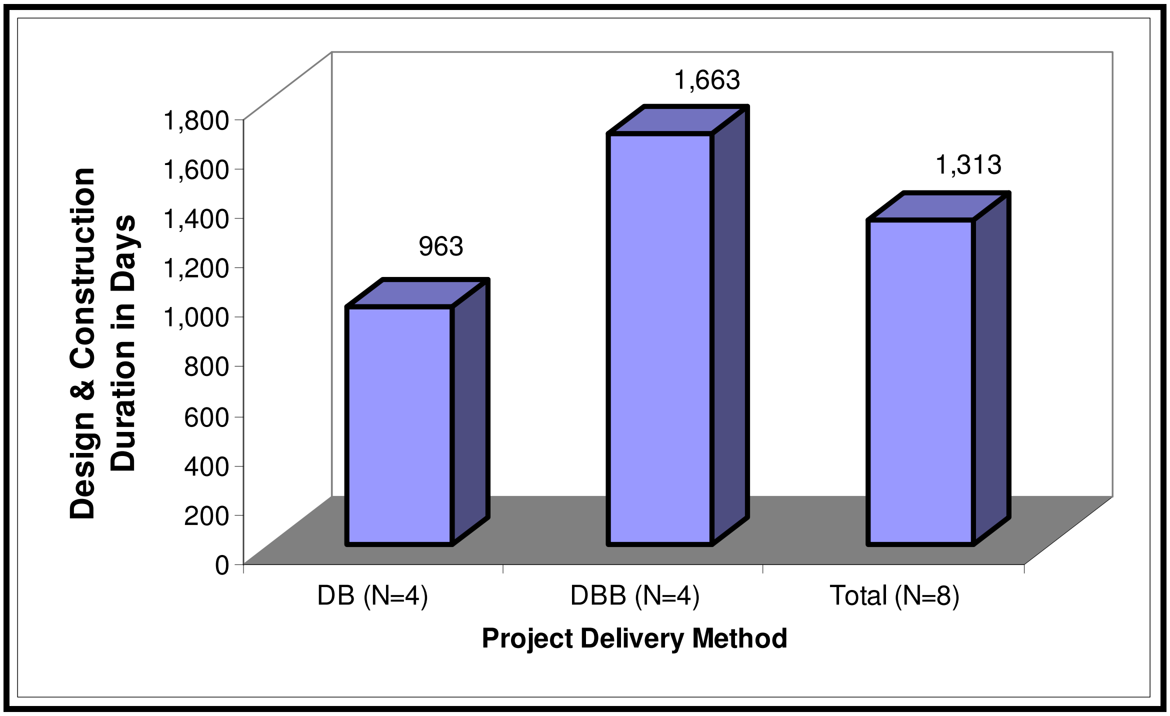


Figure 5.3: Average Design and Construction Duration by Project Delivery Method

The highway projects selected for comparison purpose consisted of two different "Project Nature"; new construction and reconstruction. The distribution of the number of projects by "Project Nature" was also calculated. From this analysis it was found that DBB projects were equally proportioned (50 percent each) as reconstruction and new construction projects. Twenty-five percent of DB projects were new construction and 75 percent were reconstruction projects. The entire sample contained 62.5 percent of reconstruction projects and 37.5 percent of new projects. Figure 5.4 shows the distribution of contracts by "Project Nature." The analysis showed that the distribution of new and reconstruction projects in DB and DBB contract samples were nearly similar.

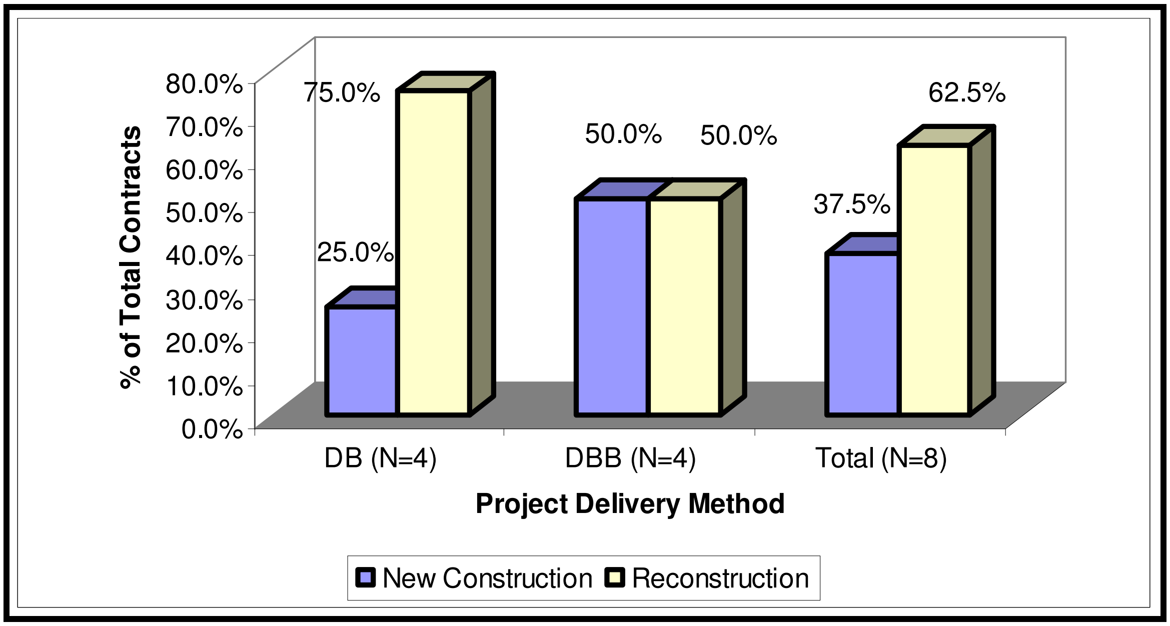


Figure 5.4: Percentage of Total Contracts by Nature of Projects

The highway projects selected for benchmarking fall into two main "Location" categories: urban and rural. One hundred percent of DBB projects were located in urban areas whereas 50 percent of DB projects were located in urban areas and the rest, 50 percent were located in rural areas. Three-fourth of total sample projects was located in urban areas and rest one-fourth was located in rural areas. Figure 5.5 shows the distribution of projects by "Location."

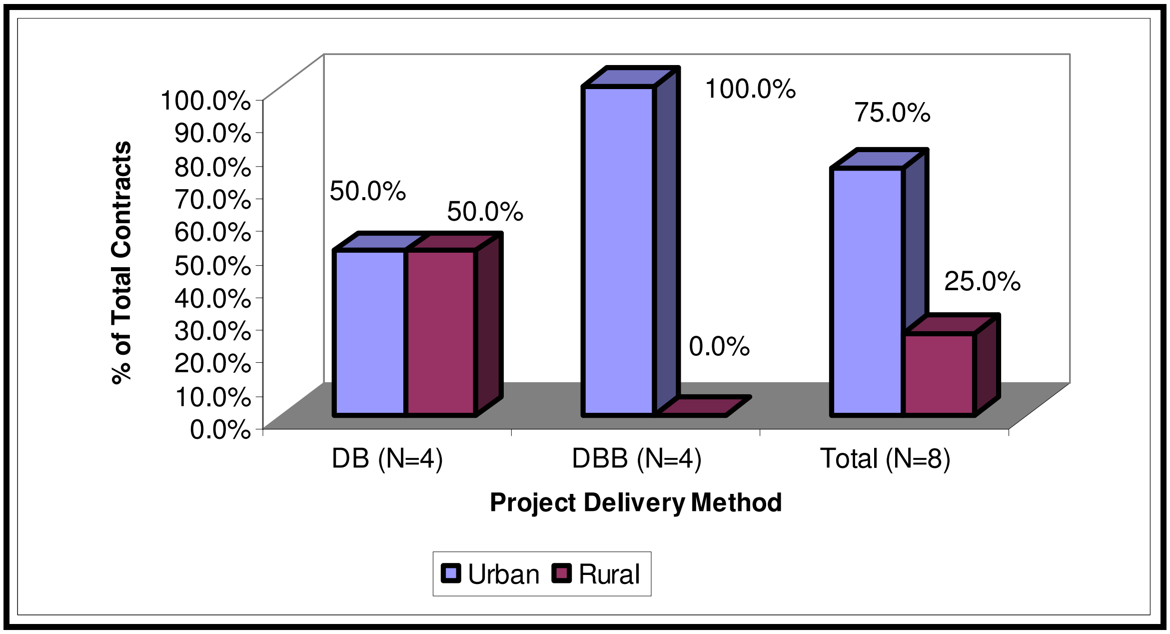


Figure 5.5: Percentage of Contracts by Location

The construction of highways is a complex process. Reconstruction and expansion projects are generally constructed interfacing with traffic. The data analysis shows that nearly equal proportion of DB and DBB projects were constructed interfacing with traffic; 75 percent for DB and 100 percent for DBB projects. The total sample contained 87.5 percent of projects that were constructed interfacing with traffic. Figure 5.6 shows the percentage of "Projects Constructed with Traffic Interface."

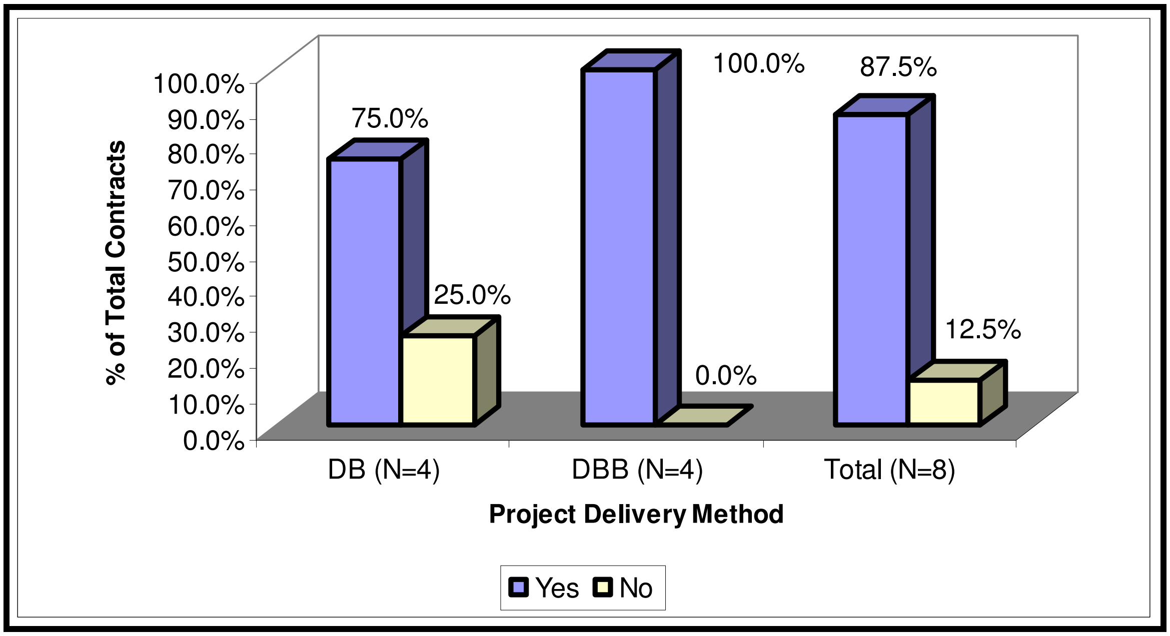


Figure 5.6: Percentage of Contracts Constructed with Traffic Interface

5.2 PROJECT SCOPE

The data was also analyzed by "Highway Length in Lane Mile." This analysis shows that the average length of DB contracts was 99.5 lane miles, whereas the average length of DBB contracts was 66.8 lane miles per each contract. The average length of the entire sample contracts was 83.2 lane miles. Figure 5.7 shows the average "Highway Length in Lane Mile" by project delivery method.

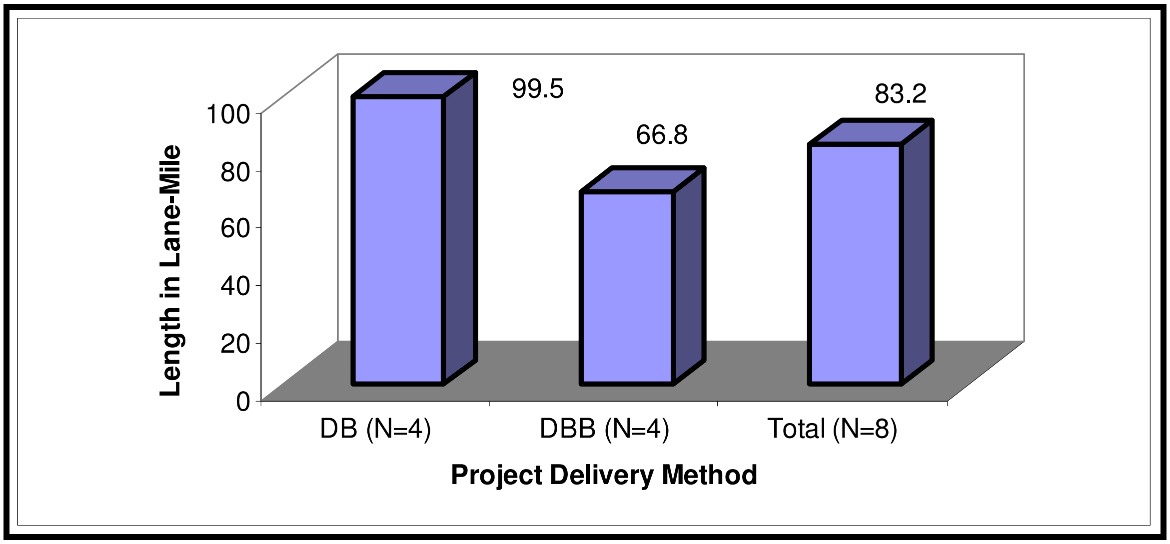


Figure 5.7: Average Highway Length in Lane Mile per Contract

The average “Number of Bridges” per DB and DBB contract was 43 and 21 respectively. In the sample DB projects had more bridges than DBB projects. The average “Number of Bridges” per contract for entire sample was 32. Figure 5.8 shows the “Number of Bridges” per DB and DBB highway contracts.

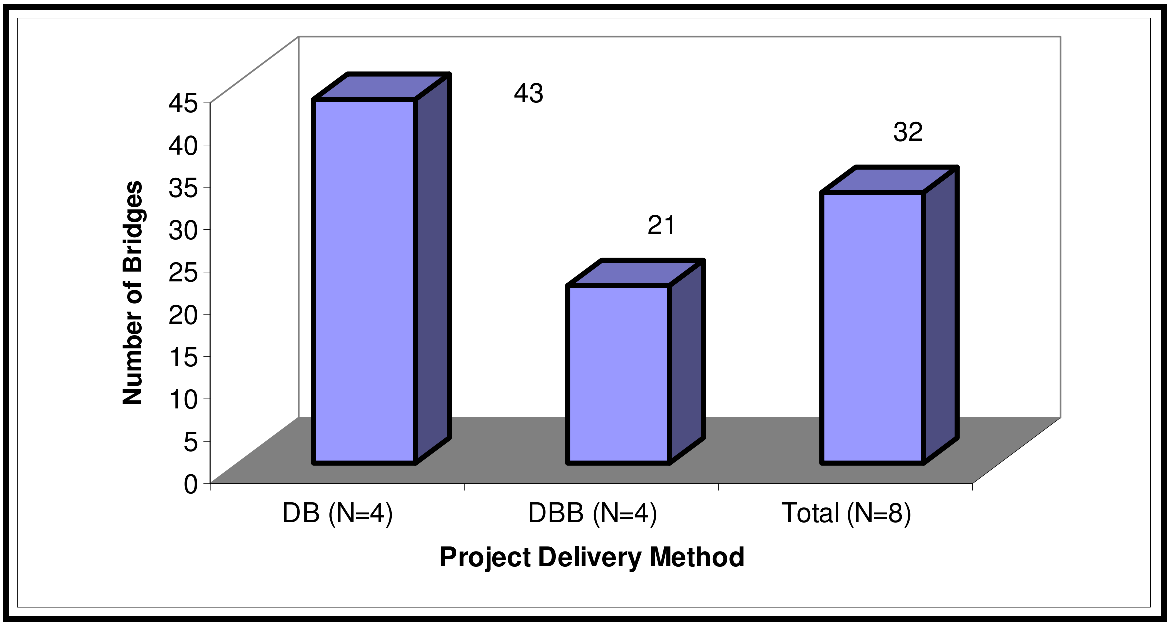


Figure 5.8: Average Number of Bridges per Contract

The "Number of Interchanges" data was also collected for these contracts. The data analysis shows that sample DB projects had 3 interchanges on average, whereas DBB projects had about 1 interchange per contract. The total sample projects had 2 interchanges on average. The distribution of "Number of Interchange" is shown in Figure 5.9.

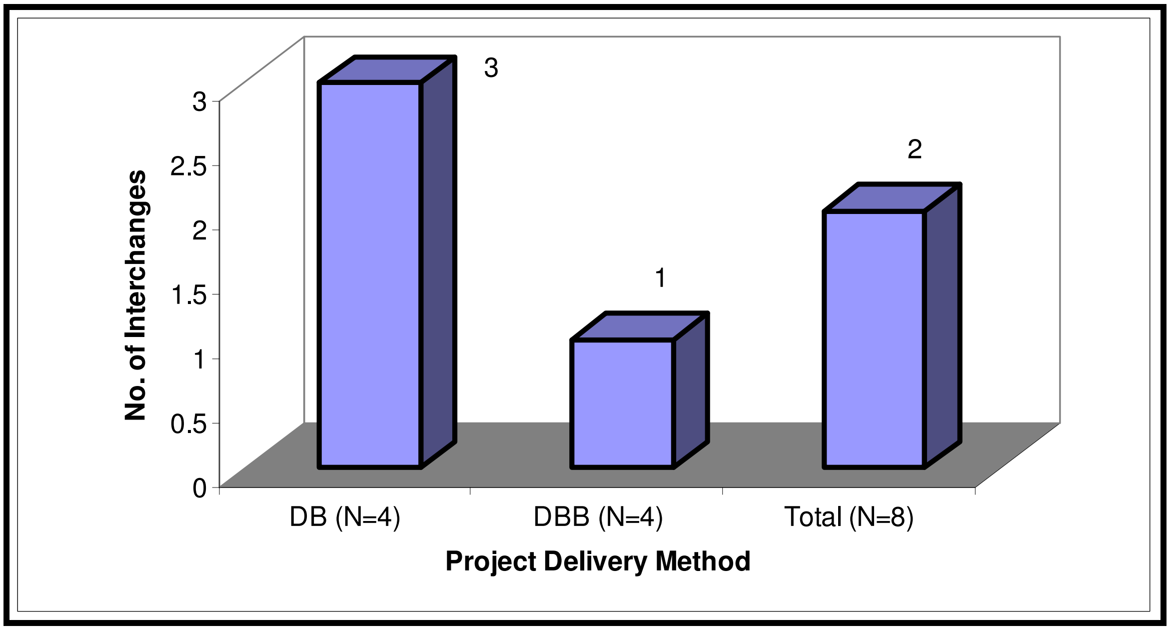


Figure 5.9: Average Number of Interchanges per Contract

Some highway projects involved predominantly concrete pavement while others were asphalt. About 65 percent of the total lengths of DB projects were concrete pavement and 35 percent were asphalt pavement. However, all DBB projects were concrete pavement. The data shows that there was not much difference in "Pavement Types" in the samples. About 79 percent of the total lengths of sample projects were concrete pavement. Figure 5.10 shows the percentage of total length of projects by "Pavement Types."

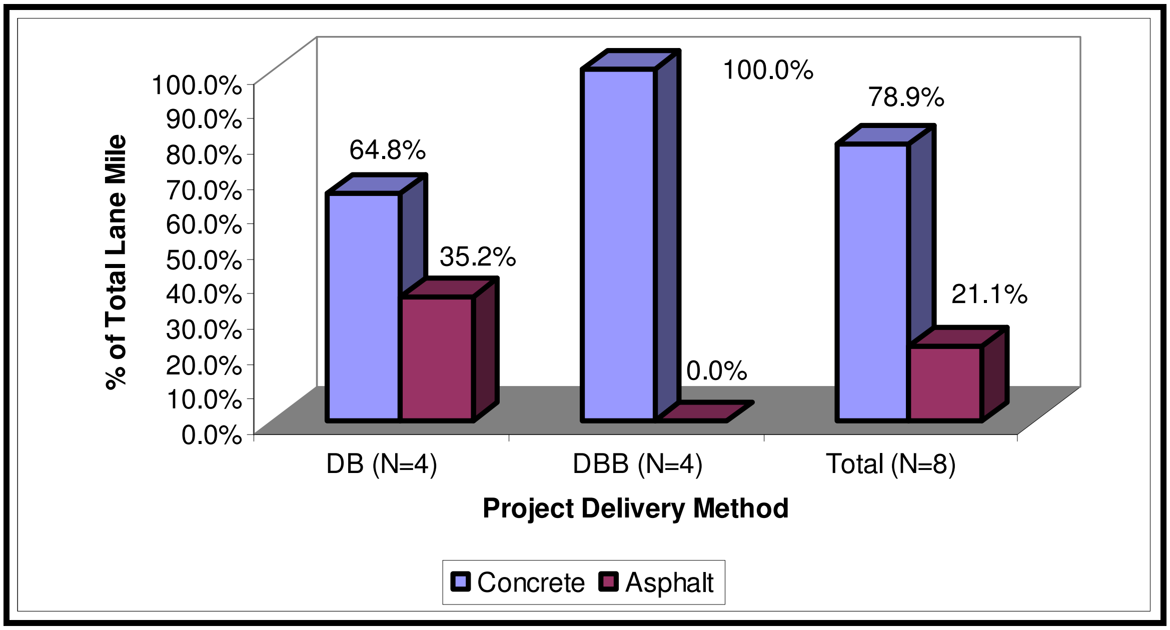


Figure 5.10: Percentage of Total Lane Miles by Pavement Type

5.3 Contract Provision

Two types of "Project Delivery Methods" considered in this study were DB and DBB. The distribution of DB and DBB contracts was equal; 50 percent each. Figure 5.11 depicts the percentage of total contracts by "Project Delivery Method."

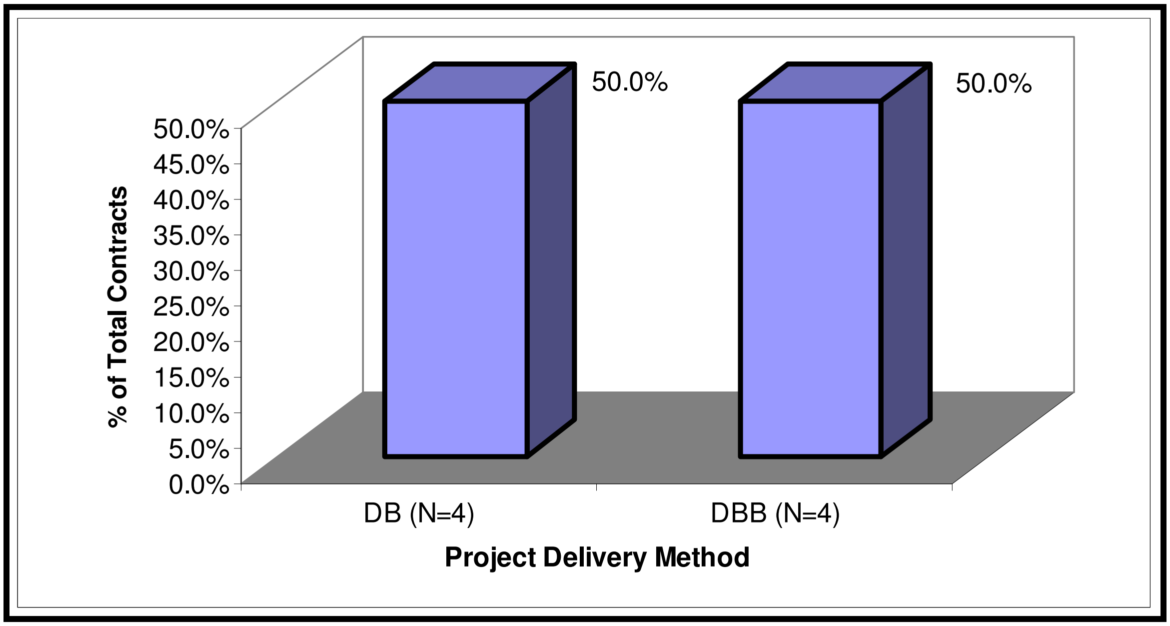


Figure 5.11: Percentage of Contracts by Project Delivery Methods

The "Contract Award Methods" for the DB contracts were best value, negotiation, and B bidding. Fifty percent of DB contracts used best value methods, 25 percent used negotiation, and likewise 25 percent used B bidding. However, in DBB projects, only one contract award method, competitive unit price-based lump sum, was used. The percentage of contracts by "Contract Award Methods" in the sample is given in Figure 5.12.

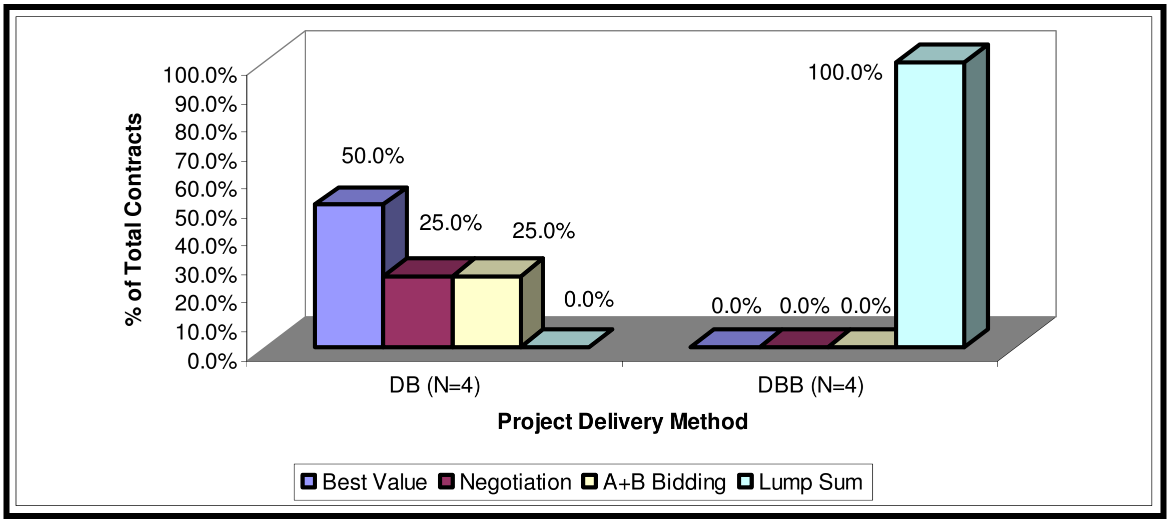


Figure 5.12: Percentage of Contracts by Contract Award Methods

The DB project respondents were asked about number of previous DB projects built by their organization. The respondents indicated the number of projects ranging from none to three or more. The data shows that 50 percent of owner had not built any DB projects before. This finding suggests that DB project delivery method is new to DOTs. The percentage of owners who had "Previous DB Experience" is shown in Figure 5.13.

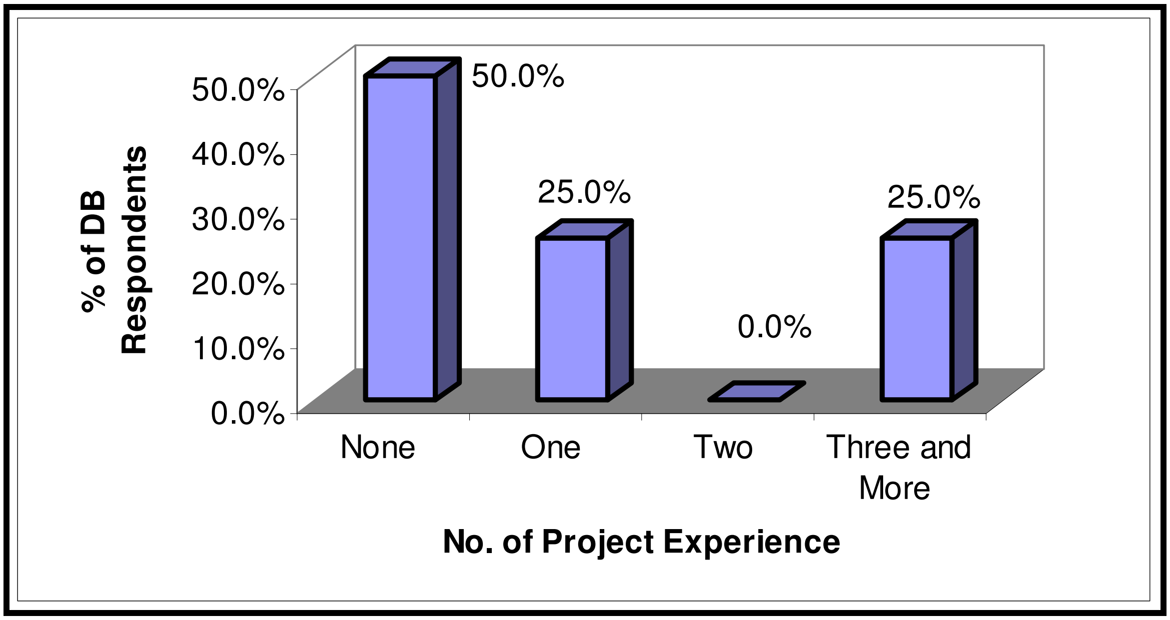


Figure 5.13: Percentage of DB Respondents with Previous DB Experience

The study conducted by FHWA shows that there is a correlation between "Percentage of Design Complete" at authorization and project performance of DB highway projects (FHWA, 2006). Researchers concluded that 30 percent design complete at the time of contract award, is appropriate to allow contractors to use their innovative ideas during construction. Out of four DB projects collected for this study, 75 percent projects had less than 30 percent design complete and 25 percent project had more than 30 percent design complete at the time of the contract award. Figure 5.14 shows the percentage of DB projects by "Percentage of Design Complete" at the time of contract award.

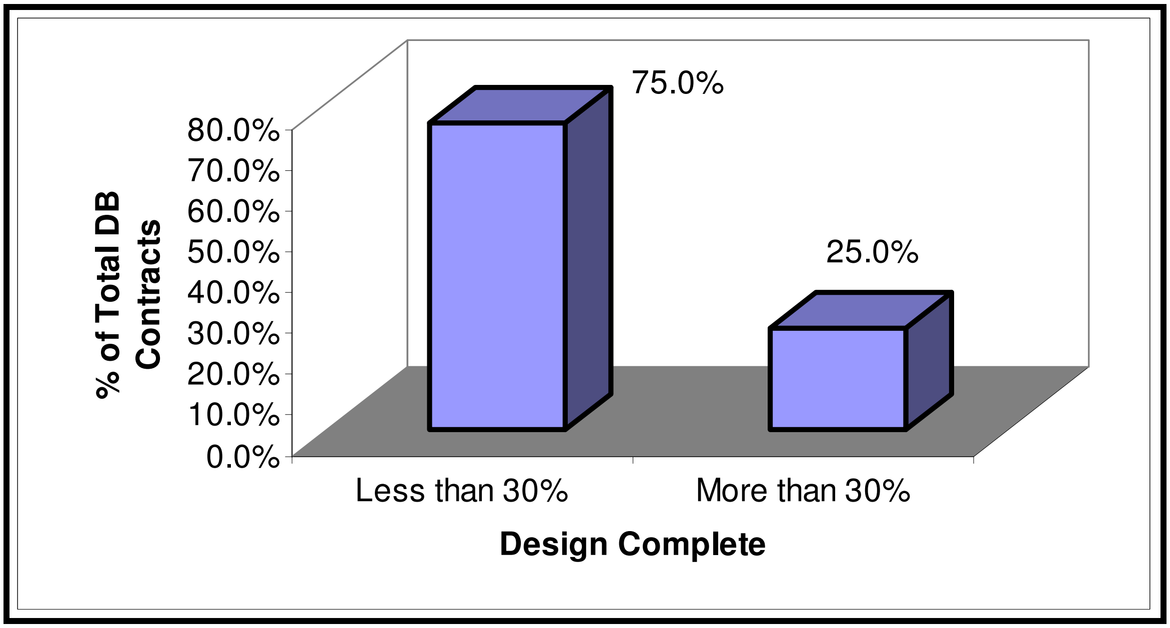


Figure 5.14: Percentage of DB Contracts by Percentage of Design Complete at Contract Award Time

The "Liquidated Damage Provision" is put into contracts to compensate the damage caused to owner by completing the project late. This provision ensures that the contractor is liable for the late completion of the project. In highway projects, this provision is frequently used. The rate of liquidated damage in highway construction is often calculated by the road user costs. In the sample contracts, 7 contracts used liquidated damage provisions in their contract. The data shows that 75 percent of DB projects used a liquidated damage provision whereas 100 percent of DBB projects used this provision. The data sample distribution shows that "Liquidated Damage Provision" was equally used in DB as well as DBB. Eighty-seven percent of total sample projects used a liquidated damage provision. Figure 5.15 shows the percentage of total contracts by the "Liquidated Damage Provision."

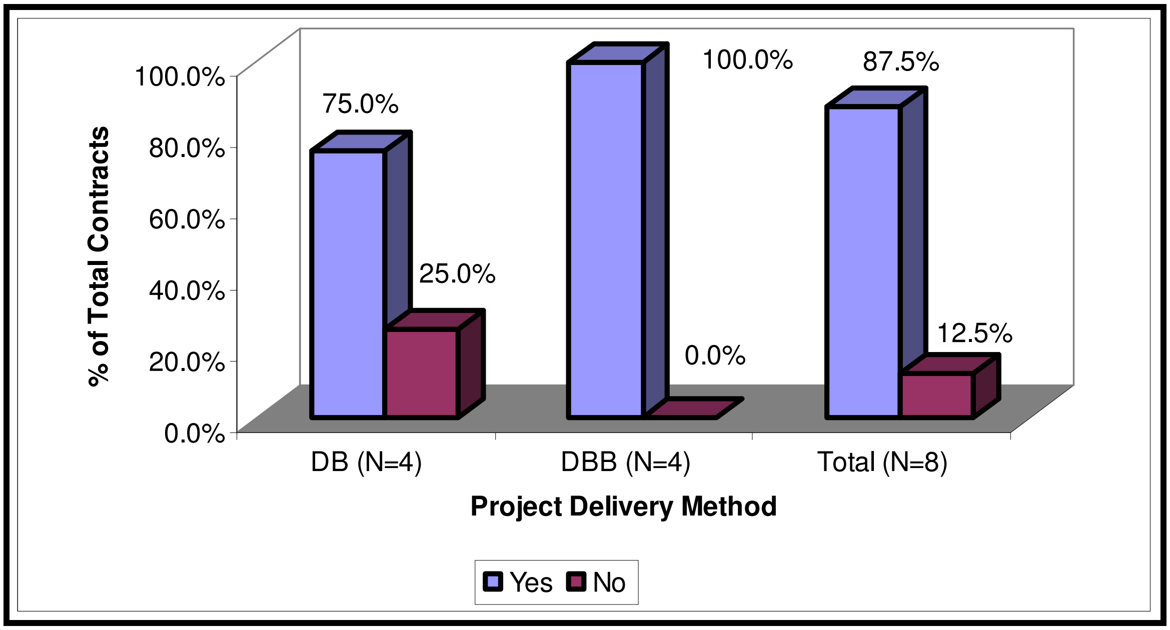


Figure 5.15: Percentage of Contracts by Liquidated Damage Provision

In order to encourage the contractor to complete the project ahead of schedule, the owner will generally put a "Schedule Performance Bonus" in the contract. The bonus will be calculated by multiplying the dollar amount per day by the number of days, if the contractor completes the work ahead of the planned date of completion. The maximum amount of bonus is fixed, however. From the data analysis it can be seen that all DBB used "Schedule Performance Bonus," whereas only 50 percent of DB projects used this provision as shown in Figure 5.16. Three-fourth of total sample projects used "Schedule Performance Bonus" in their contract.

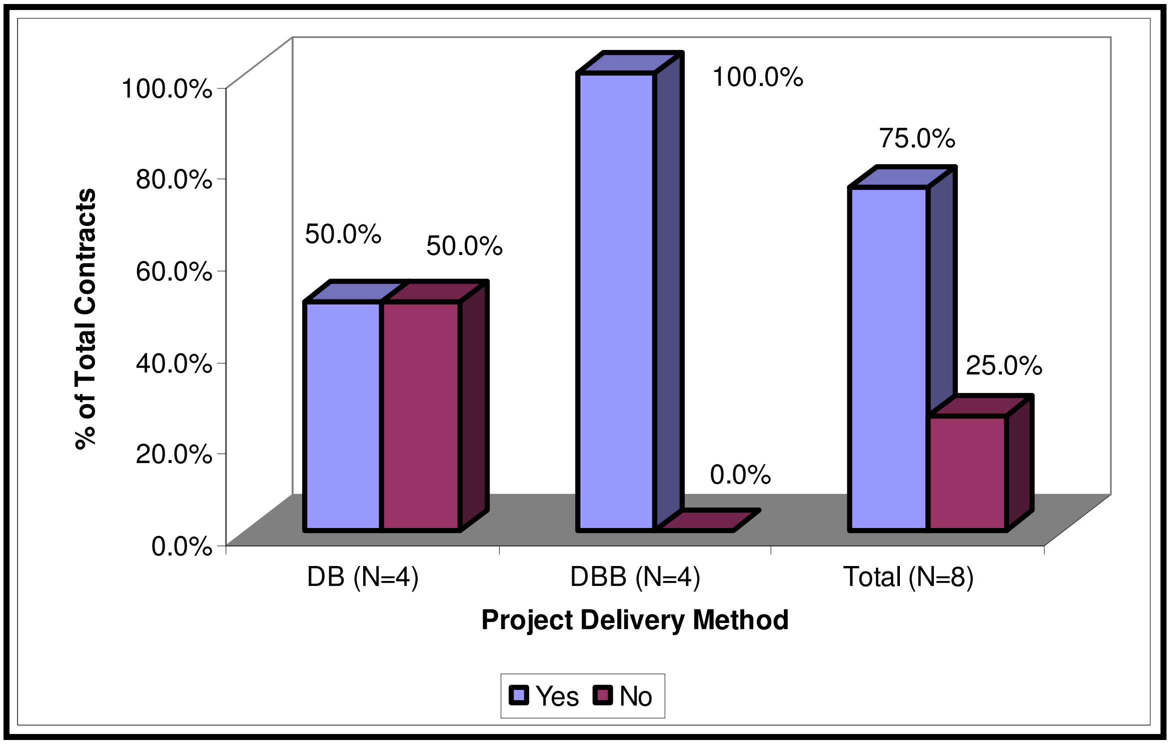


Figure 5.16: Percentage of Contracts by Schedule Performance Bonus

In highway projects, the owner oftentimes establishes a "Lane Rental Provision" in order to charge the contractor if they close a lane for traffic. The rate for lane rental is often calculated by assessing the road user costs for each lane of road. This provision is generally used in reconstruction-type work, where the contractor has to work under traffic. Out of the 8 highway contracts in this data set, only 5 contracts used a lane rental provision; 50 percent of DB and 75 percent of DBB projects. The use of a lane rental provision in contract was about 63 percent for entire sample projects. Figure 5.17 depicts the distribution of use of "Lane Rental Provision," by project delivery method.

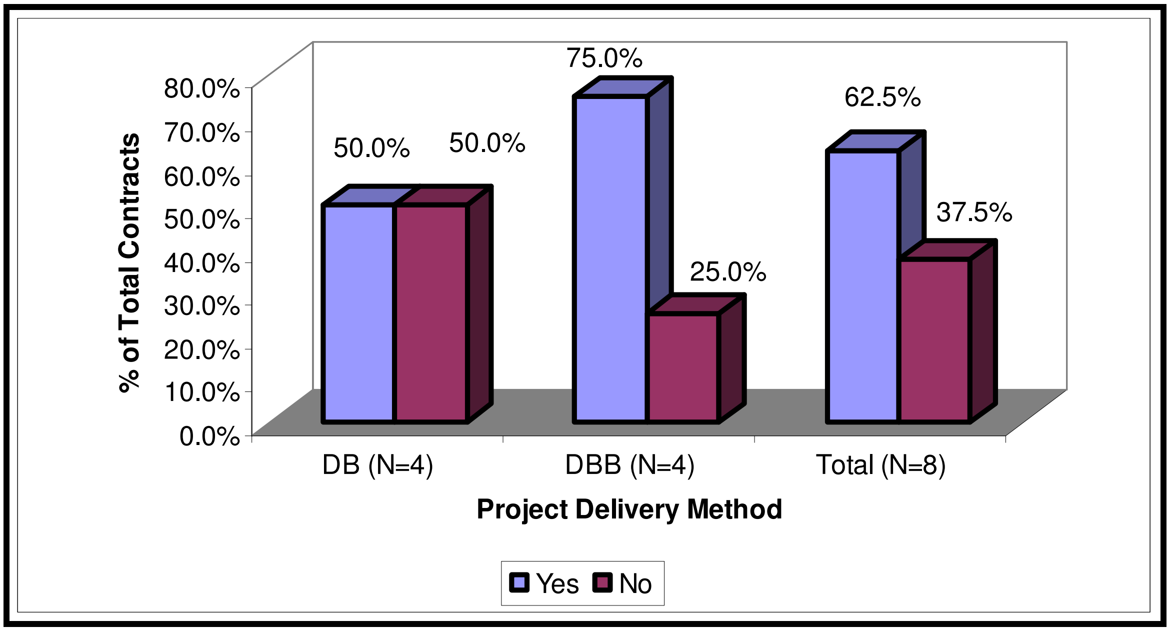


Figure 5.17: Percentage of Contracts with Lane Rental Provision

There are two "Types of Specifications" used in the construction project contracts. One is performance specification and another is blend specification. Most of the highway projects used blend specification. Some of the highway contract used performance specification, in which the contractor will construct the project producing the quality end product and the method of working will be developed by the contractor himself. From our data sample, the analysis shows that DB contracts used more performance specifications than DB projects; 50 percent of DB projects used performance specifications in comparison to 25 percent used by DBB projects. The data shows that the use of performance and blend specification was nearly similar in DB and DBB contracts. The overall project data shows that more projects used blend specification than performance specification. Figure 5.18 depicts the breakdown.

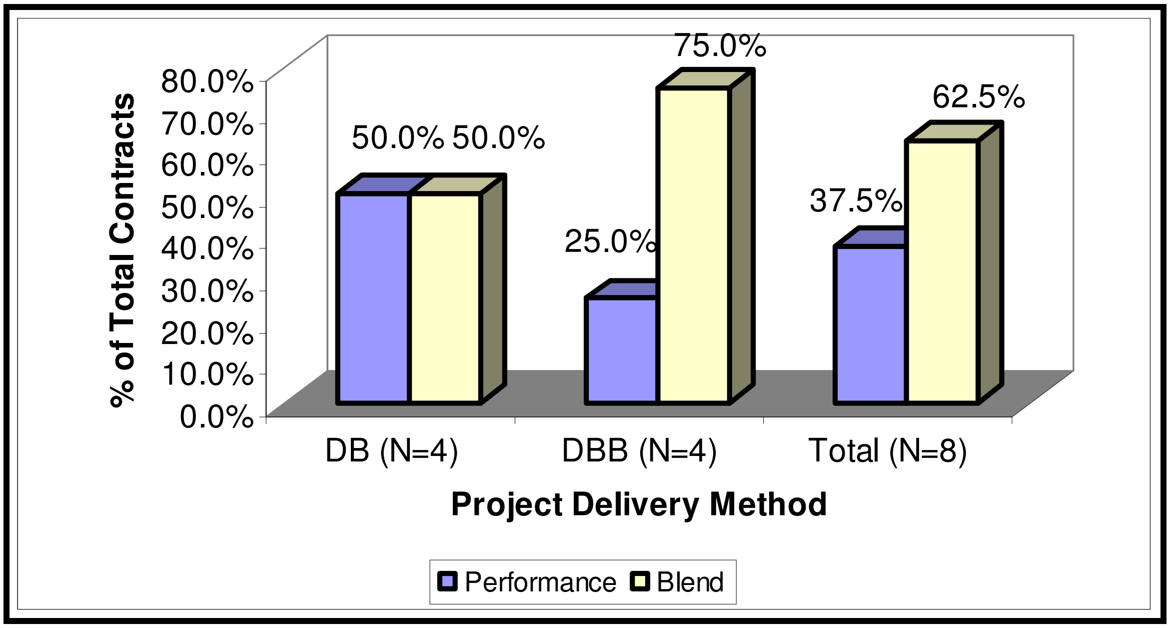


Figure 5.18: Percentages of Contracts by Types of Specification Used

5.4 ORGANIZATIONAL APPROACHES

CII has identified Partnering as one of the best practices to improve the performance of construction projects. In our sample projects, all DB projects had hired "Partnering Consultants" whereas only 50 percent of DBB projects had hired one. In total sample, 75 percent of the projects had hired "Partnering Consultants." Figure 5.19 shows involvement of "Partnering Consultant" in DB and DBB projects. Similarly, the "Frequency of Partnering Session" varied from project to project. The "Frequency of Partnering Session" for DB projects was 4 times per year to 12 times per year. Out of the DBB projects which did have a partnering session, they held them 2 to 4 times per year. The data sample shows that DB projects held more frequent partnering session than DBB projects.

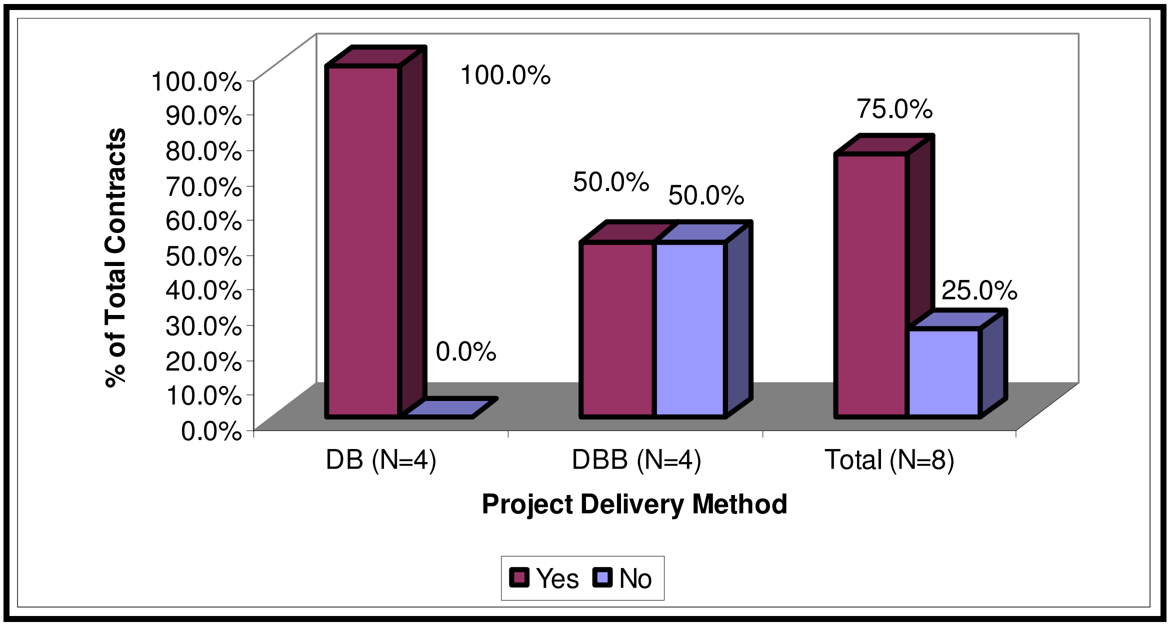


Figure 5.19: Percentage of Contracts with Partnering Consultant Involved

Pre-project planning is an integral part of project development and studies have shown that good pre-project planning helps to improve the cost and schedule performance of projects. In this study, researchers also asked the project respondent to gauge the "Level of Environmental Assessment" and "Level of Right-of-Way Assessment" done during the pre-project planning phase. From our data sample, 50 percent of DB projects had high-level and 50 percent had medium-level of environmental assessment done during pre-project planning phase. One hundred percent of DBB projects had high-level of environmental assessment done during pre-project planning phase. The data sample shows that there was no much variance in "Level of Environmental Assessment" done in DB and DBB contracts. It was also true in the case of right-of-way acquisition. For the "Level of Right-of-Way Assessment," 75 percent DB projects had a high "Level of Right-of-Way Assessment" done in comparison to 100 percent for DBB projects. The total sample data analysis shows that the majority of projects had a high level of environmental and ROW assessment done. Figures 5.20 and 5.21 show the percentage of DB and DBB projects by environmental and right-of-way assessment level.

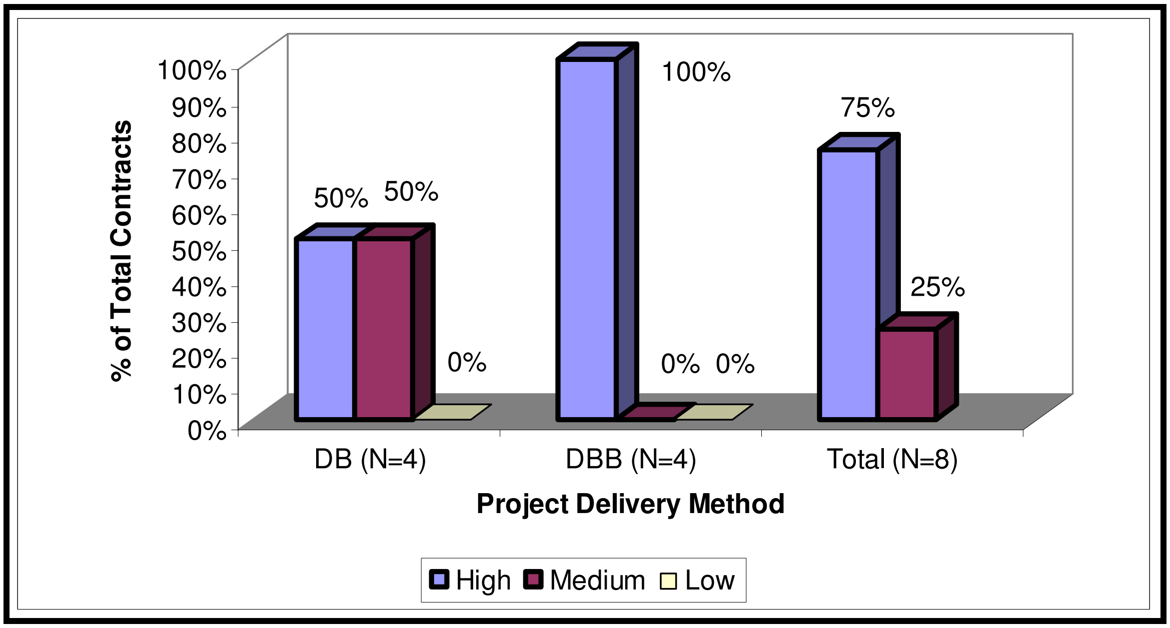


Figure 5.20: Percentage of Contracts by Environmental Assessment Level

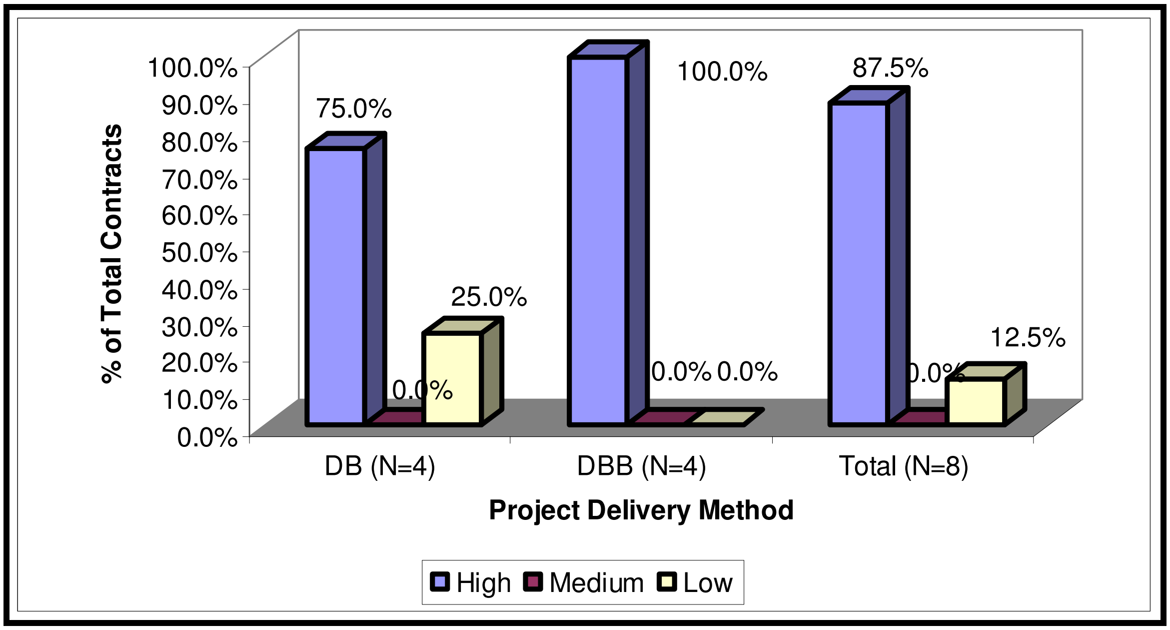


Figure 5.21: Percentage of Contracts by ROW Assessment Level

Owners sometimes do in-house design of highways, when the project is to be built under the DBB project delivery method. In the DB project delivery method, detailed design will be done by the design-builder. The design-builder or owner hires multiple designers to design a large highway project in order to complete the design on time. Depending upon the project size, the "Number of Design Sub-contractors" involved will vary. In this study, project respondent were asked for the "Number of Design Sub-contractors" involved in designing the project. From the data analysis, it was found that sample DB and DBB contracts had more design sub-contractors involved. About 75 percent of DB contracts had less than or equal to five design sub-contractors involved in designing the projects. While, 50 percent of DBB contracts had less than or equal to five design sub-contractors involved, and 50 percent of DBB contracts had more than five. This sample analysis shows that even the DBB projects were small in regards to length, the percentage of contracts having more design sub-contractors involved, was higher.

Considering the fact that the owner procures design separately in DBB, this data trend shows that owners tend to divide the design of the project into small sub-contracts. In contrary, in DB projects, the design-builder is responsible for designing the highway, and therefore, they hire less design sub-contractors to complete the design work. The total project data shows that the majority of projects hired less than equal to 5 design sub-contractors. Figure 5.22 shows the distribution of contracts by "Number of Design Sub-contractor" involved.

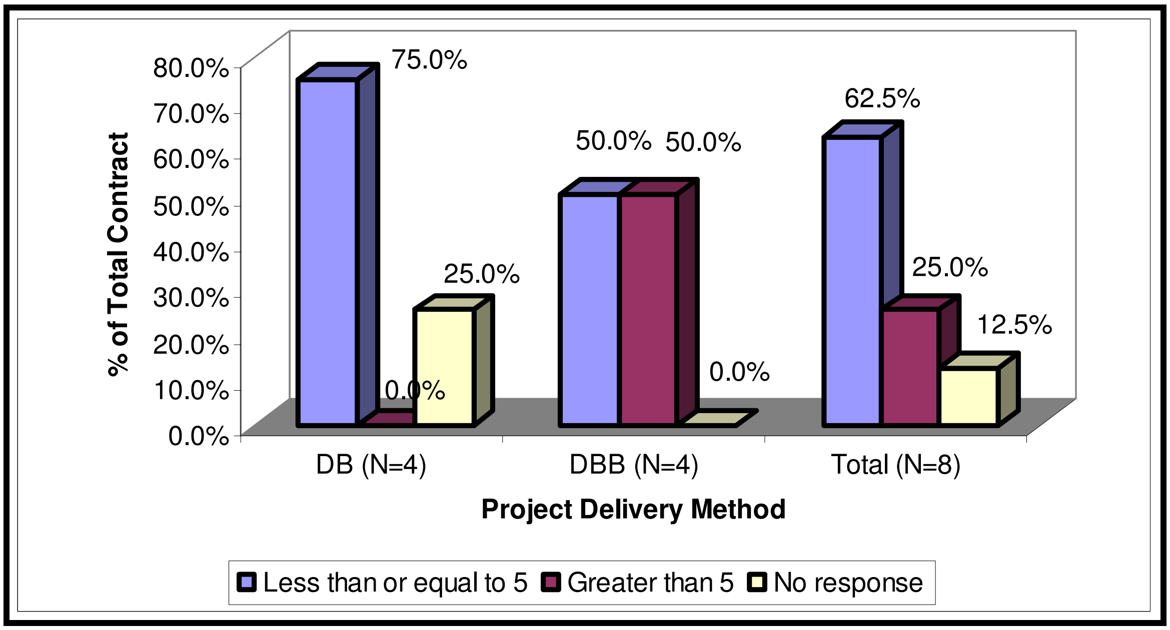


Figure 5.22: Percentage of Contract by Number of Design Sub-contractors

Construction sub-contractors in DB and DBB projects are selected by the design-builder and prime contractor respectively. The data analysis shows that the "Number of Construction Sub-contractors" involved in DB and DBB contracts were nearly similar. The data indicates 50 percent of DB and 75 percent of DBB projects had more than ten construction sub-contractors involved in construction. The total sample data analysis shows that about 63 percent of projects had more than ten construction sub-contractor involved in construction. Figure 5.23 shows the "Number of Construction Sub-contractors" involved in DB and DBB projects.

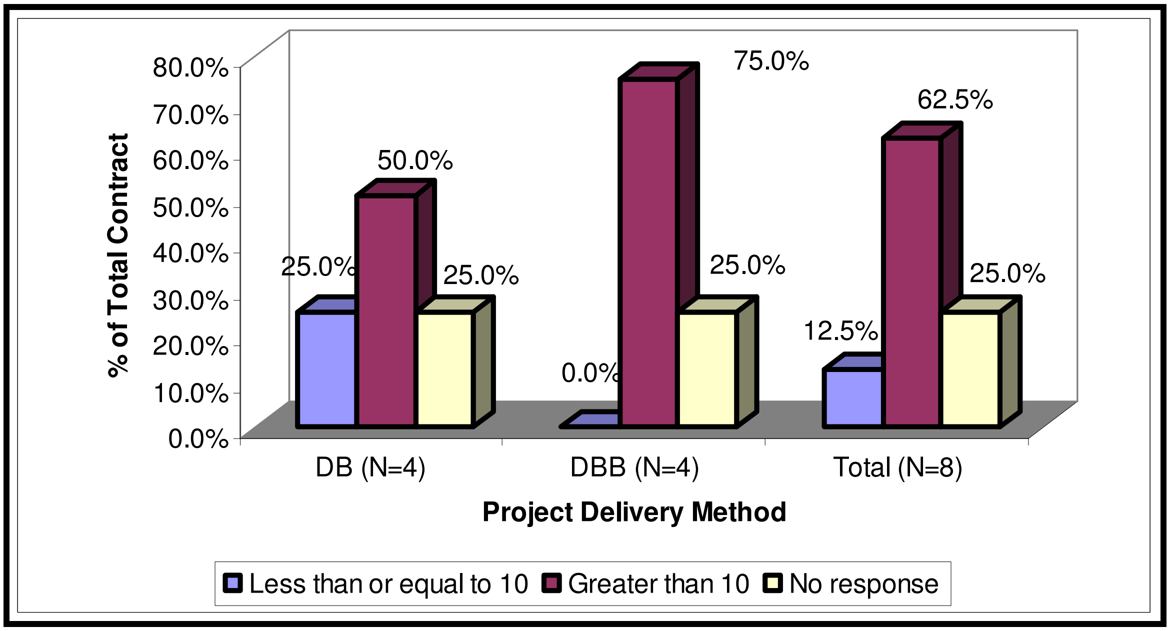


Figure 5.23: Percentage of Contract by Number of Construction Sub-contractors

"Co-location" of owner, program manager and contractor helps the project personnel to solve issues in a timely manner. "Co-location" helps project personnel communicate effectively. This is considered one of the best practices to be followed to improve project performance. In this study, the researchers collected data of "Co-location" for DB and DBB projects and found 100 percent of DB and DBB projects were co-located. This finding shows that owners had institutionalized "Co-location" as a best practice in large highway projects. Figure 5.24 depicts the distribution of DB and DBB projects by owner and contractor co-located.

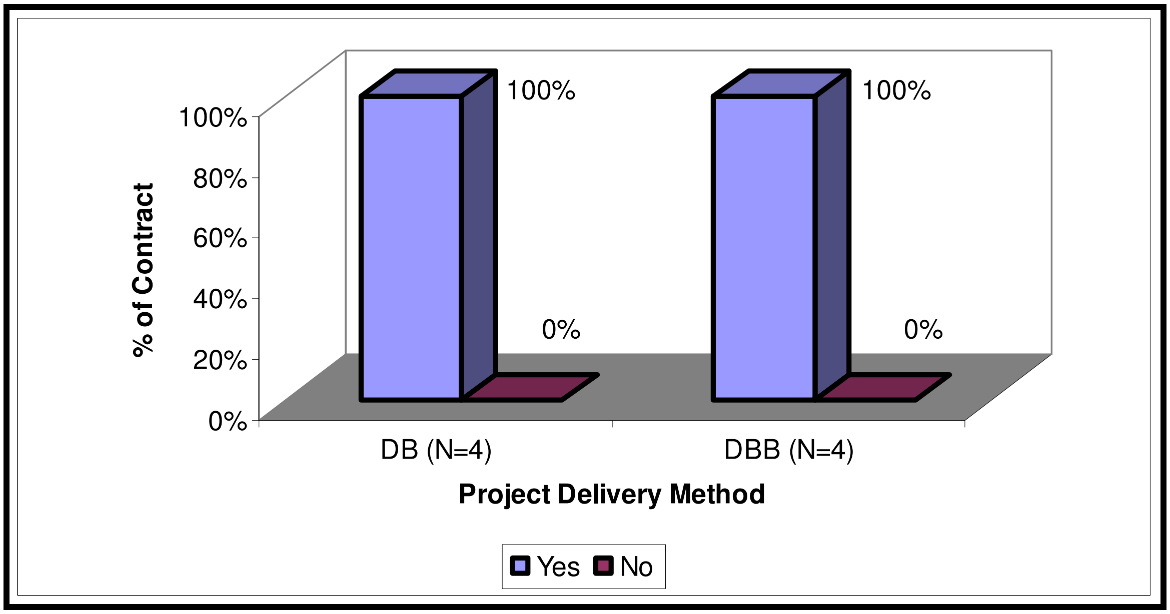


Figure 5.24: Percentage of Contracts with Owner and Contractor Co-located

"Change Management" is a process of managing all the changes that occur in a project. Changes in a project can cause schedule delay, interruptions in the work, and reduction of labor productivity. In order to reduce the risks of having adverse impacts of change in a project, it is necessary to have a well-organized change management process. A huge percentage of projects both in DB and DBB were found to use change management. In DB, the use of "Change Management" was 100 percent whereas in DBB it was 75 percent. This finding shows that the highway industry had institutionalized the change management process as a best practice to improve project performance. Figure 5.25 shows the distribution of use of "Change Management" in DB and DBB contracts.

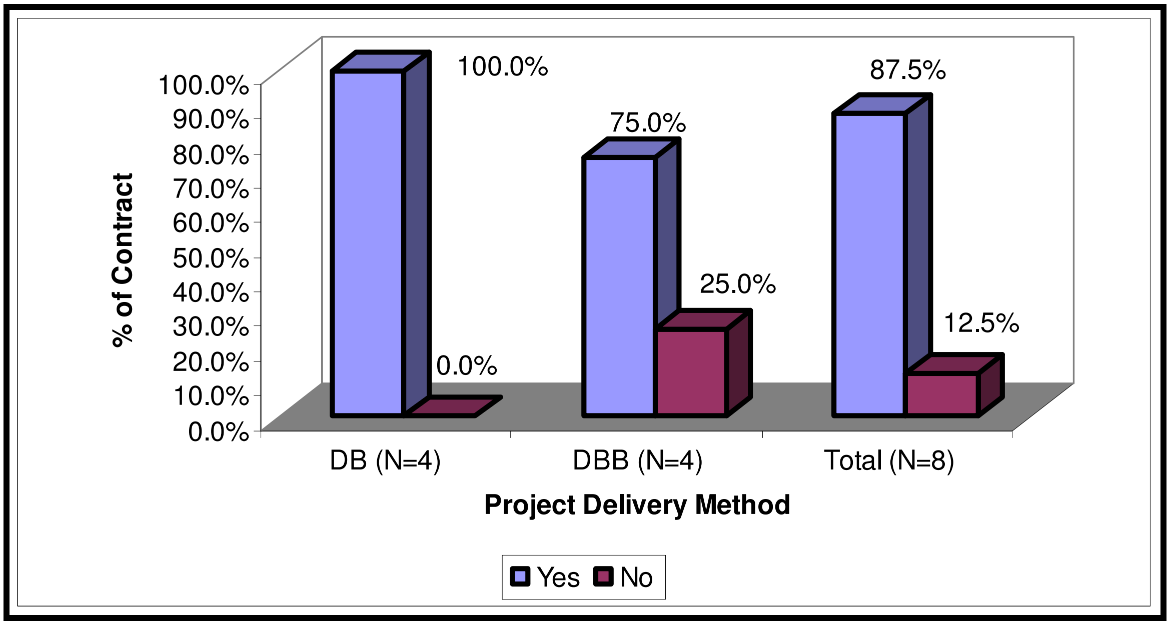


Figure 5.25: Percentage of Contracts that Use Change Management

CII has identified "Value Engineering" as a practice to improve construction project performance. The use of "Value Engineering" can reduce the cost of highway projects substantially. The data collected from the sample shows equal number of DB and DBB contracts used value engineering: 50 percent of DB and DBB projects used value engineering. Figure 5.26 shows the percentage of DB and DBB contracts that used value engineering.

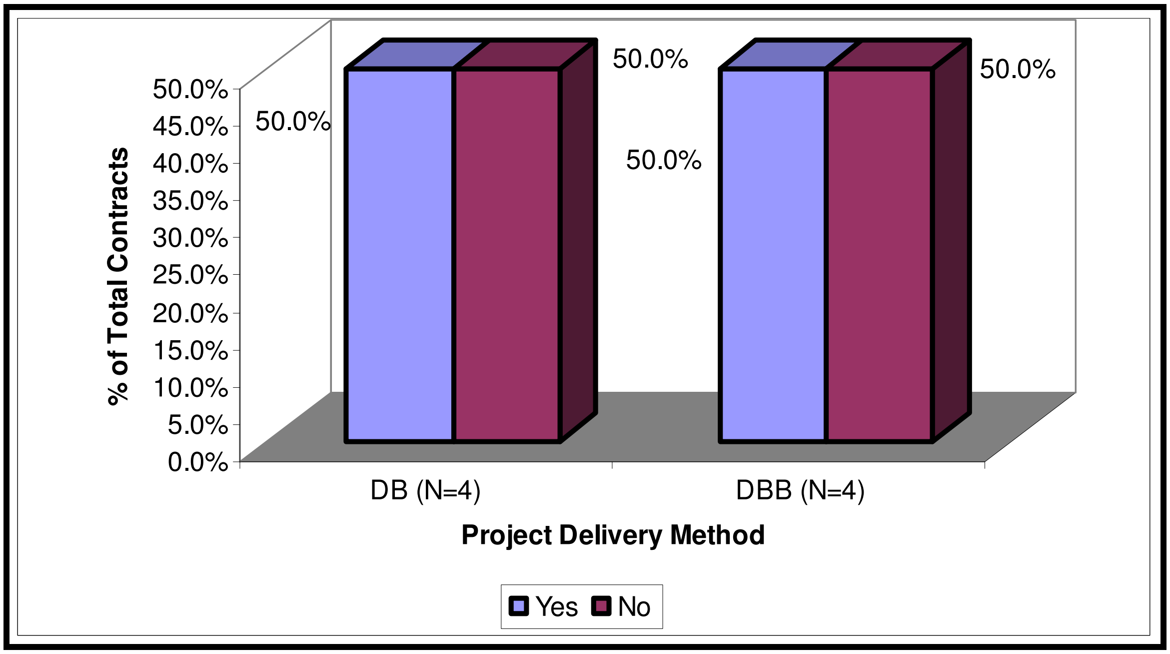


Figure 5.26: Percentage of Contracts that Use Value Engineering

"Constructability" is a best practice that improves construction project performance. According to CII, constructability is the process of integrating construction expertise into all phases of the project. The major benefit of constructability is the reduction of design changes in the project and also making the design easier to build. In this study, researchers tried to find it out whether constructability was used in the highway projects. It was found that all the projects considered for benchmarking used constructability reviews in their projects. This suggests that highway construction has also institutionalized constructability reviews as best practice. Figure 5.27 shows the distribution of use of constructability in DB and DBB contracts.

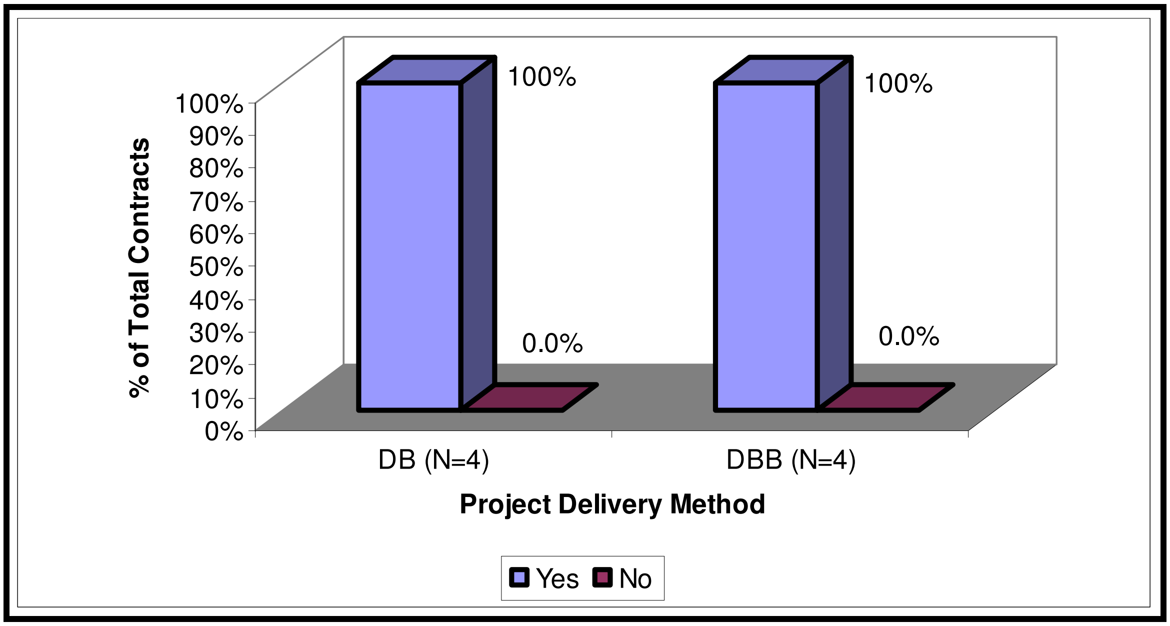


Figure 5.27: Percentage of Contracts by Constructability Use

5.5 Work Processes

During the data collection, researchers collected data indicating improved technologies used in the construction of highway. From the responses received, some projects used new construction technology to improve cost, schedule and quality performance. The "Latest Construction Technology" was use of slip form for paving concrete pavement, use of liquid nitrogen to set the concrete pavement earlier. Similarly, some structure-related technologies like wicked drains and geo-foams were also used in some of the projects. The data analysis of the samples shows that there is not significant different in number of DB and DBB projects that used "Latest Construction Technology." Fifty percent of DB and 75 percent of DBB projects used "Latest Construction Technology" during construction phase. The total sample data analysis shows that about 63 percent of projects used latest technology to improve their work processes. Figure 5.28 shows the percentage of contracts that use "Latest Construction Technology" to improve work processes in DB and DBB contracts.

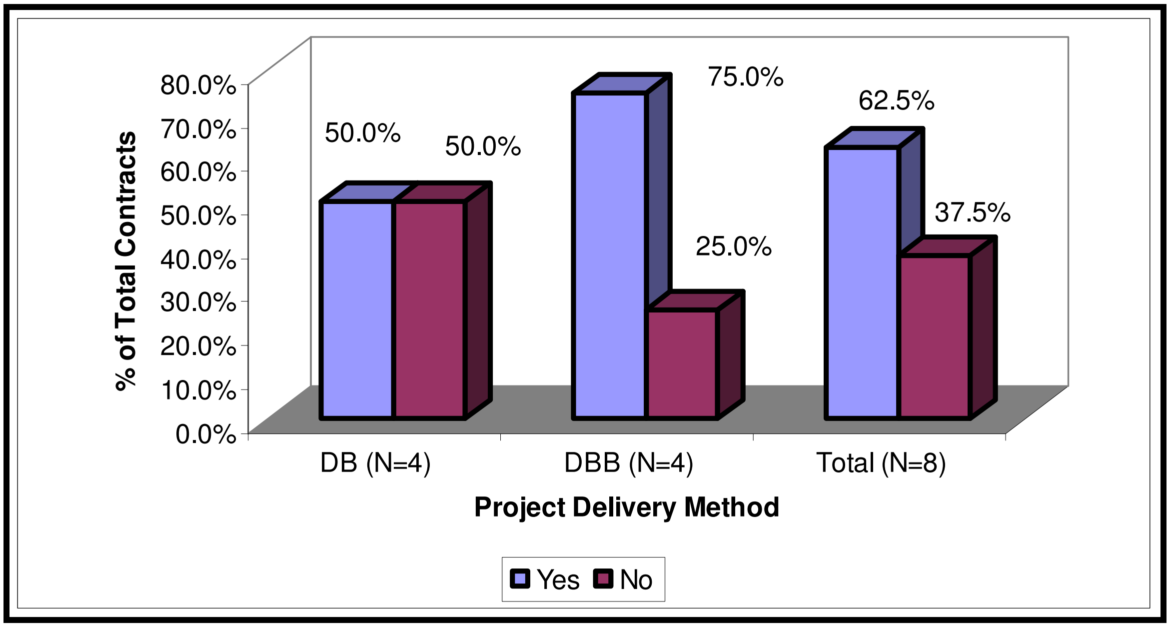


Figure 5.28: Percentage of Contracts by Use of Latest Construction Technology

The respondents were asked whether the project established a "Web Portal" to give information to the public. All DB and DBB projects had or have an official web portal. Figure 5.29 shows the percentage of projects that had a "Web Portal."

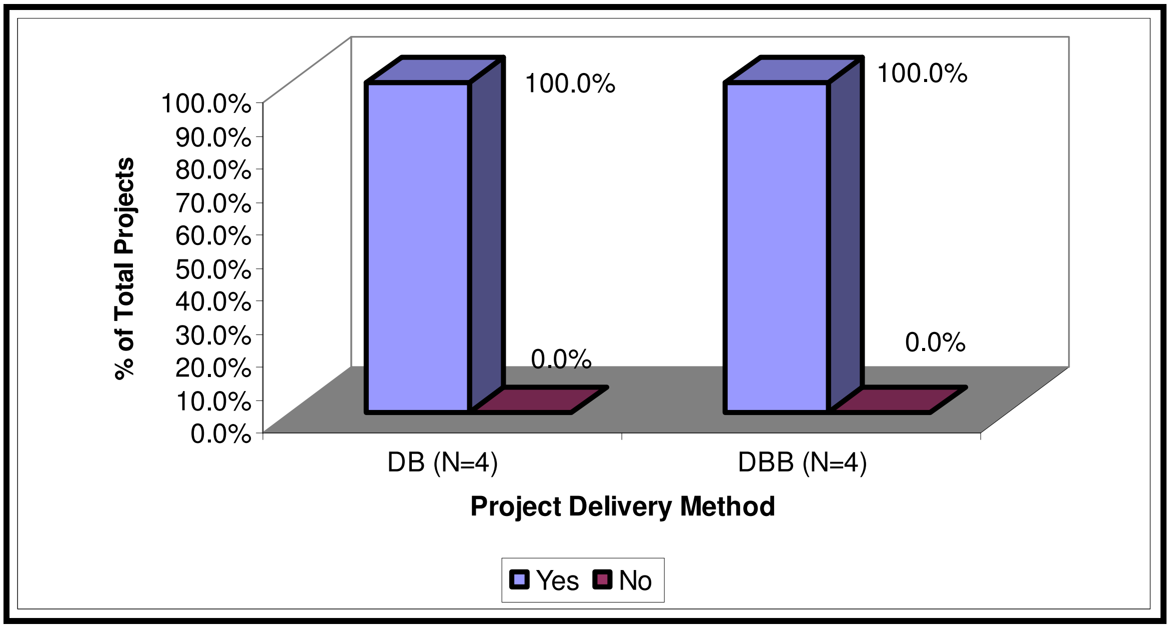


Figure 5.29: Percentage of Projects with Web Portal

5.6 Project Calendar

Designers and contractors involved in design and construction of highways have different project calendars. Yet their work calendar impacts the timeliness of project completion. In this study, researchers collected detail project calendars from the designer and construction contractors. The first variable considered was “Designer Work-hours per Day”. From the data analysis, 50 percent of DB contract designers worked eight hours per day and the rest worked more than ten hours per day. However, 100 percent of DBB contract designers worked eight to ten hours per day. The overall data analysis shows that 50 percent of total contract designers worked eight to ten hours per day. Figure 5.30 shows the percentage of contracts by “Designer Work-hours per Day.”

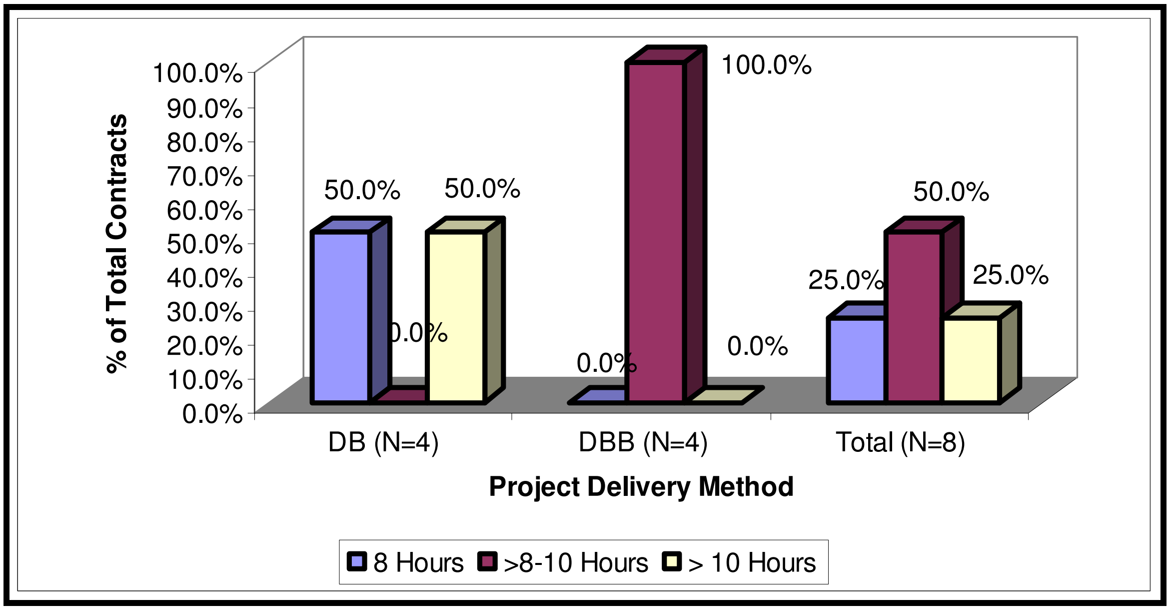


Figure 5.30: Percentage of Contracts by Designer Work Hours per Day

"Designer Work Days per Week" data was also collected and the data sample shows that 100 percent of DBB project designers worked five days a week, however only 50 percent of DB project designers worked five days a week, and the rest of them worked more than five days a week. Seventy-five percent of the total sample projects' designers worked five days a week. Figure 5.31 shows the percentage of contracts by "Designer Work Days per Week" for DB and DBB projects.

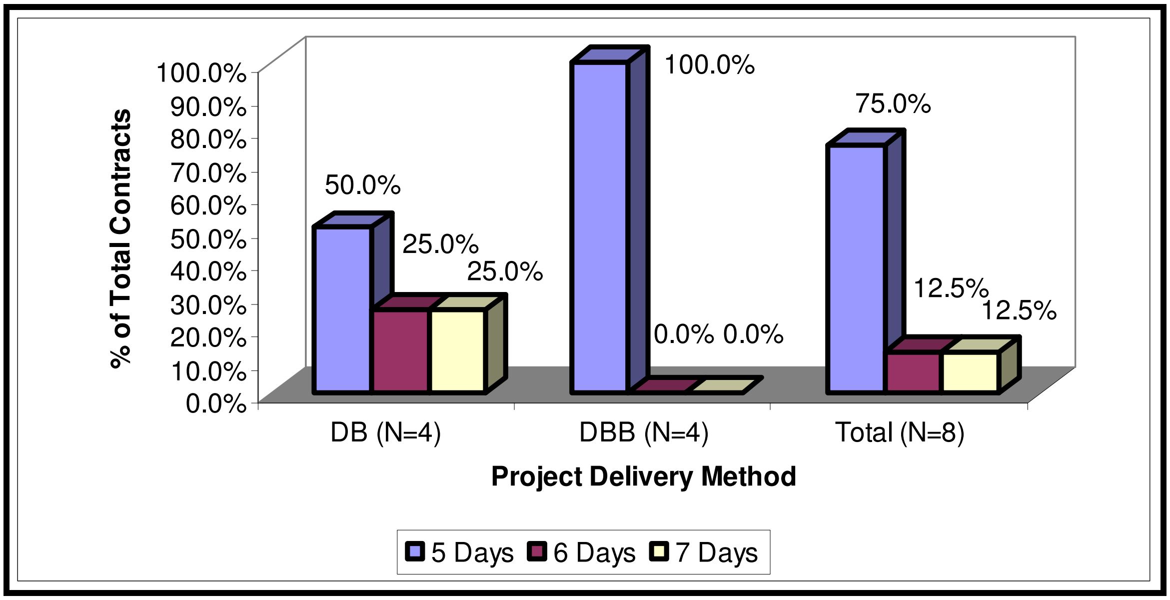


Figure 5.31: Percentage of Contracts by Designer Work Days per Week

The "Contractors Work-hours per Day" was analyzed for DB and DBB projects. The data sample shows that 75 percent of DBB contractors worked more than ten hours per day during construction of highway, but only 50 percent of DB contractors worked more than ten hours per day. The total sample data analysis shows that the majority of contractor worked more than 10 hours a day. Figure 5.32 depicts this distribution.

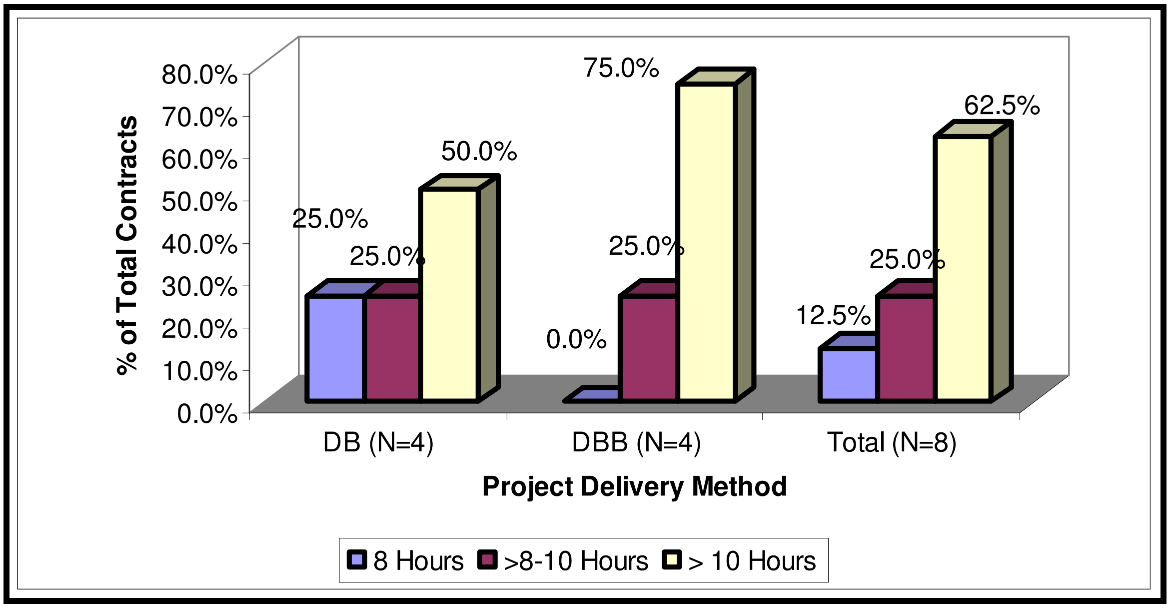


Figure 5.32: Percentage of Contracts by Construction Hours per Day

The data sample shows that the distribution "Contractor Work Days per Week" for DB and DBB contractors were exactly same. Twenty five percent of DB and DBB contractors worked five days a week, 50 percent worked six days a week, and rest 25 percent worked seven days a week. Figure 5.33 shows the percentage of contracts by "Construction Work Days per Week."

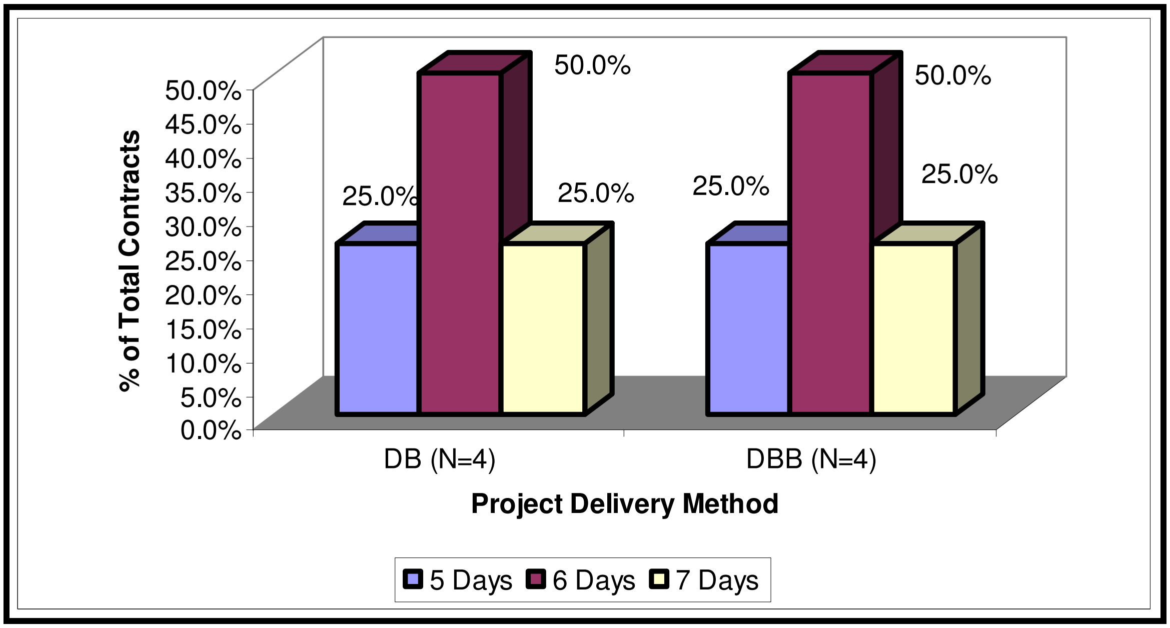


Figure 5.33: Percentage of Contracts by Construction Work Days per Week

Highway construction workers work in different "Construction Work Shifts." Depending upon the nature of construction, workers can work either one shift per day or two to three shifts per day. In the questionnaire, the project managers were asked how many shifts contractors worked during construction. The data analysis shows that 75 percent of both DB and DBB contractors worked two shifts per day. However, 25 percent of DB contractors worked one shift per day and 25 percent of DBB worked three shifts per day, with no DB contractor working three shifts per day. The overall data shows that three-fourth of the contractors worked two shifts per day for this sample. Figure 5.34 shows the percentage of contracts by "Construction Work Shifts."

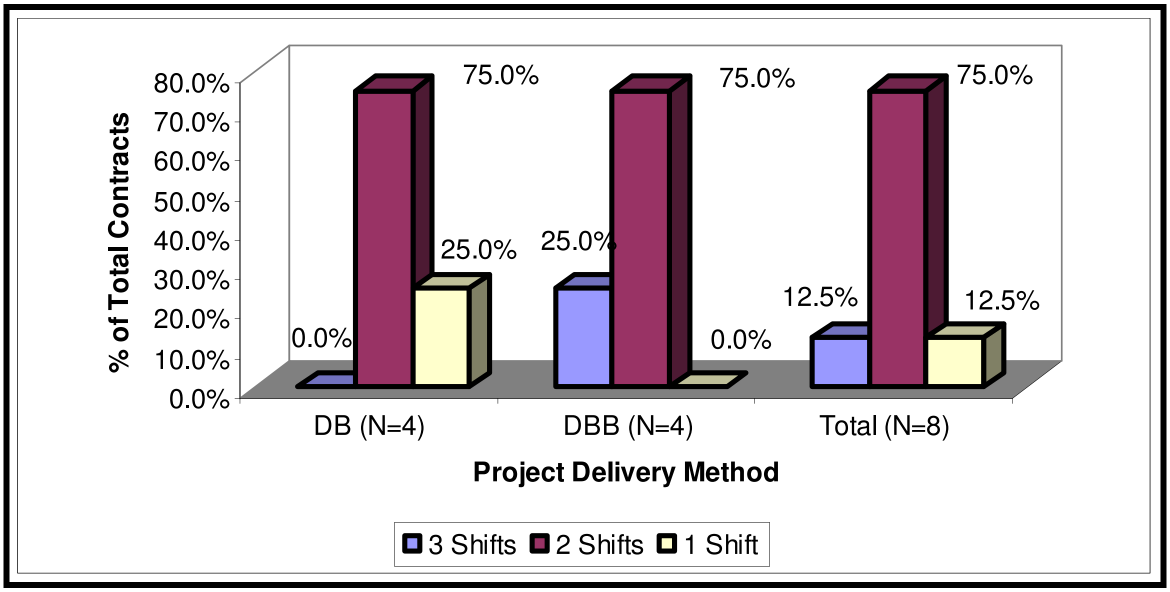


Figure 5.34: Percentage of Contracts by Construction Work Shifts

5.7 ENVIRONMENTAL ISSUES

During the data collection, the questionnaire was prepared to get information about the types of environmental issues that were encountered during construction. Researchers identified eight important environmental issues related to highway construction. They include presence of 1) "Contaminated Ground Water," 2) "Contaminated Soil," 3) "Endangered Species," 4) "Historical Sites," 5) "Wetlands," 6) "Asbestos," 7) "Wildlife Refugee," and 8) "Archeological Sites." Table 5.1 shows the percentage of contracts that encountered different environmental issues in DB, DBB, and total sample projects.

Table 5.1: Percentage of Contracts by Presence of Environmental Issues

Environmental-Related Issues	DB	DBB	Total Sample
Contaminated Soil	25.0%	25.0%	12.5%
Contaminated Ground Water	25.0%	0.0%	12.5%
Endangered Species	25.0%	0.0%	12.5%
Historical Sites	100.0%	0.0%	50.0%
Wet Lands	75.0%	25.0%	50.0%
Asbestos	0.0%	0.0%	0.0%
Wildlife Refugee	25.0%	0.0%	0.0%
Archeological Sites	75.0%	25.0%	50.0%

The data shows that DB contracts had more environmental-related issues than DBB contracts. The significant difference between DB and DBB contracts was in presence of "Historical Sites," "Wet Lands," and "Archeological Sites."

The project managers were asked about unanticipated delays due to environment-related issues, but no contracts were delayed by environmental issues. The data shows that delays caused by the environmental issues in these projects were negligible. It can be thus concluded that environmental issues in these large highway projects were dealt with effectively, so that there were no major impacts on the schedule of the project.

5.8 RIGHT-OF-WAY ACQUISITION

Right-of-way acquisition is an important phase of highway construction. The right-of-way could be acquired either before or concurrently during the construction of highway. Researchers collected data on right-of-way acquisition for all the projects in order to identify the variation in the "Number of Right-of-Way Parcels," "Number of Parcels Acquired by Condemnation," and the "Right-of-Way Delays" caused during its acquisition. From the data analysis, it was found that DB contracts had 208 ROW parcels whereas DBB projects had 71 ROW parcels acquired for highway construction.

Therefore, in the sample, DB contracts had higher “Number of Right-of-Way Parcels” than DBB contracts. The average number of right-of-way parcels for the entire sample was 140 per contract. Figure 5.35 shows the distribution of “Number of ROW Parcel” by project delivery methods.

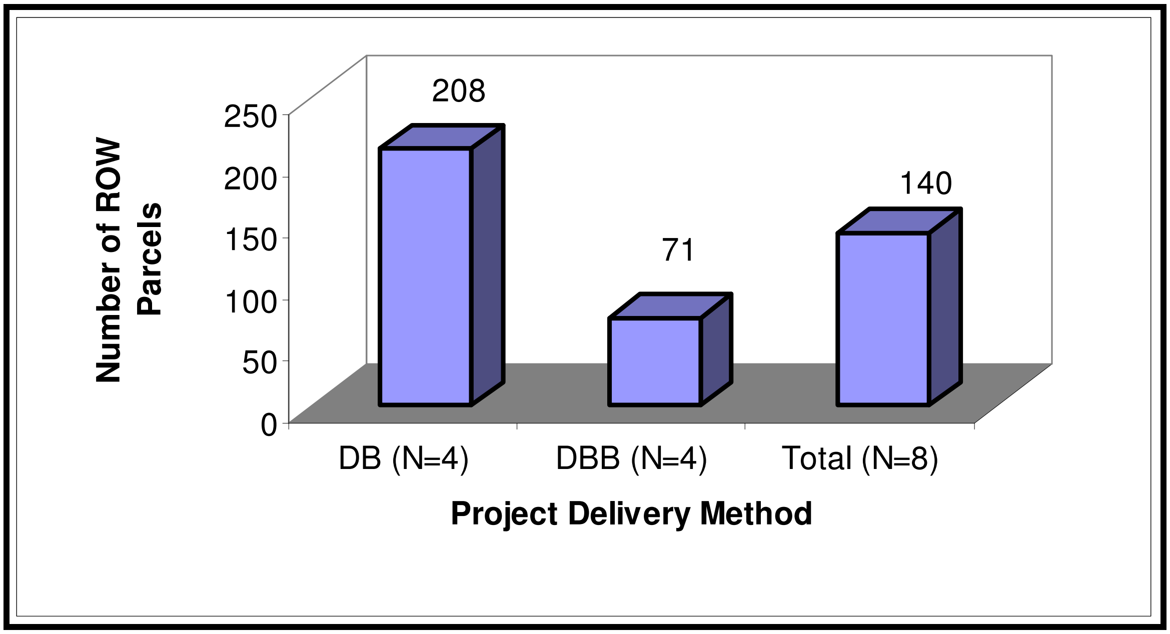


Figure 5.35: Number of ROW Parcel by Project Delivery Method

The ROW parcels can be procured either by administrative settlement or by condemnation. Administrative settlement is most commonly used to acquire ROW parcels. In this method, state highway officials negotiate with the land owner to acquire the parcels of land according to state rules. This is an effective and easy method of acquiring the ROW parcels. Sometimes the land owner will not negotiate with the state highway department; and the state official must use a condemnation process to acquire ROW parcels. In condemnation, the state highway department will use its eminent domain power to acquire private land for the public use. When the private land is taken by condemnation, the land owner receives compensation for his/her land. From the data analysis, the average “Number of ROW Parcels Acquired through Condemnation” for DB and DBB contracts were nearly equal; 19 for DB and 17 for DBB contracts. Figure 5.36 shows “ROW Parcels Acquired through Condemnation” by project delivery method.

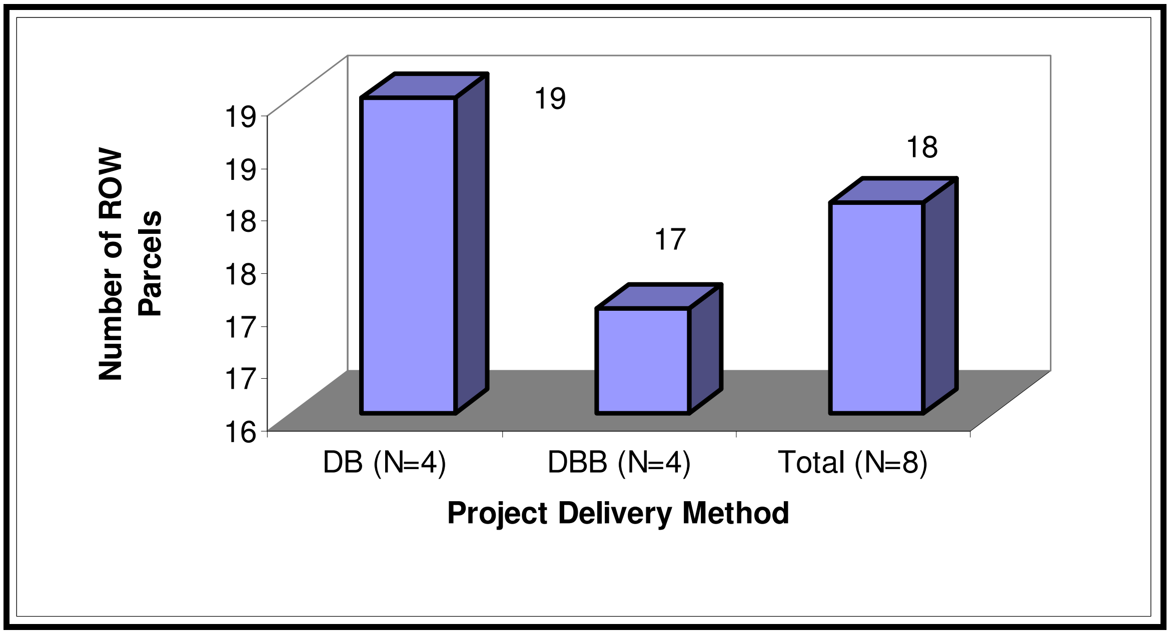


Figure 5.36: Number of ROW Parcels Acquired through Condemnation by Project Delivery Method

Researchers also asked respondents to rate the “ROW Delays” as insignificant, moderate or severe. In DB projects, the data analysis shows that two projects had insignificant “ROW Delays” and two projects had moderate “ROW Delays.” In DBB projects one project had severe ROW delays and three projects had insignificant ROW delays. Considering the overall data, the ROW delays in both of these projects were similar and insignificant.

5.9 UTILITY ADJUSTMENTS

Utility adjustment is an important activity on a highway project. It plays a key role in facilitating completion of the project on time, because construction can be delayed if the utility adjustments are delayed. One of the factors that affect construction is the "Number of Utility Adjustments" in the project. If the project has more utilities to be adjusted, then the contractor will have to coordinate more efficiently with the utilities company to ensure the timeliness of the adjustment. From the data collected, it can be concluded that the DB projects examined had more utilities to be adjusted than DBB projects. On average, DB projects had 40 utilities to be adjusted, whereas DBB projects had 10 utilities to be adjusted. The entire sample data analysis shows that 26 utilities were adjusted per contract. Figure 5.37 shows the average "Number of Utility Adjustments" in DB and DBB projects.

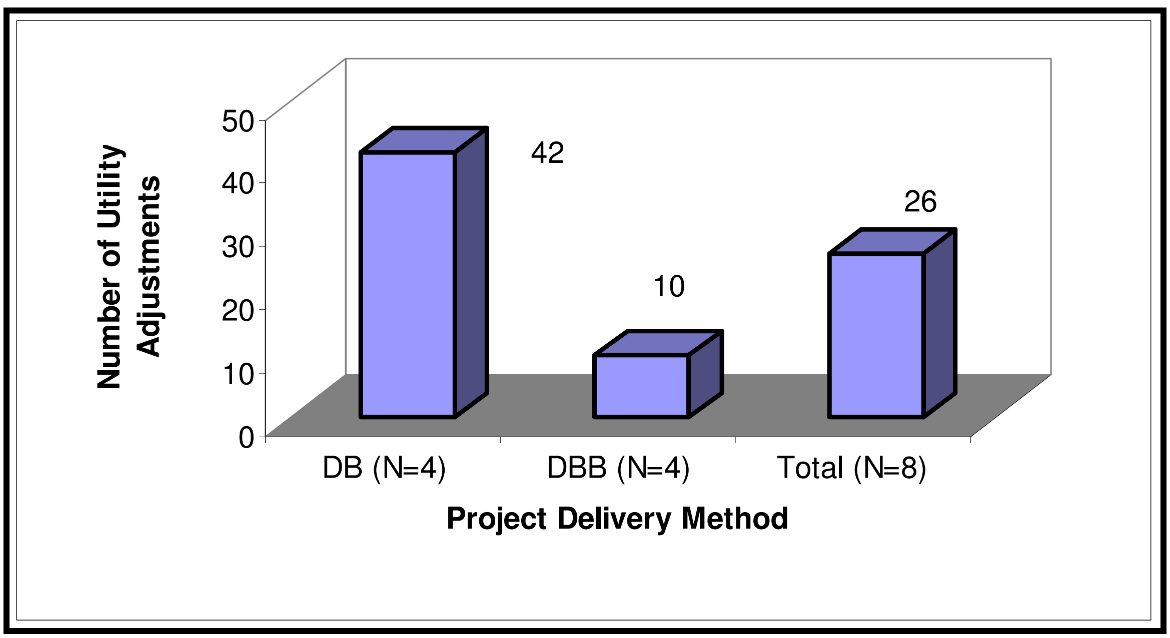


Figure 5.37: Number of Utility Adjustments by Project Delivery Method

5.10 OWNER STAFFING

The staffing of owner can also be crucial in the success of projects. The new organization approach used by some DOTs is to hire program managers as an extension of their staff. This approach can help to reduce the financial liability for the owner, because the owner can hire staff only for the project life period. In most of the projects sampled, the program manager or consultant was hired to help the owner in managing the project. The data shows that the percentage of contracts, in which owner hired a "Program Manager," was similar in DB projects and DBB projects. Out of four DB and DBB projects, three projects had hired a program manager as an extension of their staff. The idea of hiring a program manager is new and is used in DB as well as DBB projects. Figure 5.38 shows the breakdown of "Program Manager Involved" in DB and DBB projects.

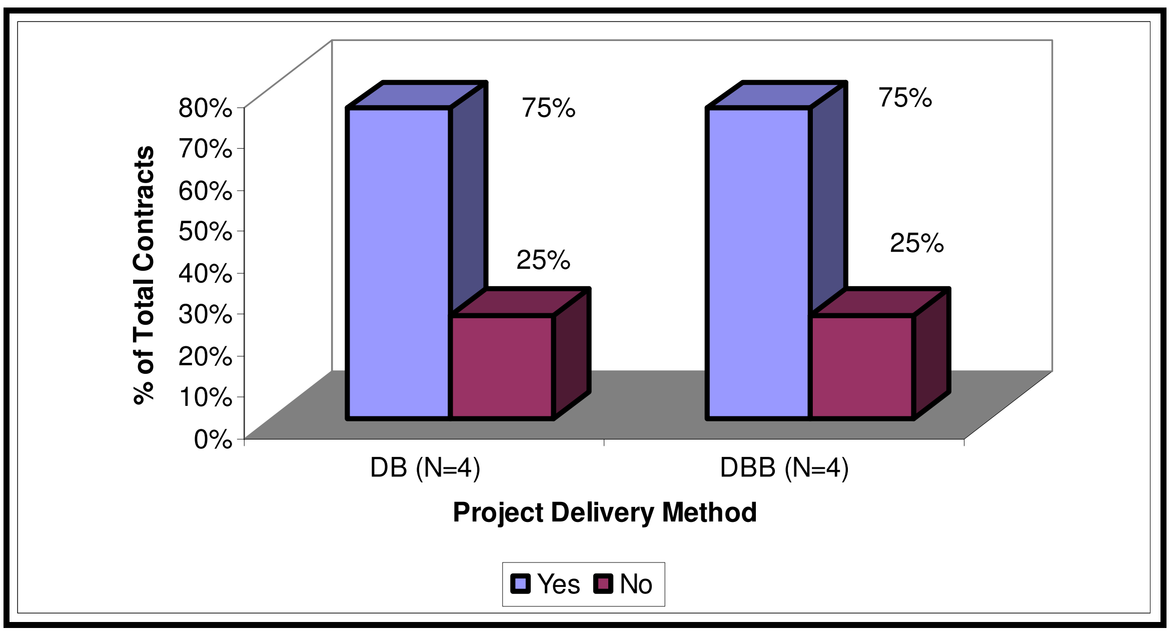


Figure 5.38: Percentage of Contracts by Program Manager Involved

5.11 SUMMARY OF KEY DIFFERENCES IN INPUT VARIABLES

Forty seven input variables were analyzed for the comparison purpose. The analysis of data shows that 40 input variables had sufficient similarity in DB and DBB sample contracts. The data sample analysis also shows that there are 7 input variables that are sufficiently different in these two types of projects. Table 5.2 shows the input variables that have key differences.

Table 5.2: Key Differences in Input Variables of DB and DBB

No.	Input Variables	DB (N=4)		DBB (N=4)	
		Median	Mean	Median	Mean
1	Design and Construction Cost	$217 M	$441 M	$210 M	$217 M
2	Design and Construction Duration	965 Days	963 Days	1499 Days	1663 Days
3	Project Location				
	Urban	-	50.0%	-	100.0%
	Rural	-	50.0%	-	0.0%
4	Contract Award Method	-	50% Best Value	-	100% Lump Sum
5	Schedule Performance Bonus	-	50.0%	-	100.0%
6	Partnering Consultant Involved	-	100.0%	-	50.0%
7	Presence of Historical Sites	-	100.0%	-	0.0%
8	Presence of Wet Lands	-	75.0%	-	25.0%
9	Presence of Archeological Sites	-	75.0%	-	25.0%

Chapter Six: Descriptive Statistics of Output Variables

This chapter compares cost, schedule, change orders, safety, and quality-related output variables of the two sub-samples. Cost-related output variables consider cost in two manners. The first comparison ("Total Cost Growth") is based upon the estimated and completion costs. The next comparison ("Adjusted Cost per Lane Mile") is based upon the adjusted completion cost. Similarly, schedule-related output variables consider schedule in two manners. "Total Schedule Growth" is analyzed based upon the estimated and completion durations. "Delivery Duration per Lane Mile" is analyzed based upon the number of days needed to complete a project. "Change Cost Factor," "Fatality Rate," and "Quality Rating" for the two sub-samples are also analyzed.

6.1 COST-RELATED OUTPUT VARIABLES

The total cost to design and construct a highway is an important element of project delivery method performance. The cost-related output variables calculated for this study are "Total Cost Growth" and "Adjusted Cost per Lane Mile."

6.1.1 Total Cost Growth

Since design and construction activities are performed separately on DBB projects, the cost of design and construction were added together to calculate total design and construction cost. However, the total design and construction cost for DB was included in a contract amount. During the calculation of "Total Cost Growth," only the cost of design and construction was considered, excluding cost of right-of-way acquisition and utility adjustments. The formula to calculate this variable is:

Total Cost Growth (%)

$$= \frac{\text{Total Design \& Construction Cost} - \text{Estimated Design \& Construction Cost}}{\text{Estimated Design \& Construction Cost}}$$

The analysis of “Total Cost Growth” data shows that the mean for DBB was eight times more than the mean for DB. The median for DBB was also sufficiently higher than the median for DB. The sample statistics show a disparity between DB and DBB (Table 6.1, Figure 6.1, and Figure 6.2). Table 6.1 also shows that the mean and median “Total Cost Growth” for total sample were near to each other. The data calculation of “Total Cost Growth” is given in Appendix D.

Table 6.1: Total Cost Growth for DB and DBB

Parameters	**Design-Build**	**Design-Bid-Build**	**Total Sample**
Sample Size	4	4	8
Mean	1.49%	12.71%	7.10%
Median	-5.73%	23.28%	10.17%
Maximum	30.98%	31.87%	31.87%
Minimum	-13.53%	-27.60%	-27.60%
Standard Deviation	20.88%	27.43%	23.35%

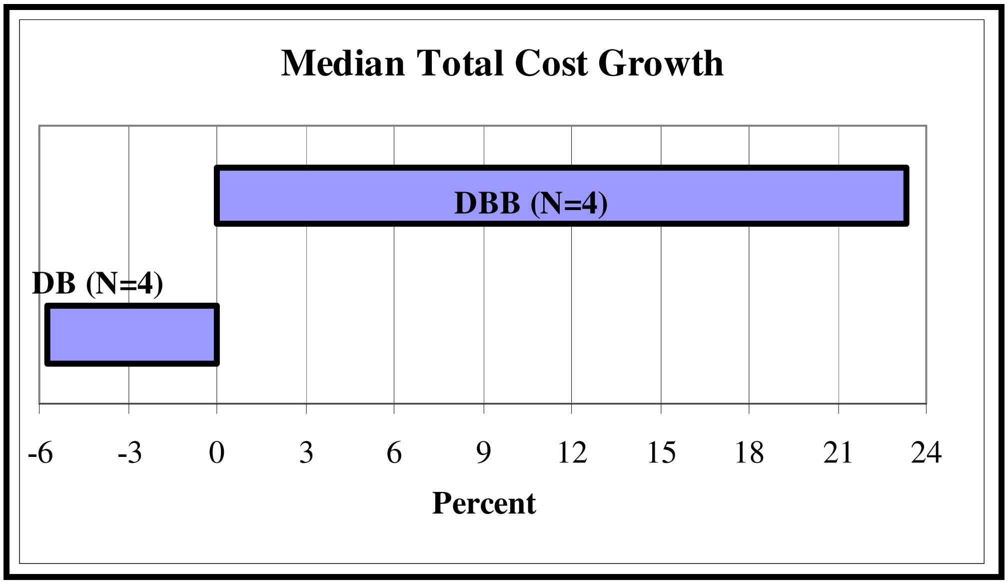


Figure 6.1: Median Total Cost Growth Comparison between DB and DBB

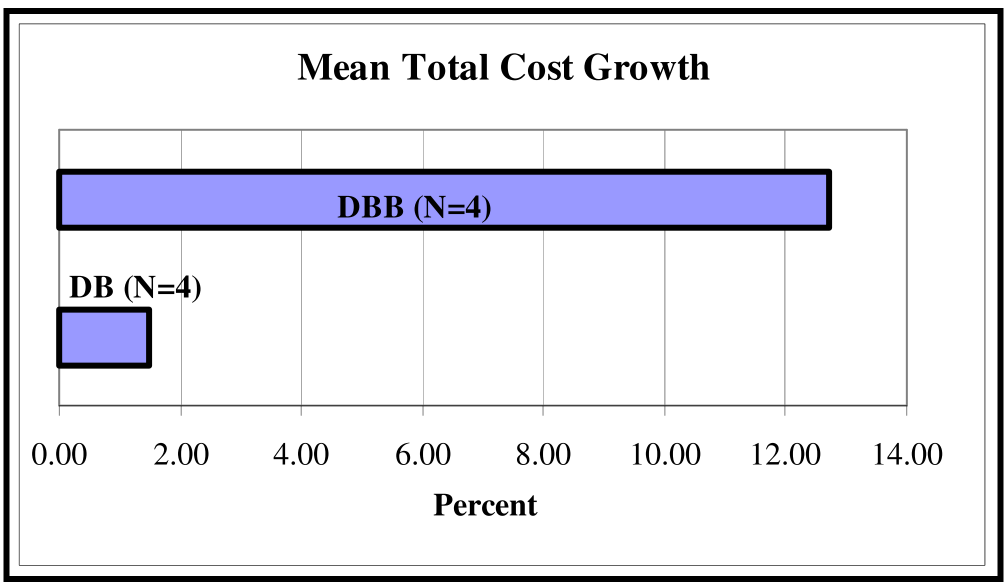


Figure 6.2: Mean Total Cost Growth Comparison between DB and DBB

6.1.2 Adjusted Cost per Lane Mile

The design and construction cost of projects are adjusted to the base cost for Texas in 2007, using the Engineering News Record (ENR) construction cost index. The projects selected for comparison were from different states and the completion year of projects ranged from 2001 to 2007. Therefore the project cost is recalculated by adjusting inflation and location variation. The following formula was used to calculate "Adjusted Cost per Lane Mile" of highway:

Adjusted Cost per Lane Mile ($/LM)

$$= \frac{\text{Total Adjusted Design \& Construction Cost}}{\text{Total Lane Mile}}$$

The adjusted total cost excludes the cost of right-of-way acquisition and utility adjustments. The analysis of data shows that the means for DB and DBB are similar (Table 6.2, Figure 6.3, and Figure 6.4). The data shows that the standard deviation for DB is higher than for DBB. However, the median cost per lane mile of DB projects is about $1.2 M less than that of DBB projects or about 30 percent. The mean and median "Adjusted Cost per Lane Mile" for entire sample is exactly same.

Table 6.2: Adjusted Costs per Lane Mile for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	$3.52 M	$3.70 M	$3.6 M
Median	$2.82 M	$4.01 M	$3.6 M
Maximum	$6.56 M	$4.80 M	$6.3 M
Minimum	$1.89 M	$1.97M	$1.9 M
Standard Deviation	$2.13 M	$1.23 M	$1.5 M

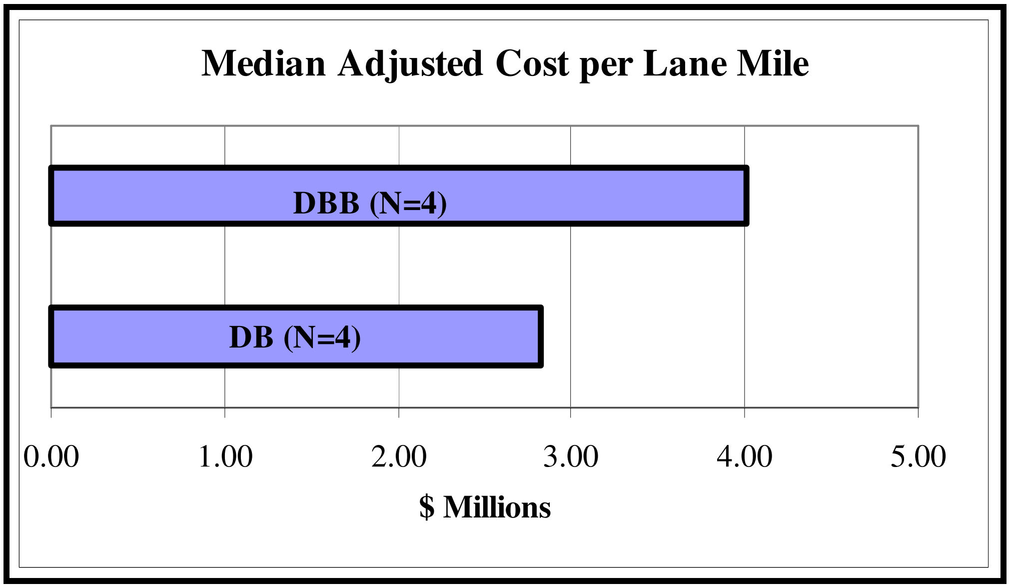


Figure 6.3: Median Adjusted Cost per Lane Mile Comparison between DB and DBB

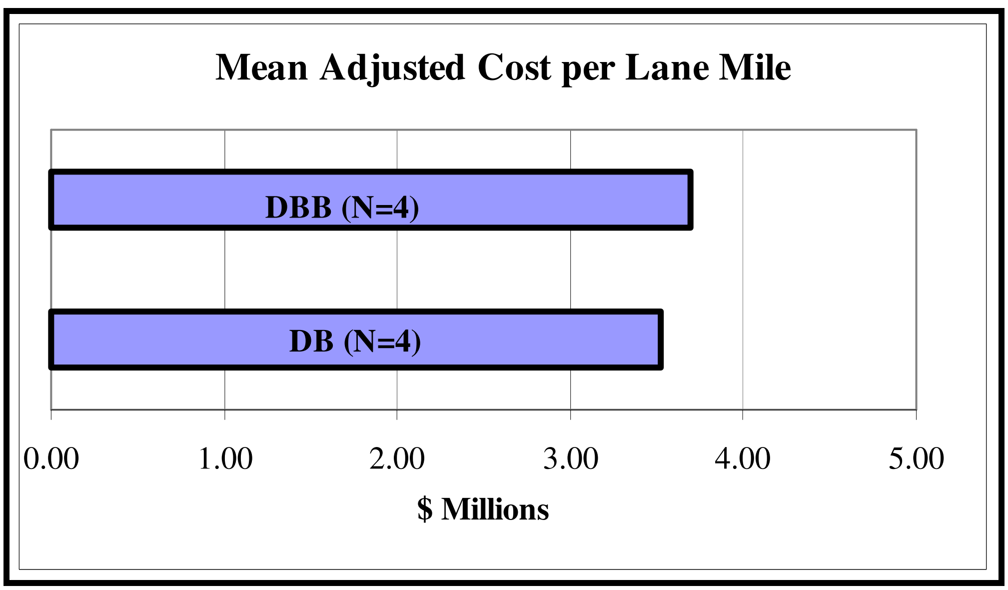


Figure 6.4: Mean Adjusted Cost per Lane Mile Comparison between DB and DBB

The small difference in "Adjusted Cost per Lane Mile" between DB and DBB may be explained by the fact that all the DBB contracts were constructed in urban areas in comparison to 50 percent of the DB contracts.

6.2 Schedule-Related Output Variables

Schedule is an important measure of project performance. Project performance can be assessed by quantifying whether the project is completed on time or not. In this study, researchers compared “Total Schedule Growth” and “Delivery Duration per Lane Mile.”

6.2.1 Total Schedule Growth

“Total Schedule Growth” is the difference between estimated and actual completed design and construction duration expressed in percentage of estimated duration. The formula for this variable is:

Total schedule growth (%)

$$= \frac{\text{Total Design \& Constr. Duration} - \text{Estimated Design \& Constr. Duration}}{\text{Estimated Design \& Construction Duration}}$$

The duration in the above formula also excludes right-of-way acquisition and environmental clearance duration. The analysis shows that DB projects had higher schedule growth than DBB projects. The median “Total Schedule Growth” for DB was nearly three times more than the median for DBB. Similarly, the means for DBB and DB show a similar disparity (Table 6.3, Figure 6.5, and Figure 6.6). The mean “Total Schedule Growth” is about three times more than the median for entire sample.

Table 6.3: Total Schedule Growth for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	11.04%	4.34%	7.69%
Median	6.70%	2.54%	2.54%
Maximum	34.48%	18.61%	34.48%
Minimum	-3.70%	-6.32%	-6.32%
Standard Deviation	18.06%	10.40%	14.10%

The data shows that "Total Schedule Growth" had a wide variation both in DB and DBB projects. The standard deviation for DB was 18.06 percent and for DBB was 10.40 percent. In either project delivery method, some projects were completed ahead of schedule and some behind schedule. The data indicates that schedule growth performance for DBB was better than for DB for this sample. One possible explanation for differences in schedule growth could be that one hundred percent of DBB projects used "Schedule Performance Bonus" provisions in their contracts for on-time completion. However, only 50 percent of DB projects used this provision in their contracts.

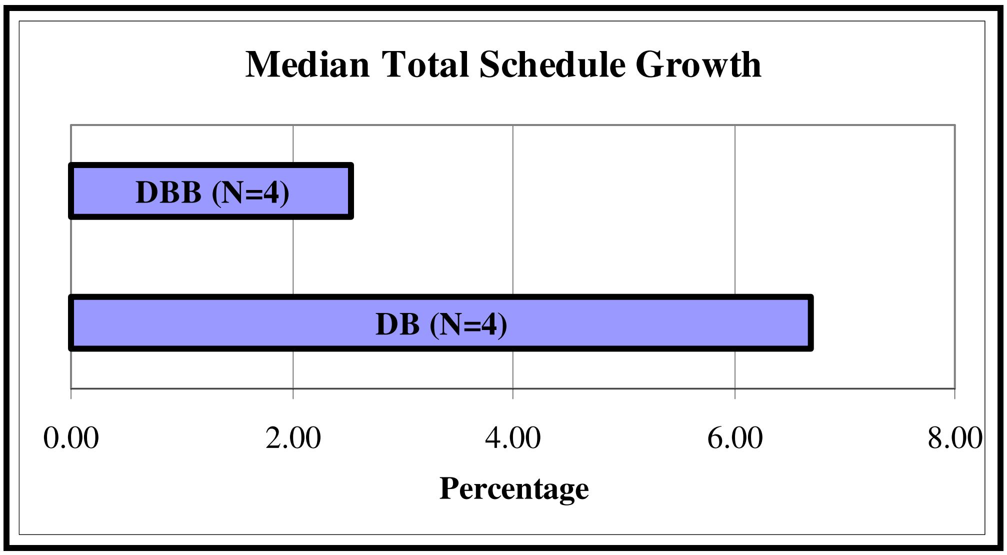


Figure 6.5: Median Total Schedule Growth Comparison between DB and DBB

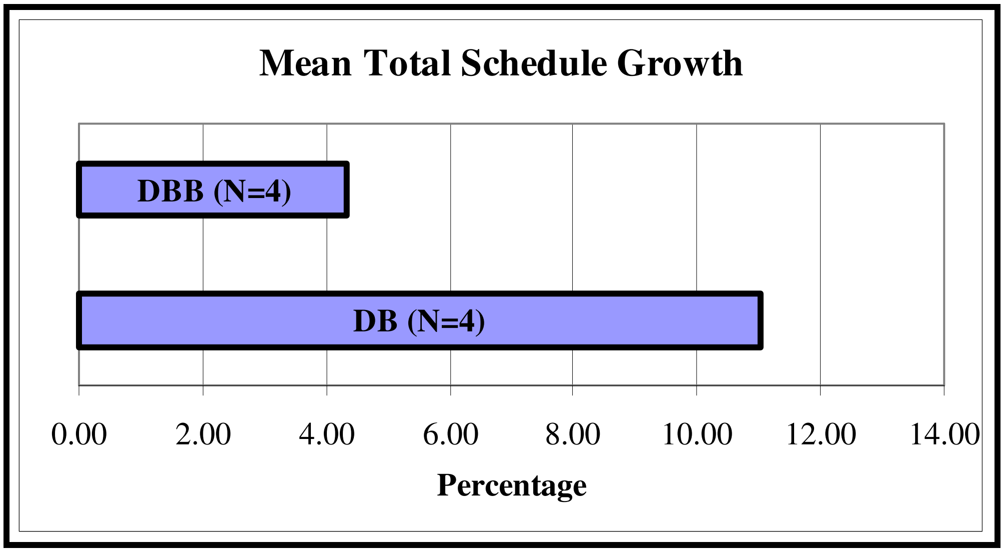


Figure 6.6: Mean Total Schedule Growth Comparison between DB and DBB

6.2.2 Delivery Duration per Lane Mile

"Delivery Duration per Lane Mile" is a measure of total design and construction duration expressed per lane mile of highway. The delivery duration per lane mile of highway is calculated by the following formula.

Delivery Duration per Lane Mile (Days/LM)

$$= \frac{\text{Total Design \& Construction Duration}}{\text{Total Lane Mile}}$$

The data analysis shows that the mean for DB is lower than the mean for DBB. It took on average 11.4 days to design and construct every lane mile of highway on DB projects, whereas on DBB projects it took 28.5 days. The DB median was less than one-half the DBB median (Table 6.4, Figure 6.7, and Figure 6.8). It should be noted that for the DB sub-sample, the percentage of design complete at the time contract award was 30 percent, whereas for DBB sub-sample the percentage design complete at the time of design contract award was usually less than 30 percent. Hence, DBB projects may take more time to design than DB projects because of reduced front end planning effort, which may explain part of the difference in design and construction duration per lane mile. Other potential explanations include the overlap between design and construction for DB projects, more efficiency in having design and construction personnel work together, and the elimination of a procurement step between design and construction. More data will be needed to conclusively determine the drivers.

Table 6.4: Delivery Duration per Lane Mile for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	11.4 Days	28.5 Days	20 Days
Median	12.7 Days	30.9 Days	13.4 Days
Maximum	14.3 Days	38.7 Days	38.7 Days
Minimum	5.9 Days	13.5 Days	5.9 Days
Standard Deviation	3.7 Days	10.9 Days	11.8 Days

The standard deviation for DB (3.7 days) is lower than for DBB (10.9 days), which shows that there is a larger variance in the DBB than in the DB sample. The data sample shows that the minimum duration to complete per lane mile of highway for DBB was 13. 5 days. However, the minimum duration to complete per lane mile of highway for DB was 5.9 days. The sample statistics for entire sample show a disparity between mean and median values.

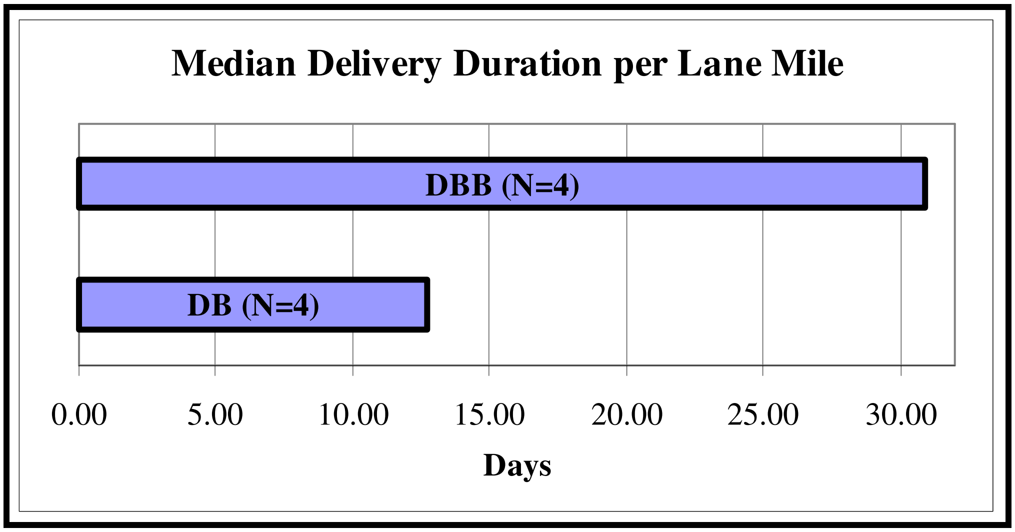


Figure 6.7: Median Delivery Duration per Lane Mile Comparison between DB and DBB

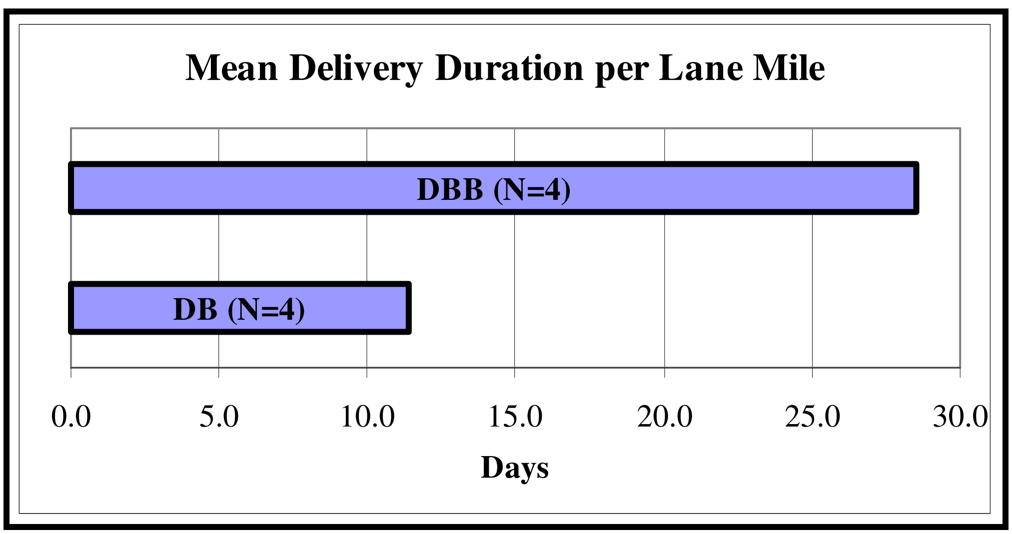


Figure 6.8: Mean Delivery Duration per Lane Mile Comparison between DB and DBB

6.3 CHANGE ORDER-RELATED OUTPUT VARIABLE

Change orders are critical in any construction project. The amount of change orders on a project affects its project performance. In this study "Change Cost Factor" was analyzed to determine change order performance of DB and DBB projects. "Change Cost Factor" is the ratio of change order cost and total design and construction cost. It is calculated by the following formula.

$$\text{Change Cost Factor (\%)} = \frac{\text{Total Change Order Cost}}{\text{Total Design \& Construction Cost}}$$

The total change order cost includes the costs of design and construction change orders. The analysis of data showed that the median "Change Cost Factor" for DB is lower than that for DBB. However, the mean value shows less disparity. The mean "Change Cost Factor" for DBB is about one half times more than the mean "Change Cost Factor" for DB (Table 6.5, Figure 6.9, and Figure 6.10). The data shows that some DB project had no change orders, while all DBB projects had change orders. The statistics for total sample shows that mean "Change Cost Factor" was higher than median value. The detailed data is given in Appendix D.

Table 6.5: Change Cost Factor for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	6.90%	9.19%	8.04%
Median	3.28%	9.07%	5.38%
Maximum	21.04%	14.09%	21.04%
Minimum	0.00%	4.53%	0.00%
Standard Deviation	9.65%	4.73%	7.14%

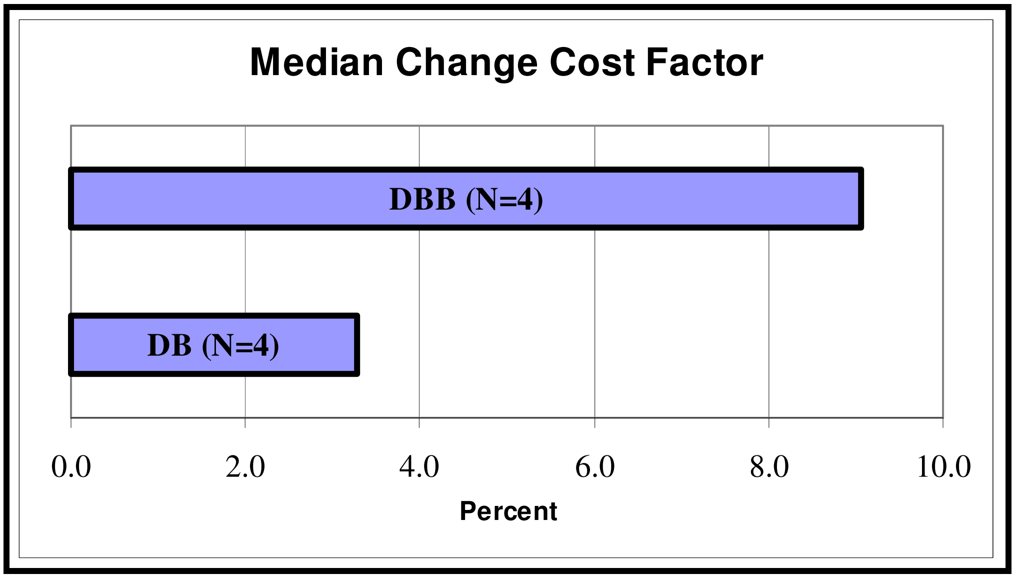


Figure 6.9: Median Change Cost Factor Comparison between DB and DBB

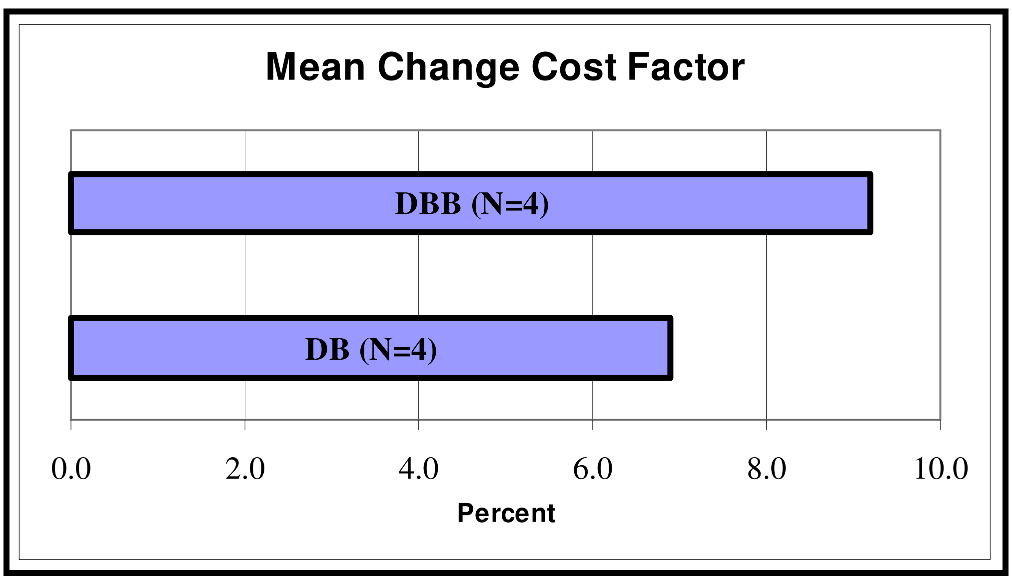


Figure 6.10: Mean Change Cost Factor Comparison between DB and DBB

6.4 SAFETY-RELATED OUTPUT VARIABLE

"Fatality Rate" measures the safety performance of construction projects. The fatality is defined by the CII as:

$$\text{Fatality Rate} = \frac{\text{Total Number of Fatalities x 200,000,000 Hours}}{\text{Total Construction Work Hours}}$$

The data analysis shows that the median values of the "Fatality Rate" for both DB and DBB are equal. The median values of fatality for DB and DBB are 4.35 and 0 respectively. The mean values for DB is 11.5 whereas for DBB it is 9.5. The standard deviations for both samples are high (Table 6.6 and Figure 6.11). The descriptive statistics for entire sample show a disparity between mean and median values. The detailed data for DB and DBB projects is shown in Appendix D.

Table 6.6: Fatality Rate for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	11.5	9.5	10.5
Median	4.4	0.0	0.0
Maximum	37.3	38.0	38.0
Minimum	0.0	0.0	0.0
Standard Deviation	17.7	19.0	17.0

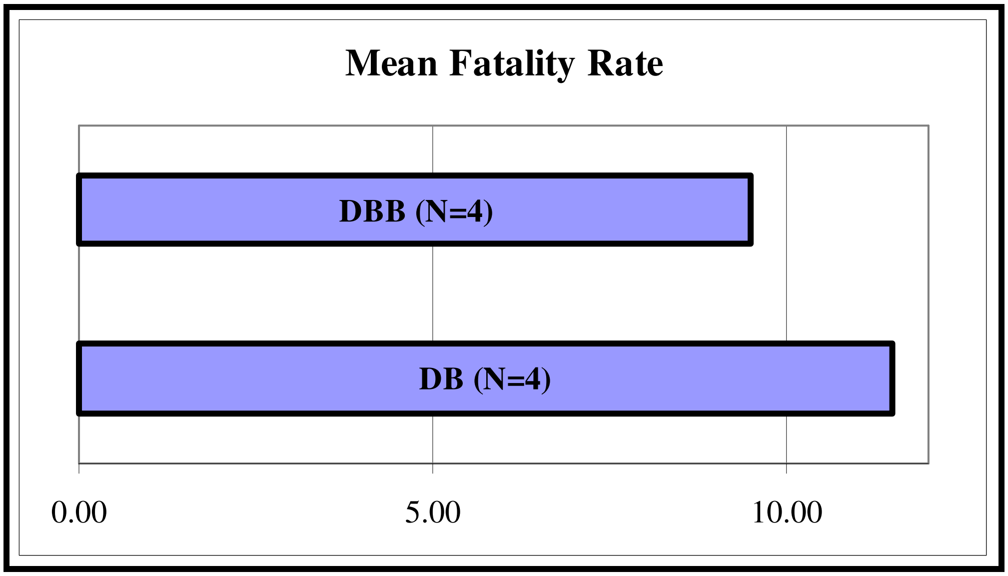


Figure 6.11: Mean Fatality Rate Comparison between DB and DBB

6.5 Quality-Related Output Variable

The project managers were asked to rate quality of projects on a scale of 1 to 4, 1 being bad and 4 being excellent. The data analysis shows that the values of "Quality Rating" for DB and DBB are similar. DB has 3.3 rating and DBB has 3.5 rating, which are nearly equal. All other descriptive statistics of DB and DBB were found to be similar. The mean and median "Quality Rating" for entire sample are nearly equal (Table 6.7, Figure 6.12, and Figure 6.13). The detailed quality data for DB and DBB projects is shown in Appendix D.

Table 6.7: Quality Rating for DB and DBB

Parameters	Design-Build	Design-Bid-Build	Total Sample
Sample Size	4	4	8
Mean	3.3	3.5	3.4
Median	3.0	3.5	3.0
Maximum	4.0	4.0	4.0
Minimum	3.0	3.0	3.0
Standard Deviation	0.5	0.58	0.5

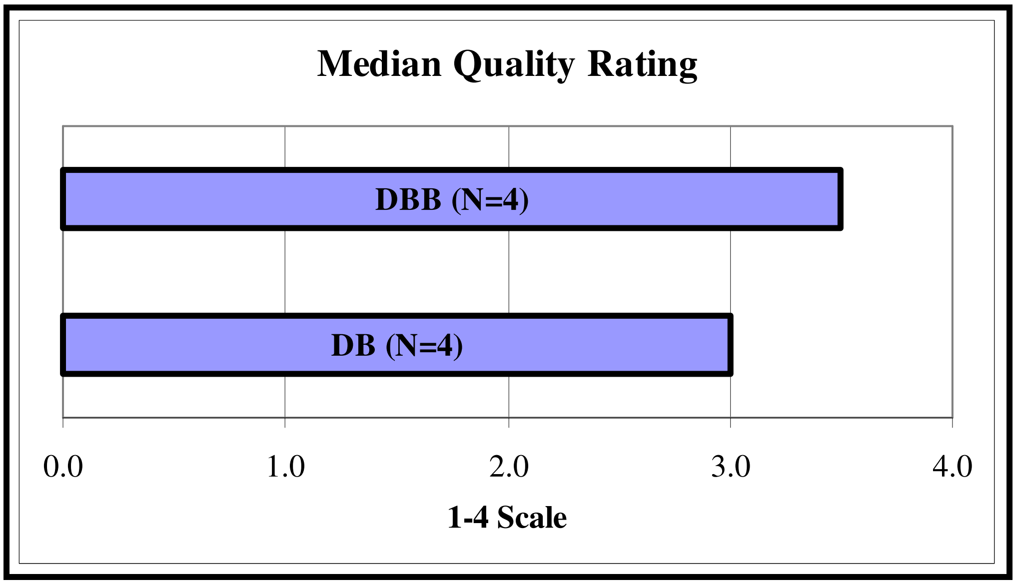


Figure 6.12: Median Quality Rating Comparison of DB and DBB

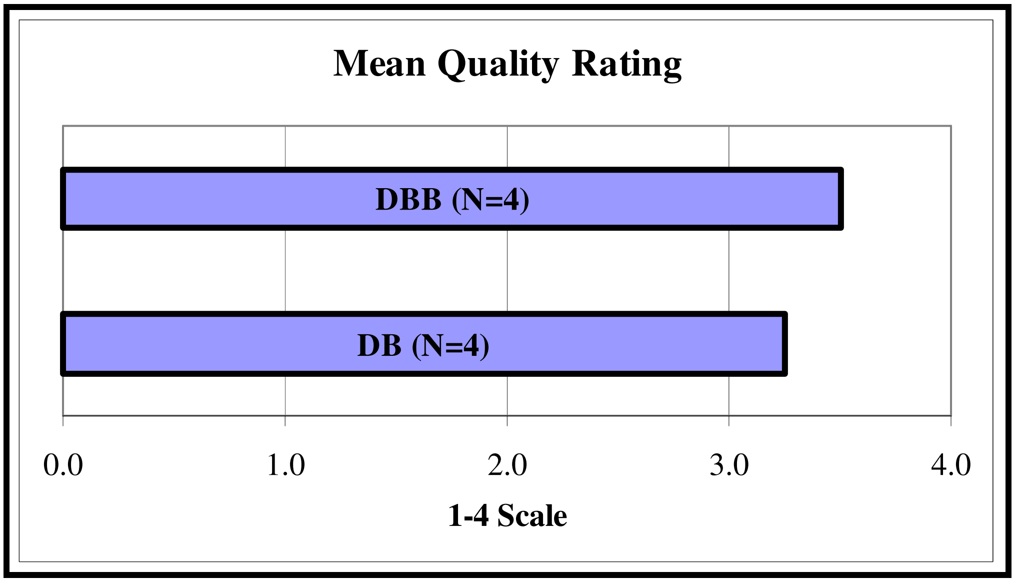


Figure 6.13: Mean Quality Rating Comparison between DB and DBB

6.6 SUMMARY OF OUTPUT VARIABLES

Comparisons of “Total Cost Growth,” “Adjusted Cost per Lane Mile,” “Total Schedule Growth,” “Delivery Duration per Lane Mile,” “Change Cost Factor,” “Fatality,” and “Quality Rating” were conducted on the samples using descriptive statistics. All the median and mean values of cost-related output variables comparisons showed that DB cost performance is better than that for DBB for this sample. The median and mean values of “Total Schedule Growth” were found to be less for the DBB sample. The data sample shows that the design and construction “Delivery Duration per Lane Mile” on DB projects was about 60 percent less than that on DBB projects. The median and mean values for “Change Cost Factor” on DB projects were lower than those values on DBB projects. The safety and quality-related output variables were nearly similar for both sub-samples. Table 6.8 shows the summary of output variable findings.

Table 6.8: Summary of Output Variables

Statistics	Design-Build		Design-Bid-Build		Total Sample	
	Median	Mean	Median	Mean	Median	Mean
Cost-Related Output Variables						
- Total Cost Growth	-5.73%	1.49%	23.28%	12.71%	10.17%	7.10%
- Adjusted Cost per Lane Mile	$2.82 M	$3.52 M	$4.01M	$3.70 M	3.6 M	3.6 M
Schedule-Related Output Variables						
- Total Schedule Growth	6.70%	11.04%	2.54%	4.34%	2.54%	7.69%
- Delivery Duration per Lane Mile	12.7 Days	11.4 Days	30.9 Days	28.5 Days	13.4 Days	20 Days
Change Order-Related Output Variable						
- Change Cost Factor	3.28%	6.90%	9.07%	9.19%	5.38%	8.04%
Safety-Related Output Variable						
- Fatality Rate	4.4	11.5	0	9.5	0	10.5
Quality-Related Output Variable						
- Quality Rating (1-4 Scale)	3.0	3.3	3.5	3.5	3.0	3.4

Chapter Seven: Input-Output Variables Association

This chapter analyzes and presents associations between input and output variables of large highway project samples. During input analysis, forty-seven input variables were identified. However, because of the lack of variability in the data set, 33 input variables were dropped from the analysis. The input variables which have at least three sample sizes in each group were considered. Fourteen input variables' descriptive statistics were analyzed to determine associations between input and output variables for large highway projects. Due to sample size limitations, the objective of such descriptive statistical analysis was not to establish a statistical model but to use statistical techniques to investigate the potential association between input and output variables of large highway projects.

For sake of interpretation, projects were divided into two categories according to "Design & Construction Cost": Projects costing more than $200 million and projects costing less than $200 million. Projects were also divided into two categories according to "Design & Construction Duration": Projects having duration more than 1,100 days and projects having duration less than 1,100 days. Projects were also divided into two groups according to "Highway Length in Lane Mile": Projects with more than 75 lane miles of roads, and projects with less than 75 lane miles of roads. Projects were also divided into two categories according to "No. of Bridges": Projects with more than 20 bridges and projects with less than 20 bridges. The projects were also categorized into two groups: Projects with interchange construction and project without interchange construction. Projects were also categorized according to "No. of ROW Parcels" into two groups. One was having more than 100 ROW parcels and another having less than 100 ROW parcels. The association between input and output variables was determined by observing the difference in mean and median values of output variables in two or more groups of input variables. The findings are described below.

7.1 INPUT VARIABLES – TOTAL COST GROWTH ASSOCIATION

Descriptive statistics were used to determine associations between input variables and "Total Cost Growth" of large highway projects. Table 7.1 shows the input variables that could have potential associations with "Total Cost Growth." These input variables were identified on the basis of mean and median values of "Total Cost Growth" and they differed by about 10 percent in two different groups. The detailed descriptive statistics of "Total Cost Growth" for all input variables are shown in Appendix G.

Table 7.1: Input Variables and Total Cost Growth Association

S.No.	Input Variables	N	Total Cost Growth		
			Median	Mean	SD
1	Project Nature				
	New	3	1.64%	-2.16%	23.42%
	Reconstruction	5	27.85%	12.81%	23.90%
2	Highway Length in Lane Mile				
	1- 75	5	1.64%	2.30%	23.85%
	>75	3	27.85%	15.10%	24.84%
3	No. of Bridges				
	0-20	4	2.80%	2.24%	27.22%
	>21	4	14.74%	11.96%	21.64%
4	Specification Type & Latest Technology				
	Blend with Latest Technology	5	-13.11%	-0.73%	24.90%
	Performance with Existing Technology	3	27.85%	20.16%	16.11%
5	Value Engineering				
	Yes	4	24.84%	17.00%	21.22%
	No	4	-5.73%	-2.80%	23.67%
6	Historical Sites				
	Yes	4	-5.73%	1.49%	20.88%
	No	4	23.28%	12.71%	27.43%
7	Archeological Sites				
	Yes	4	16.31%	12.84%	22.28%
	No	4	2.59%	1.36%	26.22%

Out of the fourteen input variables for which descriptive statistics were analyzed, eight were found to have possible associations with "Total Cost Growth." They are: "Project Nature," "Highway Length in Lane Mile," "No. of Bridges," "Specification Types," "Value Engineering," "Latest Technology," "Presence of Historical Sites," and "Presence of Archeological Sites." The data analysis shows that "Total Cost Growth" for new projects was lower than that for the reconstruction projects for this sample. It also shows that "Total Cost Growth" for projects with higher lane miles of roads was lower than that for the projects with fewer lane miles of roads. The descriptive statistic shows that the projects that used blend specification and latest technology had lower "Total Cost Growth" than the projects that used performance specification with existing technology. The "Latest Construction Technologies" included the use of slip forms for paving concrete pavement, the use of liquid nitrogen to set the concrete pavement. Similarly, some structure-related technologies like wicked drains and geo-foams were also used on some of the projects. The data analysis shows that the presence of “Historical Sites” was associated with lower “Total Cost Growth”. This association is difficult to explain. The presence of environmental issues is believed to increase the total cost growth due to unpredictability on the construction of environmental mitigation measures. This counterintuitive finding may be due to small sample size. The presence of “Archeological Sites” was associated with higher “Total Cost Growth.” The data analysis for this sample shows that the use of value engineering was associated with higher “Total Cost Growth,” a result that does not seem reasonable. Since “Value Engineering” is used to decrease construction cost by the use of alternative design, the increase in “Total Cost Growth” in these projects is not likely to be due to value engineering. A careful review of data showed that the projects that used value engineering had more changes than the projects that did not use value engineering. These changes were responsible for the increased construction cost of the project. Therefore, this association is not causal.

7.2 INPUT VARIABLES – ADJUSTED COST PER LANE MILE ASSOCIATION

The descriptive statistics of “Adjusted Cost per Lane Mile” were used to determine an association with input variables of large highway projects. Table 7.2 shows the input variables that could be associated with “Adjusted Cost per Lane Mile.” These input variables were identified on the basis of mean and median values of “Adjusted Cost per Lane Mile” and they differed by about $1.5 million in two different groups. The detailed descriptive statistics of “Adjusted Cost per Lane Mile” for all input variables were shown in Appendix G.

Table 7.2: Input Variables and Adjusted Cost per Lane Mile Association

S.No.	Input Variables	N	Adjusted Cost/ LM		
			Median	Mean	SD
1	Design & Construction Duration				
	< or = 1,100 Days	3	$2.2M	$2.5M	$0.8M
	> 1,100 Days	5	$4.3M	$4.2M	$1.6M
2	No. of Interchanges				
	None	3	$2.0M	$2.5M	$1.0M
	1-7	5	$4.3M	$4.2M	$1.5M
3	Lane Rental				
	Yes	5	$4.3M	$4.2M	$1.6M
	No	3	$2.2M	$2.5M	$0.8M
4	Specification Type				
	Blend	5	$4.2M	$4.5M	$1.1M
	Performance	3	$2.0M	$2.0M	$0.2M
5	Value Engineering				
	Yes	4	$4.5M	$4.3M	$1.8M
	No	4	$2.8M	$2.8M	$0.9M
6	Latest Technology				
	Yes	5	$4.3M	$4.5M	$1.1M
	No	3	$2.0M	$2.0M	$0.1M

The data analysis shows that the mean and median "Adjusted Cost per Lane Mile" for projects with design and construction durations greater than 1,100 days was higher than for projects with durations of fewer than 1,100 days. The projects which involved interchange construction had higher "Adjusted Cost per Lane Mile." One possible explanation for higher "Adjusted Cost per Lane Mile" for the projects involving interchange construction could be that the cost of interchange construction is higher than the cost of road construction. The data shows that the use of "Lane Rental" provision was associated with higher "Adjusted Cost per Lane Mile." The descriptive statistic shows that the use of "Value Engineering" was associated with higher "Adjusted Cost per Lane Mile." A careful review of data shows that projects that used value engineering had more changes than the projects that did not use value engineering. These changes increased "Adjusted Cost per Lane Mile" of the project. Therefore, this association is not likely to be causal. Similarly the data shows that the use of "Latest Technology" was associated with higher "Adjusted Cost per Lane Mile," which may or may not be causal.

7.3 Input Variables – Total Schedule Growth Association

Table 7.3 shows the input variables that could be associated with "Total Cost Growth." These input variables were identified on the basis of mean and median values of "Total Schedule Growth" and they differed by about 10 percent in two different groups. The detailed descriptive statistics of "Total Cost Growth" for all input variables were shown in Appendix G.

Table 7.3: Input Variables and Total Schedule Growth Association

S.No.	Input Variables	N	Total Schedule Growth		
			Median	Mean	SD
1	Design & Construction Duration				
	< or = 1,100 Days	3	16.02%	15.95%	18.55%
	> 1,100 Days	5	1.95%	2.73%	9.70%
2	No. of Bridges				
	1-20	4	0.25%	2.55%	9.78%
	>21	4	10.28%	12.83%	17.26%
3	Specification Type & Latest Technology				
	Blend with Latest Technology	5	-2.63%	1.82%	10.00%
	Performance with Existing Technology	3	16.02%	17.48%	16.31%
4	Archeological Sites				
	Yes	4	17.31%	16.62%	15.21%
	No	4	-0.87%	-1.23%	4.52%
5	Number of ROW Parcels				
	0-100	5	1.95%	2.95%	9.53%
	>100	3	16.02%	15.60%	19.09%

The descriptive statistics show that the mean and median "Total Schedule Growth" for projects that had "Design and Construction Duration" of more than 1,100 days were lower than that for the projects that had "Design and Construction Duration" of fewer than 1,100 days. The "Number of Bridges" in the projects was also associated with "Total Schedule Growth." The projects that had fewer than 20 bridges had lower "Total

Schedule Growth" than the projects that had more than 20 bridges. The data also shows that the projects that used blend specification with latest technology had lower "Total Schedule Growth" than the project that used performance specification with existing technology. The presence of "Archeological Sites" was associated with higher "Total Schedule Growth." The "Total Schedule Growth" for projects which have more than 100 ROW parcels was higher than for projects that have less than 100 ROW parcels for this sample.

7.4 INPUT VARIABLES – DELIVERY DURATION PER LANE MILE ASSOCIATION

The descriptive statistics of "Delivery Duration per Lane Mile" were used to determine an association with input variables of large highway projects. Table 7.4 shows the input variables that could be associated with "Delivery Duration per Lane Mile." These input variables were identified on the basis of mean and median values of "Delivery Duration per Lane Mile" and they differed by about 10 days in two different groups. The detailed descriptive statistics of "Delivery Duration per Lane Mile" for all input variables are shown in Appendix G.

Table 7.4: Input Variables and Delivery Duration per Lane Mile Association

S.No.	Input Variables	N	Delivery Duration/ LM		
			Median	Mean	SD
1	Design & Construction Cost				
	< or = $200 Million	3	28.2 Days	25.4 Days	9.9 Days
	> $200 Million	5	13.2 Days	16.7 Days	12.7 Days
2	Design & Construction Duration				
	< or = 1,100 Days	3	13.2 Days	13.3 Days	1.0 Days
	> 1,100 Days	5	28.2 Days	24.0 Days	13.8 Days
3	Project Nature				
	New	3	28.2 Days	24.7 Days	11.1 Days
	Reconstruction	5	13.5 Days	17.1 Days	12.5 Days
4	Highway Length in Lane Mile				
	1-75	5	28.2 Days	25.2 Days	12.0 Days
	>75	3	13.5 Days	11.2 Days	4.6 Days
5	Lane Rental				
	Yes	5	28.2 Days	24.14 Days	13.7 Days
	No	3	13.2 Days	13 Days	0.6 Days
6	Latest Technology				
	Yes	5	28.2 Days	23.9 Days	13.9 Days
	No	3	13.5 Days	13.4 Days	1.0 Days
7	Historical Sites				
	Yes	4	12.7 Days	11.4 Days	3.8 Days
	No	4	30.9 Days	28.5 Days	10.9 Days
8	Wet Land				
	Yes	4	12.9 Days	11.5 Days	3.8 Days
	No	4	30.9 Days	28.4 Days	11.0 Days
9	Number of ROW Parcels				
	0-100	5	12.3 Days	10.8 Days	11.6 Days
	>100	3	28.2 Days	25.4 Days	4.4 Days

The descriptive statistics show that the larger the project size was in terms of cost, the shorter the "Delivery Duration per Lane Mile" was. However, the data also shows that the longer the project duration was, the longer the "Delivery Duration per Lane Mile" was. Similarly reconstruction projects were completed faster than new projects. The project that had more than 75 lane miles of length had shorter "Delivery Duration per Lane Mile" than the projects that had less than 75 lane miles of length. Moreover, the data shows that the use of "Lane Rental" provisions in contracts was associated with longer "Delivery Duration per Lane Mile." The use of the "Latest Technology" is believed to decrease "Delivery Duration per Lane Mile," but the data shows otherwise for this sample. The presence of "Historical Sites" and "Wetlands" was associated with shorter "Delivery Duration per Lane Mile." This association is difficult to explain, since the presence of environmental issues is believed to increase project duration and possibly an anamoly associated with small sample size. The data shows that the more ROW parcels to be acquired in the project, the longer the "Delivery Duration per Lane Mile" would be.

7.5 INPUT VARIABLES – CHANGE COST FACTOR ASSOCIATION

Table 7.5 shows the input variables that could be associated with "Change Cost Factor." These input variables were identified on the basis of mean and median values of "Change Cost Factor" and they differed by about 5 percent in two groups. The detailed descriptive statistics of "Change Cost Factor" for all input variables are shown in Appendix G.

Table 7.5: Input Variables and Change Cost Factor Association

S.No.	Input Variables	N	Change Cost Factor		
			Median	Mean	SD
1	Design & Construction Cost				
	< or = $200 Million	3	14.09%	15.82%	4.61%
	> $200 Million	5	4.53%	3.38%	2.46%
2	No. of Bridges				
	0-20	4	3.07%	3.00%	2.65%
	>21	4	13.21%	13.10%	6.60%
3	No. of Interchanges				
	None	3	12.33%	12.63%	8.25%
	1-7	5	4.96%	5.29%	5.47%
4	Lane Rental				
	Yes	5	12.33%	10.65%	8.05%
	No	3	4.53%	3.70%	1.82%

The data analysis shows that projects that cost more than $200 million for design and construction were associated with lower "Change Cost Factor." The mean and median "Change Cost Factor" for projects that had less than 20 bridges was lower than that for projects that had more than 20 bridges. The data shows that "Number of Interchanges" was associated with "Change Cost Factor." "Change Cost Factor" was higher for projects without interchanges for this sample, a result that is difficult to explain. Similarly the sample data shows that the use of "Lane Rental" provisions was associated with higher "Change Cost Factor."

7.6 INPUT VARIABLES – FATALITY RATE ASSOCIATION

The descriptive statistics of "Fatality Rate" were used to determine an association with input variables of large highway projects. Table 7.6 shows the input variables that could be associated with "Fatality Rate." These input variables were identified on the basis of mean and median "Fatality Rate" and they differed by about five in two different groups. The detailed descriptive statistics of "Fatality Rate" for all input variables are shown in Appendix G.

Table 7.6: Input Variables and Fatality Rate Association

S.No.	Input Variables	N	Fatality Rate		
			Median	Mean	SD
1	Project Nature				
	New	3	0.0	0.0	0.0
	Reconstruction	5	8.7	16.8	19.4
2	Lane Rental				
	Yes	5	8.7	16.8	19.4
	No	3	0	0	0

The analysis shows that reconstruction projects were associated with a higher "Fatality Rate." "Lane Rental" provisions in contracts were also associated with higher

"Fatality Rate." One possible explanation for this association is that, in this sample, the "Lane Rental" provision was used mostly for reconstruction projects, and since the reconstruction projects were found to have a higher fatality rate so do the projects with "Lane Rental" provisions.

7.7 INPUT VARIABLES – QUALITY RATING ASSOCIATION

The quality rating used in this study was subjective. The data collected for all eight highway projects shows that all of the project managers rated their projects' quality as between good (3) and excellent (4). Thus, there was no variation in the data set for this variable. The association of "Quality Rating" with other input variables could not be established because there was no major difference in the mean and median values of "Quality Rating" for different groups of these fourteen input variables. The detailed descriptive statistics of the "Quality Rating" is shown in Appendix G.

7.8 SUMMARY OF INPUT – OUTPUT VARIABLES ASSOCIATION

The results of input-output variable association analysis shows that eleven input variables had possible and explainable associations with one or more output variables. Table 7.7 shows output variables that have an association with one or more input variables.

Table 7.7: Summary of Input-Output Variables Association

S.No.	Output Variables	Input Variables
1	Total Cost Growth	"Project Nature," "Highway Length in Lane Mile," "No. of Bridges," "Specification Types," "Latest Technology," and "Archeological Sites."
2	Adjusted Cost per Lane Mile	"Design & Construction Duration," "No. of Interchanges," and "Specification Types."
3	Total Schedule Growth	"Design & Construction Duration," "No. of Bridges," "Specification Types," "Archeological Sites," and "No. of ROW Parcels."
4	Delivery Duration per Lane Mile	"Project Nature," "Design & Construction Cost," "Highway Length per Lane Mile," and "Lane Rental."
5	Change Cost Factor	"Design & Construction Cost," "No. of Bridges," and "Lane Rental."
6	Fatality Rate	Project Nature" and "Lane Rental."

7.9 LEARNINGS ON METHODOLOGY

During the data analysis, some of the input variables could not be analyzed due to the lack of variability in the data set. One of the causes of low variability in data was the type of questions put into the questionnaire. For example, the questions related to constructability reviews, co-location, change management, and level of environmental and ROW assessments were too general. The respondents were expected to answer these questions subjectively, and their unquantifiable responses resulted in the non-variability in the data set. These questions should be followed up by definitive questions that will allow researchers to know whether the respondents are using these best practices properly.

Respondents did not respond to some of the questions in the questionnaire. These unanswered questions addressed the following issues: approach to traffic control planning, total design work hours needed, total construction work hours needed, number of working days lost due to delays, Subsurface Utility Engineering (SUE) budget, Full Time Equivalent (FTE) for owner, number of Requests for Information (RFI), and total number of traffic accidents. These questions should be removed from the questionnaire, since it is very difficult to capture these data during any highway construction process. Other alternatives would include rewording questions or working directly with project personnel to capture data as the projects unfold.

The quality data was very difficult to capture, so researchers used project manager's subjective quality rating data to compare large DB and DBB highway projects. It is the reason for not getting lot variability in the quality rating data. One of the quality measurements used in highway construction is International Roughness Index (IRI). IRI is the international standard for measuring pavement smoothness. This index measures pavement roughness in terms of number of inches per mile (Penndot, 2007). Therefore in future research, this data can be collected to compare the quality of highway pavement built under DB and DBB project delivery methods.

Chapter Eight: Conclusions and Recommendations

This chapter summarizes research findings by presenting conclusions and recommendations. The research objectives and hypotheses are first reviewed, followed by specific conclusions related to the research hypotheses. The recommendations for future research are discussed and, finally, contributions to the body of knowledge are set forth.

8.1 REVIEW OF RESEARCH OBJECTIVES AND HYPOTHESES

The main objectives of this research, as outlined in Section 1.5 were: (1) to develop an approach to benchmarking for large highway construction projects: (2) to compare descriptive statistics of the input variables as well as output variables of DB and DBB highway projects in terms of cost, schedule, safety, change orders and quality, and; (3) to determine associations between input and output variables. Based on these main objectives, this study has accomplished the following tasks.

1. Review existing research on benchmarking of DB and DBB projects;
2. Develop a method to collect data for benchmarking of large highway project performance;
3. Develop absolute output variables (e.g. cost per lane mile, delivery duration per lane mile) used for measuring highway project performance;
4. Summarize the differences in input variables of large DB and DBB highway projects;
5. Summarize the differences in output variables of large DB and DBB highway projects, and;
6. Determine the association between input and output variables of large highway projects using descriptive statistics.

The research hypotheses presented in Section 1.6 are listed below for review.

H1: A credible method can be developed to capture and compare input and output variables for large highway projects.

A benchmarking methodology was adapted to capture and compare input and output variables for large highway projects.

H2: There is a difference in cost, schedule, change orders, safety and quality performance on large DB and DBB highway projects.

To prove this research hypothesis, project performance metrics were compared to find any differences between DB and DBB highway projects; of these metrics two were cost-related, two were schedule-related, one was change order-related, one was safety-related, and one was quality related. Descriptive statistics were used to determine whether the means of the two samples were different.

H3: There is an association between input and output variables of large highway projects.

To prove this research hypothesis, output variables' descriptive statistics were analyzed to determine associations with input variables.

8.2 RESEARCH CONCLUSIONS

The sample size of this study was small; therefore it should be noted that this small sample size is not likely to be statistically representative of all large DB and DBB highway projects. Hence, care should be taken in applying any conclusions that are based on the results from this sample.

Conclusion 1: This research adapted an input-output benchmarking methodology to capture and compare input and output variables of large highway projects built under both DB and DBB project delivery methods. A comprehensive data collection questionnaire was also developed to collect input and output variables of large highway projects.

Conclusion 2: This research investigated the differences in large DB and DBB highway project performance in terms of cost, schedule, change orders, safety, and quality. Results presented in chapter 6 indicated that the mean and median "Total Cost Growth" for DB projects was lower than the same variable on DBB projects. The mean "Adjusted Cost per Lane Mile" for DB projects was lower than that for DBB. However, the mean and median "Total Schedule Growth" for DB was higher than that for DBB. "Delivery Duration per Lane Mile" for DB was lower than that for DBB. The mean and median "Change Cost Factor" for DB was lower than that for DBB. The mean "Fatality Rate" and "Quality Rating" for DB projects were nearly similar to the same performance variables on DBB projects.

Conclusion 3: This research determined the association between input and output variables of large DB and DBB highway projects using descriptive statistics. Results presented in chapter 7 indicate that eleven input variables had associations with six output variables.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This research provided a comprehensive methodology for the benchmarking of large highway projects. This research also conducted descriptive statistical analysis of large DB and DBB highway project performance. The sample size of this study was small to conduct inferential statistical analysis; therefore more research with larger sample sizes is necessary to validate the findings of this research. The recommendations below are made regarding this study and future research.

1. The statistical analysis shows that large DB highway projects have "Total Cost Growth," "Adjusted Cost per Lane Mile," and "Delivery Duration per Lane Mile" advantage over DBB highway projects. However, further research with large sample size should be collected to validate the significant difference in their mean values.
2. Some of the input variables that were found to have high correlation with project performance variables in previous research were not analyzed in this study. These variables include constructability, co-location, etc. It was due to the non-variation of these data in sample projects. All the sample projects used constructability and co-location; therefore future studies should look for correlations of these variables with performance variables using sample projects that have variation in these data.
3. Some of the associations between input and output variables found in this study were difficult to explain; therefore more research should be performed to better understand these findings.
4. Quality difference between DB and DBB projects were analyzed by using subjective judgment of the project manager in this study. Further study should use International Roughness Index (IRI) as a quality measurement of highway projects.

8.4 RESEARCH CONTRIBUTIONS

Previous research on benchmarking of DB and DBB project delivery methods was generally focused on building and industrial construction. In addition, these earlier research efforts compared DB and DBB building projects for all sizes of projects. The current research was an exploratory study and compared DB and DBB project delivery methods only for large (>$100M) highway projects. Major contributions of this research include:

1. This research adapts a benchmarking methodology for large (>$100M) highway projects by comparing their input and output variables.
2. This research provides the highway industry a means of assessing project performance on large DB and DBB highway projects. The questionnaire developed during this research will help industry participant's record and benchmark project data.
3. This research provides some new performance metrics related to cost and schedule that are tailored to highway projects. "Adjusted Cost per Lane Mile" and "Delivery Duration per Lane Mile" of highway are used for the first time in this research as benchmark of large highway projects.
4. This research measures the differences between large DB and DBB highway projects for this sample by using descriptive statistics.
5. This research identifies input variables that have associations with output variables for large highway projects. These input variables for large highway projects are identified for the first time.

Appendix A: Description of DB Highway Projects (> 50 M) Selected from SEP-14

No.	State	Name of Project	Date Started	Date Completed	Construction Cost ($)	Project Description
1	Arizona	Tempe - Mesa Project, US 60 Superstition Freeway Widening Project	Jun-01	Summer 03	184,292,800	Adding additional lanes including HOV and auxiliary lanes between Interstate 10 and Val Vista Road.
2	Arizona	Phoenix Project: SR 51 HOV Lanes	Jan-03	Mar-04	75,685,000	Adding HOV lane to northbound and southbound State Route 51 from I-10 to Shea Boulevard
3	Colorado	Transportation Expansion Project (TREX)	Fall 2001	Sep-06	1,670,000,000 (795,000,000 for highway construction)	Construction of 19 miles of light railroad and 17 miles of highway through southeast Denver, Aurora, Greenwood Village, Centinnial, Lone Trees
4	Florida	I 4 Reconstruction	NA	NA	72,760,000	Adding lanes and reconstruction
5	Florida	I 4 Add Lanes and Rehabilitation Project	NA	NA	59,600,000	Adding lanes and rehabilitation
6	Florida	I 95 Widening	NA	NA	67,300,000	Widening of existing I 95
7	Florida	I 4 Interchange (Major)	NA	NA	62,150,000	Interchange construction
8	Georgia	I 75 Turner Crisp Cos., SR 159 to SR 300	Nov-00	NA	51,900,000	Construction of 14.5 miles of road
9	Georgia	I 75 Lowndes Co. SR-133 to Cook Co. Line	NA	NA	67,000,000	Construction of 13.7 miles of road
10	Indiana	I 65 Reconstruction & Adding Lane	Mar-00	Oct-01	76,500,000	Reconstructing and adding lanes from Cold Spring to I 465 Indianapolis, Marion Co.
11	Indiana	I 465 / I 70 Reconstruction of Interchange	Mar-01	Nov-02	67,100,000	Reconstruction of interchange in Indianapolis, Marion county
12	Massachussets	Route 3, North from Route 128 to the NH border	Aug-00	Mar-04	385,000,000	Reconstruction of 21 miles road
13	Minnesota	Highway 52 Reconstruction Project	Summer 2002	Aug-06	220,000,000	Reconstruction of road from Highway 63 to 85th St. NW in Rochester.

No.	State	Name of Project	Date Started	Date Completed	Construction Cost ($)	Project Description
14	New Jersey	Route 29 Improvement	Sep-97	Dec-00	70,930,000	Information not available
15	New Jersey	Enhanced I & M Stations	Aug-98	NA	63,156,000	Information not available
16	New Mexico	US Hondo Valley Project	Aug-01	Jan-05	129,000,000	Construction of US 70, which includes 38 miles of four-lane highway beginning from east of Rudios Down to east of community of Riverside
17	North Carolina	Reconstruction of I 77	Nov-01	Oct-04	70,900,000	Information not available
18	North Carolina	I 26 Reconstruction	Not awarded		83,700,000	Reconstruction from NC 225 to NC 280
19	North Carolina	Widening of I 85	Nov-02	Oct-05	87,700,000	Rehabilitation and widening of I 85 from US 29 to NC 73 in Mecklenburg County
20	North Carolina	US 64 Knightdale Bypass	Jun-02	Aug-05	131,000,000	Information not available
21	South Carolina	Conway Bypass	Apr-95	Dec-01	386,300,000	28.5 miles; 4-lanes from US 501, 10 miles north of Conway, to the Carolina Bays Parkway, and 6-lanes from there to US 17 in the Myrtle Beach area
22	South Carolina	Carolina Bays Parkway	Mar-00	Jun-02	225,400,000	6-lanes from US 501 to SC 9, north/south highway intersecting the Conway Bypass in the Myrtle Beach area.
23	South Carolina	SC 170 Widening	Sep-00	Mar-03	105,000,000	12.5 miles; widening to 4-lane west of the City of Beaufort from east of the SC 462 to just west of S 761 (W.L. Alston Drive) and the replacement of bridges over the Chechessee and the Broad Rivers.
24	Utah	I 15 Reconstruction	Jun-96	NA	1,325,000,000	Information not available
25	Utah	12300 South Interchange	Jul-02	NA	65,500,000	Information not available
26	Virginia	Route 288 Reconstruction	Mar-01	Oct-03	236,000,000	Reconstruction between I 64/288 interchange and I 64 to rt. 250 connection

Appendix B.1: Questionnaire for DB Project

Section 1: Project General Information

1.1 Name of Owner Organization: ________________________________

1.2 Name of Project:____

1.3 Project ID:____

1.4 Project Description:____

1.5 Starting Location:____

1.6 Ending Location: ____

1.7 Contact Person (Name of person filling this questionnaire):

____

1.8 Contact Person's Phone: ______________________________________

1.9 Contact Person's Fax: _______________________________________

1.10 Contact Person's Email Address: _______________________________

1.11 Contact Person's Role / Title in this Project:

____

1.12 Project web address: ____

1.13 Date of Assessment: ____

Section 2: Project Characteristics

2.1 Current State of Project

2.1.1 Describe current state of this highway project.

Completed on ____

Operational from ____

OR

% of completed ____

Current planned completion date ____________________________

2.2 Type of Work and Location

2.2.1 Where is this highway project located?

Urban Rural

Other ____

2.2.2 Describe the nature of this project.

New green field construction Rehabilitation

Reconstruction Expansion

Other ____

2.2.3 Was this highway project constructed while maintaining traffic flow?

Yes No

2.3 Project Scope

Please provide following project data.

2.3.1 Total length of road ________________________________ Miles

2.3.2 Total length of freeway main lanes ________________ Lane miles

2.3.3 Total length of frontage roads – both side ___________ Lane miles

2.3.4 Total length of HOV lanes ______________________ Lane miles

2.3.5 Total number of highway interchanges ______________________

2.3.6 Total number of frontage road intersections __________________

2.3.7 Total number of freeway ramps ____________________________

2.3.8 Total number of bridge spans _____________________________

2.3.9 Total number of concrete bridge spans ______________________

2.3.10 Total number of steel bridge spans _________________________

2.3.11 Total area of bridge deck ______________________________(SF)

2.3.12 Number of rail road crossings _____________________________

2.3.13 Number of water crossings _______________________________

2.3.14 Total length of roadway tunnels ______________________ Miles

2.3.15 Total length of drainage tunnels ______________________ Miles

2.3.16 Total length of box culvert _____________________________ LF

2.3.17 Total length of pipe culvert ____________________________ LF

2.3.18 Total number of toll plazas _______________________________

2.3.19 Pavement types (concrete or asphalt or combination) ___________

2.3.20 Total quantity of earthwork excavation ___________________ CY

2.3.21 Percentage of rock excavation ___________________________ %

2.3.22 Total quantity of embankment filling ___________________ CY

2.4 Contract

2.4.1 What type of contract delivery method was used to deliver this project?

Design-Bid-Build (DBB)

Design-Build (DB)

Design-Build-Operate-Maintain (DBOM)

Finance-Design-Build-Operate-Maintain (FDBOM)

Other ___________________________

2.4.2 How many previous projects had been design-build (D-B)?

One | Two

Three | Three plus

2.4.3 How was the contractor (developer) selected?

Based on unit prices | Negotiation

Best Value | A+ B Bidding

Other ____________________________________

2.4.4 What was the rate of liquidated damages in this contract?

US $ ___________________________ per day or per month

No liquidated damage provision in contract

2.4.5 Was there any schedule performance bonus in this contract? If yes, how much was it?

Yes ____

______________________(Total amount in US $; details of system)

No

2.4.6 Were there any other disincentives for late completion? If yes, how much was it?

Yes ____

__________________________($/day or $/month; details of system)

No

2.4.7 Was there any lane rental provision in this contract? If yes, what was the fee assessed for each lane closure?

Yes _______________________________(US $/lane-hour or $/lane-day)

No

2.4.8 What percentage of design was completed when construction contract was awarded?

_________________________________ (Percentage of design complete)

2.4.9 What types of specifications were used to construct this highway?

Performance spec Prescriptive spec

Both of above Other ____________

2.5 Organizational Approaches

2.5.1 Was there a partnering consultant hired and used for this contract?

Yes No (Go to 2.5.3)

2.5.2 If yes, what was the frequency of partnering sessions?

_________________________ (Number of times per month or per year)

None

2.5.3 How would you characterize environmental assessment done during pre-project planning of this project?

High level Medium level Low level

2.5.4 How would you characterize ROW assessment done during pre-project planning of this project?

High level Medium level Low level

2.5.5 How many different sub-contractors / consultants were involved in designing this project?

________________________(Total number of sub-contractors / consultants)

2.5.6 How many sub-contractors were involved in constructing this project?

_________________________________(Total number of sub-contractors)

2.5.7 Were different entities of the project (e.g., owner, contractor, program manager, etc.) co-located in close proximity?

Yes No

2.5.8 Was there a formal documented change management process used to address design and / or construction changes on this project?

Yes No

2.5.9 Was formal Value Engineering used on this highway project? If yes, how much project cost was saved?

Yes ____(US $)

None

2.5.10 Was one or more constructability reviews carried out during the design phase of this project?

Yes No

2.5.11 Please describe any unique approaches to Traffic Control Planning?

____

None

2.6 Work Processes

2.6.1 Please describe any new technologies being used to construct the project?

____

____

None

2.6.2 Please describe any special information-sharing software used to transfer information between various project entities. (beyond email)

____

____

None

2.7 Project Calendar

2.7.1 Please fill the start and end dates (month / year) of different phases of this project.

Project phases	**Date in months & years**	
Design	/	/
ROW acquisition	/	/
Utility adjustments	/	/
Construction	/	/

2.7.2 How many days (on average) did designers work per week on this project?

4 days a week	5 days a week
6 days a week	7 days a week

2.7.3 How many hours per day (on average) did designers work during the design of this project?

6 hours per day	7 hours per day
8 hours per day	9 hours per day
10 hours per day	More than 10 hours

2.7.4 Please estimate the total design work hours needed to complete this project?

____

2.7.5 How many days (on average) did construction workers work per week?

4 days a week	5 days a week
6 days a week	7 days a week

2.7.6 How many hours per day (on average) did construction workers work on this project?

6 hours per day	7 hours per day
8 hours per day	9 hours per day
10 hours per day	More than 10 hours

2.7.7 What was the estimated peak number of construction workers?

____

2.7.8 Please estimate the total construction work hours needed to complete this project?

____

2.7.9 How many shifts did construction workers work per day?

One Two Three

2.7.10 Please describe any major delays that occurred in the construction of this project?

____

____

____

None (Go to 2.7.12)

2.7.11 Approximately how many working days had been lost due to these major delays?

______________________________(Total number of work days)

2.7.12 Please briefly describe the severity of winter weather on this project.

____

____

2.7.13 How many winter seasons occurred during the construction phase of this project?

____

2.7.14 Approximately how many working days were lost due to winter weather?

______________________________(Total number of work days)

2.8 Environmental Issue

2.8.1 Please describe any unanticipated delays due to environmental issues?

____

____

2.8.2 Did this project involve any of the following?

Contaminated soil	Yes	No
Contaminated ground water	Yes	No
Endangered species	Yes	No
Historical sites/structures	Yes	No
Wetlands	Yes	No
Asbestos	Yes	No
Wildlife refugee	Yes	No
Archeological sites (incl. cemeteries)	Yes	No
Other environmental sensitive issues	Yes	No

2.9 Right-of-Way

2.9.1 Who was responsible for procurement of the right-of-way parcels for the construction of this project?

Contractor Owner

Other ____(Name of entity)

2.9.2 How many total right-of-way parcels were procured for the construction of this project?

____(Total number of parcels)

2.9.3 How many right-of-way parcels or what percent were acquired through eminent domain / condemnation for this project?

______________________________(Total number of parcels or percent)

None

2.9.4 How many right-of-way parcels or what percent were acquired through administrative settlement for this project?

____________________________________(Total number of parcels or percent)

None

2.9.5 How would you characterize ROW delays (if any) on this project?

Severe Moderate / Typical Insignificant

2.10 Utility Adjustments

2.10.1 Approximately how many utilities were adjusted for the construction of this project?

________________________________(Total number of utilities adjusted)

None (Go to 2.10.3)

2.10.2 If any adjustments were delayed, approximately how many working days were lost as a result?

_______________________________(Total number of working days lost)

2.10.3 Approximately how much was the Subsurface Utility Engineering (SUE) budget for this project?

_____________________________________(Total budget in US $)

None

2.11 Owner Staffing

2.11.1 What is the total Full Time Equivalent (FTE) of Department of Transportation staff for this highway project?

____(Total FTE)

2.11.2 Was a program manager used to supplement the Department of Transportation personnel?

Yes No (Go to 3.1)

2.11.3 If yes, what was the FTE's for this project?

____

Section 3: Project Performance

3.1 Project Cost-Related Performance:

Please provide the following cost-related performance data of your project.

No.	Cost-related project performance	Cost (US $)
1.	Owner estimated design and construction cost	
2.	Contractor's bid / negotiated amount	
3.	Contract amount	
4.	Total project completion cost	
5.	Owner estimated design cost	
6.	Final design cost	
7.	Final ROW cost	
8.	Final utility adjustment cost	
9.	Owner estimated construction cost	
10.	Final construction cost (including change orders)	

3.2 Project Schedule-Related Performance:

Please provide the following schedule-related performance data of this project.

No.	Schedule-related project performance	Duration
1.	Owner estimated design and construction duration	
2.	Contractor's bid duration	
3.	Actual project completion duration	
4.	Owner estimated design duration	
5.	Final design duration	
6.	Owner estimated construction duration	
7.	Final construction duration	

3.3 Project Construction Safety-Related Performance:

Please provide the following construction safety-related performance data of this project.

No.	Construction safety-related performance	
1.	Total number of fatalities	
2.	Total number of days away from work, restricted activity or transfer (DART)	
3.	Total number of work zone traffic accidents	

3.4 Project Quality-Related Performance:

Please provide the following quality-related performance data of this project.

No.	Quality-related performance	
1.	Total number of Request for Information (RFI)	
2.	Total number of Non-Conformance Reports (NCR)	
NCR: NCR is a report submitted by the owner's verification team when the contractor does not meet the specification requirement.		

3.5 Project Change Order-Related Performance:

Please provide the following change order-related performance data of this project.

No.	Change order-related project performance	
1.	Total number of design change orders	
2.	Total cost of design change orders (US$)	
3.	Total number of construction change orders	
4.	Total cost of construction change orders (US$)	

3.6 Project Claim-Related Performance:

Please provide the following claims-related performance data of this project.

No.	**Claims-related project performance**	
1.	Total number of design claims	
2.	Total cost of design claims (US$)	
3.	Total number of construction claims	
4.	Total cost of construction claims (US$)	

Section 4: Stakeholders' Success

4.1 Who was the design-build contractor for this highway project? Please provide the following information.

Name of Contractor: ____

Address: ____

Website address (If any): ____

Email Address: ____

Phone Number: ____

4.2 How would you rate the overall performance of this project compared to other design-build (DB) projects?

Excellent Good

Fair Poor

Appendix B.2: Pre-completion Questionnaire for DBB Projects

Section 1: Project General Information

1.1 Name of Owner Organization:________________________________

1.2 Name of Project:____

1.3 Project ID:____

1.4 Project Description:____

1.5 Starting Location:____

1.6 Ending Location: ____

1.7 Contact Person (Name of person filling this questionnaire):

____

1.8 Contact Person's Phone: ______________________________________

1.9 Contact Person's Fax: _______________________________________

1.10 Contact Person's Email Address: ______________________________

1.11 Contact Person's Role / Title in this Project:

____

1.12 Project web address: ____

1.13 Date of Assessment: ____

Section 2: Project Characteristics

2.1 Current State of Project

2.1.1 Describe current state of this highway project.

Completed on ____

Operational from ____

OR

Percent of completed ____

Current planned completion date ___________________________

2.2 Type of Work and Location

2.2.1 Where is this highway project located?

Urban Rural

Other ____

2.2.2 Describe the nature of this project.

New green field construction Rehabilitation

Reconstruction Expansion

Other ____

2.2.3 Was this highway project constructed while maintaining traffic flow?

Yes No

2.3 Project Scope

Please provide following project data.

2.3.1 Total length of road ________________________________ Miles

2.3.2 Total length of freeway main lanes ________________ Lane miles

2.3.3 Total length of frontage roads – both side ___________ Lane miles

2.3.4 Total length of HOV lanes ______________________ Lane miles

2.3.5 Total number of highway interchanges ______________________

2.3.6 Total number of frontage road intersections __________________

2.3.7 Total number of freeway ramps ____________________________

2.3.8 Total number of bridge spans _____________________________

2.3.9 Total number of concrete bridge spans ______________________

2.3.10 Total number of steel bridge spans _________________________

2.3.11 Total area of bridge deck _____________________________(SF)

2.3.12 Number of rail road crossings _____________________________

2.3.13 Number of water crossings _______________________________

2.3.14 Total length of roadway tunnels ______________________ Miles

2.3.15 Total length of drainage tunnels ______________________ Miles

2.3.16 Total length of box culvert _____________________________ LF

2.3.17 Total length of pipe culvert ____________________________ LF

2.3.18 Total number of toll plazas _______________________________

2.3.19 Pavement types (concrete or asphalt or combination) ___________

2.3.20 Total quantity of earthwork excavation ___________________ CY

2.3.21 Percentage of rock excavation ___________________________ %

2.3.22 Total quantity of embankment filling ___________________ CY

2.4 Contract

2.4.1 How was the construction contractor selected?

Based on unit prices | Negotiation

Best Value | A+ B Bidding

Other ___________________________________

2.4.2 What was the rate of liquidated damages in this contract?

US $ __________________________ per day or per month

No liquidated damage provision in contract

2.4.3 Was there any schedule performance bonus in this contract? If yes, how much was it?

Yes ____

______________________(Total amount in US $; details of system)

No

2.4.4 Were there any other disincentives for late completion? If yes, how much was it?

Yes ____

___________________________($/day or $/month; details of system)

No

2.4.5 Was there any lane rental provision in this contract? If yes, what was the fee assessed for each lane closure?

Yes ________________________________(US $/lane-hour or $/lane-day)

No

2.4.6 What types of specifications were used to construct this highway?

Performance spec | Prescriptive spec

Both of above | Other ____________

2.5 Organizational Approaches

2.5.1 Was there a partnering consultant hired and used for this contract?

Yes No (Go to 2.5.3)

2.5.2 If yes, what was the frequency of partnering sessions?

_________________________ (Number of times per month or per year)

None

2.5.3 How would you characterize environmental assessment done during pre-project planning of this project?

High level Medium level Low level

2.5.4 How would you characterize ROW assessment done during pre-project planning of this project?

High level Medium level Low level

2.5.5 How many different sub-contractors / consultants were involved in designing this project?

______________________(Total number of sub-contractors / consultants)

2.5.6 How many sub-contractors were involved in constructing this project?

______________________________(Total number of sub-contractors)

2.5.7 Were different entities of the project (e.g., owner, contractor, program manager, etc.) co-located in close proximity?

Yes No

2.5.8 Was there a formal documented change management process used to address design and / or construction changes on this project?

Yes No

2.5.9 Was formal Value Engineering used on this highway project? If yes, how much project cost was saved?

Yes ____(US $)

None

2.5.10 Was one or more constructability reviews carried out during the design phase of this project?

Yes No

2.5.11 Please describe any unique approaches to Traffic Control Planning?

____

None

2.6 Work Processes

2.6.1 Please describe any new technologies being used to construct the project?

____

____

None

2.6.2 Please describe any special information-sharing software used to transfer information between various project entities. (Beyond email)

____

____

None

2.7 Project Calendar

2.7.1 How many days (on average) did designers work per week on this project?

4 days a week 5 days a week

6 days a week 7 days a week

2.7.2 How many hours per day (on average) did designers work during the design of this project?

6 hours per day 7 hours per day

8 hours per day 9 hours per day

10 hours per day More than 10 hours

2.7.3 Please estimate the total design work hours needed to complete this project?

____

2.7.4 How many days (on average) did construction workers work per week?

4 days a week 5 days a week

6 days a week 7 days a week

2.7.5 How many hours per day (on average) did construction workers work on this project?

6 hours per day 7 hours per day

8 hours per day 9 hours per day

10 hours per day More than 10 hours

2.7.6 What was the estimated peak number of construction workers?

____

2.7.7 How many shifts did construction workers work per day?

One Two Three

2.8 Environmental Issue

2.8.1 Did this project involve any of the following?

Contaminated soil	Yes	No
Contaminated ground water	Yes	No
Endangered species	Yes	No
Historical sites/structures	Yes	No
Wetlands	Yes	No
Asbestos	Yes	No
Wildlife refugee	Yes	No
Archeological sites (incl. cemeteries)	Yes	No
Other environmental sensitive issues	Yes	No

2.9 Right-of-Way

2.9.1 Who was responsible for procurement of the right-of-way parcels for the construction of this project?

Contractor Owner

Other ____(Name of entity)

2.9.2 How many total right-of-way parcels were procured for the construction of this project?

____(Total number of parcels)

2.9.3 How many right-of-way parcels or what percent were acquired through eminent domain / condemnation for this project?

____________________________________(Total number

2.9.4 How many right-of-way parcels or what percent were acquired through administrative settlement for this project?

____________________________________(Total number of parcels or percent)

None

2.9.5 How would you characterize ROW delays (if any) on this project?

Severe Moderate / Typical Insignificant

2.10 Utility Adjustments

2.10.1 Approximately how much was the Subsurface Utility Engineering (SUE) budget for this project?

_____________________________________(Total budget in US $)

2.11 Owner Staffing

2.11.1 Was a program manager used to supplement the Department of Transportation personnel?

Yes No

Section 3: Project Performance

3.1 Project Cost-Related Performance:

Please provide the following cost-related performance data of your project.

No.	Cost-related project performance	Cost (US $)
1.	Owner estimated design cost	
2.	Actual design cost	
3.	Owner estimated construction cost	
4.	Contractor's bid / negotiated amount	
5.	Construction contract cost	
6.	Final design cost	
7.	Final ROW cost	

3.2 Project Schedule-Related Performance:

Please provide the following schedule-related performance data of this project.

No.	Schedule-related project performance	Duration
1.	Owner estimated design duration	
2.	Actual design duration	
3.	Owner estimated construction duration	
4.	Contractor's bid duration	

3.3 Project Change Order-Related Performance:

Please provide the following change order-related performance data of this project.

No.	**Change order-related project performance**	
1.	Total number of design change orders	
2.	Total cost of design change orders (US$)	

3.4 Project Claim-Related Performance:

Please provide the following claims-related performance data of this project.

No.	**Claims-related project performance**	
1.	Total number of design claims	
2.	Total cost of design claims (US$)	

Appendix B.3: Post-completion Questionnaire for DBB Projects

Section 1: Project General Information

1.1 Name of Owner Organization:_______________________________

1.2 Name of Project:____

1.3 Project ID:____

1.4 Project Description:_______________________________________

1.5 Starting Location:____

1.6 Ending Location: ____

1.7 Contact Person (Name of person filling this questionnaire):

____

1.8 Contact Person's Phone: _____________________________________

1.9 Contact Person's Fax: _______________________________________

1.10 Contact Person's Email Address: ______________________________

1.11 Contact Person's Role / Title in this Project:

____

1.12 Project web address: ____

1.13 Date of Assessment: ____

Section 2: Project Characteristics

2.1 Current State of Project

2.1.1 Describe current state of this highway project.

Completed on ____

Operational from ______________________________________

2.2 Organizational Approaches

2.2.1 Was formal Value Engineering used on this highway project? If yes, how much project cost was saved?

Yes ____________________________________(US $)

None

2.3 Project Calendar

2.3.1 Please fill the start and end dates (month / year) of different phases of this project.

Project phases	**Date in months & years**	
Design	/	/
ROW acquisition	/	/
Utility adjustments	/	/
Construction	/	/

2.3.2 Please estimate the total construction work hours needed to complete this project?

____

2.3.3 Please describe any major delays that occurred in the construction of this project?

____

____

____

None (Go to 2.4.1)

2.3.4 Approximately how many working days had been lost due to these major delays?

______________________________________(Total number of work days)

2.4 Environmental Issue

2.4.1 Please describe any unanticipated delays due to environmental issues?

____

2.5 Utility Adjustments

2.5.1 Approximately how many utilities were adjusted for the construction of this project?

__________________________________(Total number of utilities adjusted)

None (Go to 2.6.1)

2.5.2 If any adjustments were delayed, approximately how many working days were lost as a result?

_________________________________(Total number of working days lost)

2.6 Owner Staffing

2.6.1 What is the total Full Time Equivalent (FTE) of Department of Transportation staff for this highway project?

____(Total FTE)

2.6.2 Was a program manager used to supplement the Department of Transportation personnel?

Yes No (Go to 3.1)

2.6.3 If yes, what was the FTE's for this project?

____

Section 3: Project Performance

3.1 Project Cost-Related Performance:

Please provide the following cost-related performance data of your project.

No.	Cost-related project performance	Cost (US $)
1.	Final utility adjustment cost	
2.	Final construction cost (including change orders)	

3.2 Project Schedule-Related Performance:

Please provide the following schedule-related performance data of this project.

No.	Schedule-related project performance	Duration
1.	Final construction duration	

3.3 Project Construction Safety-Related Performance:

Please provide the following construction safety-related performance data of this project.

No.	Construction safety-related performance	
1.	Total number of fatalities	
2.	Total number of days away from work, restricted activity or transfer	
3.	Total number of work zone traffic accidents	

3.4 Project Quality-Related Performance:

Please provide the following quality-related performance data of this project.

No.	Quality-related performance	
1.	Total number of Request for Information (RFI)	

3.5 Project Change Order-Related Performance:

Please provide the following change order-related performance data of this project.

No.	Change order-related project performance	
1.	Total number of construction change orders	
2.	Total cost of construction change orders (US$)	

3.6 Project Claim-Related Performance:

Please provide the following claims-related performance data of this project.

No.	**Claims-related project performance**	
1.	Total number of construction claims	
2.	Total cost of construction claims (US$)	

Section 4: Stakeholders' Success

4.1 Who was the design-build contractor for this highway project? Please provide the following information.

Name of Contractor: ____

Address: ____

Website address (If any): ______________________________________

Email Address: ____

Phone Number: ____

4.2 How would you rate the overall performance of this project compared to other design-build (DB) projects?

Excellent Good

Fair Poor

Appendix C: Raw Data of Input Variables

Project Size, Duration, Location, and Nature

Project Name	Total Cost	Total Duration (Days)	Location	Construction Type	Construction under Traffic
DBB-1	$188,476,000	1,240	Urban	New Construction	Yes
DBB-2	$146,000,000	1,312	Urban	New Construction	Yes
DBB-3	$231,728,107	1,621	Urban	Reconstruction	Yes
DBB-4	$301,000,000	2,479	Urban	Reconstruction	Yes
DB-1	$1,150,000,000	1,144	Urban	Reconstruction	Yes
DB-2	$207,907,183	779	Urban	Reconstruction	Yes
DB-3	$165,079,721	1,072	Rural	Reconstruction	Yes
DB-4	$239,861,000	858	Rural	New Construction	No

Project Scope

Project Name	Total Length (Lane Mile)	No. of Interchanges	No. of Bridges	Pavement Types
DBB-1	44	1	13	Concrete
DBB-2	39	0	11	Concrete
DBB-3	120	0	22	Concrete
DBB-4	64	1	36	Concrete
DB-1	194	3	134	Concrete
DB-2	59	1	7	Concrete
DB-3	75	0	5	Asphalt
DB-4	70	7	25	Asphalt

Contract Provision

Project Name	Contract Award Method	Project Delivery Method	Previous DB Experience	% of Design Complete	Liquidate Damage	Schedule Performance	Lane Rental	Specification Type
DBB-1	Unit Price	DBB	-	100	Yes	Yes	Yes	Blend
DBB-2	Unit Price	DBB	-	100	Yes	Yes	Yes	Blend
DBB-3	Unit Price	DBB	-	100	Yes	Yes	No	Performance
DBB-4	Unit Price	DBB	-	100	Yes	Yes	Yes	Blend
DB-1	Best Value	DB	None	30	No	Yes	Yes	Blend
DB-2	A+B Bidding	DB	Three	30	Yes	Yes	No	Blend
DB-3	Best Value	DB	One	30	Yes	No	Yes	Performance
DB-4	Negotiation	DB	None	90	Yes	No	No	Performance

Organization Approaches and Work Processes

Project Name	Partnering Consultant	Frequency of Partnering per Year	Environmental Assesment during Pre-project	ROW Assessment during Pre-project	No. of Design Subcontractors	No. of Construction Sub-contractor
DBB-1	No	0	High	High	3	35
DBB-2	Yes	4	High	High	2	77
DBB-3	No	0	High	High	13	
DBB-4	Yes	2	High	High	6	23
DB-1	Yes	4	Medium	High	4	60
DB-2	Yes	4	Medium	Low	2	94
DB-3	Yes	12	High	High	2	3
DB-4	Yes	4	High	High	-	-

Project Name	Co-location	Formal Change Management Process	Value Engineering	Constructability Reviews	New Construction Technologies
DBB-1	Yes	Yes	Yes	Yes	Liquid nitrogen to concrete cool
DBB-2	Yes	Yes	No	Yes	Liquid nitrogen to concrete cool
DBB-3	Yes	Yes	No	Yes	None
DBB-4	Yes	No	Yes	Yes	Precast Bent Cap
DB-1	Yes	Yes	Yes	Yes	Geofoam, Wick Drains
DB-2	Yes	Yes	No	Yes	Slipform median barrier on bridge
DB-3	Yes	Yes	Yes	Yes	None
DB-4	Yes	Yes	No	Yes	None

Project Calendar

Project Name	Design Work per Week	Design Hours per Day	Construction Work per Week	Construction Hours per Day	Construction Work Shift
DBB-1	5	10	6	10 plus	2
DBB-2	5	10	6	10 plus	2
DBB-3	5	9	7	10 plus	2
DBB-4	5	9	5	10	3
DB-1	5	8	6	10	2
DB-2	6	10 plus	7	10 plus	2
DB-3	7	10 plus	6	10 plus	2
DB-4	5	8	5	8	1

Environmental Issue

Project Name	Contaminated Soil	Contaminated Ground Water	Endangered Species	Historical Sites	Wet Lands	Asbestos	Wildlife Refugee	Archeological Sites
DBB-1	No	No	No	No	No	No	No	No
DBB-2	No	No	No	No	No	No	No	No
DBB-3	No	No	No	No	Yes	No	No	No
DBB-4	Yes	No	No	No	No	No	No	Yes
DB-1	Yes	Yes	No	Yes	Yes	No	No	No
DB-2	No	No	No	Yes	No	No	No	Yes
DB-3	No	No	Yes	Yes	Yes	No	Yes	Yes
DB-4	No	No	No	Yes	Yes	No	No	Yes

Right-of-Way Acquisition

Project Name	Total ROW Parcels	ROW Acquired by Condemnation	ROW Delays
DBB-1	85	17	Insignificant
DBB-2	57	23	Insignificant
DBB-3	55	17	Severe
DBB-4	85	11	Insignificant
DB-1	600	60	Moderate
DB-2	0	0	Insignificant
DB-3	110	7	Insignificant
DB-4	120	9	Moderate

Utility Adjustments

Project Name	No. of Utility Adjusted
DBB-1	5
DBB-2	5
DBB-3	26
DBB-4	5
DB-1	15
DB-2	0
DB-3	150
DB-4	4

Owner Staffing

Project Name	Program Manager Involved
DBB-1	Yes
DBB-2	Yes
DBB-3	Yes
DBB-4	No
DB-1	Yes
DB-2	Yes
DB-3	Yes
DB-4	No

Appendix D: Raw Data & Calculation of Output Variables

Cost-Related Output Variables

Project Name	Estimated Project Cost	Total Project Completion Cost	Total Cost Growth	Actual Cost per Lane Mile	Cost Index Factor for Location and Year	Adjusted Cost per Lane Mile
DBB-1	$158,772,000	$188,476,000	18.71%	$4,283,545	1.00	$4,283,545
DBB-2	$201,654,000	$146,000,000	-27.60%	$3,743,590	1.00	$3,743,590
DBB-3	$181,255,837	$231,728,107	27.85%	$1,931,068	1.02	$1,969,689
DBB-4	$228,250,000	$301,000,000	31.87%	$4,703,125	1.02	$4,797,188
		$216,801,027				
DB-1	$1,330,000,000	$1,150,000,000	-13.53%	$5,927,835	1.06	$6,283,505
DB-2	$239,285,800	$207,907,183	-13.11%	$3,523,851	0.98	$3,453,374
DB-3	$126,032,520	$165,079,721	30.98%	$2,201,063	0.86	$1,892,914
DB-4	$236,000,000	$239,861,000	1.64%	$3,426,586	0.64	$2,193,015

Schedule-Related Output Variables

Project Name	Estimated Project Duration	Total Project Duration	Total Schedule Growth	Delivery Duration per Lane Mile
DBB-1	1323.6	1240	-6.32%	28.2
DBB-2	1272	1312	3.14%	33.6
DBB-3	1590	1621	1.95%	13.5
DBB-4	2090	2479	18.61%	38.7
DB-1	1188	1144	-3.70%	5.9
DB-2	800	779	-2.63%	13.2
DB-3	924	1072	16.02%	14.3
DB-4	638	858	34.48%	12.3

Change Orders-Related Output Variables

Project Name	Total Cost of Change Order	Change Order Cost Factor
DBB-1	$26,564,000	14.09%
DBB-2	$18,000,000	12.33%
DBB-3	$10,500,000	4.53%
DBB-4	$17,500,000	5.81%
DB-1	$0	0.00%
DB-2	$10,311,332	4.96%
DB-3	$34,732,300	21.04%
DB-4	$3,861,000	1.61%

Safety-Related Output Variables

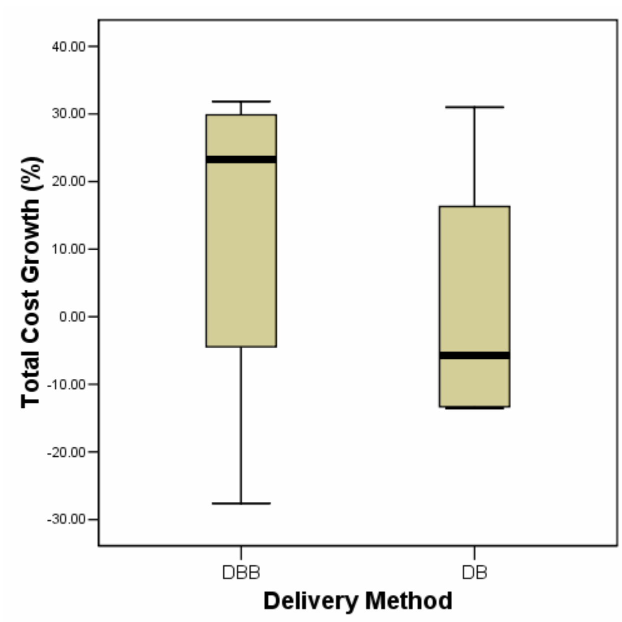
Project Name	No. of Fatalities	Fatality Rate
DBB-1	0	0.00
DBB-2	0	0.00
DBB-3	0	0.00
DBB-4	1	38.03
DB-1	1	8.74
DB-2	0	0.00
DB-3	1	37.31
DB-4	0	0.00

Quality-Related Output Variables

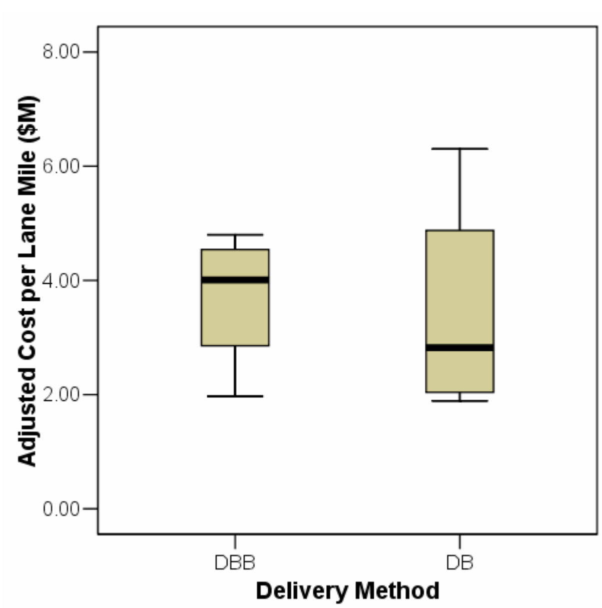
Project Name	Quality Rating
DBB-1	4
DBB-2	4
DBB-3	3
DBB-4	3
DB-1	3
DB-2	4
DB-3	3
DB-4	3

Appendix E: Box Plots of Output Variables

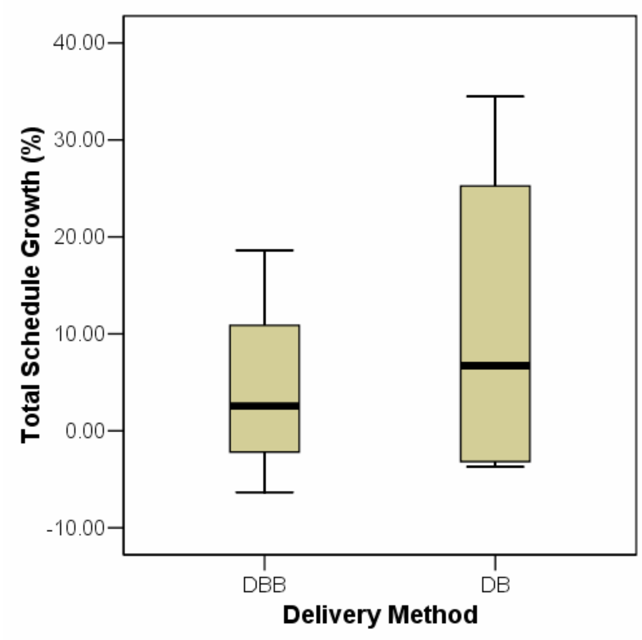
Total Cost Growth



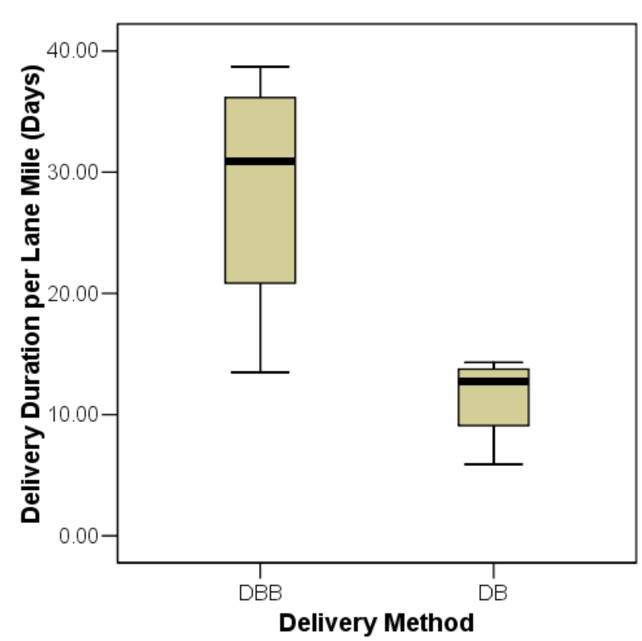
Adjusted Cost per Lane Mile



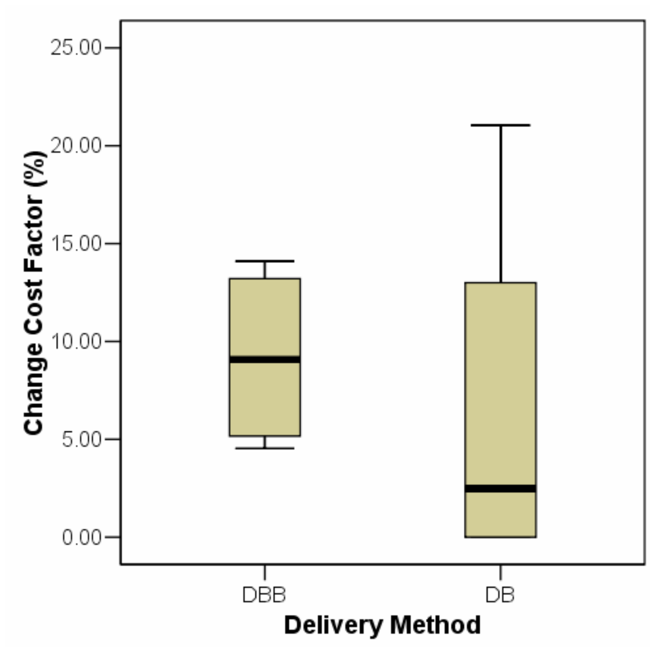
Total Schedule Growth



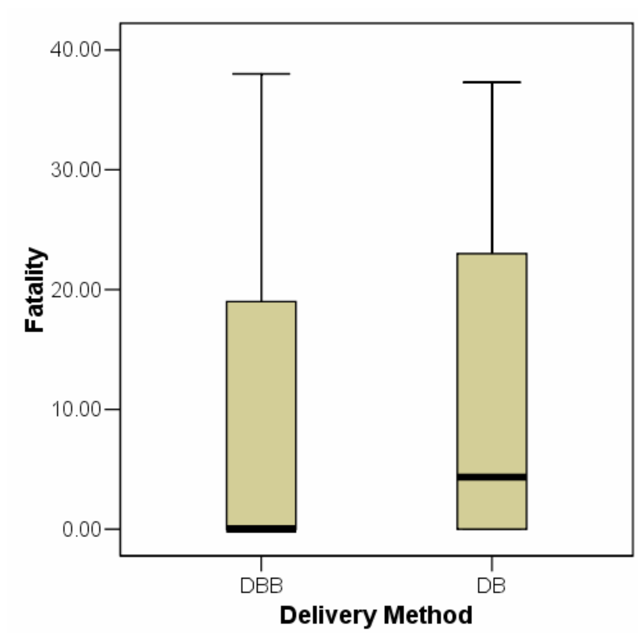
Delivery Duration per Lane Mile



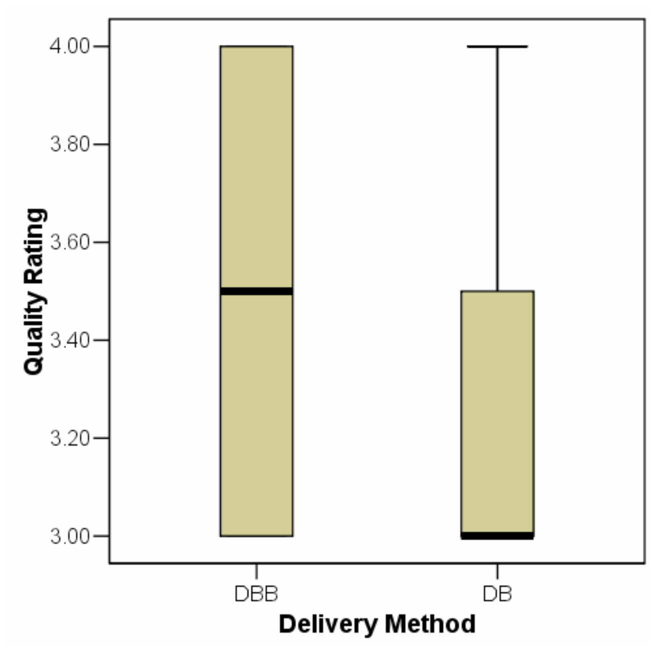
Change Cost Factor



Fatality Rate



Quality Rating



Appendix F: Descriptive Statistics of Output Variables

Descriptive Statistics for Cost-Related Output Variables

Statistics

Delivery_Method			Total_Cost_Growth	Adjusted_Cost_LM
DBB	N	Valid	4	4
		Missing	0	0
	Mean		12.7075	3.6975
	Median		23.2800	4.0100
	Std. Deviation		27.43004	1.23029
	Minimum		-27.60	1.97
	Maximum		31.87	4.80
DB	N	Valid	4	4
		Missing	0	0
	Mean		1.4950	3.4575
	Median		-5.7350	2.8200
	Std. Deviation		20.88415	2.01192
	Minimum		-13.53	1.89
	Maximum		30.98	6.30

Statistics

		Total_Cost_Growth	Adjusted_Cost_LM
N	Valid	8	8
	Missing	0	0
Mean		7.1013	3.5775
Median		10.1750	3.5950
Std. Deviation		23.35167	1.54917
Minimum		-27.60	1.89
Maximum		31.87	6.30

Descriptive Statistics for Schedule-Related Output Variables

Statistics

Delivery_Method			Total_Schedule_Growth	Delivery_Duration_LM
DBB	N	Valid	4	4
		Missing	0	0
	Mean		4.3450	28.5000
	Median		2.5450	30.9000
	Std. Deviation		10.39905	10.88026
	Minimum		-6.32	13.50
	Maximum		18.61	38.70
DB	N	Valid	4	4
		Missing	0	0
	Mean		11.0425	11.4250
	Median		6.6950	12.7500
	Std. Deviation		18.05889	3.77304
	Minimum		-3.70	5.90
	Maximum		34.48	14.30

Statistics

		Total_Schedule_Growth	Delivery_Duration_LM
N	Valid	8	8
	Missing	0	0
Mean		7.6938	19.9625
Median		2.5450	13.9000
Std. Deviation		14.10422	11.83795
Minimum		-6.32	5.90
Maximum		34.48	38.70

Descriptive Statistics for Change Order-Related Output Variables

Statistics

Change_Cost_Factor

DBB	N	Valid	4
		Missing	0
	Mean		9.1900
	Median		9.0700
	Std. Deviation		4.72615
	Minimum		4.53
	Maximum		14.09
DB	N	Valid	4
		Missing	0
	Mean		6.9025
	Median		3.2850
	Std. Deviation		9.64879
	Minimum		.00
	Maximum		21.04

Statistics

Change_Cost_Factor

N	Valid	8
	Missing	0
Mean		8.0463
Median		5.3850
Std. Deviation		7.13915
Minimum		.00
Maximum		21.04

Descriptive Statistics for Safety-Related Output Variables

Statistics

Fatality

DBB	N	Valid	4
		Missing	0
	Mean		9.5000
	Median		.0000
	Std. Deviation		19.00000
	Minimum		.00
	Maximum		38.00
DB	N	Valid	4
		Missing	0
	Mean		11.5000
	Median		4.3500
	Std. Deviation		17.68219
	Minimum		.00
	Maximum		37.30

Statistics

Fatality

N	Valid	8
	Missing	0
Mean		10.5000
Median		.0000
Std. Deviation		17.02511
Minimum		.00
Maximum		38.00

Descriptive Statistics for Quality-Related Output Variables

Statistics

Quality_Rating

DBB	N	Valid	4
		Missing	0
	Mean		3.5000
	Median		3.5000
	Std. Deviation		.57735
	Minimum		3.00
	Maximum		4.00
DB	N	Valid	4
		Missing	0
	Mean		3.2500
	Median		3.0000
	Std. Deviation		.50000
	Minimum		3.00
	Maximum		4.00

Statistics

Quality_Rating

N	Valid	8
	Missing	0
Mean		3.3750
Median		3.0000
Std. Deviation		.51755
Minimum		3.00
Maximum		4.00

Appendix G: Association between Input and Output Variables

Descriptive Statistics of Cost-related Output Variables for Input Variables

S.No.	Input Variables	N	Output Variables					
			Total Cost Growth			Adjusted Cost/ LM		
			Median	Mean	SD	Median	Mean	SD
1	Design & Construction Cost							
	< or = $200 Million	3	18.71%	7.36%	30.89%	$3.7M	$3.3M	$1.2M
	>$200 Million	5	1.64%	6.94%	21.84%	$3.5M	$3.7M	$1.8M
2	Design & Construction Duration							
	< or = 1,100 Days	3	1.64%	5.40%	22.44%	$2.2 M	$2.5M	$0.8M
	> 1,100 Days	5	18.71%	7.46%	26.49%	$4.3M	$4.2M	$1.6M
3	Project Nature							
	New	3	1.64%	-2.16%	23.42%	$3.7M	$3.4M	$1.1M
	Reconstruction	5	27.85%	12.81%	23.90%	$3.4M	$3.7M	$1.9M
4	Lane Mile							
	1- 75	5	1.64%	2.30%	23.85%	$3.7M	$3.7M	$1.0M
	>75	3	27.85%	15.10%	24.84%	$2.0M	$3.4M	$2.5M
5	No. of Bridges							
	0-20	4	2.80%	2.24%	27.22%	$3.6M	$3.3M	$1.0M
	>21	4	14.74%	11.96%	21.64%	$3.5M	$3.8M	$2.1M
6	No. of Interchanges							
	None	3	27.85%	10.41%	32.95%	$2.0M	$2.5M	$1.0M
	1-7	5	1.64%	5.11%	19.95%	$4.3M	$4.2M	$1.5M
7	Lane Rental							
	Yes	5	18.70%	8.08%	27.10%	$4.3M	$4.2M	$1.6M
	No	3	1.64%	5.46%	20.74%	$2.2M	$2.5M	$0.8M
8	Specification Type & Latest Technology							
	Blend with Latest Techbology	5	-13.11%	-0.73%	24.90%	$4.2M	$4.5M	$1.1M
	Performance with Existing Technology	3	27.85%	20.16%	16.11%	$2.0M	$2.0M	$0.2M
9	Value Engineering							
	Yes	4	24.84%	17.00%	21.22%	$4.5M	$4.3M	$1.8M
	No	4	-5.73%	-2.80%	23.67%	$2.8M	$2.8M	$0.9M
10	Historical Sites							
	Yes	4	-5.73%	1.49%	20.88%	$2.8M	$3.5M	$2.0M
	No	4	23.28%	12.71%	27.43%	$4.0M	$3.7M	$1.2M
11	Wet Land							
	Yes	4	14.74%	11.74%	21.37%	$2.1M	$3.1M	$2.1M
	No	4	2.80%	2.47%	27.53%	$4.0M	$4.1M	$0.6M
12	Archeological Sites							
	Yes	4	16.31%	12.84%	22.28%	$2.8M	$3.1M	$1.3M
	No	4	2.59%	1.36%	26.22%	$4.0M	$4.1M	$1.8M
13	Number of ROW Parcels							
	0-100	5	18.71%	7.54%	26.14%	$3.7M	$3.6M	$1.1M
	>100	3	1.64%	6.36%	22.63	$2.2M	$3.5M	$2.5M

Descriptive Statistics of Schedule-related Ouput Variables for Input Variables

S.No.	Input Variables	N	Output Variables					
			Total Schedule Growth			Delivery Duration/ LM		
			Median	Mean	SD	Median	Mean	SD
1	Design & Construction Cost							
	< or = $200 Million	3	3.14%	4.28%	11.21%	28.2 Days	25.4 Days	9.9 Days
	> $200 Million	5	1.95%	9.74%	16.47%	13.2 Days	16.7 Days	12.7 Days
2	Design & Construction Duration							
	< or = 1,100 Days	3	16.02%	15.95%	18.55%	13.2 Days	13.3 Days	1.0 Days
	> 1,100 Days	5	1.95%	2.73%	9.70%	28.2 Days	24.0 Days	13.8 Days
3	Project Nature							
	New	3	3.14%	10.43%	21.35%	28.2 Days	24.7 Days	11.1 Days
	Reconstruction	5	1.95%	6.05%	10.54%	13.5 Days	17.1 Days	12.5 Days
4	Highway Length in Lane Mile							
	1-75	5	3.14%	9.45%	16.92%	28.2 Days	25.2 Days	12.0 Days
	>75	3	1.95%	4.76%	10.16%	13.5 Days	11.2 Days	4.6 Days
5	No. of Bridges							
	0-20	4	0.25%	2.55%	9.78%	12.9 Days	17.6 Days	14.5 Days
	>21	4	10.28%	12.83%	17.26%	21.2 Days	22.3 Days	10.1 Days
6	No. of Interchanges							
	None	3	3.14%	7.03%	7.80%	14.3 Days	20.5 Days	11.4 Days
	1-7	5	-2.63%	8.08%	17.81%	13.2 Days	19.7 Days	13.4 Days
7	Lane Rental							
	Yes	5	5.55%	3.14%	11.32%	28.2 Days	24.14 Days	13.7 Days
	No	3	1.95%	11.26%	20.22%	13.2 Days	13 Days	0.6 Days
8	Specification Type & Latest Technology							
	Blend with Latest Technology	5	-2.63%	1.82%	10.00%	28.2 Days	23.9 Days	13.9 Days
	Performance with Existing Technology	3	16.02%	17.48%	16.31%	13.5 Days	13.4 Days	1.0 Days
9	Value Engineering							
	Yes	4	6.16%	6.15%	12.98%	21.2 Days	21.8 Days	14.5 Days
	No	4	2.54%	9.23%	17.01%	13.3 Days	18.1 Days	10.3 Days
10	Historical Sites							
	Yes	4	6.69%	11.04%	18.06%	12.7 Days	11.4 Days	3.8 Days
	No	4	2.54%	4.34%	10.40%	30.9 Days	28.5 Days	10.9 Days
11	Wet Land							
	Yes	4	8.98%	12.19%	17.01%	12.9 Days	11.5 Days	3.8 Days
	No	4	0.25%	3.20%	10.98%	30.9 Days	28.4 Days	11.0 Days
12	Archeological Sites							
	Yes	4	17.31%	16.62%	15.21%	13.7 Days	19.6 Days	12.7 Days
	No	4	-0.87%	-1.23%	4.52%	20.8 Days	20.3 Days	12.8 Days
13	Number of ROW Parcels							
	0-100	5	1.95%	2.95%	9.53%	12.3 Days	10.8 Days	11.6 Days
	>100	3	16.02%	15.60%	19.09%	28.2 Days	25.4 Days	4.4 Days

Descriptive Statistics of Change Cost Factor and Fatality Rate for Different Input Variables

S.No.	Input Variables	N	Output Variables					
			Change Cost Factor			Fatality Rate		
			Median	Mean	SD	Median	Mean	SD
1	Design & Construction Cost							
	< or = $200 Million		14.09%	15.82%	4.61%	0	12.4	21.5
	> $200 Million		4.53%	3.38%	2.46%	0	9.3	16.5
2	Design & Construction Duration							
	< or = 1,100 Days	3	4.96%	9.20%	10.38%	0	12.4	21.5
	> 1,100 Days	5	5.81%	7.35%	5.80%	0	9.3	16.5
3	Project Nature							
	New	3	12.33%	9.34%	6.75%	0.0	0.0	0.0
	Reconstruction	5	4.96%	7.27%	8.02%	8.7	16.8	19.4
4	Highway Length in Lane Mile							
	1-75	5	5.81%	7.76%	5.25%	0	7.6	17
	>75	3	4.53%	8.52%	11.07%	8.7	15.3	19.5
5	No. of Bridges							
	0-20	4	3.07%	3.00%	2.65%	0	9.3	18.6
	>21	4	13.21%	13.10%	6.60%	4.3	11.7	18
6	No. of Interchanges							
	None	3	12.33%	12.63%	8.25%	0	12.4	21.5
	1-7	5	4.96%	5.29%	5.47%	0	9.34	16.4
7	Lane Rental							
	Yes	5	12.33%	10.65%	8.05%	8.7	16.8	19.4
	No	3	4.53%	3.70%	1.82%	0	0	0
8	Specification Type & Latest Technology							
	Blend with Latest Technology	5	5.81%	7.44%	5.75%	0	9.34	16.5
	Performance with Existing Technology	3	4.53%	9.06%	10.48%	0	12.4	21.5
9	Value Engineering							
	Yes	4	9.95%	10.20%	9.23%	23	21	0
	No	4	4.74%	5.85%	4.56%	0	0	0
10	Historical Sites							
	Yes	4	3.28%	6.90%	9.65%	4.4	11.5	17.7
	No	4	9.07%	9.19%	4.72%	0	9.5	19
11	Wet Land							
	Yes	4	3.07%	6.80%	9.68%	4.4	11.5	17.7
	No	4	9.07%	9.30%	4.59%	0	9.5	19
12	Archeological Sites							
	Yes	4	5.38%	8.35%	8.64%	18.6	18.8	21.7
	No	4	8.43%	7.73%	6.62%	0	2.2	4.3
13	Number of ROW Parcels							
	0-100	5	5.81%	8.34%	4.51%	0	7.6	17
	>100	3	1.61%	7.55%	11.71%	8.7	15.3	19.5

Descriptive Statistics of Quality Rating for Different Input Variables

S.No.	Input Variables	N	Output Variables Quality Rating		
			Median	Mean	SD
1	Design & Construction Cost				
	< or = $200 Million	3	4	3.7	0.6
	> $ 200 Million	5	3	3.2	0.4
2	Design & Construction Duration				
	< or = 1,100 Days	3	3	3.3	0.6
	> 1,100 Days	5	3	3.4	0.5
3	Project Nature				
	New	3	4.0	3.7	0.6
	Reconstruction	5	3.0	3.2	0.5
4	Highway Length in Lane Mile				
	1 to 75	5	4	3.6	0.5
	>75	3	3	3	0
5	No. of Bridges				
	0-20	4	4	3.7	0.5
	>21	4	3	3	0
6	No. of Interchanges				
	None	3	3	3.3	0.6
	1-7	5	3	3.4	0.5
7	Lane Rental				
	Yes	5	3	3.4	0.5
	No	3	3	3.3	0.6
8	Specification Type & Latest Technology				
	Blend with Latest Technology	5	4	3.6	0.5
	Performance with Existing Technology	3	3	3	0
9	Value Engineering				
	Yes	4	3	3.2	0.5
	No	4	3.5	3.5	0.6
10	Historical Sites				
	Yes	4	3	3.3	0.5
	No	4	3.5	3.5	0.6
11	Wet Land				
	Yes	4	3	3	0
	No	4	4	3.8	0.5
12	Archeological Sites				
	Yes	4	3	3.2	0.5
	No	4	3.5	3.5	0.6
13	Number of ROW Parcels				
	0-100	5	4	3.6	0.5
	>100	3	3	3	0

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Vita

Pramen Prasad Shrestha was born in Kathmandu, Nepal on August 5, 1964. He is the son of Shreebatsa Prasad Shrestha and Sumati Shrestha. After completing his studies at Amrit Science College in Kathmandu, Nepal, in 1984, he attended the Regional Institute of Technology, Ranchi University of India, graduating with a Bachelor of Science in Civil Engineering degree in July 1988. In August, 2001, after working for nearly 10 years for the Department of Roads in Nepal, he entered the Construction Engineering Management Program of Civil Engineering at Oklahoma State University to pursue his Master‘s degree. He completed his Master of Science in Civil Engineering in May, 2003.

In August, 2004, he enrolled at the University of Texas at Austin to pursue his Ph.D. degree in the Construction Engineering and Project Management program under the Department of Civil, Architectural, and Environmental Engineering. During his Ph.D. study, he worked in research projects for the Texas Department of Transportation and the Center for Construction Industry Studies. His primary research areas include the benchmarking of large construction projects, innovative project delivery methods, and highway construction processes. He worked as a teaching assistant for three years at the University of Texas at Austin. Two of his research papers were published in the Transportation Research Record.

Permanent address: 26 Sanepa, Kathmandu, Nepal

This dissertation was typed by the author. Pramen Prasad Shrestha