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Impact of design cost on project performance of design bid build projects

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IMPACT OF DESIGN COST ON PROJECT PERFORMANCE OF DESIGN BID BUILD PROJECTS

by

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ABSTRACT

Impact of Design Cost on Project Performance of Design Bid Build Projects

by

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The majority of public projects in the United States are procured and constructed by state or local governments using the design-bid-build (DBB) project delivery method. In the DBB method, the detailed design is completed by a design firm, then, a contractor builds the project according to the plans and specifications prepared by the design firm. Some studies show that a project's performance depends upon the quality of the design. If the errors in a design are minimized, the construction cost and schedule growth of the project also will be minimized.

This study analyzed data from Clark County, Nevada public works projects to determine the impact of design cost on construction cost and schedule growth. The sample included projects completed between 1992 and 2007 and over $ 803 million in construction value, converted to 2010 base cost. The correlation among design cost with other parameters, such as construction cost growth, construction schedule growth, total cost growth, and contract award cost growth, were determined. The correlation between basic design cost and total cost growth for Clark County road projects was found to be 0.29, which was statistically significant at alpha level 0.05. The correlation was negative. This investigation revealed that the higher the cost expended in the design, the lower the total cost growth. A regression model was developed to predict the final construction cost

of the projects using the design cost as an input variable. The R-square value of Clark County road projects' model was found to be 62.30%.

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CHAPTER 1

INTRODUCTION

1.1 Background

Public road projects generally are constructed using traditional design-bid-build (DBB) project delivery method. DBB is used extensively all over the United States in such government agencies as federal and state Departments of Transportation as well as related state and county agencies. In the DBB method, the design and construction are performed by two separate entities. An engineer prepares design drawings and specifications of the project. Once the detailed design is completed, the project is put to bid during the contract procurement phase. The owner selects a contractor based on different selection criteria, for instance, low bid, lump sum, or best value. Then, the contractor that is awarded the bid constructs the project. By using the DBB method, there is no contractual relationship between the designer and the contractor. If any problem arises during the construction phase regarding design, the contractor proceeds with change orders. Errors in design and a lack of communication between the designer and the contractor can have a negative impact on the project cost and schedule.

In DBB projects, the role of the designer and the quality of design are important factors that can have a huge impact on the engineer's estimate as well as the actual cost and duration of the construction phase. If the quality of design is good, the engineer's estimate will also be accurate and the contractor will bid near to the estimate. There will be little variation between the engineer's estimate and the cost and duration of contract award. If the design is of good quality, then there will be fewer change orders issued during the construction phase due to design errors. This will control the cost and schedule growth during the construction phase. However, if there are many errors in the design, the engineer's estimate will not be accurate. That results in a large variation between the engineer's estimate and the contractors' bid. Failure to find mistakes during the bidding period of the contract will result in change orders during construction, and these change orders will contribute to an increase in the duration of the projects as well as an increase in cost. Figure 1 shows the impact of the design cost in the contract procurement and the construction phases of the projects.

Like other public owners, Clark County Department of Public Works (CCDPW) of Nevada generally uses the DBB project delivery method to build roads and flood control infrastructures. Little research has been conducted to determine the effect of design cost on the construction phase performance. Gransberg et al. tested the hypothesis that there is a correlation between design cost and construction cost performance in highway projects. The study found, that as design cost of a highway increased, the construction cost performance improved (Gransberg et al., 2007).

Cost growth in construction projects occurs due to various reasons. Some of the factors influencing the cost growth are project characteristics, project delivery methods, contract types, unforeseen site conditions, inaccurate bidding, design fees, and weather conditions (Gransberg et al., 2007; Carr, 2005; Li et al., 2008; Shrestha et al., 2007; Hale et al., 2009; Konchar et al., 1998; Jahren & Ashe, 1990; Odeck, 2004; Knight & Fayek, 1999; Chua & Li, 2000). A contract award cost growth occurs during the procurement phase, and a construction cost growth occurs during the construction phase. If both of these growths are combined, this is called the total cost growth for the project.

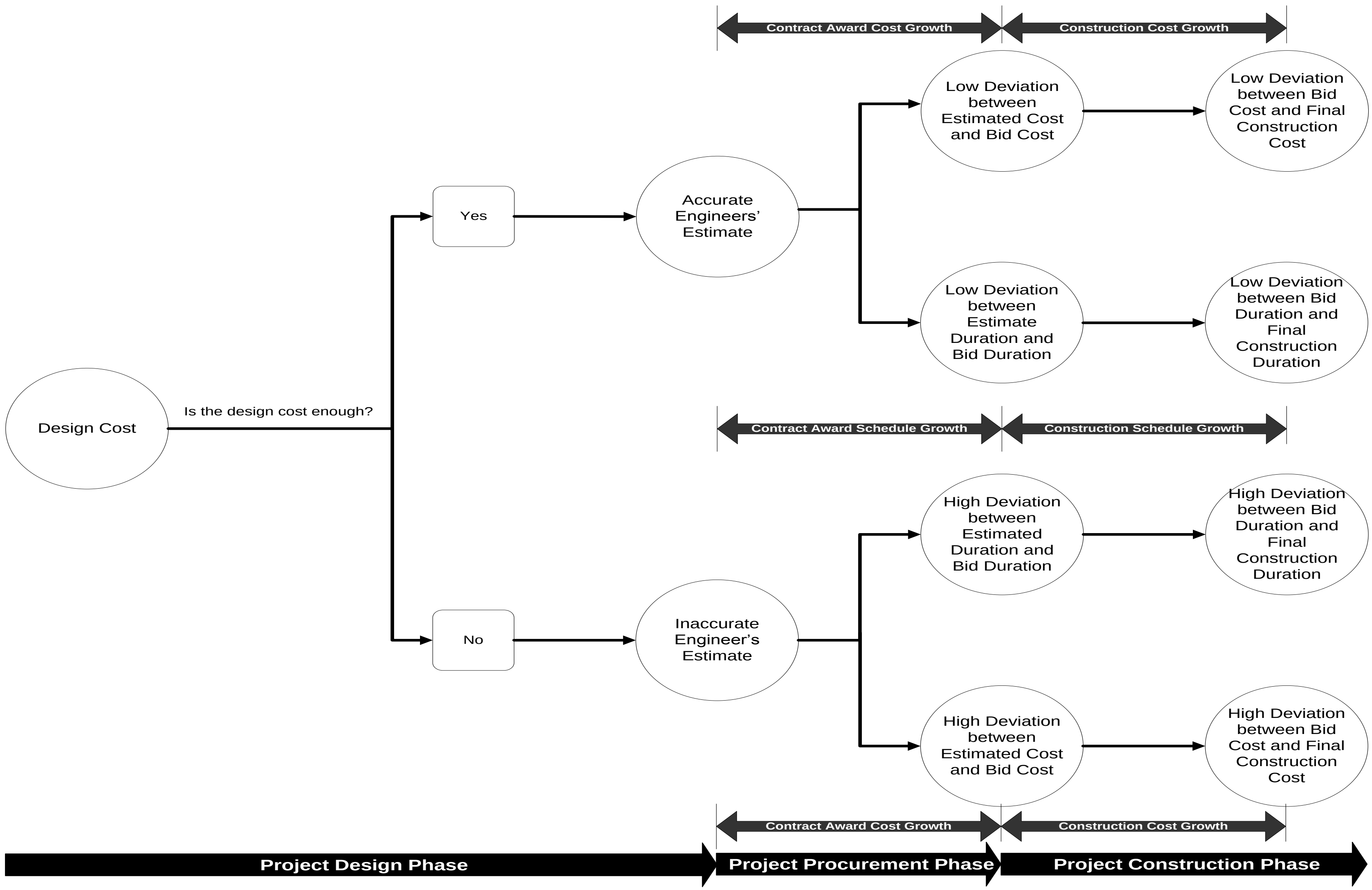

Figure 1. Flow chart depicting the effect of design cost on construction projects

The hypothesis of this study is that the design cost impacts the construction cost and schedule performance of the projects. This paper analyzes the correlations of the design cost and duration with total cost growth, contract award cost growth, construction cost growth, and construction schedule growth of CCDPW road and flood control projects. The terminology “basic design cost” used in this paper refers to the pure design cost of the project. A pure design cost is composed of the engineer’s or architecture fees as well as expenses for design drawings and specifications. On the other hand, total design cost is composed of all expenses during designing, such as geotechnical works, surveys, and right of way and includes basic design cost. In this paper, the basic design cost is the ratio of the basic design cost to the total project cost, expressed as percentage. The total design cost is the total design cost to the total project cost, expressed as percentage. In context of this paper, a deviation of bid price from the engineer’s estimate is defined as “contract award cost growth” and is the difference between the owner’s estimate and the bid price calculated as the percentage increase from the owner’s estimate. Construction cost growth is the difference between the final construction cost and bid cost, calculated as the percentage increase from the bid cost. The total cost growth is the difference between the final construction cost and estimated construction cost, expressed as the percentage of the estimated construction cost. Construction schedule growth is the difference between the final construction cost and construction contract duration, expressed as the percentage of the construction contract duration.

The first analysis of this study will determine the effect of the design cost on total cost growth. The second analysis will determine whether design cost has an impact on the contract award cost growth. The third analysis will determine the effect of the design cost on the construction cost growth. The fourth analysis will determine whether the design cost has an impact on the construction schedule growth. The final analysis will determine the correlation between the design cost and final construction cost of the project. A regression equation also will be developed to predict the final construction cost of the public roads and flood control projects, with the design cost as an input variable.

1.2 Scope and Objectives of Research

The objective of this research is to determine the relationship of design cost and design duration with the project performance parameters. In this research, the project performance is measured on the basis of changes in its parameters, such as construction cost growth, construction schedule growth, total cost growth, contract award cost growth, and final construction cost. To achieve the objective, the research focused on 47 public road projects, and 11 flood control projects undertaken by Clark County Department of Public Works (CCDPW), Nevada, from the years 1992 through 2007. The sample consists of the projects costing from $337,644 to $53 million in total design and construction costs. The total value of design and construction is equivalent to $803 million when converted into a 2010 base cost. The road projects consisted of the construction of road elements, including detail design, and a thorough inspection during construction. Flood control project encompassed design and construction of flood control elements.

The objective of this research not only is to determine the relationship between design parameters and construction parameters, but also to develop a tool that will provide an early reliable estimation of final construction cost based on the design cost of any project.

Even though; the database consists of less than one hundred data points to develop the model, it will conceptualize and add knowledge that will aid future research. Furthermore, for validation of the model, this study analyzes and compares the Clark County road and flood control projects data with Texas Department of Transportation (TXDOT) road projects data. This model will support designers, estimators, and contractors in visualizing the final construction cost, construction duration, and possibly the quality of final product or performance of projects, specifically in public works.

To summarize, some major objectives of this research are:

- Determine the correlation of design cost with the total cost growth of the public road and flood control projects.
- Determine the correlation of design cost with the contract award cost growth of the public road and flood control projects.
- Determine the correlation of design cost with the construction cost growth of the public road and flood control projects.
- Determine the correlation of design cost with the construction schedule growth of the public road and flood control projects.
- Determine the correlation of design cost with the final construction cost of the public road and flood control projects.

1.3 Research Hypothesis

To achieve the objectives of this research, five research hypotheses are formulated based on basic design cost, as shown in Table 1; another five research hypotheses are formulated based on total design cost, as shown in Table 2.

Table 1. Research hypotheses based on basic design cost

No.	Research Hypotheses
I	H_a1: A lower basic design cost will result in an increased total cost growth of public road and flood control projects
II	H_a2: A lower basic design cost will result in an increased contract award cost growth of public road and flood control projects
III	H_a3: A lower basic design cost will result in an increased construction cost growth of public road and flood control projects
IV	H_a4: A lower basic design cost will result in an increased construction schedule growth of public road and flood control projects
V	H_a5: A basic design cost can be used to predict the final construction cost of the public road and flood control projects

Table 2. Research hypotheses based on total design cost

No.	Research Hypotheses
I	H_a6: A lower total design cost will result in an increased total cost growth of public road and flood control projects
II	H_a7: A lower total design cost will result in an increased contract award cost growth of public road and flood control projects
III	H_a8: A lower total design cost will result in an increased construction cost growth of public road and flood control projects
IV	H_a9: A lower total design cost will result in an increased construction schedule growth of public road and flood control projects
V	H_a10: A total design cost can be used to predict the final construction cost of the public road and flood control projects

1.4 Null Hypothesis

The above research hypothesis will be converted to null hypotheses to conduct the statistical test. The p- value must be less than or equal to 0.05 for the justification of the false null hypothesis. Given that the null hypothesis is true, the p-value represents the probability of observing a test static that is at least as large as the one that is actually observed. The statistical test hypothesizes that the correlation coefficient between these variables is not significantly different from zero. Mathematically, it can be expressed as

[redacted]

Table 3. Null hypotheses based on basic design cost

No.	Null Hypotheses
I	$H_0$1: There is no relationship between the basic design cost and the total cost growth of public road and flood control projects
II	$H_0$2: There is no relationship between the basic design cost and the contract award cost growth of public road and flood control projects
III	$H_0$3: There is no relationship between the basic design cost and the construction cost growth of public road and flood control projects
IV	$H_0$4: There is no relationship between the basic design cost and the construction schedule growth of public road and flood control projects
V	$H_0$5: There is no relationship between the design cost and the final construction cost of the public road and flood control projects

Table 4. Null hypotheses based on total design cost

No.	Null Hypotheses
I	$H_0$6: There is no relationship between the total design cost and the total cost growth of public road and flood control projects
II	$H_0$7: There is no relationship between the total design cost and the contract award cost growth of public road and flood control projects
III	$H_0$8: There is no relationship between the total design cost and the construction cost growth of public road and flood control projects
IV	$H_0$9: There is no relationship between the total design cost and the construction schedule growth of public road and flood control projects
V	$H_0$10: There is no relationship between the total design cost and the final construction cost of the public road and flood control projects

1.5 Thesis Structure

This thesis consists of seven chapters. It is a compilation of documents in a single report describing the background of that research, the research's significance, methodology followed to conduct the research, a description about the database and its sources, analytical results obtained from statistical analysis, formation of models and their validation, and a discussion about the limitations of the research as well as recommendations for further research. The structure of thesis with its components is described briefly below:

Chapter 1 Introduction: This chapter concentrates on the scope and objectives of the research; the effect of design cost and duration on the project performance; and sources of data, characteristics of data, and hypotheses of the research.

Chapter 2 Literature Review: This chapter covers the foundation and guidelines of research. This chapter discusses previous research papers on this subject and their findings related to this research. The various research papers relevant to this thesis are collected and described briefly in this chapter.

Chapter 3 Research Methodology: This chapter thoroughly describes the steps of the research, history of data collection and statistical background.

Chapter 4: Data Description: The sources of data, brief description of project identification, selection and execution methodology, Clark County road and flood control projects data collection information and data distribution histograms, discussion of sources of data of Texas Department of Transportation road projects, description of each terminology of data set, and stepwise procedure of analysis, are encompassed in this chapter.

Chapter 5 Data Analysis and Results: In this chapter, the detailed discussion on the data analysis, descriptive statistics of each metrics, regression models developments, checking of statistical analysis with various histograms and scatter plots are demonstrated.

Chapter 6 Comparison of Results of Clark County Data with TXDOT Data: For the validation of the results, a new set of data are collected from Texas Department of Transportation and are analyzed as before. This data are compared with the results of Clark County data.

Chapter 7 Conclusions and Recommendations: The conclusions and limitations of this research are discussed in this chapter. Potential research areas are recommended in this section.

CHAPTER 2

LITERATURE REVIEW

This thesis focuses on the study of the design cost and their impact on the project performance, especially in design-bid-build projects. To achieve this objective, various books, published and currently proceeding research papers on various kinds of construction projects were reviewed. In particular, the literature review focuses on studies done on the development of regression models for prediction of construction cost, based on the design cost of projects; and the impact of design cost on construction cost growth as well as construction schedule growth. Although, not all papers reviewed have a direct impact on the regression models developed for this study, even so, they helped to form a baseline for research.

The success of a construction project is a reflection of good performance of the project. Cost, schedule and quality are the major metrics to measure performance of a project. Using 341 U.S. building projects, Konchar and Sanvido (1998) conducted research to compare these metrics for three project delivery systems: construction management at risk, design-build (DB), and design-bid-build (DBB). The owner contracts with a single entity to perform both design and construction under a single design-build contract in DB project delivery method. Table 5 shows the performance metrics used in this study along with their definitions. If all the other variables were held constant, this study indicated that design-build projects had lesser unit cost, faster construction speed, faster delivery speed, lesser cost growth, and lesser schedule growth than design-bid-build projects.

Table 5. Project success measurement performance metrics (Konchar & Sanvido, 1998)

Performance Metrics	Definition
Unit Cost ($ /m^2)	(Final project cost/Area)/Cost Index
Cost growth (%)	(Final project cost – Contract project cost)/Contract project cost] x 100
Intensity ($/m^2/month)	(Unit cost/Total Time)
Construction Speed (m^2/month)	Area/ (As-built construction end date –As-built construction start date)/30
Delivery Speed (m^2/month)	(Area / Total time)/30
Schedule Growth (%)	[(Total time –Total as-planned time)/Total as-built time] x 100
Turnover Quality	Ease of starting up and extent of call backs (5 = exceed owner's expectation; 1 = not satisfactory)
System Quality	Performance of building elements, interior space and environment (5 = exceed owner's expectation; 1 = not satisfactory)
Equipment quality	(5 = exceed owner's expectation; 1 = not satisfactory)

A study conducted to predict the project performance of design-build and design-bid-build project generated models, by using project-specific data collected from 87 building projects in Singapore (Ling et al., 2004). These projects were grass-root public and private building construction projects exceeding $5 million, and were completed between 1993 and 2001. From the review of past works, 59 potential factors were identified, that affect project performance. All these factors were categorized into three major headings: project characteristics, owner- consultant characteristics, and contractor characteristics. A multivariate regression analysis was used to develop models in order to determine the statistical relationship between DBB and DB projects variables, such as cost growth and construction speed: other variables included floor area, type of client, and adequacy of contractor's plant and equipment. The major factors determined to analyze the project success were cost performance, time performance, quality performance, and owner's satisfaction. This study Ling et al. is an extension of research done by Konchar and Sanvido (1998). Additional terminologies, such as turnover quality, system quality, equipment quality, owner's satisfaction, and administrative burden were discussed in this study. Additionally, Ling et al. (2004) developed models to determine the delivery speed and construction speed of DBB and DB projects.

In order to identify factors affecting duration of design-bid procurement and effect of duration on project success, Migliaccio and Shrestha (2009) conducted a study on the design-build procurement activities durations for highway projects. These authors collected 19 highway projects of sizes ranging from $9 million to $1.3 billion dollars, constructed between 1997 and 2006. The correlation coefficient between the total procurement duration and the total construction cost was found to be 0.61. The results showed that the total procurement duration was linearly correlated with total construction cost, indicating that, by increasing the project construction cost, the total procurement duration also increased for project costing greater than $250 million. The correlation between procurement durations and project cost was very weak for projects having less than $250 million total project cost.

Migliaccio et al. (2009) conducted research to determine the impact of procurement duration on project performance, using 146 design-build transportation projects. These projects were collected from 15 states, especially from Florida. The projects used best value, low bid, and adjusted bid selection methods. The metrics used to measure the project performance were: schedule growth, cost growth, and total project time growth. The study found that low-bid projects had the longest average procurement duration (3.06 months), and adjusted-bid projects had the shortest average procurement duration (2.65

months). The Pearson correlation value between variables procurement duration and schedule growth was -0.8, which showed that the schedule growth decreases with increasing procurement duration. The R-square value 0.64 indicated high reliability and strong linear correlation between these variables. Additionally, the correlation between procurement duration and total time based schedule growth was -0.79. However, the R-square value for the variables procurement duration and cost growth performance, which was 0.05, showed that there was little influence of procurement duration on cost growth performance. Furthermore, the Pearson correlation value between cost growth and schedule growth was found to be 0.29, which indicated that there was weak linear correlation between these variables. This study found that the projects with longer procurement duration had lower schedule growth by the awarded bidder. On the other hand, the degree of linear correlation between procurement duration and schedule growth was different for different complexity levels.

A study funded by Asian Development Bank was conducted to identify the main causes of project delay and cost under-run, studying about 100 projects (Ahsan and Gunawan, 2010). The ultimate objective of this study was to examine international development project costs and schedule performances as well as the main reasons for poor project outcome. The authors found that, on average, 86% of projects were late, with time overruns of about 2 years, and projects took approximately 39% more time than the planned average. Authors analyzed the time and cost performance for all international development projects and found an unusual relationship. Most projects, 73%, were late (schedule overruns) and operated with less budgeted cost, with a cost under-run of 20%. This showed that most late projects experienced cost under-runs. It was found that about

83% projects were found successful. The major causes of project delay were duration of contract procurement, civil works and land acquisition, and consultant recruitment. The major reasons for the cost under-runs were devaluation of local currency, competitive bidding price, lower than estimated bid, and large contingency budgets.

In conventional project procurement methods, change orders are common during design and construction processes, often causing cost overrun or schedule growth. A study in Taipei, Taiwan reviewed 90 metropolitan public work projects, those were completed before the year 2000 (Hsieh et al., 2004). The researchers studied 40 building constructions, 14 road constructions, 14 bridge and culvert constructions, 12 flood control constructions, and 10 subway tunnel construction projects. The chain of events was identified, and the causes for change orders were categorized based on information from the database. The causes of change orders were: discrepancies in planning and design, underground conditions, safety considerations, incidents due to natural causes, change of work rules/regulations, change of decision-making authority, special needs for project commissioning and ownership transfer, neighborhood pleading, and miscellaneous causes. The study showed that the problems incurred in the planning and design stage accounted for the most critical causes of change orders: the proportion of change orders for planning and design was 23.17%. Based on statistical testing, a 10-17% ratio of change order cost to total project cost (COR) was typical in metropolitan public works. It was suggested that more comprehensive planning and design would be required in order to improve project performance.

External factors such as political and economic factors, natural environmental factors, and third party factors and internal factors such as owner's demand changes, quality of design done by the consultant, and performance of the contractors were major causes of change orders. Moreover, design changes in construction projects often cause cost overrun or schedule growth. To clarify the causes of construction changes and to analyze the influence of these changes, the authors conducted multiple-case studies using statistics analysis to identify change in highway projects in Taiwan (Wu et. al. 2004). Authors interpreted the impact of change order in two aspects: 1) cost variation, and 2) schedule variation. The study showed that changes were due to difficulties in the pre-engineering investigation of the structures; as a result, the designer was unable to control all the factors in the designing phase. For instance, the study revealed that the cost for design change caused by insufficient geologic survey was 0.92% (NT $ 407,233,790) to the total contract amount (NT$44,412,072,900). The ratio on the cost of planning and design was low in the life cycle of construction engineering, but its influence to the entire engineering project was the greatest. The study suggested that detailed feasibility analysis and planning during the design phase was needed to prevent changes in the future.

A quantity analysis on construction delay was conducted by Al-Momani (2000), studying 130 public projects in nation of Jordan. The five kinds of projects were taken under consideration during the period of 1990 to 1997: residential, office and administration buildings, school buildings, medical centers and communication facilities. The data collection was done to investigate the reasons behind the construction delay and over-runs. These reasons were: 1) the planned duration of contract, 2) the actual completion date, 3) design changes, 4) disputes, 5) notification of extra work, 6) the date of notice to proceed, 7) delays encountered during construction, 8) conflict between the drawings and the specifications, 9) time extensions, and 10) late delivery of materials and equipments among others. The authors identified the major causes of delays which included: poor design, change orders, weather, site conditions, late delivery, economic conditions, and increase in quantity. About 106 out of 130 projects (81.5 %) were delayed. Poor design was the major cause of delay about 24.6 %, meanwhile, change orders was second major cause of delay about 15.4 %. The mean actual duration and planned duration for all public projects were 426.6 days and 343.1 days. Linear regression models were used to estimate the relationship between the actual and planned time for all five kinds of projects. The R-square value found for housing projects, office and administrative buildings projects, school projects, medical centers, and communication facilities were 72.85%, 58.96%, 51.47%, 79.24%, and 73.97%, respectively.

Design cost and quality are associated with each other. Design fees and design cost are synonymous. Design cost is defined as the cost to design the facilities, either roads (horizontal construction) or buildings (vertical construction). The method for calculating design cost or fees varies according to the type of owner. There are a number of methods to compensate the engineers and architects for their design work. Some of the prevalent methods in the construction industry mentioned in ASCE, Manuals and reports on engineering practice – No. 45 (2003) are: 1) per diem, 2) cost plus a fixed fee, 3) fixed lump-sum payment, 4) salary cost times a multiplier plus direct non-salary expense, 5) retainer, and 6) percentage of construction cost (ASCE. Manuals and reports on engineering practice – No. 45, 2003).

Surveys conducted by PSMJ have shown that the fixed lump-sum payment type design cost is widely used by engineers and architects to calculate the design cost of the buildings (CEO Snapshot: A/E fees and pricing survey. 23rd Edition, PSMJ Inc.). They reported that in 2006, 51% of owners used the fixed lump-sum form of payment to determine the design fee. Carr and Beyor have found that both professional fees and design fees have not been uniformly adjusted for inflation in the last three decades. There has been a decline of professional service fees when the impact of thirty years of inflation is considered (Carr and Beyor, 2005).

The relationship between design cost and design quality of the project is difficult to predict. It is a generally held belief that higher design costs result in a higher quality of design, up to some point of diminishing returns. Bubshait et al. conducted research investigating the correlation between design fees and design quality (Bubshait et al., 1998). These researchers collected project cost, design fees, and change order cost data for 58 large building projects in Saudi Arabia. The authors measured the design deficiency using the metric Total Cost of Design Deficiency (TCDD) given in Equation 1.

$$TCDD \text{ [redacted] } CDC_i \text{ [redacted] } CCO_i) \qquad (1)$$

where DCDCi is the direct cost of the ith design deficiency, and is the contractor's charges for the change to correct the design deficiency. The ICCOi is the i[th] charge for the indirect costs of the change order resulting from delayed project completion as is given by the Equation 2.

$$ICCO \text{ [redacted] } nnual\ Expected\ \Pr ofit\ per\ year \text{ [redacted] } \frac{ime\ Delay\ (in\ months)}{12} \qquad (2)$$

The authors assumed 15% as the expected annual profit in their analyses. A fifth-order polynomial statistical model was developed where the dependent variable was

TCDD and the independent variable was design cost. Using the data from 58 projects, the researchers found that the TCDD decreases as the design cost increases. In their data, the average design cost on building projects was found to be 2.4% of the total project cost, and the average project cost was $2 million. The authors also developed a statistical model to predict the design deficiency cost with the design fees. The coefficient of determination was 0.85 for the statistical model. However, the validity of fitting the data with a 5^{th} order polynomial is questionable, and it should be noted that goodness-of-fit is no guarantee of predictive success.

Currently, Japanese construction industry is paying more attention to the quality of design documents. Defective design is considered to be the most important risk factor in determining the success of a project. The research conducted a number of interviews and questionnaire surveys involving 105 designers and 91 construction personnel (Andi and Minato, 2003). In investigating the perceptions of the designers and contractors, the quality of design and its documentation (such as drawings and specifications) was evaluated based on several attributed indicators, including whole life cycle cost issues, material efficiency, economy, relevancy, constructability, innovation, expressiveness, aesthetics, ecological sustainability, site compatibility, material selection, and functionality. It was determined that there are two influential factors of design documents quality, which were design duration and design fees. The researchers determined the impact of deficient design documents on construction process efficiency. The defective designs impacts negatively on the performances of projects, which results rework, delays, cost overruns, changes, accidents, disputes, and loss of profit. The respondents of the surveys believed that almost 40% construction changes originated from defective design, 30% from cost overruns during construction, 30% from rework, 29% from loss of profit, 28% from delays in construction, 26% from disputes arising during construction, and 12% from accidents that occurred during construction; these results are shown in Figure 2. Based on the responses of the surveys, the reduction in the level of design fees, together with limited time results decreased the quality of design documents as well as the efficiency of the construction process.

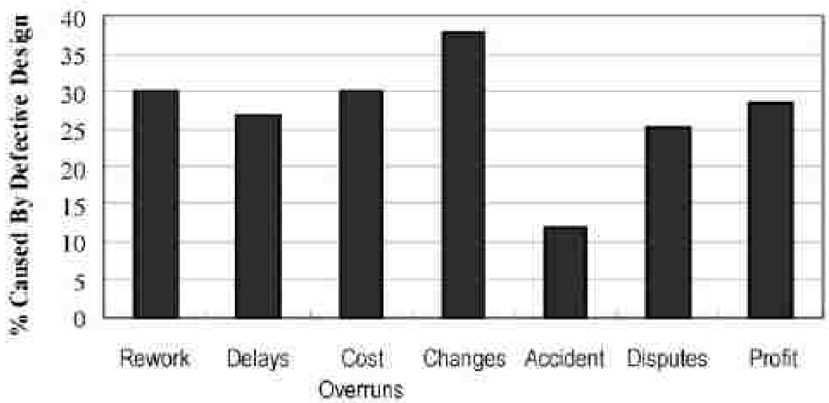

Figure 2. Proportion of poor performance caused by defective design (Adopted from Andi and Minato, 2003)

Kuprenas (2003) conducted research to determine the factors that improve cost performance during the design phase. Data from 270 engineering design projects was used to assess the impact of project management processes on design phase cost performance. The data was derived from capital improvement projects of the City of Los Angeles, Department of Public Works. Researchers investigating the design phase cost performance used the Design Cost Performance Index (DCPI) metric which is calculated by using Equation 3.

$$DCPI = \frac{ACDWP}{BCDWP} \qquad (3)$$

where, ACDWP is the actual cost of design work performed and BCDWP is the budgeted cost of design work performed. The cost of projects ranged from $25,000 to $25 million, and the construction completion period of these projects were between 1993 and 2000. Four project management processes were selected to find the correlation with the design phase cost performance: organizational structure (matrix or functional), project management training tools, design phase progress reporting frequency, and meeting frequency. The findings of the research showed that the frequency of design team meetings and reporting of design phase progress were significantly correlated with design phase cost performance.

The study of the number of changes that occurred in the construction projects revealed that 78% of the changes are related to design (Burati et al., 1992). The data of nine industrial projects of Construction Industry Institute (CII) member firms showed that about 19.7% of the design changes were related to design error; 13.3% were related to design revision, modifications, and improvements; 10.9% were related to design changes initiated by operations or processes; 9.1% were related to design changes initiated by the owners; and 6.1% were related to design omissions. It was found that, on average, 9.5% of the total project cost growth was accounted for by the design changes. However, the construction deviation only accounted for 2.5% of the total project cost growth. The study showed that design changes, which frequently occurred in the projects, contributed the most to the total project cost growth. Therefore, the researchers recommended that the owners needed to control the design changes in order to control the total project cost growth.

Gransberg et al. (2007) investigated the relationship between design fees and construction quality of transportation projects. The design cost for this analysis is the percentage of total design and construction cost of the projects. Due to unavailability of detailed data, the researchers used construction cost growth of the project as an indicator of construction quality. Data from 31 Oklahoma Turnpike Authority projects were used to investigate the correlation between these variables. They also created a regression model so that the project construction cost growth could be predicted with the design cost. The cost of projects ranged from $490,000 to $27.4 million. The total value of the projects was $90 million. The project data was analyzed collectively; then, the data was then subdivided into bridge and road projects, each of which were and analyzed separately. The cost growth metric used in these analyses was cost growth from the initial estimate (CGIE), calculated by using Equation 4.

$$CGIE \blacksquare \frac{Final\ Construction\ Cost - Intital\ Estimated\ Cost}{Intital\ Estimated\ Cost} \blacksquare 00\% \qquad (4)$$

To calculate this metric, the researchers used the estimated cost of the project before the design started as the value for the variable initial estimated cost. This metric differs from the cost growth metric in the way that the initial estimated cost of the project is defined. In the construction industry, using the DBB project delivery method, the initial estimated cost of the construction is generally fixed after the design of the project is completed.

Gransberg et al. (2007) found the average design fee for the projects to be 5.2% of the total project cost, and the average CGIE was 36.31%. Also, as the design fees decreased, the absolute construction cost growth from the engineer's early estimate increased. The research also found that this correlation is stronger in bridge projects than in road projects, because bridge projects have more technical issues during design than road projects. A second-order polynomial regression analysis was used to determine the correlation between design fees and cost growth. The analysis showed that the value of the coefficient of determination was higher in bridge projects than in road projects. The coefficient of determination, R square, quantifies the percentage of variation created in the dependent variable (in this case, CGIE) by the independent variable (in this case, design fees). The value of the coefficient of determination calculated for road and bridge projects were 0.39 and 0.95 respectively. A conclusion of this study was that design fees and construction cost growth were inversely correlated. Another conclusion was that, in their data set, design fees were higher in bridge projects than in road projects.

A study was conducted to determine the association of design costs with construction cost growth, construction cost per lane mile, construction schedule growth, and construction delivery speed per lane mile (Shrestha and Shields, 2009). To conduct this analysis, researchers collected data from 11 highway projects built in Texas. The findings showed that the design cost is strongly correlated with construction cost growth and construction cost per lane mile. It showed that the higher the design cost of the highway project, the lower the construction cost growth and construction cost per lane mile.

Research on the correlation between the design quality and the annual maintenance and rehabilitation cost of the buildings showed that an improved quality of design resulted in decreased annual maintenance and rehabilitation costs (Newton and Christian, 2006). The analysis was based on 28 new building projects collected from the Canadian Department of National Defense. To determine the design quality of the projects, the authors considered seven qualitative factors: performance, reliability, serviceability, conformance, durability, perceived quality, and aesthetics of the design drawings. The study showed that the design quality has significant impact on the maintenance and rehabilitation cost of the buildings. The R-square value for this model was found to be 56%.

Table 6. Summary of research findings

No	Researchers	Size	Types of data	Findings
1	Migliaccio et.al. (2009)	146	Transportation projects	Longer the procurement duration, the lower the schedule and total project time growth are
2	Migliaccio and Shrestha (2009)	19	Highway projects	Higher the total project cost, longer the total procurement duration for total project costing greater than $250 million There is weak correlation between these variables for project costing less than $250 million
3	Ahsan & Gunawan (2010)	100	Agricultural, infrastructure development, water supply and sanitation projects	Delay in project completion depends upon the duration of contract procurement, civil works and land acquisition, consultant recruitment Cost variation of the projects depends upon devaluation of local currency, competitive bidding price, lower than estimated bid, and large contingency budgets
4	Al-Momani (2000)	130	Buildings, communication facilities	Causes of construction completion delays were poor design, change orders, weather, site conditions, late delivery, economic conditions, and increase in quantity Poor design is the major cause of delay and change orders is the second major cause of delay for 20 projects
5	Wu et al. (2004)	NA	Highway projects	Cost variation and schedule variation are due to insufficient design consideration
6	Hsieh et al. (2004)	90	Building, road, bridge, flood control and subway tunnel	Causes of change order were planning and design, underground conditions, safety considerations, natural incident, change of work rules/regulations, change of decision-making authority etc.
7	Andi and Minato (2003)	196	NA	The quality of design documents depends upon the design fees and design duration. Rework, delays, cost overruns, changes, accidents, disputes, and loss of profit were the results of the defective designs

No	Researchers	Size	Types of data	Findings
8	Burati et al. (1992)	9	Industrial projects	Design changes occurs due to design error, design revision, operation process, design omission and design change initiated by the owners Total project cost growth is the result of design changes
9	Bubshait et al. (1998)	58	Large building projects	Total cost of design deficiency decreases with the increase in the design cost Higher the design cost, higher the quality of design
10	Kuprenas (2003)	270	Municipal facilities, storm-water, sewer, street projects	For a constant level of quality and schedule performance, frequency of design team meetings and reporting of design phase progress, project manager training, and organization structures play significant role in the design phase cost performance
11	Newton & Christian (2006)	28	Building projects	Seven factors to determine the design quality of the projects are performance, reliability, serviceability, conformance, durability, perceived quality, and aesthetics of design drawings Better the quality of design, lower the annual maintenance and rehabilitation cost
12	Gransberg et al. (2007)	31	Road and bridge projects	Lower the design fees, higher the construction cost growth The correlation between these two variables is stronger in bridge projects than in road projects
13	Shrestha & Shields (2009)	11	Highway projects	Higher the design cost of the highway projects, the lower the construction cost growth and construction cost per lane mile

CHAPTER 3

RESEARCH METHODOLOGY

This research statistically analyzes the design and construction costs and the schedule data of public projects in Clark County, Nevada, completed between the 1992-2007 timeframe. To validate the findings, the results of this data will be compared to that of the Texas Department of Transportation. The detailed methodology for this research is discussed below.

3.1 Outline of Research Methodology

The methodology of this study consists of seven steps which are shown in Figure 3. The seven steps are as follows:

- Define scope and objectives
- Review literature
- Collect data from Clark County, Nevada and Texas Department of Transportation
- Analyze data
- Summarize results
- Compare the results of Clark County and TXDOT data
- Make conclusion and recommendation

Each step of this research methodology is discussed below.

3.1.1 Define Scope and Objectives

The scope and objectives of the research are illustrated in this section. The major objective of this research is to determine the correlation between the design cost with construction cost growth and schedule growth. The results of the correlation analysis of this study will be compared to that of TXDOT's road project data's results. The detailed research hypotheses, background, study objectives were described in Chapter 1.

3.1.2 Review Literature

A literature review is the foundation of any research; therefore, various sources, such as journals, research papers on various kinds of construction projects, theses, books and articles were reviewed before finalizing the methodology and refining the scope of the research. The literatures review was discussed in Chapter 2 and is listed in the bibliography section.

3.1.3 Collect Data from Clark County, Nevada and Texas Department of Transportation

Data are the backbone of any research. Research without adequate and reliable data has no definable shape. To perform statistical analysis, sufficient data should be available. Various methodologies, such as surveys, questionnaires, and personal interviews could be implemented in order to collect data. However, to conduct this research, the data of road and flood control projects were collected from the Clark County Department of Public Works (CCDPW). Data of road projects from Texas Department of Transportation (TXDOT) were collected by questionnaire survey. The history behind the data collection and the statistical background are discussed in Section 3.2. Clark County road and flood control projects as well as Texas Department of Transportation road projects' data are described in Chapter 4. The type and size of data samples, histogram plots of various costs and durations, and description of metrics are discussed.

3.1.4 Analyze Data

Descriptive statistics as well as correlation and regression analyses of Clark County road and flood control projects and Texas Department of Transportation road projects are done by using SPSS software. The statistical assumptions tests for correlation and regression analysis are discussed in Chapter 5. Regression models are developed for final construction cost and design cost metrics. Detailed procedures regarding the statistical analysis of Clark County road and flood control projects and Texas DOT road projects are described in Chapter 5.

3.1.5 Summarize Results

The results of descriptive statistics as well as correlation and regression analyses of Clark County road and flood control projects and Texas Department of Transportation road projects are discussed in Chapter 5. The results obtained after comparison between Clark County data and Texas DOT data, are described in Chapter 6.

3.1.6 Compare the Results of Clark County and TXDOT Data

The results obtained from Clark County road and flood control data analyses are compared with the data from Texas Department of Transportation (TXDOT) road projects. The models formed from the regression analysis were checked for validation. The detailed procedures are discussed in Chapter 6.

3.1.7 Make Conclusions and Recommendation

The conclusions of this research, the limitations, and the scope of future research are identified and presented in Chapter 7.

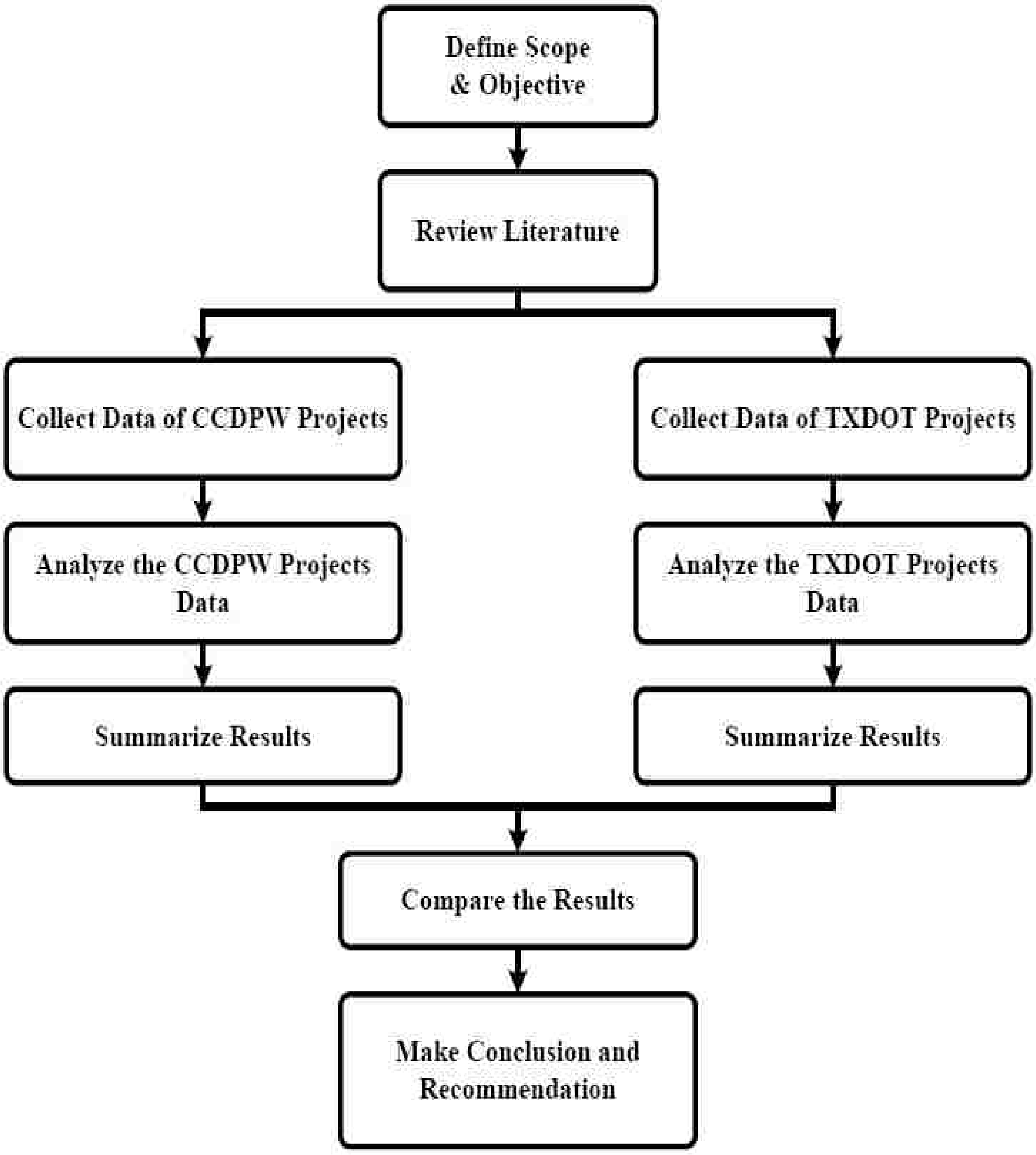

Figure 3. Flowchart of research methodology

3.2 History of Data Collection

To conduct this research, data were collected from the Clark County Department of Public Works (CCDPW), Clark County, Nevada. The data consists of data sheets from the design phase and the construction phase. The data related to design were collected directly from Design division of CCDPW, whereas the data related to construction was collected with the help of a graduate student from UNLV's Construction Management Program, who is now working as construction manager in CCDPW. This data set consists of Clark County's standard construction bid forms, with bid schedule information and invoices of design works of transportation and flood control projects constructed by CCDPW from 1992 to 2007.

Clark County uses Global 360 Software, previously known as Kovis, to archive construction related data of completed projects (Burns, 2008). These data are available to the public for informational purposes from the County Archives, if requested through the proper channel. A final affidavit of settlement is signed by the contractor after completion of a project. The project records are then stamped, delivered to the Construction Management Division of the CCDPW, scanned, and stored into the Global 360 database. Hard copies of completed projects are destroyed to reduce the storage space that the physical retention of records demands. However, the database of design documents (invoices) can be obtained in spreadsheet format.

Project data were obtained in pdf format and manually entered into a spreadsheet. The data obtained included project year, lists of items (by number and description), quantities, units, engineer's estimates of probable cost, bid price for each item, total estimates of cost, and bids for each projects. Final completion costs for each project were entered separately in an Excel worksheet format. However, the design phase data were obtained in spreadsheets format and entered in haphazardly. These spreadsheets included contract date, authorized funding amount and date, item-wise parameters with amount, and invoices amount for each project. The required data were extracted from these spreadsheets in suitable format. The invoice spreadsheets consisted of data from more than one projects' design phase, so there was some difficulty in extracting the required data.

In addition, the data related to the design and construction of Texas Department of Transportation road projects were collected by means of a questionnaire, which surveyed information regarding design cost, design start date, construction start and completion date, final construction cost, estimated cost, contract award cost, construction cost growth, and total cost growth.

3.3 Statistical Background

The public projects, such as the road and flood control construction projects design and construction phase data for Clark County, were analyzed by conducting uni-variate statistical analysis. Pearson correlation and linear regression analysis were used to analyze the data in this study. The terms and methodologies used in this analysis are described below.

3.3.1 Types of Variables

Dependent and independent variables are two types of variables, used in any statistical correlation and regression analysis. The variable to be predicted is called the dependent, or response, variable. The value of dependent variable cannot be controlled because its value depends on an independent variable. A variable that is used to predict the dependent variable; is called an independent variable; this variable can be controlled during the period of research.

3.3.2 Correlation Analysis

Correlation is a measure of the relation between two or more variables. The degree of correlation can be measured by correlation coefficients. Pearson correlation coefficient is the most common correlation coefficient which is widely used to determine linear relationship between two variables. Correlation can be negative correlation or positive correlation depending upon its correlation coefficient values from -1 to +1. If coefficient of correlation is -1, it is called a perfect negative correlation. If coefficient of correlation is +1, it is called a perfect positive correlation. The correlation value “0” indicates a lack of correlation. The normality test, linearity test, heteroscedasticity test and outliers test should be conducted to prove the assumptions of correlation analysis. In this study, the metrics used for correlation analyses are: basic design cost, total design cost, total cost growth, contract award cost growth, construction cost growth, construction schedule growth, and final construction cost. Among these metrics, basic design cost and total design cost are independent variables. Rest metrics are dependent variables.

3.3.3 Regression Analysis

It is a statistical technique, which is used to find the relationship between dependent and independent variables, for the purpose of predicting future values. The regression model, also called “prediction equation,” is an expression that reveals the relations between these variables (Mendenhall and Sincich, 2007). Depending upon the nature of complexity in the relationship, the regression model can involve simple to extremely complicated mathematical functions. In this research, a simple regression model is used to understand the relationship between variables. A simple regression model consists of one independent variable and one dependent variable. The independent variable is denoted by “x,” whereas, the symbol “y” stands for the dependent variable (Devore, 1999).

Equation 5 represents a simple linear model, in which “x” stands for the independent variable and “y” stands for the dependent variable. The symbol “β_0” and “β_1” are the constant and the coefficient of the independent variable, respectively. In this study, the dependent variable, “final construction cost” can be predicted using the independent variables “basic design cost” and “total design cost”.

y [redacted] (5)

3.3.4 Types of Modeling Approaches

3.3.4.1 Deterministic Approach

The deterministic approach is the ideal case approach, in which all the points exactly lie on the fitted-line plot (Mendenhall and Sincich, 2007). Although, it has no provision for errors in prediction, some points always substantially deviate from a fitted line plot. A linear deterministic model is represented by Equation 6.

y [redacted] (6)

3.3.4.2 Probabilistic Approach

In real field data, all the points do not lie exactly on a fitted line plot. Therefore, no one could expect exactness in the prediction. In the probabilistic approach, there will be an additional error factor "ε" in addition to the equation of the deterministic approach. A linear probabilistic model is represented by Equation 7.

y [redacted] [redacted] (7)

3.3.5 Least Squares Line

A least-square line is one that has a smaller sum of squares of the deviation (SSE) than any other straight-line model; that is, the deviation of the predicted values from the actual value is minimized. This line is also called the least squares prediction equation. This method is used to make the best fitted line plot.

Let x_i and y_i be the observed values, $\hat{y}_i$ be the estimator of the mean value of y for case i among n number of cases, and $\bar{x}$ and $\bar{y}$ be the averages for x and y series respectively. Let [redacted] and [redacted] be the estimators of [redacted] and [redacted] respectively. Then, the term to be minimized is [redacted] y_i [redacted] $)^2$. But, we know that, $\hat{y}_i$ [redacted]. Hence, our term to be minimized is [redacted] y_i [redacted] $)^2$. Taking the partial derivative and solving for it, we get Equation 8.

[redacted] [redacted] x_i [redacted] $)(y_i$ [redacted] $)$ / [redacted] x_i [redacted] $)^2$ (8)

Equation 9 results from Equations 7 and 8,

[redacted] (9)

3.3.6 Coefficient of Determination

It is the proportion of the total variation in the dependent variable y that is explained, by the variation in the independent variable x (Mendenhall and Sincich, 2007). The Coefficient of Determination used in the regression analysis is actually the square of the Pearson Correlation Coefficient between y and $\hat{y}$. The general expression for “r” is shown in Equation 10.

$$r \;\text{[redacted]}\; \frac{\text{[redacted]}\, x_i \,\text{[redacted]})(y_i \,\text{[redacted]})}{\sqrt{\text{[redacted]}\, x_i \,\text{[redacted]})^2 \,\text{[redacted]}\, y_i \,\text{[redacted]})^2}} \qquad (10)$$

The above equation gives the correlation between the two random variables. If x is replaced by $\hat{y}$ in the above equation, it will actually give the correlation between y and $\hat{y}$ for the regression model, which is R.

In the case of the simple correlation, the value of r lies in the interval $-1 \leq r \leq 1$. In multiple correlations, R cannot be negative and lies in the interval $0 \leq R \leq 1$. The value is the same, regardless of the interchange of the axis and their units. The higher value of R^2 means a higher correlation and a better fit of the curve, representing the data when graphically plotted.

3.4 Limitation of Study

Following are some limitations of this study,

- There is unavailability of detailed data. The total design costs of TXDOT data are not available.
- This study only does univariate analysis whereas a good reliable relationship would have consisted of multiple variables.

- There are only two types of projects: flood control and road projects. The numbers of flood control projects were not sufficient for analysis.
- There were no parameters defining the complexity of the projects for analysis.
- There were only DBB roads and flood control projects. If there were other projects with different project delivery methods, then the impact of the types of project delivery methods with the project performance could be determined.

CHAPTER 4

DATA DESCRIPTION

This chapter discusses the description of data and some statistical assumptions tests required before data analysis. Details about identification, selection, and execution of projects in Clark County, Nevada and Texas Department of Transportation are discussed below.

4.1 Project Identification, Selection, and Execution

The Clark County Public Works Department follows the typical process to select and build a project. Initially, Clark County, the Regional Transportation Commission (RTC), and the Regional Flood Control District (RFCD) identify the necessity of the project. The project is prioritized by each entity and then assigned to an in-house Public Works Engineer or a consultant engineering firm, selected through an interview process, and design work begins (Burns, 2008). Design documents are reviewed three to four times at various stages of completion such as 35, 60, and 100 percent by Clark County's Design Division. The constructability review is done by the Construction Management Division in order to prevent change orders and delays during construction. After securing the funds, the documents are forwarded for approval within the Department of Public Works as well as outside agencies. The project is advertised for bids by the Purchasing Office. The construction of a project is awarded to the lowest bidder; during the construction phase, the project is monitored by the Construction Management Division. The data associated with design and construction are scanned and sent to the Design and Construction Management Divisions, respectively. The design data are recorded by the

Design Division and construction data are recorded by the Construction Management Division.

4.2 Data Description of Clark County Projects

The database of public works projects constructed by CCDPW was obtained from the Design and Construction Management Divisions. The data retrieved from the database for this study included total invoice cost of design; an engineer's estimate with a bid price of the contractors; and the completion memorandum to the Clark County Purchasing Office, including the estimating cost, contract award cost, final construction cost, and change order costs, bid duration, and final construction duration. The total invoice design cost consists of costs expended for basic design, surveying, geotechnical investigation, and right of way, etc. The invoice spreadsheet also consists of the invoice contract date, funding supplementary date, and closing date.

In this study, all data were from public projects completed in Clark County, Nevada, between 1992 and 2007. Data sets of 11 flood control and 47 road projects of Clark County were considered for study. Section 4.2.1 describes the road projects, and Section 4.2.2 describes the flood control. All 58 projects are discussed in Section 4.2.3

Data of 17 road projects from Texas Department of Transportation (TXDOT) were also collected in order to determine whether these project data show similar trend as found in CCDPW road project data. The TXDOT road projects were completed between 1994 and 2009. The data related to design and construction mention above for TXDOT projects were collected for these 17 road projects by means of a questionnaire. The data description of these projects is discussed below.

4.2.1 Clark County Public Road Projects Data

Figure 4 shows the distribution of CCDPW road projects with respect to the year in which the contract for the design was signed. In 1996, eight design contracts were signed, which is the maximum. In 1999, 2002 and 2004, one project had a signed design contract in each year, representing the minimum. The distribution shows that the number of design contract signed from 1992 to 2004 varies from one to eight.

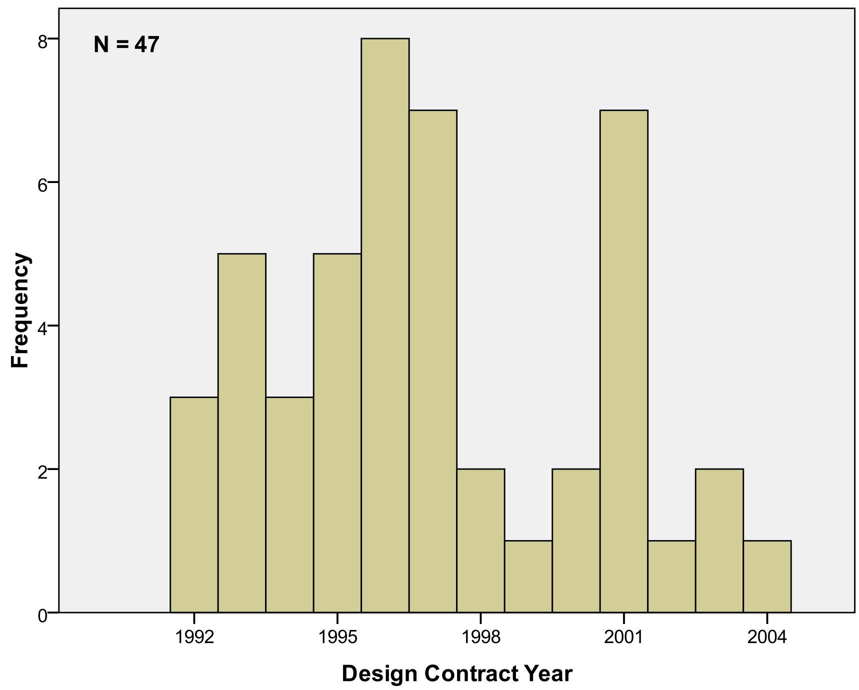

Figure 4. Histogram of the contract signed CCDPW road projects distribution by year

Figure 5 shows the distribution of CCDPW road projects with respect to construction start date ("Notice to Proceed" date). The maximum number of projects that underwent construction phases was seven in 1999; the minimum number of projects was one in each 2002 and 2006. The distribution shows that the number of construction for projects that were started from 1992 to 2004 varies from one to seven.

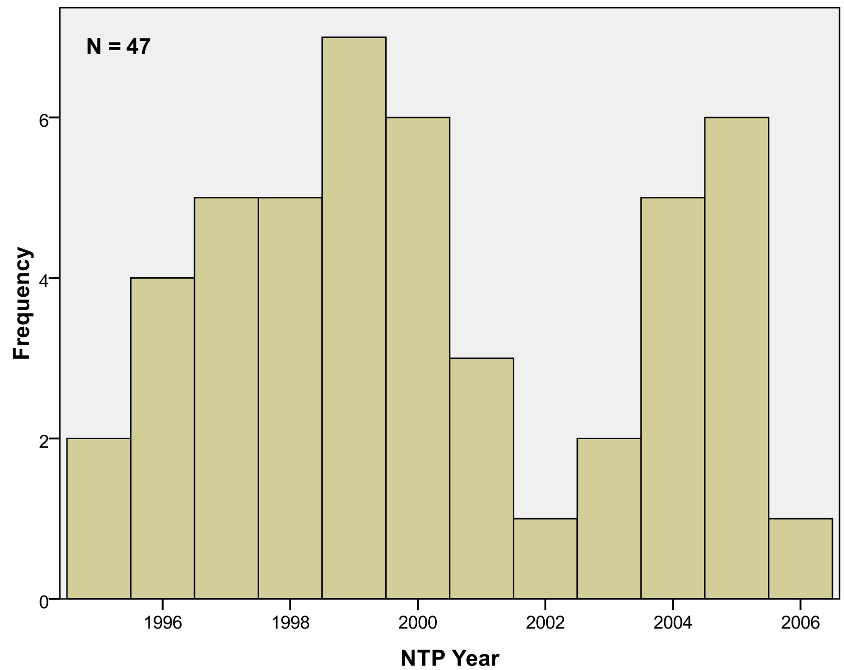

Figure 5. Histogram of the "Notice to Proceed" by year for CCDPW road projects

Figure 6 shows the distribution of CCDPW road projects with respect to construction completion by year. In 2001, the maximum number of construction completed projects was eight. The minimum number of construction completed projects was one in 1996, 2002, and 2007. The distribution shows that the number of completed construction projects from 1996 to 2007 varies from one to eight.

Figure 6. Histogram of completed CCDPW road projects by year

The distribution of the construction contract duration (in calendar days) of 47 CCDPW public road projects is presented in a histogram with normality curve (Figure 7). The curve plotted with the histogram indicates the normality of the data distribution. The minimum and maximum construction contract durations of CCDPW road projects are 60 and 540 calendar days, respectively. The mean construction contract duration was 270 calendar days.

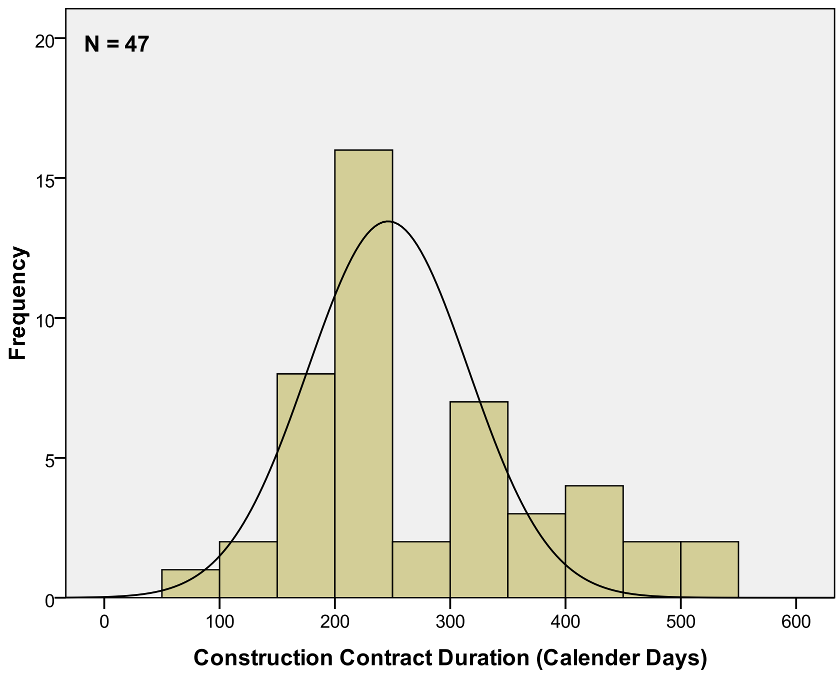

Figure 7. Histogram of construction contract duration for CCDPW road projects

The distribution of the final construction duration (in calendar days) of 47 CCDPW public road projects is presented in a histogram with normality curve (Figure 8). The curve plotted with the histogram indicates the normality of the data distribution. The minimum and maximum final construction durations of CCDPW road projects are 38 and 775 calendar days, respectively. The mean final construction duration was 328 calendar days.

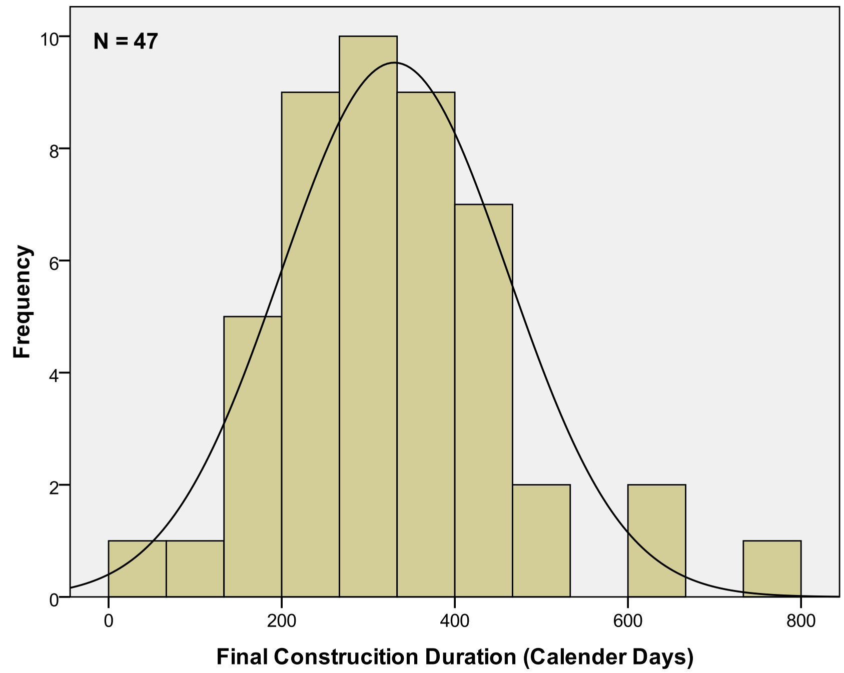

Figure 8. Histogram of final construction duration for CCDPW road projects

4.2.2 Clark County Public Flood Control Projects Data

Figure 9 shows the distribution by year of CCDPW flood control projects with respect to design contract signed. In 1999, the maximum design projects signed were three. The minimum design projects signed was one each in 1996, 2000 and 2002. The distribution shows that the number of contract signed for design of projects from 1996 to 2003 varies from one to three.

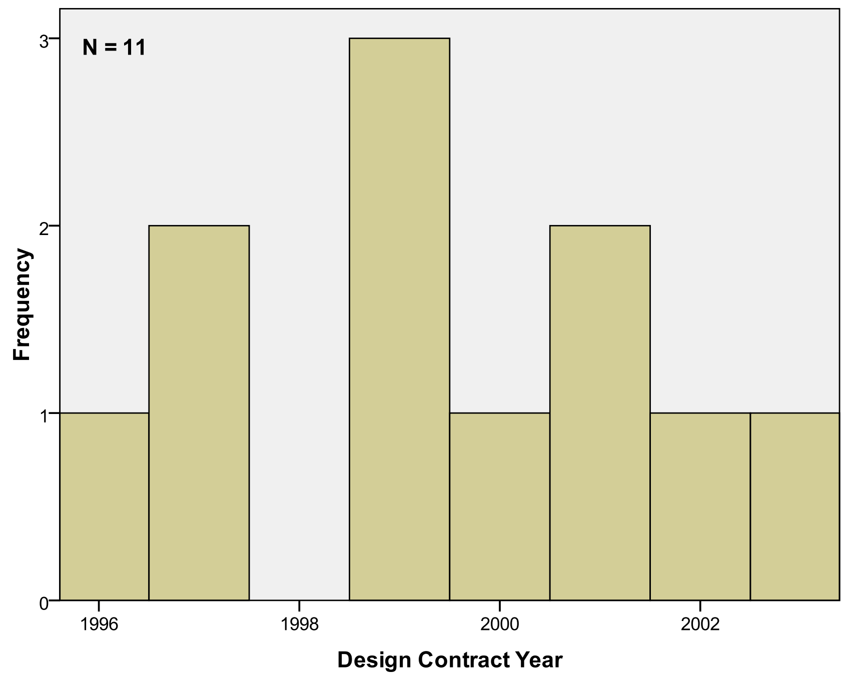

Figure 9. Histogram of contracts signed for CCDPW flood control projects by year

Figure 10 shows the distribution of CCDPW flood control projects with respect to construction start date (“Notice to Proceed” date). The maximum number of projects that underwent the construction phase was five in 2004; the minimum number of projects was one in each in year 2003, 2005, 2006 and 2007. The distribution shows that the number of construction projects started from 1999 to 2007 varies from one to five.

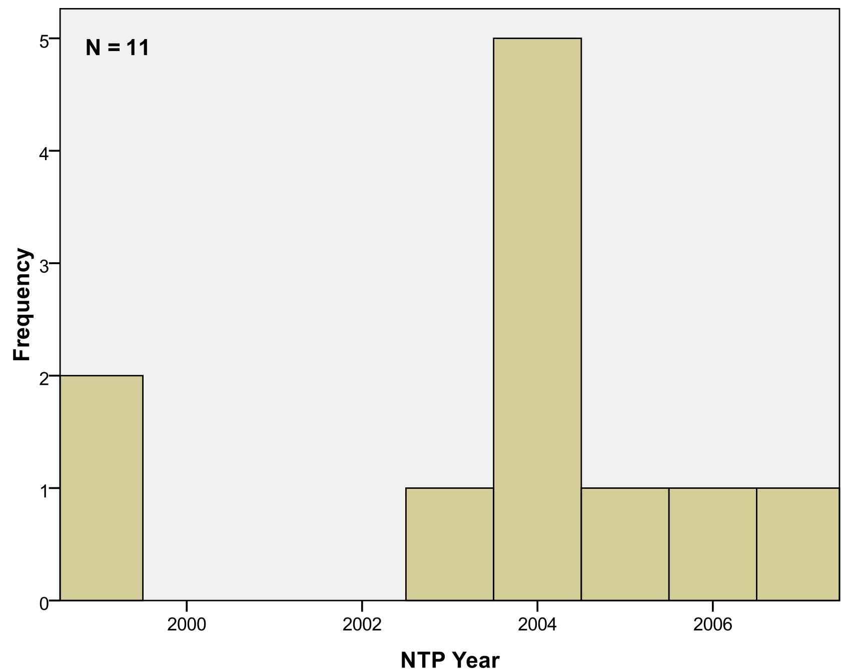

Figure 10. Histogram of the “Notice to Proceed” by year for CCDPW flood control projects

Figure 11 shows the distribution by year of CCDPW flood control projects with respect to construction completion. In 2005, the maximum number of completed construction projects was four. The minimum number of construction completed projects was one in year 2004. The distribution shows that the number of construction completed projects during 2000 to 2007 varies from 1 to 4.

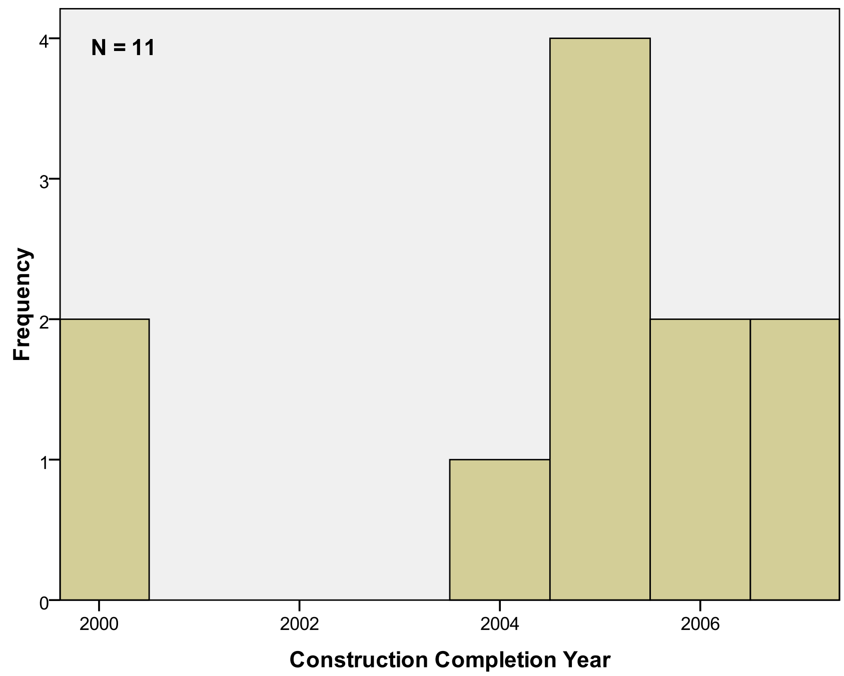

Figure 11. Histogram of completed CCDPW flood control projects, by year

The distribution of the construction contract duration (in calendar days) and final construction duration (in calendar days) of 11 CCDPW public flood control projects are presented in a histogram with normality curve as shown in Figures B-1 and B- 2. The minimum and maximum construction contract duration of CCDPW public flood control projects are 120 and 455 calendar days, respectively. The mean construction contract duration was 247 calendar days. The minimum and maximum final construction duration of CCDPW public flood control projects are 144 and 680 calendar days, respectively. The mean final construction duration was 337 calendar days.

4.2.3 Both Road and Flood Control Projects Data of Clark County

Figure 12 shows the distribution by year of CCDPW road and flood control projects with respect to design contract signed. In each of the years 1996, 1997, and 2001, the maximum design projects signed were nine. The minimum design projects signed was one in 2004. The distribution shows that the number of design contracts signed from 1992 to 2004 varies from one to nine.

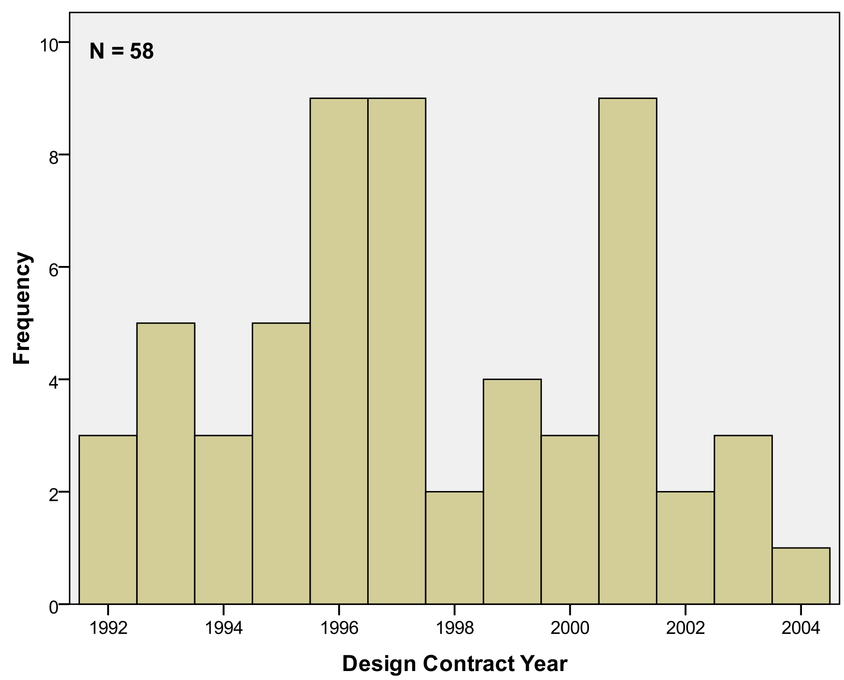

Figure 12. Histogram of contract signed for CCDPW road and flood control projects, by year

Figure 13 shows the distribution by year of both road and flood control projects for the CCDPW with respect to construction start date ("Notice to Proceed" date). The maximum number of projects that underwent construction phases were 10 in 2004; and the minimum number of projects was one each in year 2002 and 2007. The distribution shows that the number of projects that started construction from 1995 to 2007 varies from one to ten.

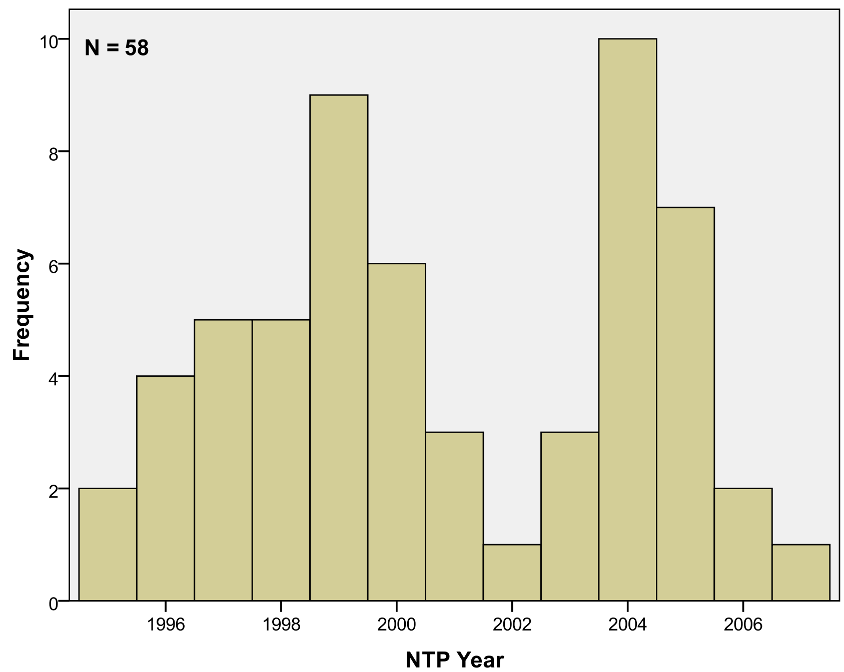

Figure 13. Histogram of the "Notice to Proceed" by year for CCDPW road and flood control projects

Figure 14 shows the distribution by year of CCDPW road and flood control projects with respect to construction completion. In 2000, the maximum number of construction projects completed was nine. The minimum number of construction projects completed was one in 1996 and 2002. The distribution shows that the number of completed construction projects from 1996 to 2007 varies from one to nine.

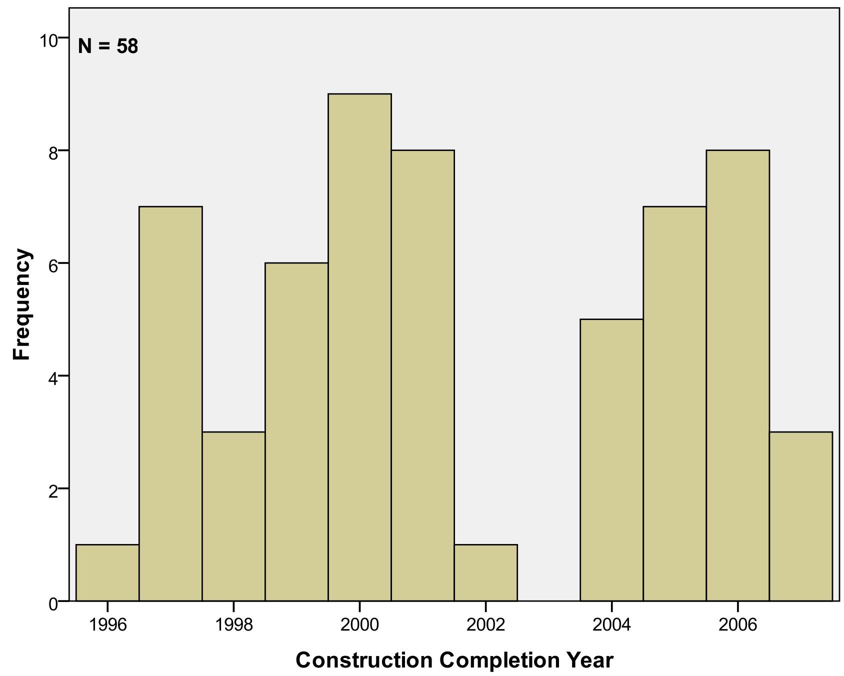

Figure 14. Histogram of the construction completed for CCDPW road and flood control projects, by year

The distribution of the construction contract duration (in calendar days) of CCDPW both public road and flood control projects is presented in a histogram with normality curve (Figure 15). The curve plotted with the histogram indicates the normality of the data distribution. The minimum and maximum construction contract durations of these projects are 60 and 540 calendar days, respectively. The mean construction contract duration was 266 calendar days.

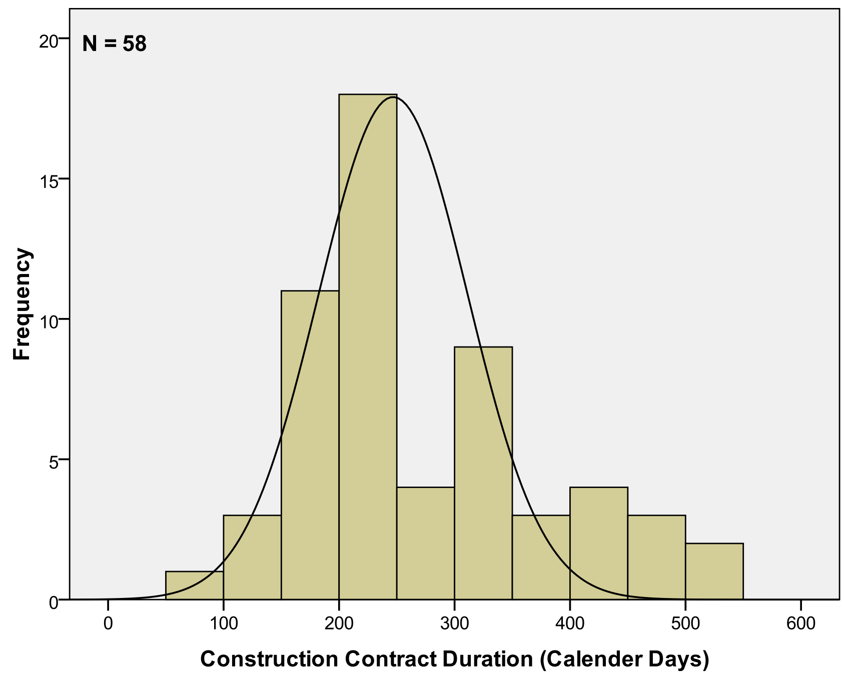

Figure 15. Histogram of the construction contract duration for CCDPW both road and flood control projects

The distribution of the final construction duration (in calendar days) of CCDPW both public road and flood control projects is presented in a histogram with normality curve (Figure 16). The curve plotted with the histogram indicates the normality of the data distribution. The minimum and maximum final construction durations of these projects are 38 and 775 calendar days, respectively. The mean final construction duration was 330 calendar days.

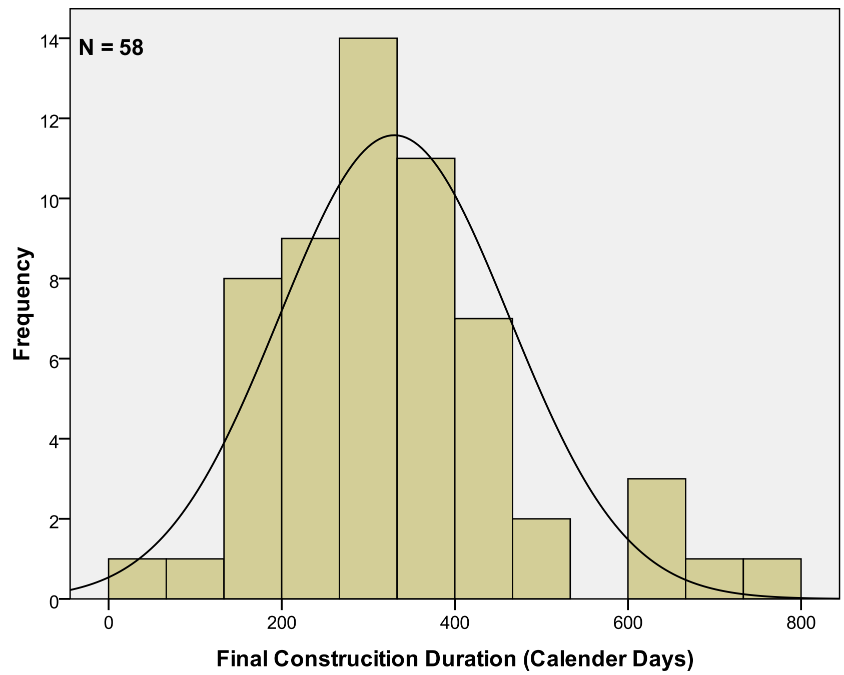

Figure 16. Histogram of the final construction duration for CCDPW both road and flood control projects

4.3 Data Description of Texas Department of Transportation Projects

The database of road projects constructed in Texas was obtained from the Texas Department of Transportation. All the data required for this study of TXDOT road projects data was collected by means of questionnaire survey. The information obtained from survey was entered into Microsoft Excel worksheets. The data in the database for this study included basic design cost; design start date, design completion date, an engineer's estimate with a bid price of the contractors; construction start date, construction completion date, final construction cost, total project cost (means sum of design cost and construction cost), change order costs, bid duration, and final construction duration.

The distribution by year of TXDOT projects for a signed design contract is shown in Figure 17. In 2000, the maximum design contract signed was eight. The minimum contract signed was one in 1994 and 2003. The distribution shows that the number of design contracts signed from 1992 to 2004 varies from one to nine.

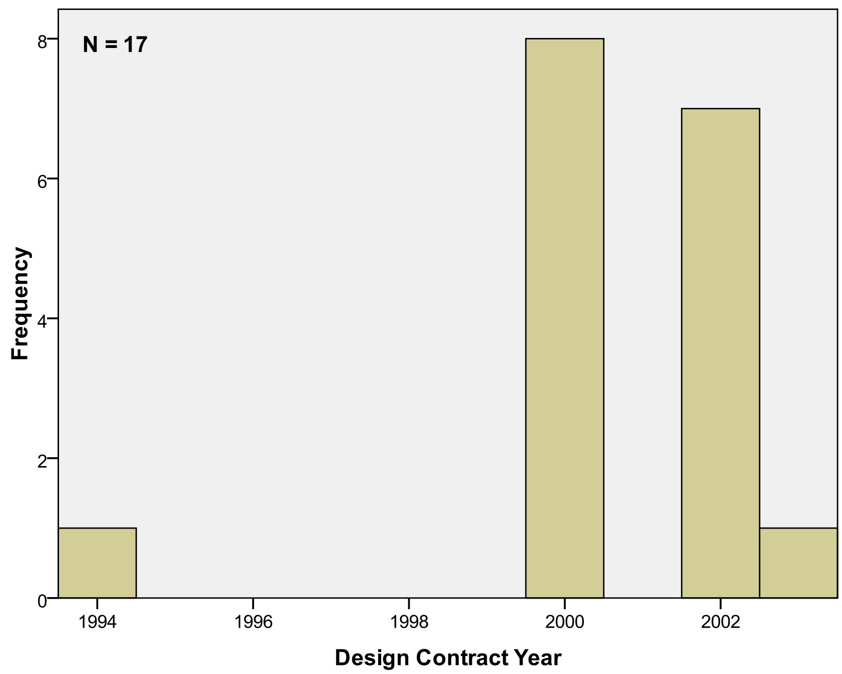

Figure 17. Histogram of the contract signed TXDOT road projects distribution by year

Figure 18 shows the distribution of TXDOT road projects with respect to construction start date (“Notice to Proceed” date). The maximum number of projects that underwent construction was eight in 2003; the minimum number of projects was one in 2001. The distribution shows that the number of construction projects started from 2001 to 2005 varies from one to eight.

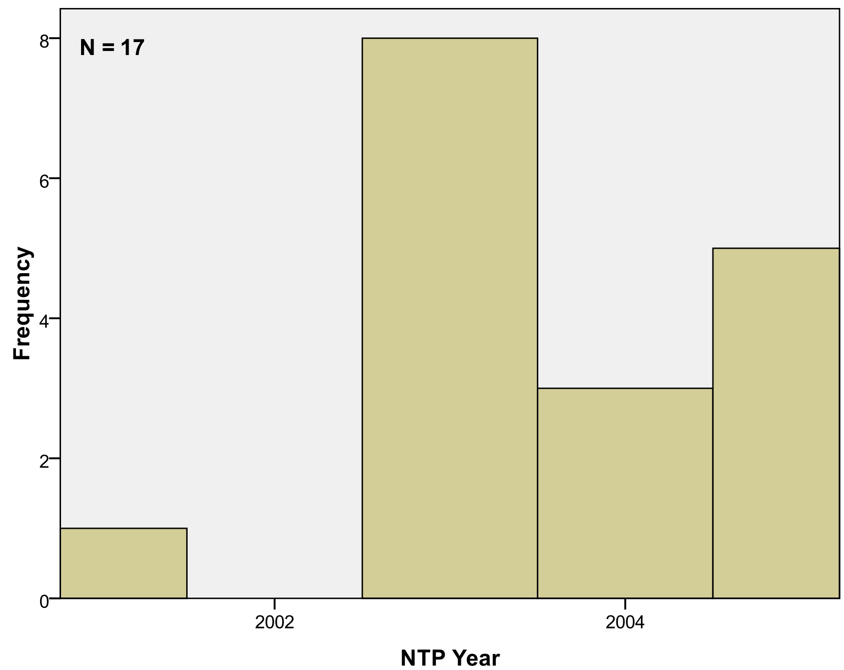

Figure 18. Histogram of the "Notice to Proceed" by year for TXDOT road projects

Figure 19 shows the distribution by year of TXDOT road projects with respect to construction completion. In 2006, the maximum number of construction projects completed was eight. The minimum number of construction projects completed was one in 2010. The distribution shows that the number of projects completed from 2006 to 2010 varies from one to eight.

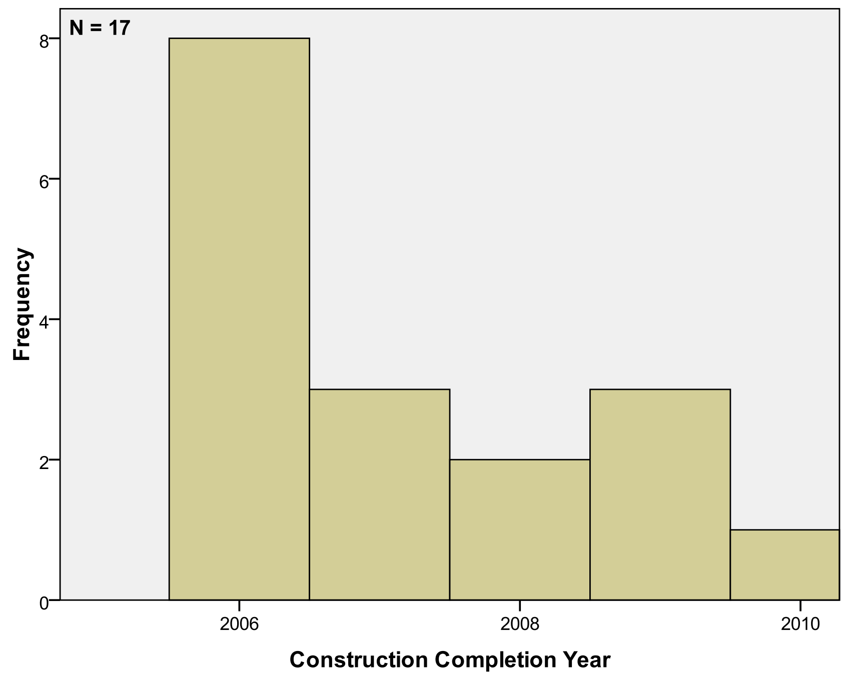

Figure 19. Histogram of the completed TXDOT road projects, by year

The distribution of the final construction duration (in calendar days) of TXDOT road projects is presented in a histogram with normality curve (Figure B-3). The curve plotted with the histogram indicates the normality of the data distribution. The minimum and maximum final construction durations of these projects are 870 and 1920 calendar days, respectively. The mean final construction duration was 1348 calendar days.

4.4 Distribution of Projects by Design and Construction Costs

In this section, Clark County road and flood control projects as well as Texas DOT road projects are described on the basis of basic design cost, total design cost, final construction cost, and total project cost. All the costs are expressed in million dollars.

The maximum, minimum, and sum of each kind of projects are described in the sub-sections.

4.4.1 Design and Construction Costs for Clark County's Public Flood Control Projects

The distribution of the basic design cost (in $ million) of 11 Clark County public flood control projects is presented in a histogram with normality curve (Figure 20). The curve plotted with the histogram indicates the normality of the data distribution. The normality test procedure and results are described in Chapter 5.

The minimum and maximum basic design costs are 0.04 and 1.10 million dollars, respectively. The sum of basic design cost is 6.23 million dollars.

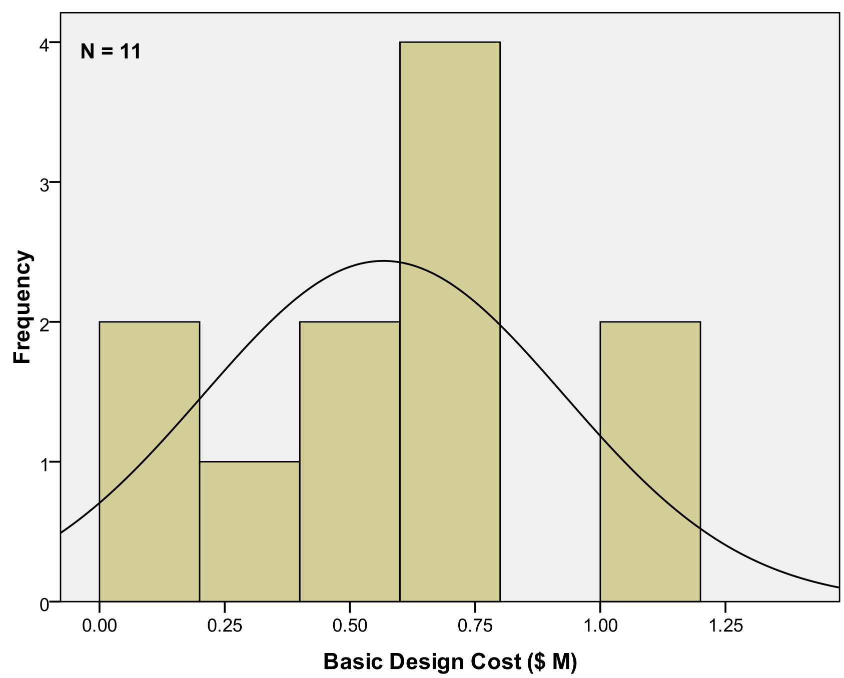

Figure 20. Histogram of the basic design cost (in $ million) of Clark County flood control projects

The distribution of total design cost (in $ million) of 11 Clark County public flood control projects is expressed in a histogram with normality curve (Figure 21). The curve plotted with the histogram indicates the normality of the data distribution. The normality test procedure and results are described in Chapter 5.

The minimum and maximum total design costs are 0.09 and 1.64 million dollars, respectively. The sum of total design cost is 9.39 million dollars. .

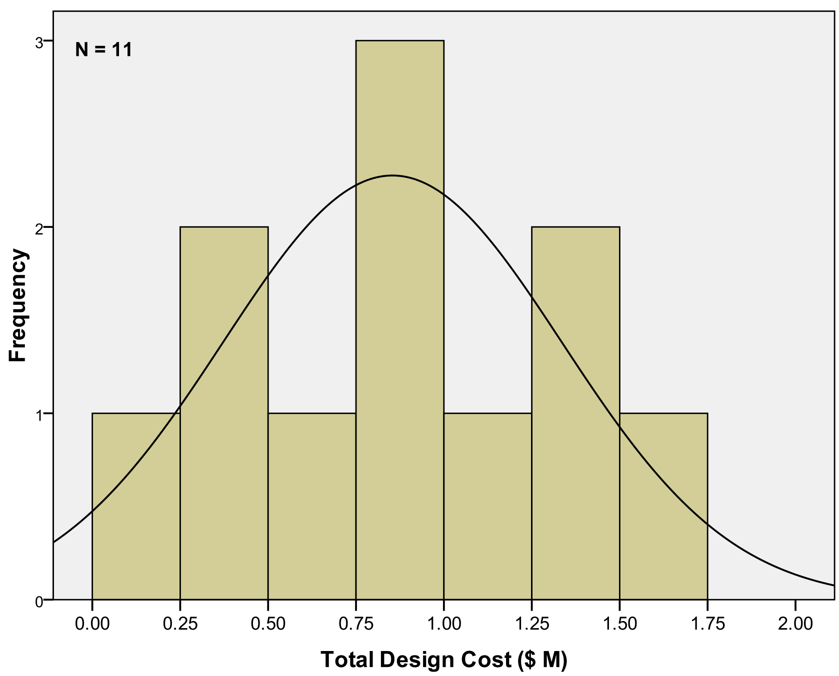

Figure 21. Histogram of the total design cost ($ million) of Clark County flood control projects

The distribution of the final construction cost (in $ million) of 11 Clark County public flood control projects is expressed in a histogram with normality curve (Figure 22). The curve plotted with the histogram indicates a slightly right-skewed data distribution. Thorough normality test procedures and their results are described in Chapter 5.

The minimum and maximum total design costs are 2.99 and 18.57 million dollars, respectively. The sum of final construction cost is 85.01 million dollars.

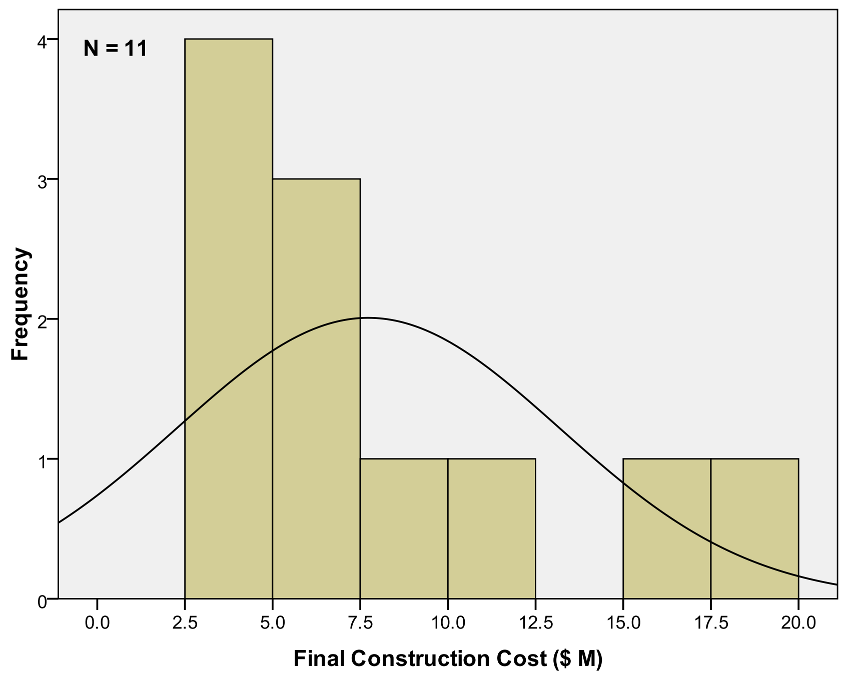

Figure 22. Histogram of the final construction cost (in $ million) of Clark County flood control projects

The distribution of total project cost which the sum of the total design cost and the final construction cost in $ million of 11 Clark County public flood control projects is expressed in a histogram with normality curve (Figure 23). The curve plotted with the histogram indicates an almost normally distributed data set. Thorough normality test procedures and their results are described in Chapter 5.

The minimum and maximum total design costs are 3.31 and 19.03 million dollars, respectively. The sum of total project cost is 94.39 million dollars.

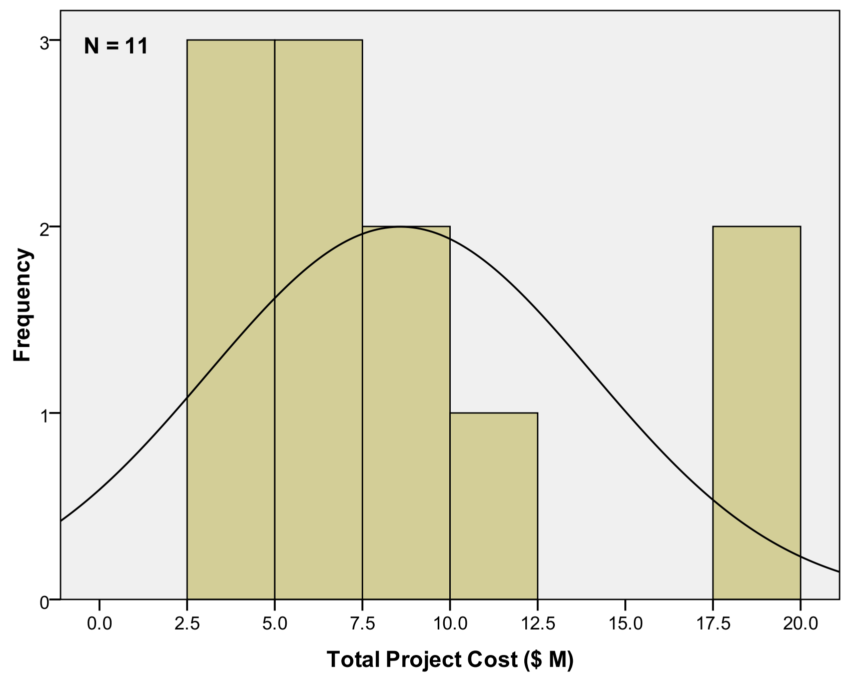

Figure 23. Histogram of the total project cost (in $ million) of Clark County flood control projects

4.4.2 Clark County Public Road Projects' Design and Construction Costs

The histogram with normality curves of distribution for 47 Clark County public road projects, with respect to final construction cost, basic design cost, total design cost, and total project cost in million dollars, are plotted in Figure B- 10, Figure B- 11, Figure B- 12, Figure B- 13, respectively. The curves were slightly right-skewed, indicating a non-normally distributed data set. Detailed normality test procedures and their results are described in Chapter 5.

The minimum and maximum basic design costs are 0.12 and 4.15 million dollars, respectively. The sum of basic design cost of all projects cost is 59.16 million dollars. The minimum and maximum total design cost of 47 road projects are 0.12 and 4.88 million dollars. The sum of total design cost is 75.33 million dollars. The minimum and maximum final construction costs of these projects are 0.21 to 50.39 million dollars, respectively. The sum of final construction cost is 634.27 million dollars. The sum of total project cost of all 47 road projects is 709.60 million dollars. The minimum and maximum total project cost is 0.34 to 53.35 million dollars, respectively.

4.4.3 Design and Construction Costs for Clark County's Public Road and Flood Control Projects

Clark County road and flood control projects were collected in a single data set, and studied. The histogram with normality curves of distribution of 58 Clark County public road projects, with respect to final construction cost, basic design cost, total design cost, and total project cost in million dollars, was plotted as shown in Figure B- 20, Figure B- 21, Figure B- 22, Figure B- 23, respectively. The curves were slightly right-skewed, indicating a non-normally distributed data set. Detailed normality test procedures and their results are described in Chapter 5.

The minimum and maximum basic design costs are 0.04 and 4.15 million dollars, respectively. The sum of basic design cost of all projects cost is 65.40 million dollars. The minimum and maximum total design costs of 58 projects are 0.09 and 4.88 million dollars, respectively. The sum of total design cost is 84.72 million dollars. The minimum and maximum final construction costs of these projects are 0.21 to 50.39 million dollars, respectively. The sum of final construction cost is 719.28 million dollars. The sum of total project cost of all 58 projects is 804 million dollars. The minimum and maximum total project costs are 0.34 to 53.35 million dollars, respectively.

4.4.4 TXDOT Road Projects' Design and Construction Costs

The distribution of basic design cost (in $ million) of 17 Texas Department of Transportation road projects is presented in a histogram with normality curve (Figure 24). The curve plotted with histogram indicates a non-normal distribution of data. The normality test procedure and results are described in Chapter 5.

The minimum and maximum basic design costs are 0.04 and 1.10 million dollars, respectively. The sum of basic design cost is 214.79 million dollars.

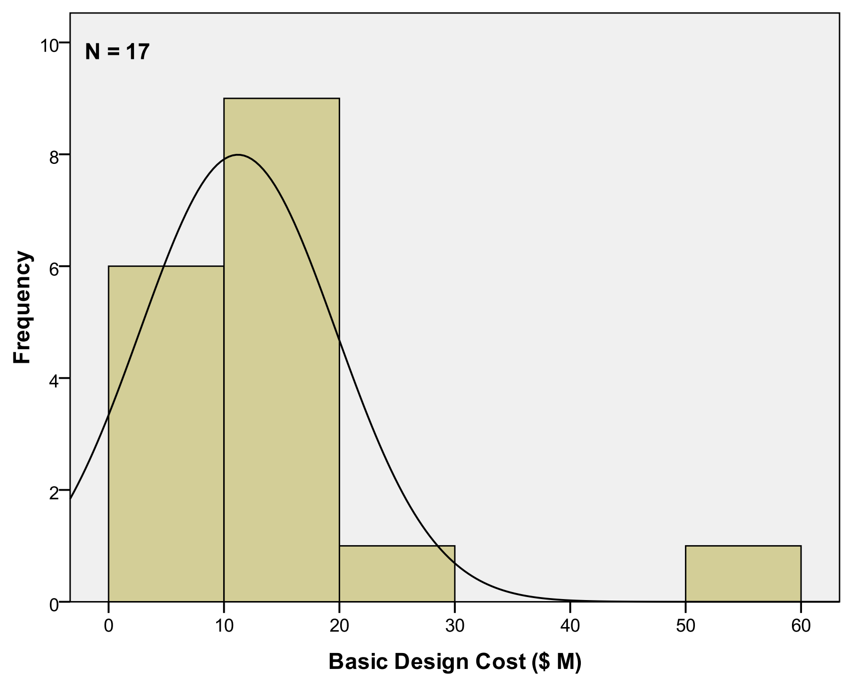

Figure 24. Histogram of the basic design cost (in $ million) of TXDOT road projects

The distribution of final construction cost (in $ million) of 17 Texas DOT road projects is presented in a histogram with a normality curve (Figure 25). The curve plotted with histogram indicates a normality of data distribution. The normality test procedure and results are described in Chapter 5. The minimum and maximum final construction costs are 31.24 and 288 million dollars, respectively. The sum of basic design cost is 2,526.04 million dollars.

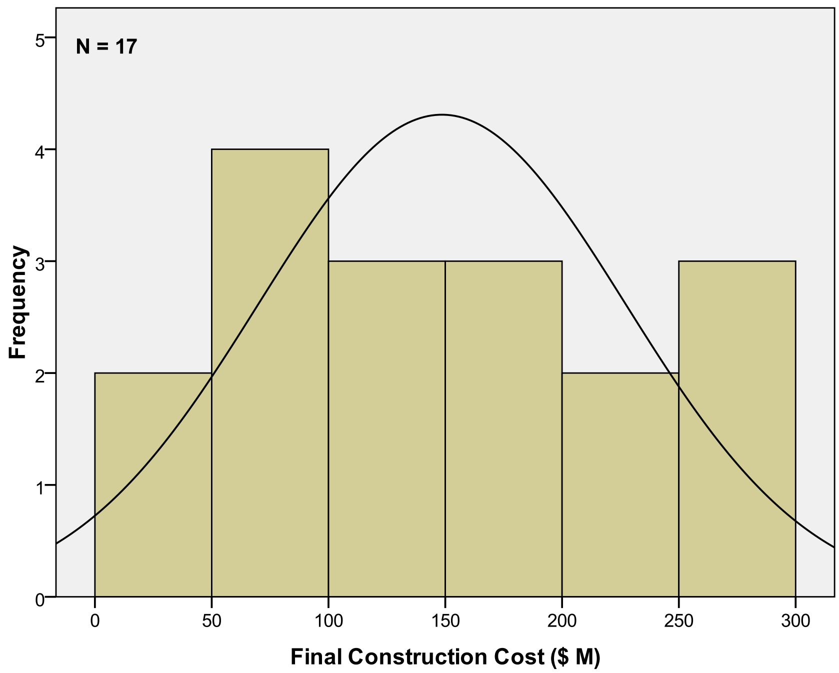

Figure 25. Histogram of the final construction cost (in $ million) of TXDOT road projects

The distribution of total project cost (in $ million) of 17 Texas DOT road projects is presented in a histogram with a normality curve (Figure 26). The curve plotted with the histogram indicates a normality of data distribution. The normality test procedure and results are described in Chapter 5.

The minimum and maximum final construction costs are 44.24 and 301 million dollars, respectively. The sum of basic design cost is 2740.84 million dollars.

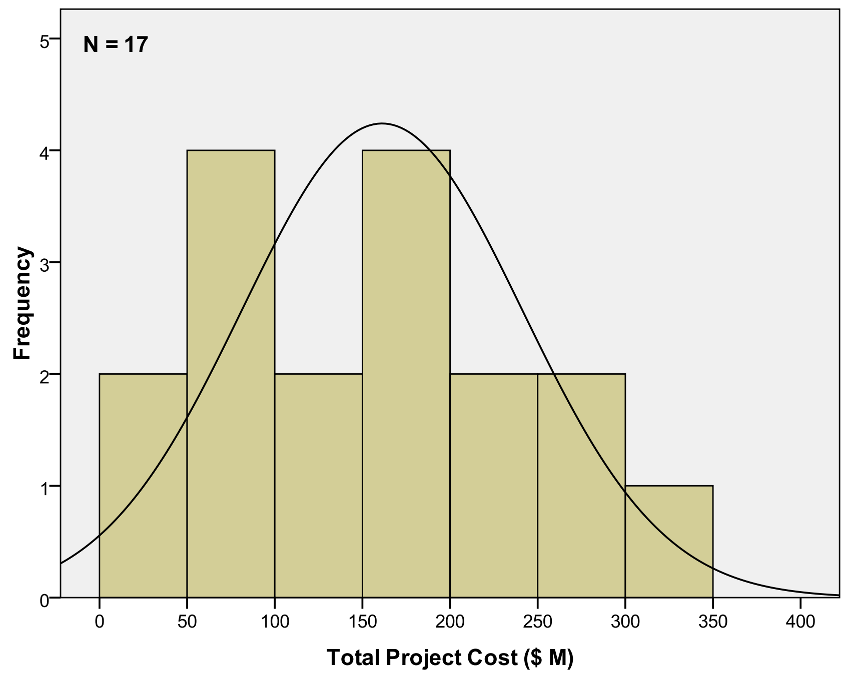

Figure 26. Histogram of total project cost (in $ million) of TXDOT road projects

4.5 Database Formation

The required data were extracted from the source, and tabulated in spreadsheets. For the Clark County projects, the invoice spreadsheets of the design phase and the bid item data of construction phase for all 58 projects' were checked thoroughly. In design phase worksheet, the following items were manually entered, including project number, type of projects, contract date, last supplement date of funds, basic design cost, total design cost, right of way cost, geotechnical cost, and survey cost. Similarly, for the construction phase worksheet, the bid number, type of projects, NTP date, construction completion date, engineer estimate, award cost, final construction cost, and total project cost (means total design and construction cost) were manually entered into Microsoft Excel worksheets.

In the case of the TXDOT road construction projects, data obtained by the survey were compiled in the separate worksheets.

Six metrics were developed from these data to test the null hypotheses. Basic design cost is a pure design cost of the project, consisting of the engineer’s or architect’s fees as well as expenses for design drawings and specifications. Total design cost consists of all expenses during the design phase, such as geotechnical works, surveys, and right of way; also includes basic design cost. Equations 11 to 16 are used to calculate these metrics, which are expressed as percentages.

$$\text{Total Design Cost}(\%) = \frac{\text{Design Cost}}{\text{Total Design and Construction Cost}} \; x\,100 \tag{11}$$

$$\text{Basic Design Cost}(\%) = \frac{\text{Basic Design Cost}}{\text{Total Design and Construction Cost}} \; x100 \tag{12}$$

$$\text{Total Cost Growth}(\%) = \frac{\text{Final Construction Cost} - \text{Engineer's Estimated Construction Cost}}{\text{Engineer's Estimated Construction Cost}} \; x100 \tag{13}$$

$$\text{Contract Award Cost Growth}(\%) = \frac{\text{Construction Contract Cost} - \text{Engineer's Estimated Construction Cost}}{\text{Engineer's Estimated Construction Cost}} \; x100 \tag{14}$$

$$\text{Construction Cost Growth } (\%) = \frac{\text{Final Construction Cost} - \text{Construction Contract Cost}}{\text{Construction Contract Cost}} \, x \, 100 \qquad (15)$$

$$\text{Construction Schedule Growth } (\%) = \frac{\text{Final Construction Duration} - \text{Construction Contract Duration}}{\text{Construction Contract Duration}} \, x \, 100 \qquad (16)$$

For further analysis, all these metrics were calculated by using Microsoft Excel spreadsheets. The Engineering News Record Construction Cost Indices were manually entered into the spreadsheets to get the 2010 equivalent costs. These cost indices were used to normalize the cost data. All the design cost and final construction data were converted to 2010 equivalent costs. All the above metrics were relative metrics expressed in terms of percentages. Therefore, it was not necessary to convert all the cost data into 2010 equivalent cost. However, the design costs and final construction cost were converted to 2010 equivalent cost, because this study determines the relationship between these two variables; and the regression model was developed to predict the final construction cost of the projects by using the design cost as an input variable. If the cost data was not normalized, then the model developed would not have reflected an accurate prediction of the final construction cost.

4.6 Engineering News Record Construction Cost Indices

The Engineering News Record Construction Cost Indices were used to convert all costs, such as basic design cost, total design cost, final construction cost, and total project cost, to their 2010 equivalent costs. Table 7 shows the average ENR Cost Indices to adjust the cost. Table A- 12 shows the detailed ENR Cost Indices in monthly basis.

Table 7. ENR cost indices

Year	Index	Year	Index
1991	4835	2001	6334
1992	4985	2002	6538
1993	5210	2003	6695
1994	5408	2004	7115
1995	5471	2005	7446
1996	5620	2006	7751
1997	5826	2007	7959
1998	5920	2008	8310
1999	6059	2009	8570
2000	6221	2010	8952

Equations 17 and 18 were used for adjusting the design and construction costs.

$$\textit{Equivalent Design Cost in } 2010 = \textit{Design Cost based on the Contract Date*Factor} \quad (17)$$

Where,

$$Factor = \left(\frac{ENR\ Cost\ Index\ of\ December\ 2010}{ENR\ Cost\ Index\ of\ Contract\ Date} \right)$$

$$\textit{Equivalent Construction Cost in } 2010 = \textit{Construction Cost based on the NTP Date*Factor} \quad (18)$$

Where,

$$Factor = \left(\frac{ENR\ Cost\ Index\ of\ December\ 2010}{ENR\ Cost\ Index\ of\ NTP\ Date} \right)$$

CHAPTER 5

DATA ANALYSIS AND RESULTS

This chapter thoroughly describes data analysis and includes statistical assumptions tests, descriptive statistics, correlation tests, regression analyses, and scatter plots with detailed interpretations. The purpose of this analysis was to find correlation of design cost with cost growth and schedule growth, and also to find a reliable mechanism to display the relationship between the predicted and historical data.

To achieve objective of this research, 47 Clark County road projects and 11 Clark County flood control projects were analyzed separately, and then the combined 58 Clark County projects for both road and flood control were analyzed. The separate and combined project analyses were compared.

5.1 Data Preparation for Analysis

A set of data were prepared for 47 Clark County road projects in a spreadsheet and uploaded to Statistical Package for the Social Sciences Incorporated (SPSS Inc.) to conduct statistical analyses. Another set of data were prepared for 11 Clark County flood control projects in a spreadsheet and those data were copied to SPSS software to conduct statistical analyses. Similarly, a combined 58 Clark County road and flood control projects data set were analyzed using SPSS software. Then, the results of these analyses were compared. Additionally, a set of data were prepared for 17 Texas Department of Transportation road projects and analyzed with similar procedure as discussed above. To prove the results from Clark County data, the results of both TXDOT and CCDPW data were compared.

5.2 Descriptive Statistics Overview

A descriptive statistics of Clark County road and flood control projects were determined in separate and combined set of data for different types of costs: basic design cost, total design cost, estimated cost, contract award cost, final construction cost, total project cost, contract award cost growth, total cost growth, and construction cost growth. A similar procedure was followed for Texas Department of Transportation road projects. This section summarizes the various types of costs, including their maximum, minimum, mean and standard deviation.

5.2.1 Descriptive Statistics for Clark County Road Projects

Various types of costs of all metrics for 47 Clark County road projects are summarized in Table 8. The mean basic design cost is $1,258,800, and the minimum and maximum values are $124,770 and $4,150,740, respectively. The basic design cost deviated by $971,600. The mean total design cost is $ 1,602,800, and the minimum and maximum values are $124,770 and $ 4,880,570, respectively. The total design cost deviated by $ 1,193,100. The maximum and minimum final construction costs of these projects are $212,880 and $50,385,080, respectively, and the mean is $13,495,000. The mean of contract award cost growth, total cost growth, and construction cost growth are -$ 592,940, $ 69,390 and $ 662,340 respectively. The negative sign for dollar amount of $ 524,390 indicates a decrease in contract award cost growth. The minimum costs of contract award cost growth, total cost growth, and construction cost growth have negative values, indicating a decrease in cost growth.

Table 8. Descriptive statistics of CCDPW road projects costs ($ K)

Metrics	Minimum	Maximum	Mean	Std. Deviation
Basic Design Cost	124.77	4150.74	1258.80	971.60
Total Design Cost	124.77	4880.57	1602.80	1193.10
Estimated Cost	275.36	59612.09	13426	12913.40
Award Cost	212.88	45857.97	12833	12203.80
Final Construction Cost	212.88	50385.08	13495	12930.90
Total Project Cost	337.64	53348.10	15098	13812.50
Contract Award Cost Growth	-14297.21	10134.75	-592.94	2919.48
Total Cost Growth	-13070.91	11856.45	69.39	3016.01
Construction Cost Growth	-280.74	4527.10	662.34	1161.92

5.2.2 Descriptive Statistics of Clark County Flood Control Projects

Various types of costs of all metrics for 11 flood control projects are summarized in Table 9. The mean basic design cost is $ 566,670, and the minimum and maximum values are $ 41,600 and $ 1,099,180, respectively. The basic design cost deviated by $ 360,300. The mean total design cost is $ 853,320, and the minimum and maximum values are $ 88,940 and $ 1,635,340, respectively. The total design cost deviated by $ 481,850. The minimum and maximum final construction costs of these projects are $ 2,988,710 and $ 18,572,870, respectively, and the mean was $ 7,727,900. The mean of contract award cost growth, total cost growth, and construction cost growth are - $ 265,570, $ 413,370 and $ 147,780, respectively. The negative sign for the dollar amount $ 265,570 indicates a decrease in contract award cost growth. The minimum costs of contract award cost growth, total cost growth, and construction cost growth are negative, indicating a decrease in cost growth.

Table 9. Descriptive statistics of CCDPW flood control projects costs ($ K)

Metrics	Minimum	Maximum	Mean	Std. Deviation
Basic Design Cost	41.60	1099.18	566.67	360.30
Total Design Cost	88.94	1635.34	853.32	481.85
Estimated Cost	2195.93	17729.01	7314.50	5573.58
Award Cost	2919.21	18701.82	7580.10	5508.93
Final Construction Cost	2988.71	18572.87	7727.90	5466.29
Total Project Cost	3307.16	19026.59	8581.20	5488.14
Contract Award Cost Growth	-1446.73	1848.71	-265.57	1037.35
Total Cost Growth	-1265.88	1759.10	413.37	1008.29
Construction Cost Growth	-209.34	739.03	147.78	270.10

5.2.3 Descriptive Statistics of Combined Clark County Road and Flood Control Projects

Various types of costs of all metrics for the combined 58 road and flood control projects are summarized in Table 10. The mean basic design cost is $ 1,127,500, and the minimum and maximum value was $ 41,600 and $ 4,150,740, respectively. The basic design cost deviated by $ 927,100. The mean total design cost is $ 1,460,700, and the minimum and maximum values are $ 88,940 and $ 4,880,570, respectively. The total design cost deviated by $ 1,130,210. The minimum and maximum final construction costs of these projects are $ 212,880 and $ 50,385,080, and the mean is $ 12,401,000. The mean of contract award cost growth, total cost growth, and construction cost growth are - $ 430 120, $ 134,630 and $ 564,750, respectively. The negative sign for the dollar amount of $ 430,120 indicates a decrease in contract award cost growth. The minimum costs for contract award cost growth, total cost growth, and construction cost growth were negative, indicating a decrease in cost growth.

Table 10. Descriptive statistics of CCDPW road and flood control projects costs ($ K)

Metrics	Minimum	Maximum	Mean	Std. Deviation
Basic Design Cost	41.60	4150.74	1127.50	927.10
Total Design Cost	88.94	4880.57	1460.70	1130.21
Estimated Cost	275.36	59612.10	12267	12077.40
Award Cost	212.88	45857.97	11837	11394.30
Final Construction Cost	212.88	50385.08	12401	12057.50
Total Project Cost	337.64	53348.10	13862	12880
Contract Award Cost Growth	-14297.21	10134.75	-430.12	2680
Total Cost Growth	-13070.91	11856.45	134.63	2745.49
Construction Cost Growth	-280.74	4527.10	564.75	1069.45

5.2.4 Descriptive Statistics of Texas Department of Transportation Road Projects

Various types of costs of all metrics for 17 road projects are summarized in Table 11. The mean basic design cost is $ 12,635,000, and the minimum and maximum values are $ 3,633,260 and $ 58,893,000, respectively. The basic design cost deviated by $ 12,571,300. The minimum and maximum final construction costs of these projects are $ 34,239,320 and $ 288,000,000, respectively, and the mean is $ 148,590,000.

Table 11. Descriptive statistics of TXDOT road projects costs ($ K)

Metrics	Minimum	Maximum	Mean	Std. Deviation
Basic Design Cost	3633.26	58893	12635	12571.30
Final Construction Cost	34239.32	288000	148590	78699.70
Total Project Cost	44239.32	301000	161230	79972.60

5.2.5 Descriptive Statistics of Construction Schedule Growth of various projects

Construction schedule growth for various projects is summarized in Table 12. The mean construction schedule growth of CCDPW road projects is 21.18%, and the minimum and maximum values are -36.67% and 100%, respectively. The construction schedule growth deviated by 24.28%. Similarly, the descriptive statistics of construction schedule growth of CCDPW flood control projects, CCDPW both road, and flood control projects, TXDOT road projects are listed in Table 12. The mean of construction schedule growth of TXDOT road projects is lower than that for other projects. The standard deviation of construction schedule growth of CCDPW flood control projects is greater than that for other projects.

Table 12. Descriptive statistics of construction schedule growth of various projects (%)

Projects	No. of Projects	Minimum	Maximum	Mean	Std. Deviation
CCDPW Road Projects	47	-36.67	100	21.18	24.28
CCDPW Flood Control Projects	11	-46.67	151.85	40.43	56.48
CCDPW Both Road and Flood Control Projects	58	-46.67	151.85	24.83	33.07
TXDOT Road Projects	17	0	66	10.18	15.71

5.3 Statistical Tests

5.3.1 Statistical Tests for Verification of Assumptions of the Correlation Analysis

Correlation tests were conducted for design cost (basic design cost as well as total design cost) with contract award cost growth, total cost growth, construction cost growth, and construction schedule growth; the results are discussed in Sections 5.5.

Before conducting correlation analysis, the assumptions of correlation analysis, such as the normality test, linearity test, heteroscedasticity test, and outliers test should be conducted.

5.3.1.1 Normality Test

The Anderson-Darling test was conducted to check the normality of the data distribution curves. This test assumes that the higher the p-value ($p > 0.05$), the better the normality of curve. The p-value of various metrics obtained from the Anderson-Darling test is presented in Table 13. The results show that data of contract award cost growth, and total cost growth of Clark County road projects are normally distributed. Similarly, basic design cost (%), total design cost (%), contract award cost growth (%), total cost growth (%), construction cost growth (%), construction schedule growth (%), basic design cost ($ million), and total project cost ($ million) of Clark County flood control projects are normally distributed. Combined Clark County road and flood control projects were tested, and it was found that total cost growth is normally distributed. The contract award cost growth (%), total cost growth (%), final construction cost growth ($ million), and total project cost ($ million) of the 17 TXDOT road projects are normally distributed. Also, the contract award cost growth (%) and total cost growth (%) of combined TXDOT and Clark County road projects are normally distributed.

Table 13. Anderson-Darling normality test results

P value of Normality Test					
	Clark County			TXDOT	TXDOT and Clark County
Metrics	Road Projects (N = 47)	Flood Control Projects (N = 11)	Road and Flood Control Projects (N = 58)	Road Projects (N = 17)	Road Projects (N = 64)
Basic Design Cost (%)	0.0005	0.38	0.0005	0.0005	0.0005
Total Design Cost (%)	0.0005	0.48	0.0005	NA	NA
Contract award cost growth (%)	0.21	0.51	0.047	0.18	0.08
Total Cost Growth (%)	0.31	0.89	0.141	0.08	0.08
Construction cost growth (%)	0.0005	0.84	0.0005	0.0005	0.0005
Construction Schedule growth (%)	0.035	0.55	0.0005	0.0005	0.0005
Final Construction Cost ($ M)	0.0005	0.024	0.0005	0.62	0.0005
Basic Design Cost ($ M)	0.0008	0.64	0.0005	0.0005	0.0005
Total Project Cost ($ M)	0.0005	0.06	0.0005	0.61	0.0005

Figure 27 shows the histogram of contract award cost growth for Clark County road projects. This histogram shows that the curve is normally distributed. The histograms with normality curves for other costs are listed in Appendix B.

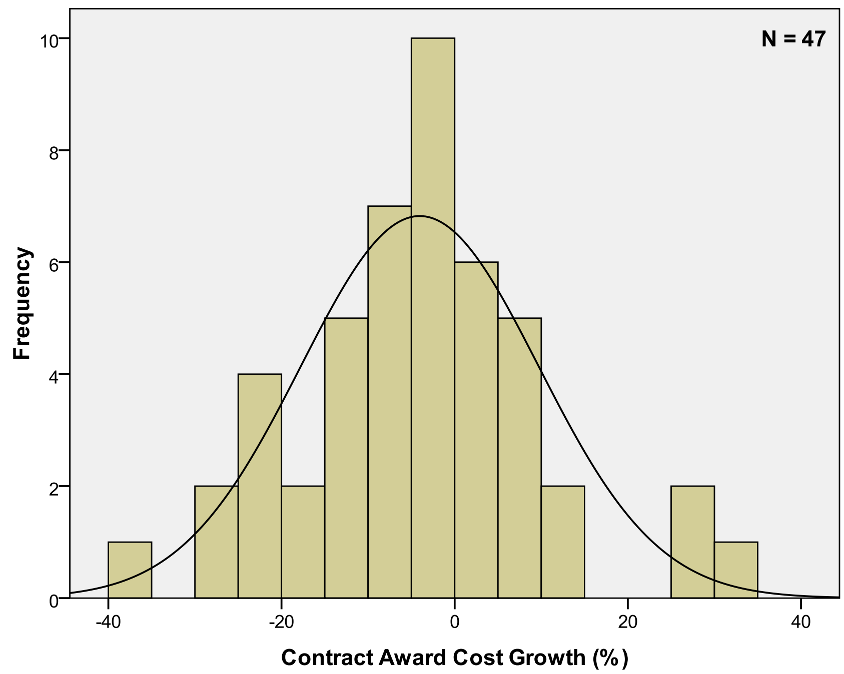

Figure 27. Histogram of contract award cost growth (%) of CCDPW road projects

5.3.1.2 Outliers Test

The outliers test can be conducted by box plots of the data set. Figure 28, which shows the box plot for the basic design cost (%) of Clark County flood control projects, indicates that all data lie within ranges, with no outliers. Similarly, there are no outliers for the basic design cost and total design cost of Clark County flood control projects. All box plots of various costs are listed in Appendix C.

Figure 28. Box plot of basic design cost (%) of CCDPW flood control projects

5.3.1.3 Linearity Test

Scatter plots of correlation between independent variable and its studentized residual was plotted to conduct linearity test. Figure 29 shows the scatter plot between total design cost and its studentized residual. The horizontal line in this scatter plot indicates the condition of linearity.

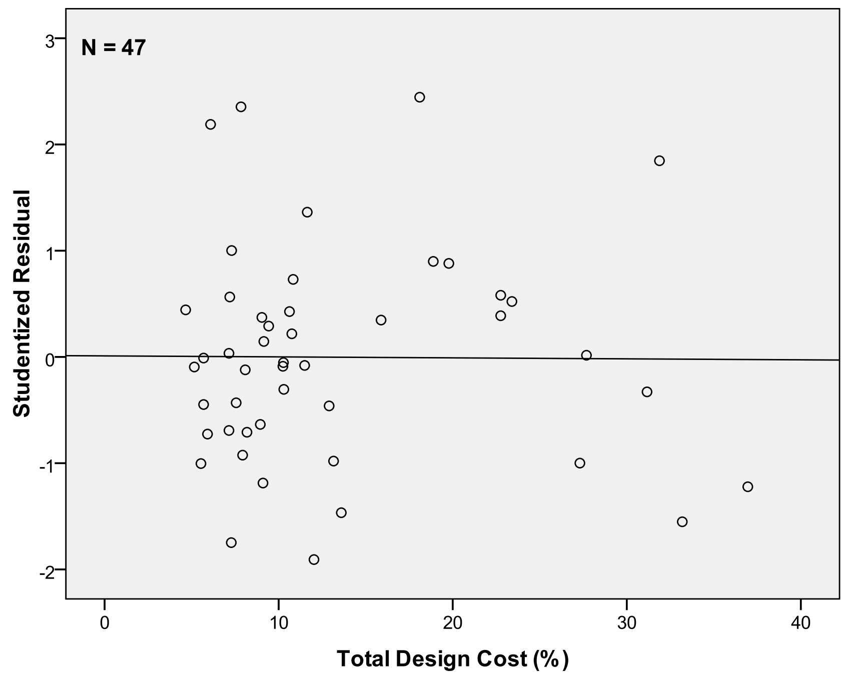

Figure 29.Residual plot with for total design cost for CCDPW road projects

5.3.1.4 Heteroscedasticity Test

Heteroscedasticity can be studied by plotting the predicted values against the residual values. After conducting regression analysis of total design cost and total cost growth, studentized residual and unstandardized predicted values were determined, and plotted a scatter diagram between predicted values and residual values, as shown in Figure 30. There is no constant variance in errors, indicating absence of homoscedasticity. Similarly, the studentized residual and unstandardized predicted values for other variables were plotted and analyzed for heteroscedasticity , as shown in Appendix F.

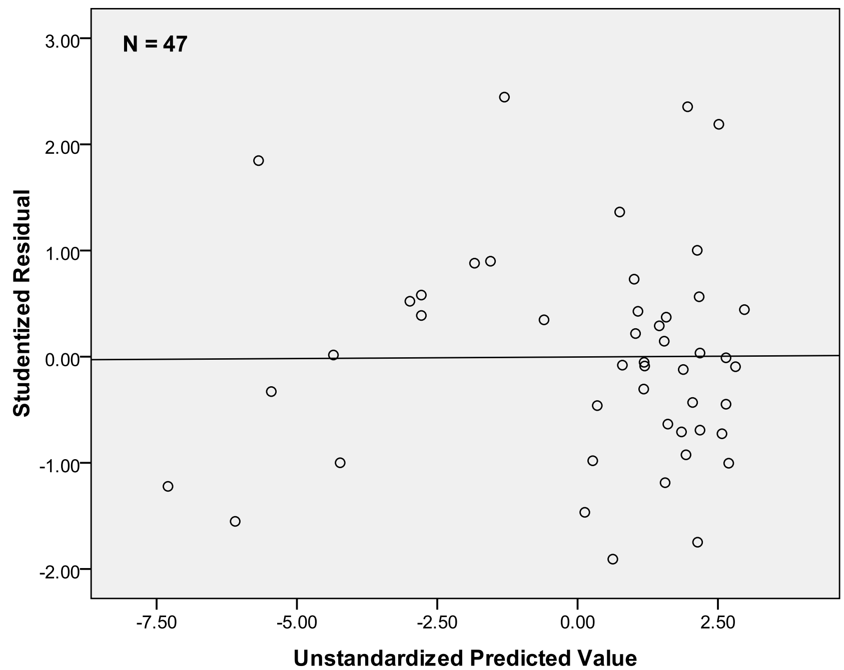

Figure 30.Residual plot with predicted value (for total design cost) for CCDPW road projects

5.3.2 Statistical Tests for Verification of Assumptions of Regression Analysis

Residual data analysis was conducted to determine the more precise prediction of dependent variables on the basis of the independent variables. The term “residual” is equal to the difference between the observed value of y and predicted value of y. It is also called the estimated error value (ε = *y* [redacted]). The assumptions of the linear regression model can be checked by residual analysis (Mendenhall and Sincich, 2007). For the residual analysis, the variables were transformed into their respective required forms, and then, a linear regression analysis was conducted with the transformed variables and residuals that were generated. To conduct this research, un-standardized predicted values and standardized residuals were studied to determine their sensitivity. The tests for the assumptions of the linear regression were performed from the data generated by the linear regression of the transformed variables. The residual value often provides information that can lead to modifications and improvements in a regression model. These modifications may result from any one of three reasons: (1) The deterministic component of the model has been mis-specified, (2) one or more of the assumptions about ε is violated, and (3) the data used to fit the model contain one or more unusual values (Mendenhall and Sincich 2007). The different checks performed are discussed in the following subsections.

5.3.2.1 Check for a Mis-specified Model

This is a method for analyzing the residuals in a regression analysis, which can be checked by plotting the each residual against the corresponding value of the independent variable. If there is more than one independent variable in the model, a plot would be constructed for each of the independent variables. If there is a random scatter around the zero line, then there is no relation between the residual and the independent variable. If a curvilinear pattern is observed, then a polynomial of the independent variable can probably improve the model's efficiency. Figure E- 4 shows the plot of residual versus basic design cost ($ million) of CCDPW road projects, to check for a mis-specified model. Similar scatter plots for other variables are shown in Appendix E.

5.3.2.2 Check for Heteroscedasticity / Unequal Variance

A plot of the residuals also can be used to check the assumption of a constant error variance. This error is called heteroscedastic. Relating to the sequence of random variables within the data set, in case of heteroscedasticity, the residual and predicted values of y shows a definitive pattern. From plotting the predicted values against the residual values, it may be observed that the value of the residuals increases with the increase of predicted values. In this case, different transformations on the independent variables should be implemented depending upon the nature of the plot. Poisson, Binomial, and Multiplicative are some commonly encountered transformations. A scatter plot is desirable to avoid any further transformations of variables. Figure F-2 shows the scatter plot between studentized residual and unstandardized predicted value for CCDPW road projects, to check heteroscedasticity. Similar scatter plots for other variables are shown in Appendix F.

5.3.2.3 Check for Non-normal Errors

Normality refers that the distribution of both variables is not skewed in either the positive or the negative direction. The distribution of errors can be tested by plotting a histogram of errors. Three statistical tests: the Kolmogorov-Smirnov test, the Anderson-Darling test, and the Shapiro-Wilk test can be used to check the normality of the sample distribution. In this study, the Anderson-Darling test is used to conduct the normality test. Moreover, the histogram-normality curve is plotted and compared with the results obtained from the Anderson-Darling test for validation.

The transformation of variables requires extremely skewed plots. The transformations, in this case, resemble the transformations in the previous case. Non-normality may also result, due to outliers. However, moderate departures from the assumption of normality have very little effect on the validity of the statistical tests, confidence intervals, and prediction intervals. Table 12 shows the results for Anderson-Darling test for regression model parameters, such as total design cost, basic design cost, and final construction cost.

5.3.2.4 Check for Correlated Errors

Whenever the data in the research corresponds to different time frames, a correlated errors check should be performed. If any pattern is observed in the plot of residuals against time, a time series analysis should be done to address the problem. In such conditions, the introduction of time variables can be helpful. A random scatter plot is useful to verify that the linear model is sufficient for the analysis. Figure I-1 shows the scatter plot between studentized residual and design contract year.

5.3.2.5 Check for outliers

Outliers are checked by locating residuals that lie a distance of 3s or more above or below 0 on a residual plot versus $\hat{y}$. An investigation should be conducted to determine the cause of any outlier before eliminating it. Those outliers found due to coding or recording error should be fixed or removed. Figure C-7 shows the box plot of basic design cost ($ million). The outlier was removed before developing a regression model. Similarly, box plot for other parameters are shown in Appendix C.

5.4 Correlation of Basic Design Cost with Other Metrics for Clark County Projects

The data was analyzed to determine the Pearson correlation coefficients of the basic design cost with the contract award cost growth, total cost growth, construction cost growth, and construction schedule growth for Clark County road and flood control projects. Two sets of analyses were done to determine the effect of basic design cost on contract award cost growth, total cost growth, construction cost growth, and construction schedule growth. The first analysis was conducted with all the sample data, and the second analysis was conducted by separating the data of road projects and flood control projects of Clark County, Nevada. The results of these analyses are described below.

5.4.1 Correlation between Basic Design Cost and Contract Award Cost Growth

The results of the correlation test between the basic design cost and contract award cost growth, presented in Table 14, indicate that there is a statistical relationship between these variables. The correlation between the basic design cost and contract award cost growth was found to be -0.062 for all projects. Also, the correlation between the basic design cost and contract award cost growth was found to be -0.221 for road projects. Though, these correlations were not significant at alpha level 0.1 for these samples, it showed a negative pattern. This indicates that the higher the cost expended in design, the lower the contract award cost growth. However, there was positive correlation between basic design cost and contract award cost growth for flood control projects.

Table 14. Pearson Correlation – Basic design cost versus contract award cost growth

Contract Award Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.062	-0.221	0.631**
Significance value (2-tailed)	0.644	0.135	0.037
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the bid cost and engineer's estimate. This showed that the higher design cost will improve the quality of design and will reduce errors in the design, resulting in the engineer's estimate to be accurate. Figure 31 shows the scatter plot of design cost and contract award cost growth of road projects. Figure D- 2 shows the scatter plot of basic design cost and contract award cost growth of CCDPW flood control projects. Figure D- 3 shows the scatter plot of basic design cost and contract award cost growth of combined road and flood control projects of Clark County public projects.

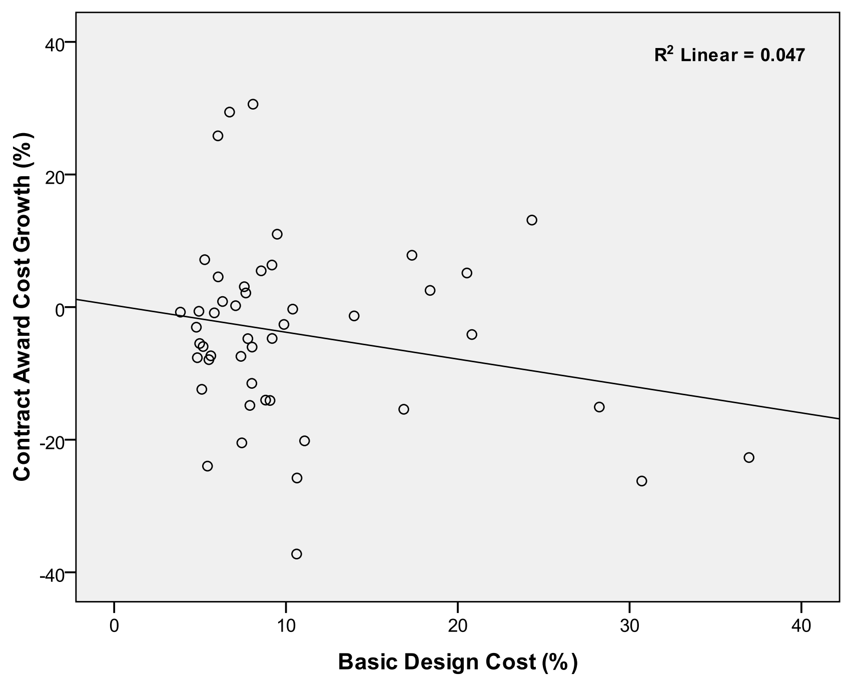

Figure 31. Scatter plot of basic design cost and contract award cost growth for road projects

5.4.2 Correlation between Basic Design Cost and Total Cost Growth

The results of the correlation test between the basic design cost and total cost growth, presented in Table 15, indicate that there is a statistical relationship between these variables. The correlation between the basic design cost and total cost growth was found to be -0.115 for all projects. Although the correlation was not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. Also, the correlation between the basic design cost and total cost growth was found to be -0.287 for road projects. This correlation was significant at alpha level 0.05 for this sample. This indicates that the relationship between the design cost and the total cost growth is a negative correlation, which indicates that the higher the cost expended in design, the lower the total cost growth, resulting in better cost performance. However, there was positive correlation between basic design cost and contract award cost growth for flood control projects.

Table 15. Pearson correlation – basic design cost versus total cost growth

Total Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.115	-0.287**	0.559*
Significance value (2-tailed)	0.389	0.05	0.074
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and the engineer's estimate. This showed that the higher design cost will improve the quality of design and will reduce errors in design resulting in the engineer's estimate to be accurate. Figure 32 shows the scatter plot of basic design cost and total cost growth for road projects. Figure D- 5 shows the scatter plot of basic design cost and total cost growth for flood control projects. Figure D- 6 shows the scatter plot of design cost and total cost growth for the combined road and flood control projects of Clark County public projects.

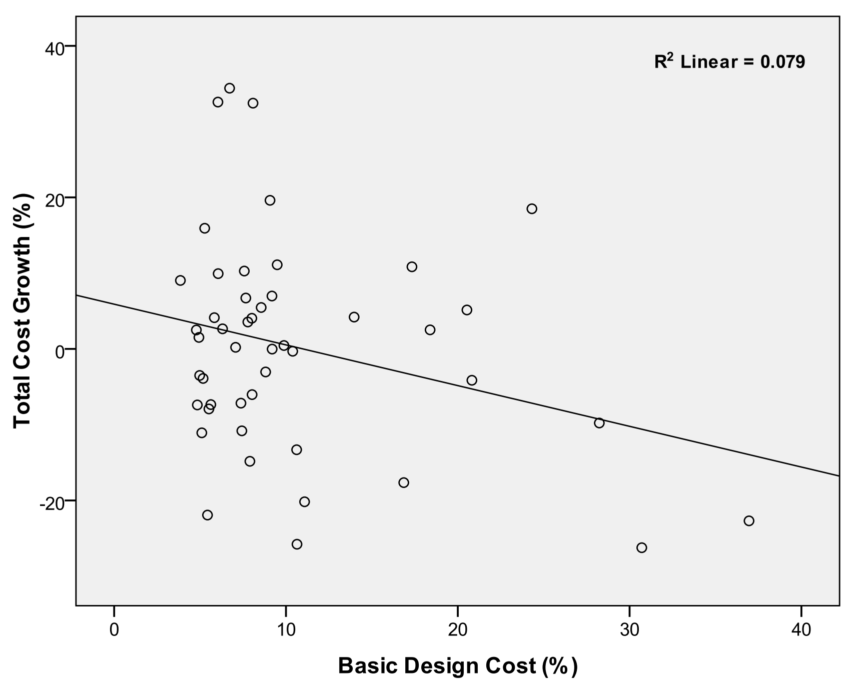

Figure 32. Scatter plot of basic design cost and total cost growth for road projects

5.4.3 Correlation between Basic Design Cost and Construction Cost Growth

The results of the correlation test between basic design cost and construction cost growth, presented in Table 16, indicate that there is a statistical relationship between these variables. The correlation between basic design cost and construction cost growth was found to be -0.110 for combined projects, -0.119 for road projects, and -0.163 for flood control projects. Although, the correlation values were not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the construction cost growth, resulting in better cost performance.

Table 16. Pearson correlation – basic design cost versus construction cost growth

Construction Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.110	-0.119	-0.163
Significance value (2-tailed)	0.411	0.425	0.632
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and construction contract cost. Figure D- 7 shows the scatter plot of basic design cost and construction cost growth for road projects. Figure 33 shows the scatter plot of design cost and construction cost growth for flood control projects. Figure D- 9 shows the scatter plot of design cost and construction cost growth for combined road and flood control projects of Clark County.

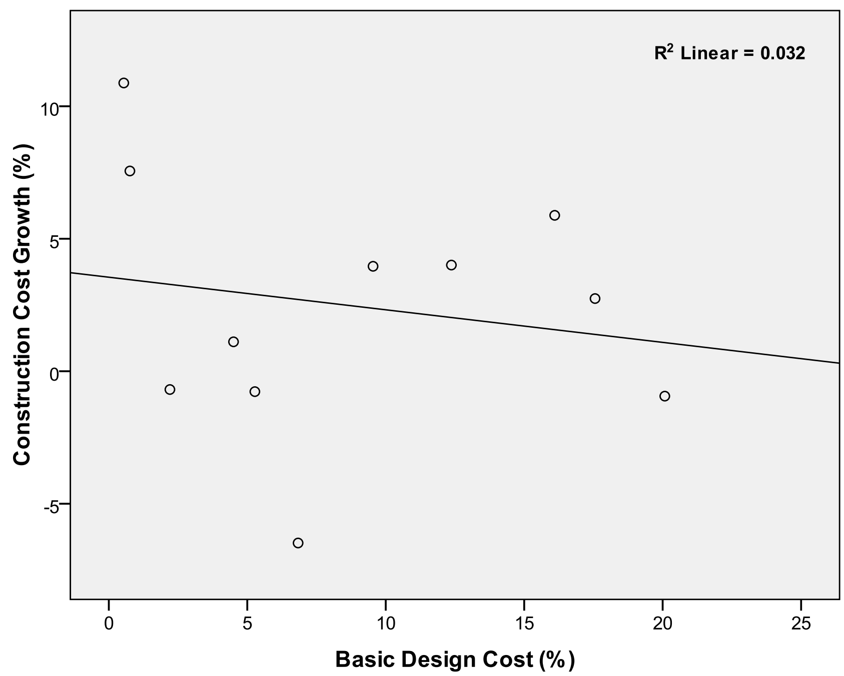

Figure 33. Scatter plot of basic design cost and construction cost growth of CCDPW flood control projects

5.4.4 Correlation between Basic Design Cost and Construction Schedule Growth

The results of the correlation test between the basic design cost and construction schedule growth, presented in Table 17, indicate that there is a statistical relationship between these variables. The correlation between the basic design cost and construction schedule growth was found to be -0.178 for all projects, -0.183 for road projects, and -0.159 for flood control projects. Although, the correlation values were not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the construction schedule growth, thus the better schedule performance.

Table 17. Pearson correlation – basic design cost versus construction schedule growth

Construction Schedule Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.178	-0.183	-0.159
Significance value (2-tailed)	0.182	0.219	0.640
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the schedule deviation between the final construction duration and construction contract duration. Figure D-10 shows the scatter plot of basic design cost and construction schedule growth of road projects. Figure D- 11 shows the scatter plot of basic design cost and construction schedule growth of flood control projects. Figure 34 shows the scatter plot of basic design cost and construction schedule growth of CCDPW combined road and flood control projects of Clark County public projects.

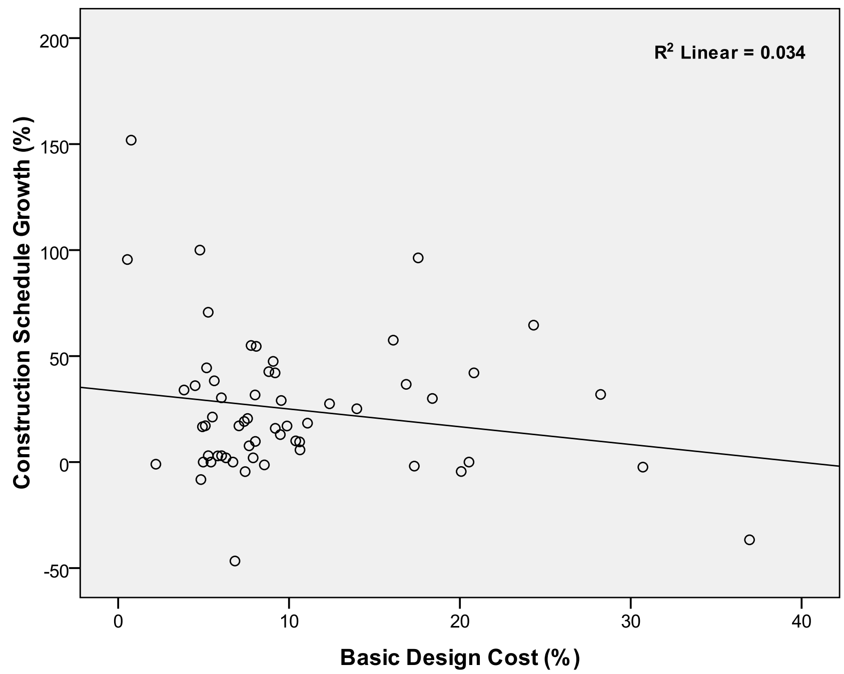

Figure 34. Scatter plot of basic design cost and construction schedule growth of combined CCDPW flood control and road projects

5.5 Correlation between Total Design Cost and Other Metrics for Clark County Projects

The data was analyzed to determine the Pearson correlation coefficients of the total design cost with the contract award cost growth, total cost growth, construction cost growth, and construction schedule growth for Clark County road and flood control projects. Two sets of analyses were done to determine the effect of total design cost on contract award cost growth, total cost growth, construction cost growth, and construction schedule growth. The first analysis was conducted with all the sample data, and the second analysis was conducted by separating the data of the road projects and the flood control projects of Clark County, Nevada. These analysis results are described below.

5.5.1 Correlation between Total Design Cost and Contract Award Cost Growth

The results of the correlation test between the total design cost and contract award cost growth, presented in Table 18, indicate that there is a statistical relationship between these variables. The correlation between the total design cost and contract award cost growth was found to be 0.024 for all projects, -0.129 for road projects, and 0.62 for flood control projects. Although the correlation value for road projects was not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the contract award cost growth, thus better cost performance.

Table 18. Pearson correlation – total design cost versus contract award cost growth

Contract Award Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	0.024	-0.129	0.620**
Significance value (2-tailed)	0.859	0.389	0.042
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the construction contract cost and engineer's estimated cost. Figure 35 shows the scatter plot of total design cost and contract award cost growth of road projects. Figure D- 14 shows the scatter plot of total design cost and contract award cost growth of flood control projects. Figure D- 15 shows the scatter plot of total design cost and contract award cost growth of combined road and flood control projects of Clark County.

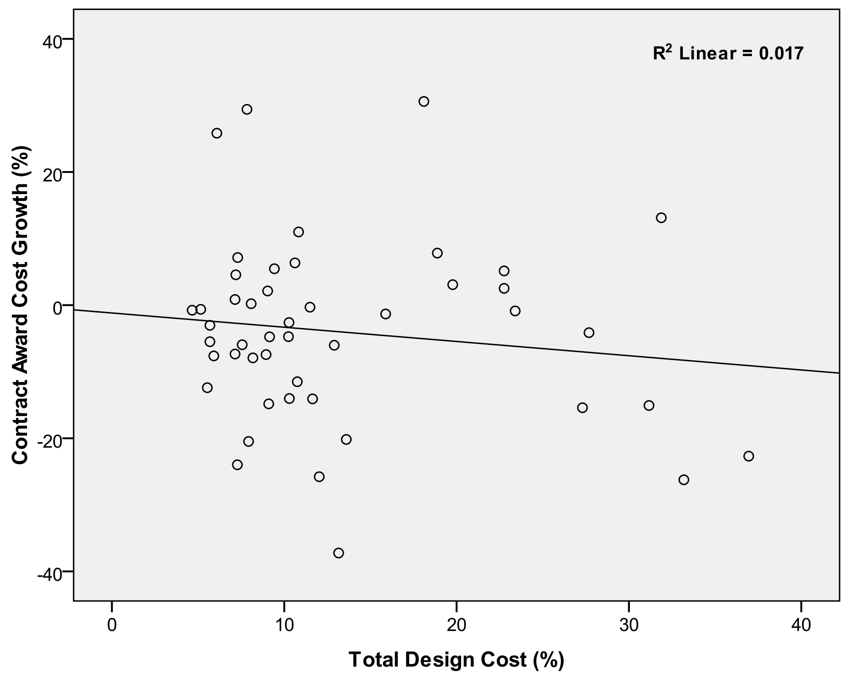

Figure 35. Scatter plot of total design cost and contract award cost growth of road projects

5.5.2 Correlation between Total Design Cost versus Total Cost Growth

The results of the correlation test between the total design cost and total cost growth, presented in Table 19, indicate that there is a statistical relationship between these variables. The correlation between the total design cost and total cost growth was found to be -0.011 for all projects, -0.192 for road projects, and 0.639 for flood control projects. Although the correlation value for road projects was not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the total cost growth, thus the better cost performance.

Table 19. Pearson correlation – total design cost versus total cost growth

Total Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.011	-0.192	0.639
Significance value (2-tailed)	0.937	0.195	0.034
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and engineer's estimated cost. Figure 36 shows the scatter plot of total design cost and total cost growth of CCDPW road projects. Figure D- 17 shows the scatter plot of total design cost and total cost growth of flood control projects. Figure D- 18 shows the scatter plot of total design cost and total cost growth of combined road and flood control projects of Clark County.

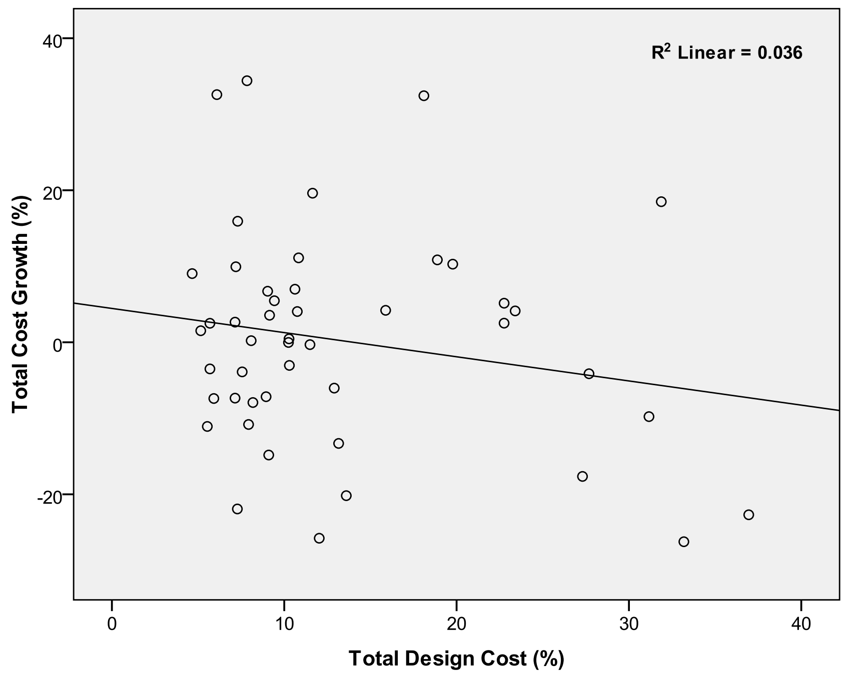

Figure 36. Scatter plot of total design cost and total cost growth of CCDPW road projects

5.5.3 Correlation between Total Design Cost versus Construction Cost Growth

The results of the correlation test between the total design cost and construction cost growth, presented in Table 20, indicate that there is a statistical relationship between these variables. The correlation between the total design cost and construction cost growth was found to be -0.075 for all projects, -0.115 for road projects, and 0.198 for flood control projects. Although the correlation values for all projects and road projects were not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the construction cost growth, thus better cost performance.

Table 20. Pearson correlation – total design cost versus construction cost growth

Construction Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.075	-0.115	0.198
Significance value (2-tailed)	0.577	0.442	0.559
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and construction contract cost. Figure 37 shows the scatter plot of total design cost and construction cost growth of road projects. Figure D 20 shows the scatter plot of total design cost and construction cost growth of flood control projects. Figure D 21 shows the scatter plot of total design cost and construction cost growth of combined road and flood control projects of Clark County.

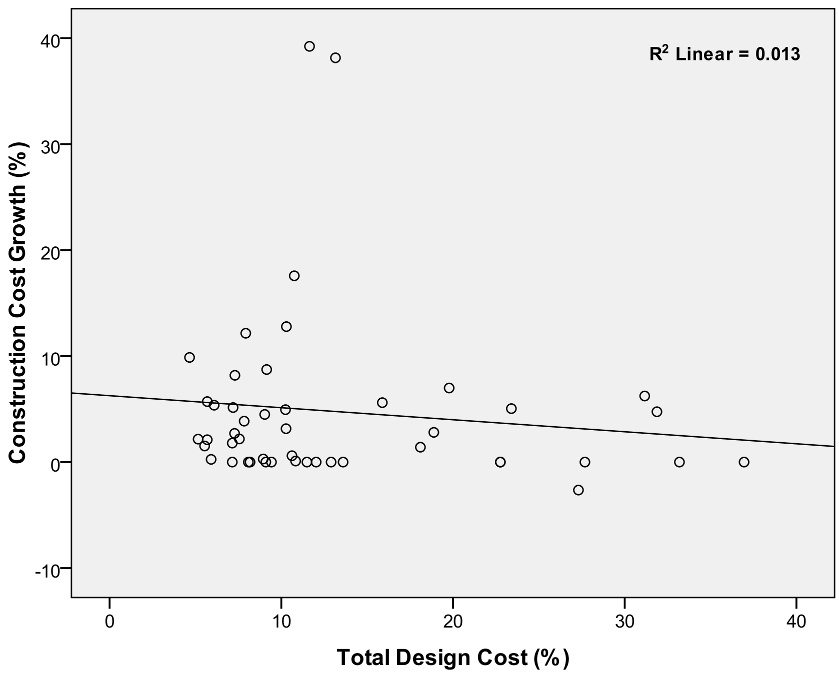

Figure 37. Scatter plot of total design cost and construction cost growth of CCDPW road projects

5.5.4 Correlation between Total Design Cost versus Construction Schedule Growth

The results of the correlation test between the total design cost and construction schedule growth, presented in Table 21, indicate that there is a statistical relationship between these variables. The correlation between the total design cost and construction schedule growth was found to be -0.042 for all projects, -0.080 for road projects, and 0.054 for flood control projects. Although the correlation values for all projects and road projects were not significantly correlated at alpha level 0.1 for this sample, it showed a negative correlation. This indicates that the higher the cost expended in design, the lower the construction cost growth, thus the better cost performance.

Table 21. Pearson correlation – total design cost versus construction schedule growth

Construction Schedule Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 47)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	-0.042	-0.080	0.054
Significance value (2-tailed)	0.754	0.595	0.874
Number of sample (N)	58	47	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the schedule deviation between the final construction duration and construction contract duration. Figure D- 22 shows the scatter plot of total design cost and construction schedule growth of road projects. Figure D- 23 shows the scatter plot of total design cost and construction schedule growth of flood control projects. Figure D- 24 shows the scatter plot of total design cost and construction schedule growth of combined road and flood control projects of Clark County.

5.6 Regression Model of Basic Design Cost with Final Construction Cost

The data set of basic design cost and final construction cost were tested for assumption of correlation. From the box plot, one extreme outlier was removed, and the correlation analysis conducted. Out of 47 Clark County road projects, only 46 projects were considered for further analysis. The correlation test was conducted between basic design cost ($ million) and final construction cost ($ million), result is shown in Table 22, and indicates that there is a significant statistical relationship between these variables.

The correlation between the basic design cost and final construction cost was found to be 0.8 for Clark County road projects. The correlation was significant at alpha level 0.01 for this sample. This indicates that the relationship between the design cost and the total cost growth is a positive correlation, which indicates that the higher the cost expended in design, the higher the final construction cost.

Table 22. Pearson correlation – basic design cost versus final construction cost

Final Construction Cost	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 46)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	0.75**	0.80**	0.015
Significance value (2-tailed)	0.0001	0.0001	0.965
Number of sample (N)	58	46	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

In considering the Clark County road projects (N = 46), mis-specified model, heteroscedasticity, and non-normal and correlated errors checks were performed; data were re-plotted as per regression model assumptions. The scatter plot between the unstandardized residual and basic design cost ($ million) is shown in Figure E- 3. Also, the scatter plot between the studentized residual plot and basic design cost ($ million) is shown in Figure E- 4. The studentized residual versus the unstandardized predicted value scatter plot is shown in Figure F- 2. The histogram of the residuals shows the normal distribution of data as shown in Figure G- 2. The plot in Figure H-1 shows that almost all the data point lie between the 95% confidence interval lines. The predicted points and the historical points for basic design cost ($ million) both lie along the diagonal line. Therefore, the linear regression model was found acceptable for expressing this relation. Figure 38 shows the scatter plot between basic design cost and final construction cost for CCDPW road projects. R-square value of the model found to be 62.30%.

Mathematically, the regression equation for Clark County road project is expressed in Equation 19. In this equation, final construction cost and basic design cost are expressed in terms of $ million.

Final Construction Cost [redacted].58 *x Basic Design Cost* [redacted].8 (19)

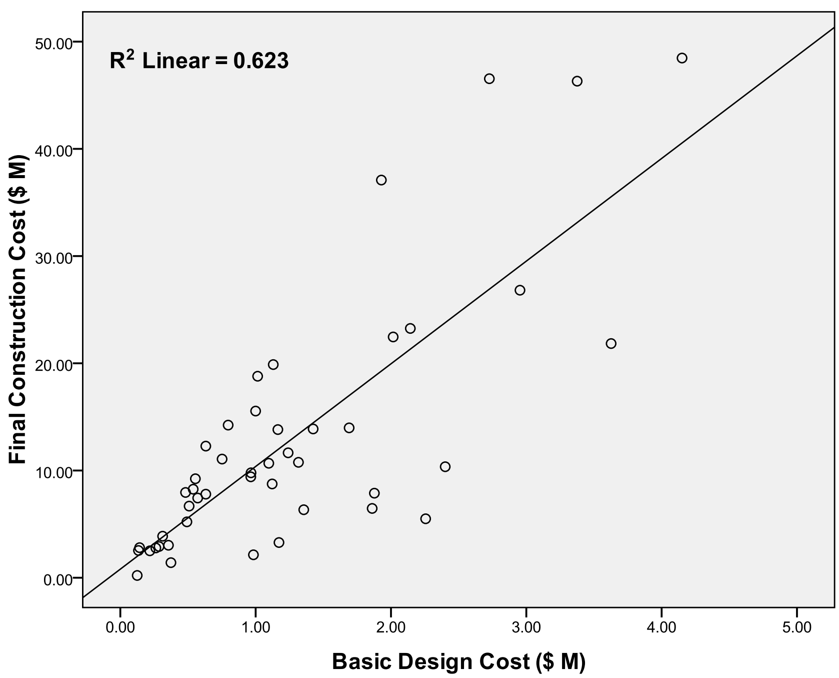

Figure 38. Scatter plot of basic design cost versus final construction cost for CCDPW road projects (N = 46)

In case of Clark County flood control projects (N = 11), the correlation value between basic design cost and final construction cost was insignificant, and the number of samples was very few. Therefore, further analysis was not conducted for this sample.

Additionally, for combined Clark County road and flood control projects (N = 58), mis-specified model, heteroscedasticity, and non-normal and correlated errors checks were performed; data were re-plotted as per regression model assumptions. The scatter plot between unstandardized residual and basic design cost ($ million) is shown in Figure E- 5. Also, the scatter plot between studentized residual plot and basic design cost ($ million) is shown in Figure E- 6. Studentized residual versus unstandardized predicted value scatter plot is shown in Figure F- 3. The histogram of the residuals shows the normal distribution of data as shown in Figure G- 3. The plot in Figure H-3 shows that almost all the data point lie between the 95% confidence interval lines. The predicted points and the historical points for basic design cost ($ million) points both lie along the diagonal line. Therefore, the linear regression model was found acceptable for expressing this relation. Figure 39 shows the scatter plot between basic design cost and final construction cost of CCDPW combined road and flood control projects. R-square value of the model found to be 55.60%.

Mathematically, the regression equation for combined Clark County road and flood control projects is expressed in Equation 20. In this equation, final construction cost and basic design cost are expressed in terms of $ million.

Final Construction Cost [redacted].7 *x Basic Design Cost* [redacted].46 (20)

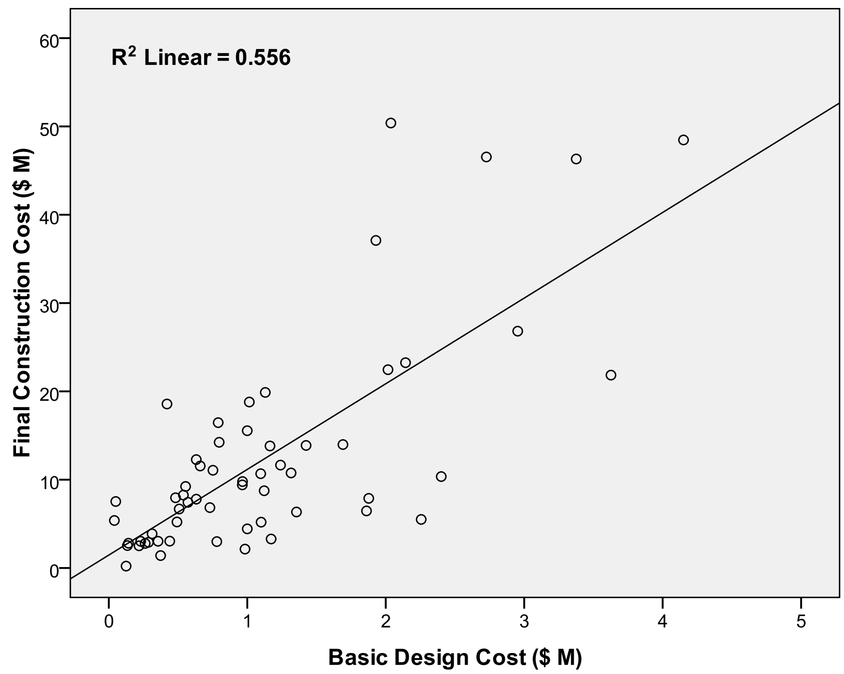

Figure 39. Scatter plot of basic design cost versus final construction cost for combined CCDPW road and flood control projects (N = 58)

5.7 Regression Model of Total Design Cost with Final Construction Cost

The data set of total design cost and final construction cost were tested for assumption of correlation. From the box plot, on extreme outlier was removed, and the correlation analysis was conducted. Out of 47 Clark County road projects, only 46 projects were considered for further analysis. The correlation test was conducted between total design cost ($ million) and final construction cost ($ million). The result shown in Table 23, indicates that there is a significant statistical relationship between these variables. The correlation between the total design cost and final construction cost was found to be 0.75 for Clark County road projects. The correlation was significant at alpha level 0.01 for this sample. This also indicates that the relationship between the design cost and the total cost growth is a positive correlation, which indicates that the higher the cost expended in design, the higher the final construction cost.

Table 23. Pearson correlation – total design cost versus final construction cost

Final Construction Cost	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 58)	Road Projects (N= 46)	Flood Control Projects (N=11)
Pearson Correlation Coefficient	0.71***	0.75***	0.00
Significance value (2-tailed)	0.0001	0.0001	0.998
Number of sample (N)	58	46	11

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

In considering the Clark County road projects (N = 46), the mis-specified model, heteroscedasticity, and non-normal and correlated errors checks were performed, and the data were re-plotted as per regression model assumptions. The scatter plot between unstandardized residual and total design cost ($ million) is shown in Figure E- 1. Also, the scatter plot between studentized residual plot and total design cost ($ million) is shown in Figure E- 2. Studentized residual versus unstandardized predicted value scatter plot is shown in Figure F- 1. The histogram of the residuals shows the normal distribution of data as shown in Figure G- 1. The plot in Figure H-2 shows that almost all the data points lie between the 95% confidence interval lines. The predicted points and the historical points for total design cost ($ million) points both lie along the diagonal line. Therefore, the linear regression model was found acceptable for expressing this relation.

Figure 40 shows the scatter plot between total design cost and final construction cost of CCDPW road projects. R-square value of the model found to be 55.80%.

Mathematically, the regression equation for Clark County road projects is expressed in Equation 21. In this equation, final construction cost and total design cost are expressed in terms of $ million.

Final Construction Cost [redacted].37 *x Total Design Cost* [redacted].01 (21)

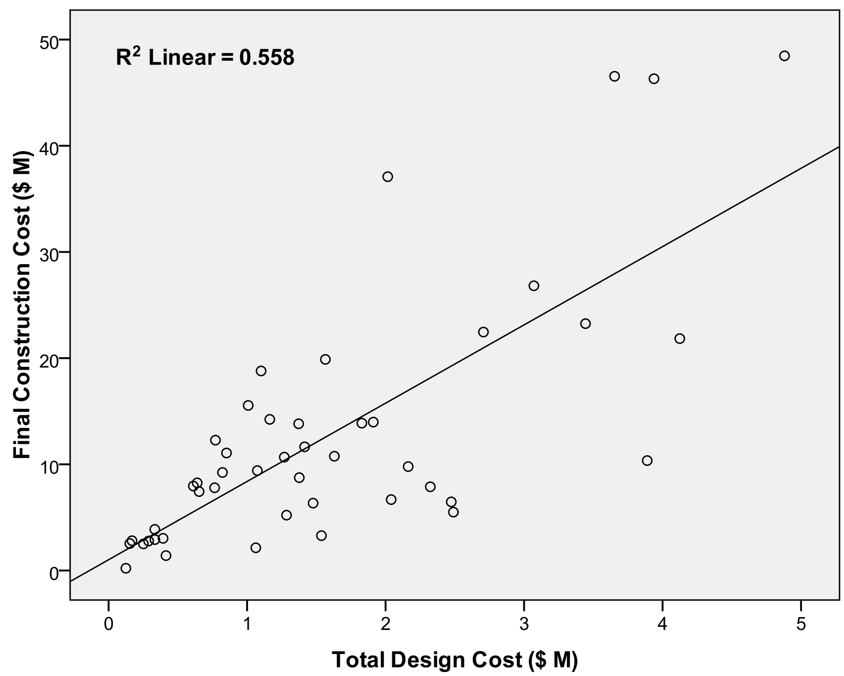

Figure 40. Scatter plot of total design cost versus final construction cost for CCDPW road projects (N = 46)

In case of Clark County flood control projects (N = 11), the correlation value between total design cost and final construction cost was insignificant, and the number of the samples was very few. Therefore, further analysis was not conducted for this sample.

In considering the combined Clark County road and flood control projects (N = 58), the mis-specified model, heteroscedasticity, and non-normal and correlated errors checks were performed and the data were re-plotted as per regression model assumptions. The scatter plot between unstandardized residual and total design cost ($ million) is shown in Figure E- 7. Also, the scatter plot between studentized residual plot and total design cost ($ million) is shown in Figure E- 8. Studentized residual versus unstandardized predicted value scatter plot is shown in Figure F- 4. The histogram of the residuals shows the normal distribution of data as shown in Figure G- 4. The plot in Figure H- 4 shows that almost all the data points lie between the 95% confidence interval lines. The predicted points and the historical points for the total design cost ($ million) both lie along the diagonal line. Therefore, the linear regression model was found acceptable for expressing this relation. Figure 41 shows scatter plot between total design cost and final construction cost for CCDPW road and flood control projects. R-square value of the model found to be 49.80%.

Mathematically, the regression equation for combined Clark County road and flood control project is expressed in Equation 22. In this equation, the final construction cost and the total design cost are expressed in terms of $ million.

Final Construction Cost [redacted]7.53 *x Total Design Cost* [redacted].41 (22)

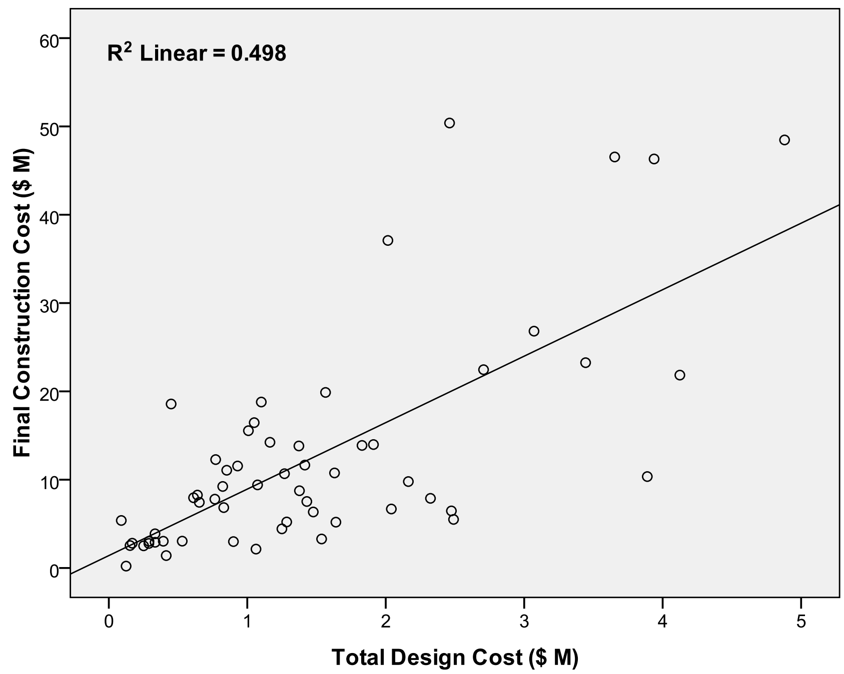

Figure 41. Scatter plot of basic design cost versus final construction cost for combined CCDPW road and flood control projects (N = 58)

CHAPTER 6

COMPARISON BETWEEN CLARK COUNTY AND TEXAS DOT DATA

The main objective of this chapter is to compare the regression models of Clark County public road projects and Texas Department of Transportation road projects. If both of them are statistically significant, then the models can be validated. By using design cost as an independent variable for similar kind of projects, the validated models can be used to predict dependent variables, such as contract award cost growth, total cost growth, construction cost growth, and construction schedule metrics.

Clark County public road projects and Texas Department of Transportation road projects were analyzed separately. The Pearson correlations of basic design cost with cost growth and schedule growth are described in detail in this chapter. The same analysis procedure is followed for combined Clark County public road and Texas DOT road projects. The correlation and regression analyses between total design cost and other parameters were not able to be performed due to unavailability of total design cost for Texas DOT road projects.

6.1 Correlation between Basic Design Cost and Other Metrics for CCDPW Projects

6.1 .1 Correlation between Basic Design Cost and Contract Award Cost Growth

The correlation test was conducted between the basic design cost and contract award cost growth for road projects, as shown in Table 24. The correlation value between these variables was -0.322 for all projects, -0.221 for Clark County road projects, and -0.501 for Texas DOT road projects. These relationships were statistically significant at alpha level 0.05 for all road projects (combined Clark County and Texas DOT road projects) and Texas DOT road projects. The negative correlation indicates that the higher the cost expended in design, the lower the contract award cost growth. The TXDOT road projects correlation value was higher than that for Clark County public road projects.

Table 24. Pearson correlation – basic design cost versus contract award cost growth

Contract Award Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 64)	Clark County Road Projects (N= 47)	TXDOT Road Projects (N=17)
Pearson Correlation Coefficient	-0.322***	-0.221	-0.501**
Significance value (2-tailed)	0.010	0.135	0.041
Number of sample (N)	64	47	17

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the bid cost and engineer's estimate. This showed that the higher design cost will improve the quality of design, and will reduce errors in design, resulting in the engineer's estimate to be accurate. Figure D- 29 shows the scatter plot of basic design cost and contract award cost growth of all road projects. Figure D- 1 shows the scatter plot of basic design cost and contract award cost growth of Clark County road projects. Figure 42 shows the scatter plot of basic design cost and contract award cost growth of TXDOT road projects.

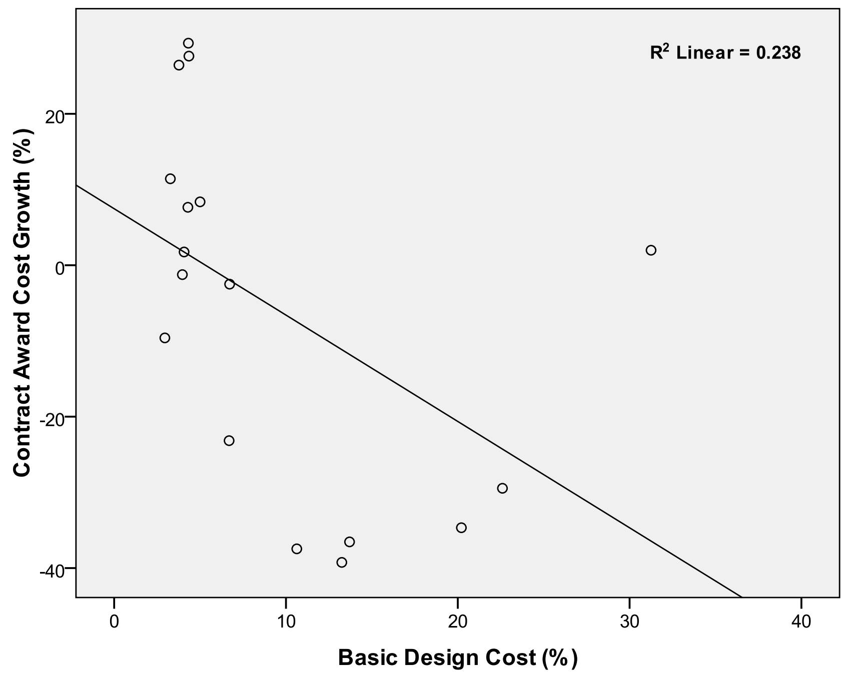

Figure 42. Scatter plot of basic design cost and contract award cost growth for TXDOT road projects

6.1.2 Correlation between Basic Design Cost and Total Cost Growth

The correlation test was conducted between the basic design cost and total cost growth for road projects, as shown in Table 25. The correlation value between these variables was -0.332 for all projects, -0.287 for Clark County road projects, and -0.424 for Texas DOT road projects. These relationships were statistically significant at alpha level 0.05. The negative correlation indicates that the higher the cost expended in design, the lower the total cost growth. The TXDOT road projects correlation value was higher than that of Clark County public road projects, but, Clark County road projects were more significant.

Table 25. Pearson correlation – basic design cost versus total cost growth

Total Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 64)	Clark County Road Projects (N= 47)	TXDOT Road Projects (N=17)
Pearson Correlation Coefficient	-0.332**	-0.287**	-0.424*
Significance value (2-tailed)	0.007	0.05	0.090
Number of sample (N)	64	47	17

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and the engineer's estimate. Figure D-30 shows the scatter plot of basic design cost and total cost growth of all road projects. Figure D- 4 shows the scatter plot of basic design cost and total cost growth of Clark County road projects. Figure 43 shows the scatter plot of basic design cost and total cost growth of TXDOT road projects.

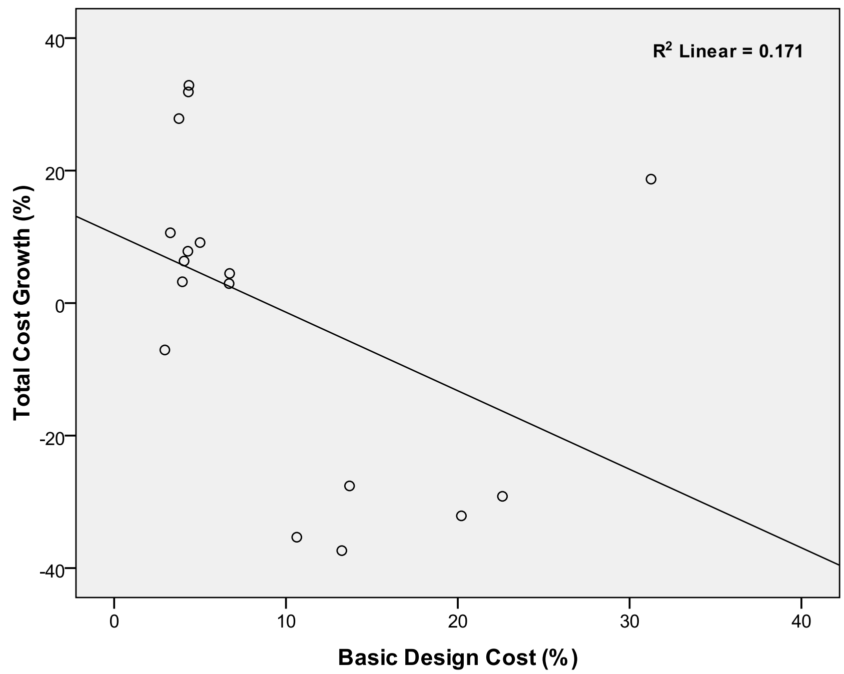

Figure 43. Scatter plot of basic design cost and total cost growth for TXDOT road projects

6.1.3 Correlation between Basic Design Cost and Construction Cost Growth

The correlation test was conducted between the basic design cost and construction cost growth for road projects, as shown in Table 26. The correlation value between these variables was -0.025 for all projects, -0.119 for Clark County road projects, and 0.224 for Texas DOT road projects. Although these relationships were not statistically significant at alpha level 0.1, the negative correlation indicates that the higher the cost expended in design, the lower the construction cost growth.

Table 26. Pearson correlation – basic design cost versus construction cost growth

Construction Cost Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 64)	Clark County Road Projects (N= 47)	TXDOT Road Projects (N=17)
Pearson Correlation Coefficient	-0.025	-0.119	0.224
Significance value (2-tailed)	0.846	0.425	0.387
Number of sample (N)	64	47	17

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the cost deviation between the final construction cost and construction contract cost. Figure D- 31 shows the scatter plot of basic design cost and construction cost growth of all road projects. Figure D- 7 shows the scatter plot of basic design cost and construction cost growth of Clark County road projects. Figure 44 shows the scatter plot of basic design cost and construction cost growth of TXDOT road projects.

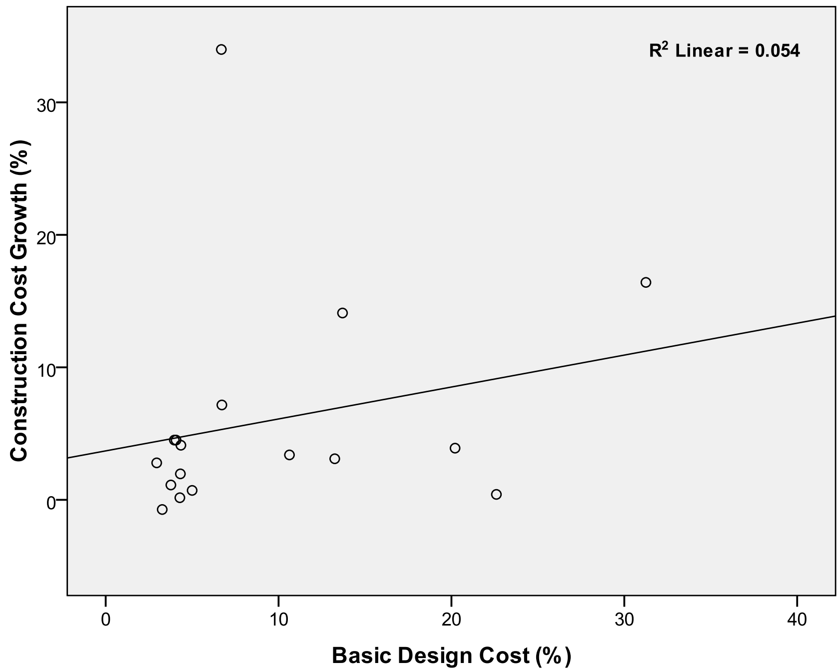

Figure 44. Scatter plot of basic design cost and construction cost growth for TXDOT road projects

6.1.4 Correlation between Basic Design Cost and Construction Schedule Growth

The correlation test was conducted between the basic design cost and construction schedule growth for road projects, as shown in Table 27. The correlation value between these variables was -0.143 for all projects, -0.183 for Clark County road projects, and -0.098 for Texas DOT road projects. Although these relationships were not statistically significant at alpha level 0.1, the negative correlation indicates that the higher the cost expended in design, the lower the construction schedule growth.

Table 27. Pearson correlation – basic design cost versus construction schedule growth

Construction Schedule Growth	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 64)	Clark County Road Projects (N= 47)	TXDOT Road Projects (N=17)
Pearson Correlation Coefficient	-0.143	-0.183	-0.098
Significance value (2-tailed)	0.260	0.219	0.709
Number of sample (N)	64	47	17

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

This investigation revealed that the higher the cost expended in the design, the lower the schedule deviation between the final construction duration and construction contract duration. Figure D- 32 shows the scatter plot of basic design cost and construction schedule growth of all road projects. Figure D- 10 shows the scatter plot of basic design cost and construction schedule growth of Clark County road projects. Figure 45 shows the scatter plot of basic design cost and construction schedule growth of TXDOT road projects.

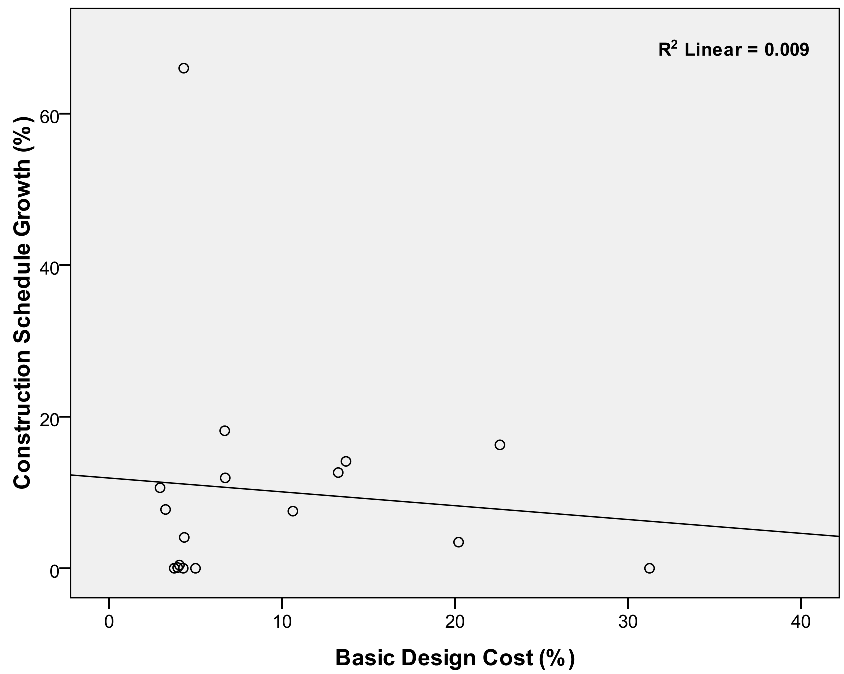

Figure 45. Scatter plot of basic design cost and construction schedule growth for TXDOT road projects

6.2 Regression Model of Basic Design Cost with Final Construction Cost

The data set of basic design cost and final construction cost were tested for assumption of correlation. From the box plot, two extreme outliers were removed and correlation analysis conducted. Out of 47 Clark County road projects, only 46 projects were considered for further analysis, and, out of 17 Texas Department of Transportation road projects, only 16 projects were considered for further analysis. A correlation test was conducted between basic design cost ($ million) and final construction cost ($ million); the result, shown in Table 28, indicates that there is a significant statistical relationship between these variables. The correlation between the basic design cost and final construction cost was found to be 0.80 for Clark County road projects. The correlation was significant at alpha level 0.01 for this sample. This indicates that the relationship between the basic design cost and the final construction cost is a positive correlation, which further indicates that the higher the cost expended in design, the higher the final construction cost.

Table 28. Pearson correlation – basic design cost versus final construction cost

Final Construction Cost	Pearson Correlation Coefficient / Significance Value		
	All Projects (N= 62)	Clark County Road Projects (N= 46)	TXDOT Road Projects (N=16)
Pearson Correlation Coefficient	0.81**	0.80**	0.256
Significance value (2-tailed)	0.0001	0.0001	0.338
Number of sample (N)	62	46	16

* Significant at alpha level 0.05 (2-tailed)
** Significant at alpha level 0.01 (2-tailed)

Considering both Clark County and TXDOT road projects (N = 62), mis-specified model, heteroscedasticity, and non-normal and correlated errors checks were performed, and the data were re-plotted as per regression model assumptions. The scatter plot between unstandardized residual and basic design cost ($ million) is shown in Figure E-9. Also, the scatter plot between studentized residual plot and basic design cost ($ million) is shown in Figure E- 10. Studentized residual versus unstandardized predicted value scatter plot is shown in Figure F- 5. The histogram of the residuals shows the normal distribution of data, as shown in Figure G- 5. The plot in Figure H-5 shows that almost all the data points lie between the 95% confidence interval lines. The predicted points and the historical points for the basic design cost ($ million) both lie along the diagonal line. Therefore, the linear regression model was found acceptable for expressing this relation. Figure 46 shows the scatter plot between basic design cost and final construction cost for both CCDPW and TXDOT road projects. R-square value for this model was found to be 63.60%.

Mathematically, the regression equation for both Clark County and TXDOT road projects is expressed in Equation 23. In this equation, final construction cost and basic design cost is expressed in terms of $ million.

Final Construction Cost [redacted] 3.44 *x Basic Design Cost* [redacted] .90 (23)

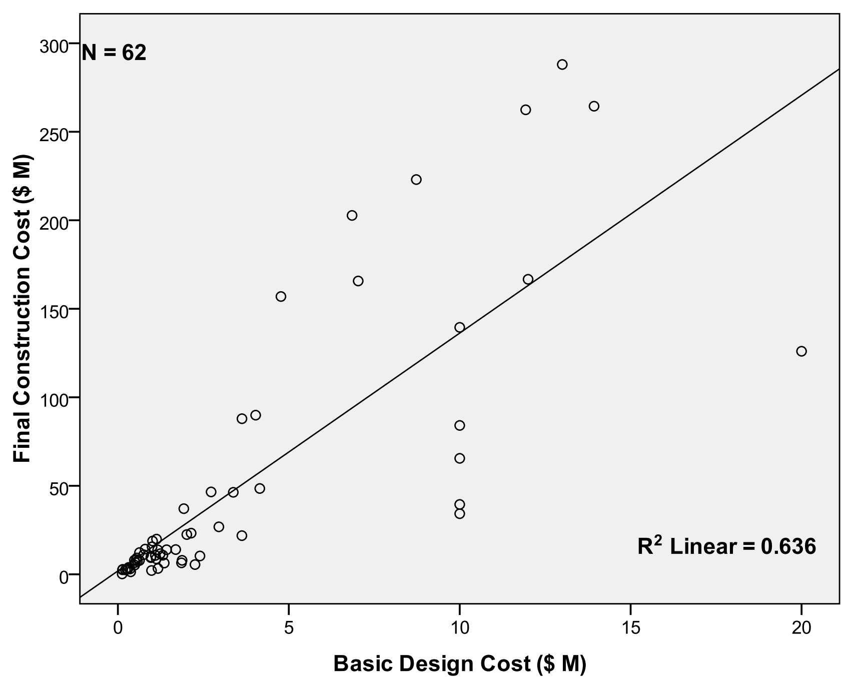

Figure 46. Scatter plot of basic design cost versus final construction cost for both CCDPW and TXDOT road projects (N = 62).

For TXDOT road projects, the correlation coefficient was not significant. This might be due to insufficient data. Therefore, further analysis was not conducted for this data.

The regression model for data from Clark County road projects was described in Section 5.6 (Chapter 5). The correlation coefficient obtained for the combined TXDOT and Clark County road projects was nearly same as that for Clark County road projects only. This result validates the finding of this research.

Table 29 describes the summary of Pearson correlation coefficients of the basic design cost (%) with various metrics. There are negative correlations between the basic design costs with almost all the metrics.

Table 29. Summary of pearson correlation – basic design cost (%) with other metrics

Metrics	Clark County			TXDOT	TXDOT and Clark County
	Road Projects (N = 47)	Flood Control Projects (N = 11)	Road and Flood Control Projects (N = 58)	Road Projects (N = 17)	Road Projects (N = 64)
Contract award cost growth	-0.221	0.631	-0.062	-0.501**	-0.322***
Significance Value (2-tailed)	0.135	0.037	0.644	0.041	0.01
Total Cost Growth	-0.287**	0.559	-0.115	-0.424*	-0.332***
Significance Value (2-tailed)	0.05	0.074	0.389	0.090	0.007
Construction cost growth	-0.119	-0.163	-0.110	0.224	-0.025
Significance Value (2-tailed)	0.425	0.632	0.411	0.387	0.846
Construction Schedule growth	-0.183	-0.159	-0.178	-0.098	-0.143
Significance Value (2-tailed)	0.219	0.640	0.182	0.709	0.260

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

Table 30 describes the summary of Pearson correlation coefficients of total design cost (%) with various metrics. There are negative correlations between the total design cost with almost all the metrics. Due to the unavailability of TXDOT road projects data, the correlation analysis was not conducted.

Table 30. Summary of pearson correlation – total design cost (%) with other metrics

Metrics	Clark County			TXDOT	TXDOT and Clark County
	Road Projects (N = 47)	Flood Control Projects (N = 11)	Road and Flood Control Projects (N = 58)	Road Projects (N = 17)	Road Projects (N = 64)
Contract award cost growth	-0.129	0.620	0.024	NA	NA
Significance Value (2-tailed)	0.389	0.042	0.859	NA	NA
Total Cost Growth	-0.192	0.639	-0.011	NA	NA
Significance Value (2-tailed)	0.195	0.034	0.937	NA	NA
Construction cost growth	-0.115	0.198	-0.075	NA	NA
Significance Value (2-tailed)	0.442	0.559	0.577	NA	NA
Construction Schedule growth	-0.080	0.054	-0.042	NA	NA
Significance Value (2-tailed)	0.595	0.874	0.754	NA	NA

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

Table 31 describes the summary of Pearson correlation coefficients of basic design cost ($ million) with various metrics. There are significant positive correlations between basic design cost with almost all the metrics.

Table 31. Summary of pearson correlation – basic design cost ($ M) and final construction cost

Metrics	Clark County			TXDOT	TXDOT and Clark County
	Road Projects (N = 46)	Flood Control Projects (N = 11)	Road and Flood Control Projects (N = 58)	Road Projects (N = 17)	Road Projects (N = 62)
Final Construction Cost	0.80***	0.015	0.75***	0.256	0.81***
Significance Value (2-tailed)	0.0001	0.965	0.0001	0.338	0.0001

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

Table 32 describes the summary of Pearson correlation coefficients of total design cost ($ million) with various metrics. There are significant positive correlations between the total design costs with almost all the metrics. Due to the unavailability of TXDOT road projects data, the correlation analysis was not conducted.

Table 32. Summary of pearson correlation – total design cost ($ M) and final construction cost

Metrics	Clark County			TXDOT	TXDOT and Clark County
	Road Projects (N = 46)	Flood Control Projects (N = 11)	Road and Flood Control Projects (N = 58)	Road Projects (N = 17)	Road Projects (N = 62)
Final Construction Cost	0.75***	0.001	0.71***	NA	NA
Significance Value (2-tailed)	0.0001	0.998	0.0001	NA	NA

* Significant at alpha level 0.10 (2-tailed)
** Significant at alpha level 0.05 (2-tailed)
*** Significant at alpha level 0.01 (2-tailed)

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Basically, this study tested five hypotheses. However, for the sake of simplicity, design cost was divided into two headings – basic design cost and total design cost. Therefore, ten research hypotheses were developed, which were stated in Table 1 and Table 2 in Section 1.3. However, significant results were not found for correlation among total design cost with cost growth and schedule growth parameters, they showed simply a trend of negative relationships. Therefore, the findings for only basic design cost are discussed in this chapter.

The first hypothesis deals with the relationship between basic design cost and total cost growth, which was proved to be true for Clark County road projects. This hypothesis was also found to be true in TXDOT road projects on one hand. On the other hand, the combined TXDOT and Clark County road projects were analyzed. This analysis result also proved the first hypothesis of the study. Pearson Coefficient for Clark County road projects and TXDOT projects were -0.287 and -0.424 respectively. In case of combined TXDOT and Clark County road projects, the coefficient value was -0.332. The correlation was found to be negative. This result showed that during the design phase, the owner must make sure that enough resources are expended to prepare a quality design, so that there will be low total cost growth during the construction. It also indicates that if the public owners expended enough resources to prepare high quality design drawings and documents, then the contractor will complete the project near to the engineer's estimate. Because public work projects are funded by the taxpayers, it is necessary that the owner should complete the projects within a reasonable cost.

When the data is divided for Clark County road projects and TXDOT road projects, the analysis showed that the design cost has stronger negative correlation with total cost growth in TXDOT road projects than that in Clark County road projects. One of the possible reasons for this is that TXDOT road projects are bigger and have more technical issues in design than Clark County road projects. This finding is in accordance with the previous findings by Gransberg et al. (2007). He found that the correlation between design cost and cost growth is stronger in bridge projects than road projects, because bridge projects are more design-intensive than road projects. However, the correlation between basic design cost and total cost growth was found to be positive and significant in case of flood control projects. This finding is exactly opposite to the finding of the road projects. One of reasons for this correlation might be the very small sample size. On the other hand, due to the type of the projects the correlation was found to be exactly opposite. Therefore, it can be suggested that, while conducting these types of correlation analysis, the data should be separated depending upon the types of projects. It is recommended to conduct further study to validate these findings with large sample size.

The second hypothesis regarding the relationship between basic design cost and contract award cost growth showed a negative correlation, indicating that the higher cost expended in design will reduce the contract award cost growth. Pearson coefficients for TXDOT road projects and combined TXDOT and Clark County road projects were found to be -0.501 and -0.322, respectively. Even though, the TXDOT road projects' correlation coefficient was greater than that for combined Clark County and TXDOT road projects, the significance value of combined TXDOT and Clark County road projects was more than TXDOT road projects. One of reasons for this case might be the very small sample size for TXDOT road projects. Although the Pearson coefficient of Clark County road projects was low, the negative correlation value indicates that the higher the design cost, lower the contract award cost growth. However, the correlation between basic design cost and contract award cost growth was found to be positive and significant in case of flood control projects. This finding is exactly opposite to the finding of the road projects. One of reasons for this correlation might be the very small sample size. On the other hand, due to the type of the projects the correlation was found to be exactly opposite. Therefore, it can be suggested that, while conducting these types of correlation analysis, the data should be separated depending upon the types of projects. It is recommended to conduct further study to validate these findings with large sample size.

The third hypothesis analyzed the relationship between the construction cost growth and basic design cost. However, there was no significant correlation between these variables. There was a negative correlation, indicating that the higher the basic design cost, the lower the construction cost growth during construction of these projects.

The relationship between construction schedule growth and basic design cost was fourth hypothesis of this study. There was no significant correlation between these variables, a negative correlation was found for all cases. This indicates that the higher cost in design will reduce the construction schedule growth.

The fifth hypothesis deals with the relationship between the basic design cost and final construction cost, which showed that there is a strong and significant positive correlation between these two variables. The regression analysis shows that the final construction cost of road projects can be predicted by using the basic design cost as an input. Table 31 describes Pearson correlations between the basic design cost and final construction cost for each case. The R-square value of the regression model for Clark County road projects was 62.30%. In addition, the R-square value of the regression model for both Clark County and TXDOT road projects was 63.60%.

This study validated the relationships of design cost and cost growth in DBB projects. To make the validation, the results from Clark County projects were compared with the Texas Department of Transportation road projects. Recently, in order to improve construction costs and schedule performance of public works projects, more public owners have been using different types of project delivery methods, such as, design-build and construction manager. More research is required to determine the relationships among design costs, construction costs, and schedule performance in these types of public projects.

Some recommendations of this study are discussed as follows:

- If all detailed data were available, then the impact of design duration or procurement duration with the project performance could be determined.
- If various kinds of projects with sufficient numbers were available for analysis, then the impact of types of projects with the project performance could be determined.
- If these parameters were available, then the impact of complexity of projects with project performance could be determined.
- If there were other projects with different project delivery methods, then the impact of the types of project delivery methods with the project performance could be determined.

The multivariate models incorporating more relevant variables, such as project characteristics, project delivery methods, contract types, weather conditions, unforeseen site conditions, design fees, construction costs, and cost growth parameters are recommended for future study. More accurate predictions could be obtained with improving the R-square value by integrating more variables for analysis. More reliable data should be analyzed to get reliable predictable output for future use.

APPENDIX A

DATA DESCRIPTION AND ANALYSIS

Table A- 1. List of CCDPW road projects with corresponding contract year, basic design cost, total design cost and final construction cost (N = 47)

SN	Contract Year	Basic Design Cost ($)	Total Design Cost ($)	Final Construction Cost ($)
1	1993	2,256,062.22	2,489,803.18	5,499,635.58
2	1995	373,991.99	414,530.46	1,406,954.72
3	1994	983,532.82	1,062,854.21	2,139,714.47
4	1993	631,682.78	765,779.15	7,794,418.28
5	1996	124,766.55	124,766.55	212,877.79
6	1994	2,037,020.44	2,460,975.01	50,385,075.94
7	1993	1,122,041.63	1,376,771.39	8,747,327.43
8	1992	965,698.13	2,163,299.03	9,787,145.99
9	1992	2,142,977.76	3,443,569.86	23,250,408.20
10	1993	2,726,812.52	3,653,684.27	46,541,186.69
11	1995	355,601.21	393,255.43	3,028,611.92
12	1997	2,400,851.48	3,889,051.06	10,353,354.62
13	1995	262,525.73	289,227.96	2,778,882.98
14	1992	1,355,444.15	1,476,674.03	6,343,454.18
15	1996	218,160.96	251,291.07	2,510,465.63
16	1996	1,172,219.73	1,536,825.70	3,284,197.67
17	1994	312,654.68	333,610.54	3,873,612.52
18	1993	1,861,015.53	2,474,244.15	6,463,605.15
19	1996	796,828.47	1,163,856.09	14,233,862.60
20	1997	134,096.31	153,231.05	2,540,893.86
21	1996	142,309.58	169,206.09	2,805,830.72
22	1997	554,533.52	822,548.52	9,232,589.16
23	1996	1,316,269.01	1,630,242.44	10,762,572.44
24	1998	1,690,818.84	1,911,376.52	13,977,961.30
25	1997	3,626,751.57	4,124,306.75	21,841,796.82
26	1996	4,150,737.53	4,880,572.56	48,468,422.73
27	1995	508,394.12	2,040,449.80	6,679,610.15
28	1996	538,506.67	639,740.32	8,256,191.96
29	1997	631,650.09	771,510.19	12,276,488.76
30	1997	1,424,719.35	1,828,676.82	13,877,120.76
31	1999	1,014,718.49	1,101,195.86	18,792,266.96
32	1998	2,016,172.13	2,706,597.60	22,455,930.30
33	1997	2,953,226.70	3,070,921.56	26,815,488.83
34	2001	286,178.52	334,264.63	2,911,959.18
35	1995	492,091.08	1,284,816.57	5,212,116.47
36	2001	571,769.75	653,631.92	7,435,334.93
37	2001	481,888.20	612,034.01	7,954,248.52

SN	Contract Year	Basic Design Cost ($)	Total Design Cost ($)	Final Construction Cost ($)
38	2001	1,877,227.59	2,323,075.93	7,885,222.01
39	2000	751,918.63	851,497.77	11,066,963.02
40	2000	1,130,135.67	1,565,213.48	19,880,440.59
41	2004	964,043.92	1,074,220.29	9,411,118.29
42	2003	1,097,009.41	1,268,701.27	10,676,085.36
43	2001	1,239,914.58	1,415,564.10	11,651,065.08
44	2001	1,164,109.50	1,372,649.59	13,818,377.26
45	2002	999,768.94	1,008,017.10	15,545,685.08
46	2003	1,928,878.06	2,015,583.83	37,088,211.35
47	2001	3,375,898.48	3,938,142.85	46,313,757.98

Table A- 2. List of CCDPW road projects with corresponding NTP year, construction completion year, engineer's estimate cost, contract award cost and total project cost (N = 47)

SN	NTP Year	Construction Completion Year	Engineer's Estimate Cost ($)	Contract Award Cost ($)	Total Project Cost ($)
1	1995	1996	6,095,744.83	5,176,839.63	7,989,438.76
2	1997	1997	1,338,155.30	1,406,954.72	1,821,485.18
3	1996	1997	2,900,754.00	2,139,714.47	3,202,568.68
4	1997	1997	8,395,610.58	7,771,754.24	8,560,197.44
5	2002	2002	275,360.05	212,877.79	337,644.34
6	1997	1999	46,209,547.11	45,857,973.35	52,846,050.95
7	1996	1997	10,958,313.18	8,747,327.43	10,124,098.81
8	1996	1997	7,390,122.63	9,651,527.40	11,950,445.02
9	1996	1997	24,742,515.07	23,250,408.20	26,693,978.06
10	1995	1997	59,612,095.69	45,314,887.98	50,194,870.97
11	1998	1998	3,037,976.35	3,028,611.92	3,421,867.35
12	2000	2001	12,571,753.18	10,634,096.97	14,242,405.69
13	1997	1998	2,634,844.72	2,778,882.98	3,068,110.94
14	1997	1998	5,723,082.63	6,170,469.32	7,820,128.21
15	1998	1999	2,947,662.89	2,510,465.63	2,761,756.69
16	1998	1999	2,771,578.82	3,135,325.78	4,821,023.37
17	1999	1999	4,343,208.25	3,453,835.47	4,207,223.06
18	1998	1999	6,742,565.42	6,463,605.15	8,937,849.29
19	1999	1999	14,810,732.36	13,929,621.25	15,397,718.69
20	1999	2000	2,633,103.42	2,488,448.56	2,694,124.91
21	2000	2000	2,737,405.14	2,654,369.42	2,975,036.81
22	1999	2000	10,027,201.92	9,232,589.16	10,055,137.68
23	1999	2000	12,414,394.90	7,791,122.23	12,392,814.88
24	1999	2000	18,832,516.44	13,977,961.30	15,889,337.82
25	1999	2000	20,961,013.76	20,682,310.99	25,966,103.57
26	1998	2000	46,804,548.97	44,576,804.60	53,348,995.30
27	2001	2001	6,414,951.04	6,358,930.13	8,720,059.96
28	2000	2001	7,510,023.16	7,852,313.67	8,895,932.28
29	2000	2001	13,256,809.43	12,245,268.48	13,047,998.95
30	2000	2001	11,601,809.58	9,967,508.11	15,705,797.58
31	2001	2001	21,132,331.02	18,511,021.93	19,893,462.81
32	2001	2001	21,582,816.42	19,099,625.32	25,162,527.90
33	2000	2001	26,695,538.34	25,996,681.32	29,886,410.39
34	2004	2004	3,003,308.88	2,581,981.87	3,246,223.81

SN	NTP Year	Construction Completion Year	Engineer’s Estimate Cost ($)	Contract Award Cost ($)	Total Project Cost ($)
35	2004	2004	4,726,333.02	4,871,672.22	6,496,933.05
36	2003	2004	7,419,679.31	7,435,334.93	8,088,966.85
37	2003	2004	8,584,889.78	7,954,248.52	8,566,282.53
38	2005	2005	7,691,723.99	7,885,222.01	10,208,297.94
39	2004	2005	10,781,157.70	10,872,198.79	11,918,460.78
40	2004	2005	17,149,596.85	18,375,986.29	21,445,654.07
41	2005	2006	9,413,302.20	8,967,646.53	10,485,338.58
42	2005	2006	9,979,305.67	10,612,456.84	11,944,786.63
43	2004	2006	10,486,479.19	11,639,403.38	13,066,629.19
44	2005	2006	12,948,704.37	13,224,050.24	15,191,026.85
45	2005	2006	11,725,559.18	14,754,117.69	16,553,702.18
46	2005	2006	36,533,548.03	36,302,084.02	39,103,795.18
47	2006	2007	34,457,304.30	44,592,052.67	50,251,900.83

Table A- 3. List of CCDPW road projects with corresponding contract award cost growth, total cost growth, construction cost growth, and construction schedule growth (N = 47)

SN	Contract Award Cost Growth ($)	Total Cost Growth ($)	Construction Cost Growth ($)	Construction Schedule Growth (%)
1	-918,905.20	-596,109.26	322,795.95	31.90
2	68,799.43	68,799.43	0.00	0.00
3	-761,039.53	-761,039.53	0.00	-2.38
4	-623,856.34	-601,192.30	22,664.04	19.17
5	-62,482.26	-62,482.26	0.00	-36.67
6	-351,573.76	4,175,528.83	4,527,102.59	34.00
7	-2,210,985.75	-2,210,985.75	0.00	18.36
8	2,261,404.77	2,397,023.36	135,618.59	54.58
9	-1,492,106.87	-1,492,106.87	0.00	9.75
10	-14,297,207.70	-13,070,908.99	1,226,298.71	0.00
11	-9,364.44	-9,364.44	0.00	10.00
12	-1,937,656.21	-2,218,398.56	-280,742.34	36.67
13	144,038.26	144,038.26	0.00	-1.33
14	447,386.69	620,371.55	172,984.86	-1.90
15	-437,197.27	-437,197.27	0.00	2.00
16	363,746.96	512,618.86	148,871.90	64.58
17	-889,372.78	-469,595.73	419,777.05	-4.50
18	-278,960.27	-278,960.27	0.00	42.08
19	-881,111.10	-576,869.76	304,241.35	44.44
20	-144,654.85	-92,209.56	52,445.29	0.00
21	-83,035.71	68,425.58	151,461.30	100.00
22	-794,612.76	-794,612.76	0.00	21.25
23	-4,623,272.67	-1,651,822.46	2,971,450.22	9.52
24	-4,854,555.14	-4,854,555.14	0.00	5.75
25	-278,702.78	880,783.06	1,159,485.83	25.15
26	-2,227,744.37	1,663,873.76	3,891,618.13	55.00
27	-56,020.91	264,659.12	320,680.02	2.92
28	342,290.51	746,168.80	403,878.29	3.00
29	-1,011,540.95	-980,320.67	31,220.28	-8.25
30	-1,634,301.47	2,275,311.18	3,909,612.66	47.50
31	-2,621,309.09	-2,340,064.06	281,245.02	17.14
32	-2,483,191.09	873,113.89	3,356,304.98	31.67
33	-698,857.02	119,950.49	818,807.51	17.04
34	-421,327.01	-91,349.70	329,977.31	42.67

SN	Contract Award Cost Growth ($)	Total Cost Growth ($)	Construction Cost Growth ($)	Construction Schedule Growth (%)
35	145,339.20	485,783.45	340,444.25	20.56
36	15,655.62	15,655.62	0.00	17.08
37	-630,641.26	-630,641.26	0.00	38.33
38	193,498.02	193,498.02	0.00	30.00
39	91,041.09	285,805.32	194,764.22	2.00
40	1,226,389.44	2,730,843.74	1,504,454.31	70.67
41	-445,655.67	-2,183.91	443,471.76	15.93
42	633,151.17	696,779.69	63,628.52	42.08
43	1,152,924.19	1,164,585.89	11,661.71	12.96
44	275,345.88	869,672.89	594,327.01	7.67
45	3,028,558.52	3,820,125.91	791,567.39	30.33
46	-231,464.01	554,663.32	786,127.33	16.67
47	10,134,748.38	11,856,453.68	1,721,705.31	0.00

Table A- 4. List of CCDPW road projects with corresponding basic design cost, total design cost, contract award cost growth, total cost growth, and construction cost growth (N = 47)

SN	Basic Design Cost (%)	Total Design Cost (%)	Contract Award Cost Growth (%)	Total Cost Growth (%)	Construction Cost Growth (%)
1	28.24	31.16	-15.07	-9.78	6.24
2	20.53	22.76	5.14	5.14	0.00
3	30.71	33.19	-26.24	-26.24	0.00
4	7.38	8.95	-7.43	-7.16	0.29
5	36.95	36.95	-22.69	-22.69	0.00
6	3.85	4.66	-0.76	9.04	9.87
7	11.08	13.60	-20.18	-20.18	0.00
8	8.08	18.10	30.60	32.44	1.41
9	8.03	12.90	-6.03	-6.03	0.00
10	5.43	7.28	-23.98	-21.93	2.71
11	10.39	11.49	-0.31	-0.31	0.00
12	16.86	27.31	-15.41	-17.65	-2.64
13	8.56	9.43	5.47	5.47	0.00
14	17.33	18.88	7.82	10.84	2.80
15	7.90	9.10	-14.83	-14.83	0.00
16	24.31	31.88	13.12	18.50	4.75
17	7.43	7.93	-20.48	-10.81	12.15
18	20.82	27.68	-4.14	-4.14	0.00
19	5.17	7.56	-5.95	-3.89	2.18
20	4.98	5.69	-5.49	-3.50	2.11
21	4.78	5.69	-3.03	2.50	5.71
22	5.51	8.18	-7.92	-7.92	0.00
23	10.62	13.15	-37.24	-13.31	38.14
24	10.64	12.03	-25.78	-25.78	0.00
25	13.97	15.88	-1.33	4.20	5.61
26	7.78	9.15	-4.76	3.55	8.73
27	5.83	23.40	-0.87	4.13	5.04
28	6.05	7.19	4.56	9.94	5.14
29	4.84	5.91	-7.63	-7.39	0.25
30	9.07	11.64	-14.09	19.61	39.22
31	5.10	5.54	-12.40	-11.07	1.52
32	8.01	10.76	-11.51	4.05	17.57
33	9.88	10.28	-2.62	0.45	3.15
34	8.82	10.30	-14.03	-3.04	12.78
35	7.57	19.78	3.08	10.28	6.99
36	7.07	8.08	0.21	0.21	0.00
37	5.63	7.14	-7.35	-7.35	0.00

SN	Basic Design Cost (%)	Total Design Cost (%)	Contract Award Cost Growth (%)	Total Cost Growth (%)	Construction Cost Growth (%)
38	18.39	22.76	2.52	2.52	0.00
39	6.31	7.14	0.84	2.65	1.79
40	5.27	7.30	7.15	15.92	8.19
41	9.19	10.24	-4.73	-0.02	4.95
42	9.18	10.62	6.34	6.98	0.60
43	9.49	10.83	10.99	11.11	0.10
44	7.66	9.04	2.13	6.72	4.49
45	6.04	6.09	25.83	32.58	5.37
46	4.93	5.15	-0.63	1.52	2.17
47	6.72	7.84	29.41	34.41	3.86

Table A- 5. List of CCDPW flood control projects with corresponding contract year, basic design cost, total design cost and final construction cost (N = 11)

SN	Contract Year	Basic Design Cost ($)	Total Design Cost ($)	Final Construction Cost ($)
1	1996	781,393.63	903,177.23	2,988,708.12
2	2002	440,931.59	528,029.19	3,036,172.39
3	2001	226,038.36	286,890.63	3,020,266.26
4	2001	41,603.23	88,938.52	5,380,830.10
5	1999	731,260.94	826,525.89	6,837,363.99
6	2003	788,509.99	1,047,270.39	16,463,130.77
7	1999	658,444.26	934,191.84	11,550,969.66
8	1997	419,651.77	453,719.02	18,572,866.09
9	1997	48,391.16	1,431,074.87	7,532,795.05
10	1999	997,954.25	1,251,365.39	4,432,127.73
11	2000	1,099,183.44	1,635,341.63	5,191,387.44

Table A- 6. List of CCDPW flood control projects with corresponding NTP year, construction completion year, engineer's estimate cost, contract award cost and total project cost (N = 11)

SN	NTP Year	Construction Completion Year	Engineer's Estimate Cost ($)	Contract Award Cost ($)	Total Project Cost ($)
1	2007	2007	2,291,522.28	3,017,064.84	3,891,885.35
2	2006	2007	2,195,934.56	2,919,206.35	3,564,201.58
3	2004	2005	4,126,674.78	3,229,611.62	3,307,156.89
4	2004	2006	5,217,246.70	5,002,783.44	5,469,768.62
5	1999	2000	7,506,271.70	6,576,929.03	7,663,889.88
6	2003	2004	17,729,008.19	16,282,280.59	17,510,401.15
7	2004	2005	9,791,872.70	11,640,585.87	12,485,161.50
8	1999	2000	17,476,958.57	18,701,822.55	19,026,585.11
9	2004	2005	6,760,625.58	6,793,768.33	8,963,869.92
10	2004	2005	3,533,961.16	4,313,823.94	5,683,493.13
11	2005	2006	3,829,425.43	4,902,943.01	6,826,729.07

Table A- 7. List of CCDPW flood control projects with corresponding contract award cost growth, total cost growth, construction cost growth, and construction schedule growth (N = 11)

SN	Contract Award Cost Growth ($)	Total Cost Growth ($)	Construction Cost Growth ($)	Construction Schedule Growth (%)
1	725,542.56	697,185.84	-28,356.72	-4.44
2	723,271.78	840,237.83	116,966.05	27.50
3	-897,063.16	-1,106,408.52	-209,345.36	-46.67
4	-214,463.26	163,583.39	378,046.65	151.85
5	-929,342.67	-668,907.71	260,434.96	29.05
6	-1,446,727.61	-1,265,877.43	180,850.18	36.04
7	1,848,713.16	1,759,096.96	-89,616.21	3.00
8	1,224,863.98	1,095,907.52	-128,956.46	-1.00
9	33,142.75	772,169.47	739,026.72	95.56
10	779,862.78	898,166.57	118,303.79	96.32
11	1,073,517.58	1,361,962.01	288,444.43	57.50

Table A- 8. List of CCDPW flood control projects with corresponding basic design cost, total design cost, contract award cost growth, total cost growth, and construction cost growth (N = 11)

SN	Basic Design Cost (%)	Total Design Cost (%)	Contract Award Cost Growth (%)	Total Cost Growth (%)	Construction Cost Growth (%)
1	20.08	23.21	31.66	30.42	-0.94
2	12.37	14.81	32.94	38.26	4.01
3	6.83	8.67	-21.74	-26.81	-6.48
4	0.76	1.63	-4.11	3.14	7.56
5	9.54	10.78	-12.38	-8.91	3.96
6	4.50	5.98	-8.16	-7.14	1.11
7	5.27	7.48	18.88	17.96	-0.77
8	2.21	2.38	7.01	6.27	-0.69
9	0.54	15.96	0.49	11.42	10.88
10	17.56	22.02	22.07	25.42	2.74
11	16.10	23.95	28.03	35.57	5.88

Table A- 9. List of TXDOT road projects with corresponding contract year, basic design cost, final construction cost, and total project cost (N = 17)

SN	Contract Year	Basic Design Cost ($)	Final Construction Cost ($)	Total Project Cost ($)
1	1994	13,000,000	288,000,000	301,000,000
2	2002	20,000,000	126,000,000	146,000,000
3	2002	10,000,000	84,086,128	94,086,128
4	2002	58,893,000	129,582,654	188,475,654
5	2002	10,000,000	39,468,652	49,468,652
6	2002	10,000,000	34,239,317	44,239,317
7	2002	10,000,000	65,500,000	75,500,000
8	2002	10,000,000	139,503,246	149,503,246
9	2000	4,029,080	89,900,000	93,929,080
10	2000	8,728,107	223,000,000	231,728,107
11	2000	4,766,303	156,927,595	161,693,898
12	2000	3,633,258	87,904,893	91,538,151
13	2000	11,933,197	262,410,706	274,343,903
14	2000	6,850,098	202,729,076	209,579,174
15	2000	7,030,031	165,697,332	172,727,363
16	2000	13,928,848	264,444,629	278,373,477
17	2003	12,000,000	166,649,011	178,649,011

Table A- 10. List of TXDOT road projects with corresponding NTP year, construction completion year, basic design cost, and contract award cost (N = 17)

SN	NTP Year	Construction Completion Year	Basic Design Cost (%)	Contract Award Cost Growth (%)
1	2001	2006	4.32	29.33
2	2003	2007	13.70	-36.54
3	2003	2006	10.63	-37.46
4	2003	2006	31.25	1.98
5	2004	2006	20.21	-34.67
6	2004	2006	22.60	-29.46
7	2003	2006	13.25	-39.25
8	2003	2008	6.69	-23.17
9	2003	2006	4.29	7.65
10	2003	2006	3.77	26.43
11	2005	2007	2.95	-9.60
12	2005	2009	3.97	-1.24
13	2004	2008	4.35	27.62
14	2005	2009	3.27	11.42
15	2005	2009	4.07	1.75
16	2003	2007	5.00	8.37
17	2005	2010	6.72	-2.50

Table A- 11. List of TXDOT road projects with corresponding total cost growth, construction cost growth, and construction schedule growth (N = 17)

SN	Total Cost Growth (%)	Construction Cost Growth (%)	Construction Schedule Growth (%)
1	31.872946	1.96	66.0037879
2	-27.59876	14.10	14.1078838
3	-35.34088	3.39	7.53768844
4	18.70837	16.41	0
5	-32.11569	3.90	3.44827586
6	-29.16949	0.41	16.2831858
7	-37.36467	3.10	12.6262626
8	2.9438166	33.99	18.1459566
9	7.8256077	0.16	0
10	27.845873	1.12	0
11	-7.075129	2.79	10.6255356
12	3.2157055	4.51	0.09090909
13	32.870556	4.12	4.07105848
14	10.60971	-0.73	7.75716695
15	6.3429748	4.51	0.41946309
16	9.1342377	0.71	0
17	4.4731058	7.16	11.9257087

Table A- 12. ENR cost index (monthly basis)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
1990	4680	4685	4691	4693	4707	4732	4734	4752	4774	4771	4787	4777	4732
1991	4777	4773	4772	4766	4801	4818	4854	4892	4891	4892	4896	4889	4835
1992	4888	4884	4927	4946	4965	4973	4992	5032	5042	5052	5058	5059	4985
1993	5071	5070	5106	5167	5262	5260	5252	5230	5255	5264	5278	5310	5210
1994	5336	5371	5381	5405	5405	5408	5409	5424	5437	5437	5439	5439	5408
1995	5443	5444	5435	5432	5433	5432	5484	5506	5491	5511	5519	5524	5471
1996	5523	5532	5537	5550	5572	5597	5617	5652	5683	5719	5740	5744	5620
1997	5765	5769	5759	5799	5837	5860	5863	5854	5851	5848	5838	5858	5826
1998	5852	5874	5875	5883	5881	5895	5921	5929	5963	5986	5995	5991	5920
1999	6000	5992	5986	6008	6006	6039	6076	6091	6128	6134	6127	6127	6059
2000	6130	6160	6202	6201	6233	6238	6225	6233	6224	6259	6266	6283	6221
2001	6281	6272	6279	6286	6288	6318	6404	6389	6391	6397	6410	6390	6334
2002	6462	6462	6502	6480	6512	6532	6605	6592	6589	6579	6578	6563	6538
2003	6581	6640	6627	6635	6642	6694	6696	6733	6741	6771	6794	6782	6695
2004	6825	6861	6957	7017	7064	7109	7126	7188	7298	7314	7312	7308	7115
2005	7297	7298	7309	7355	7398	7415	7422	7479	7540	7563	7630	7647	7446
2006	7660	7689	7692	7695	7691	7700	7721	7723	7763	7883	7911	7888	7751
2007	7880	7880	7856	7865	7942	7939	7959	8007	8050	8045	NA	NA	7959
2008	NA	NA	NA	NA	NA	8185	8293	8362	8557	8623	8602	8551	8310
2009	8549	8533	8534	8528	8574	8578	8566	8564	8586	8596	8592	8641	8570
2010	8660	8672	8671	8677	8762	8805	8865	8858	8831	8920	NA	8952	NA

APPENDIX B

HISTOGRAM OF VARIOUS METRICS

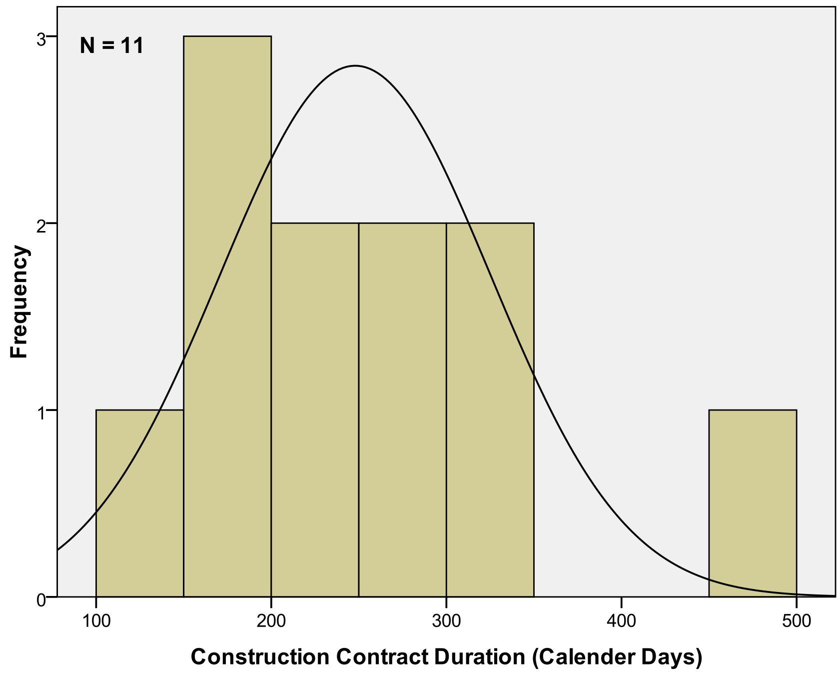

Figure B- 1. Histogram for construction contract duration of CCDPW flood control projects

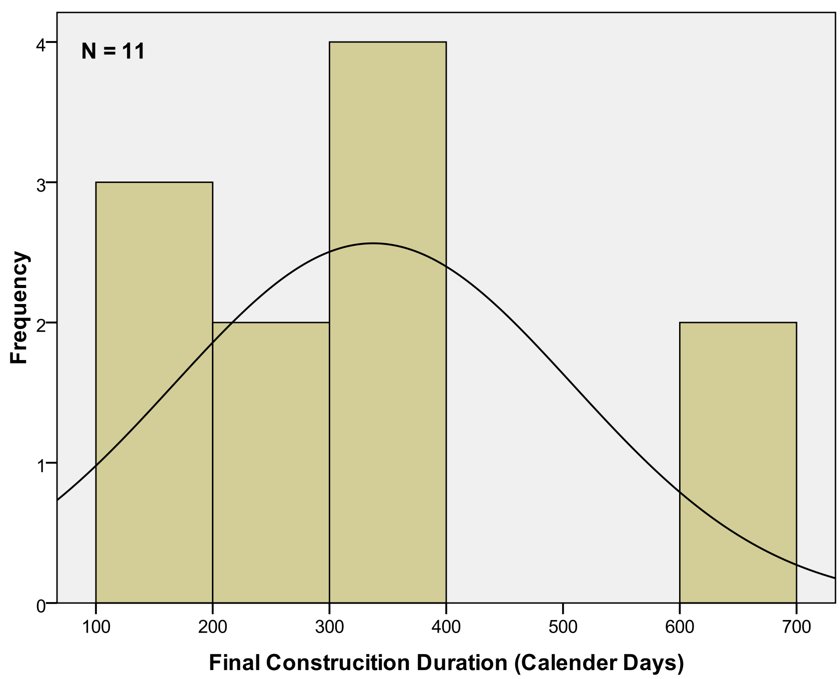

Figure B- 2. Histogram for final construction duration of CCDPW flood control projects

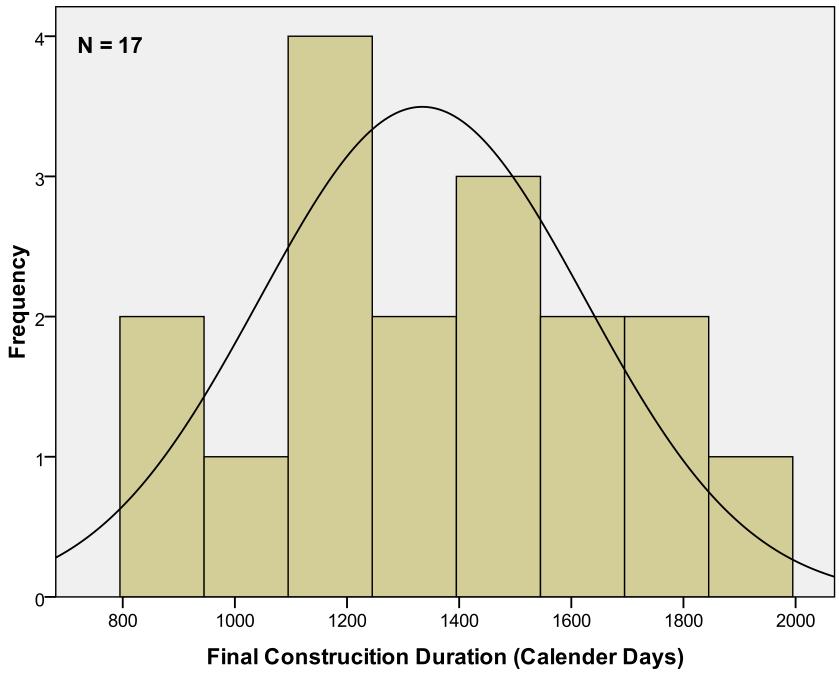

Figure B- 3. Histogram for final construction duration of TXDOT road projects

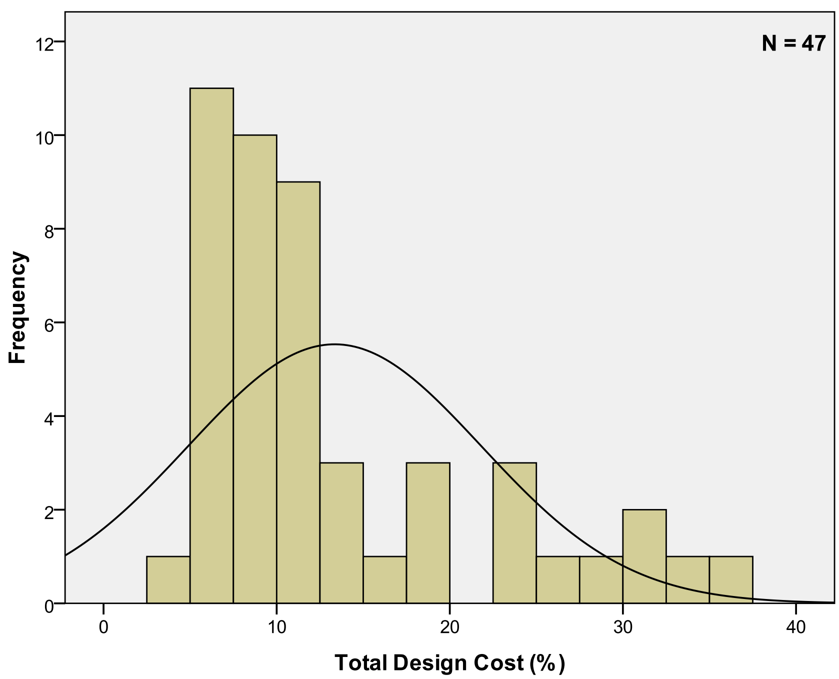

Figure B- 4. Histogram for total design cost (%) of CCDPW road projects

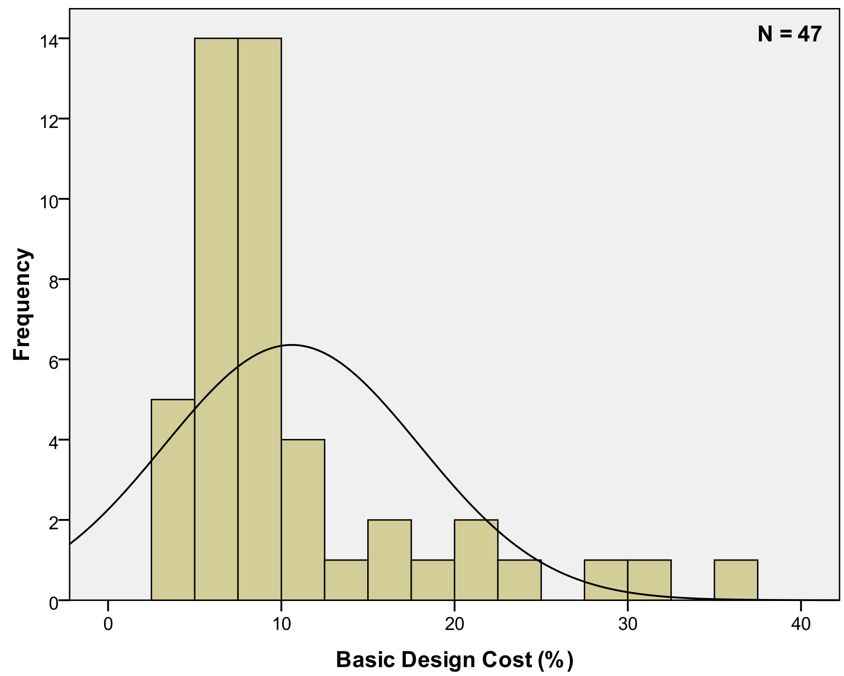

Figure B- 5. Histogram for basic design cost (%) of CCDPW road projects

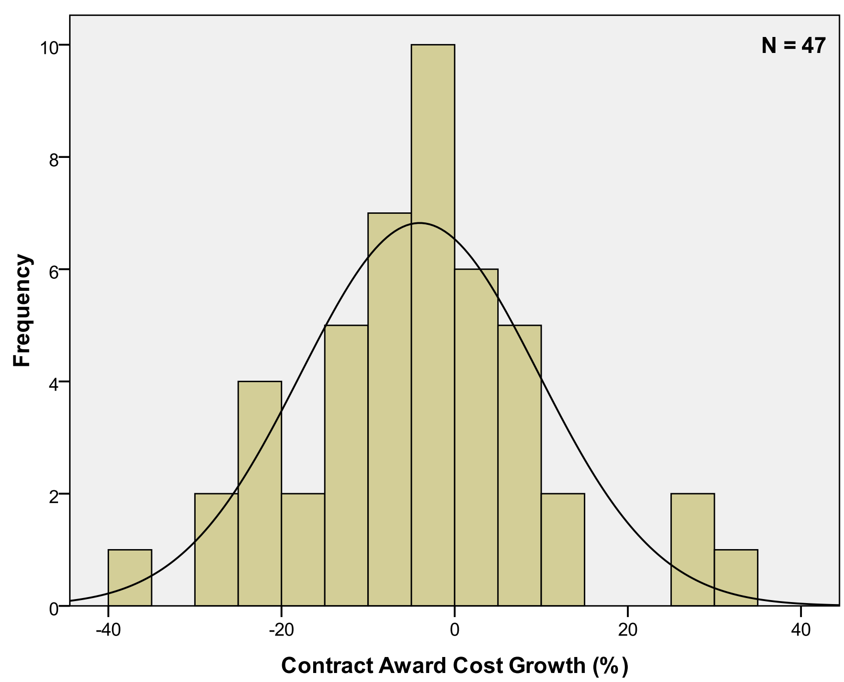

Figure B- 6. Histogram for contract award cost growth (%) of CCDPW road projects

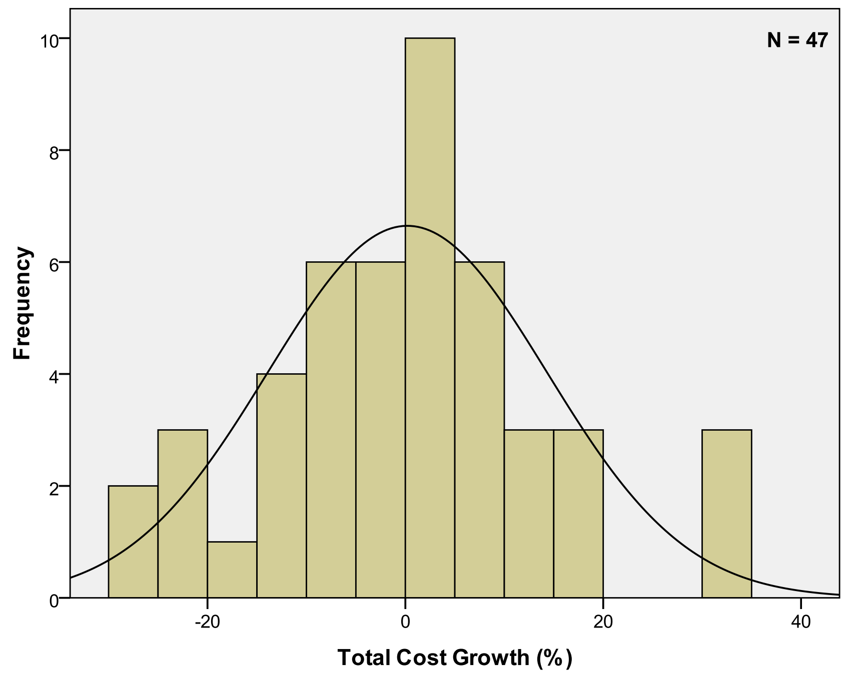

Figure B- 7. Histogram for total cost growth (%) of CCDPW road projects

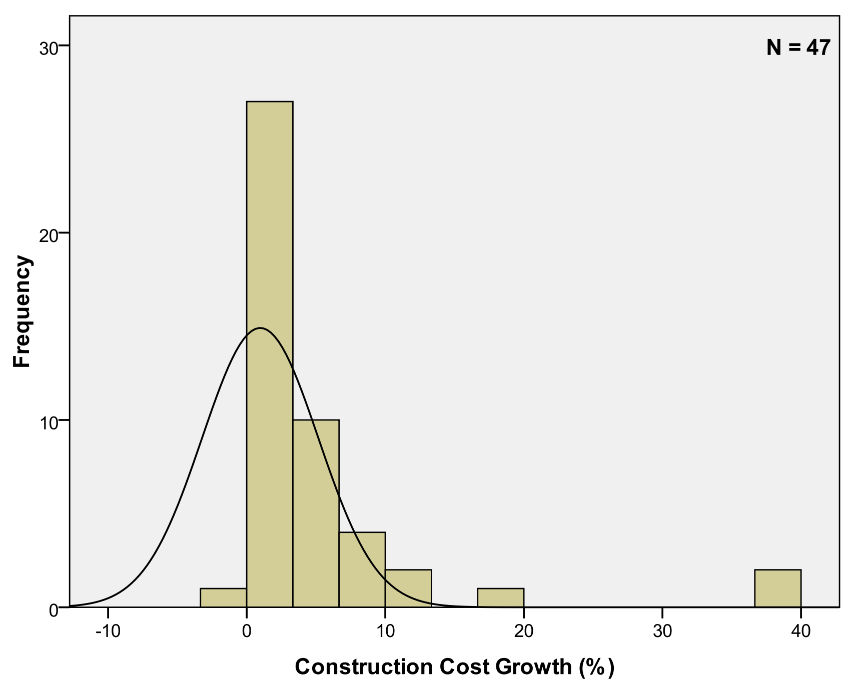

Figure B- 8. Histogram for construction cost growth (%) of CCDPW road projects

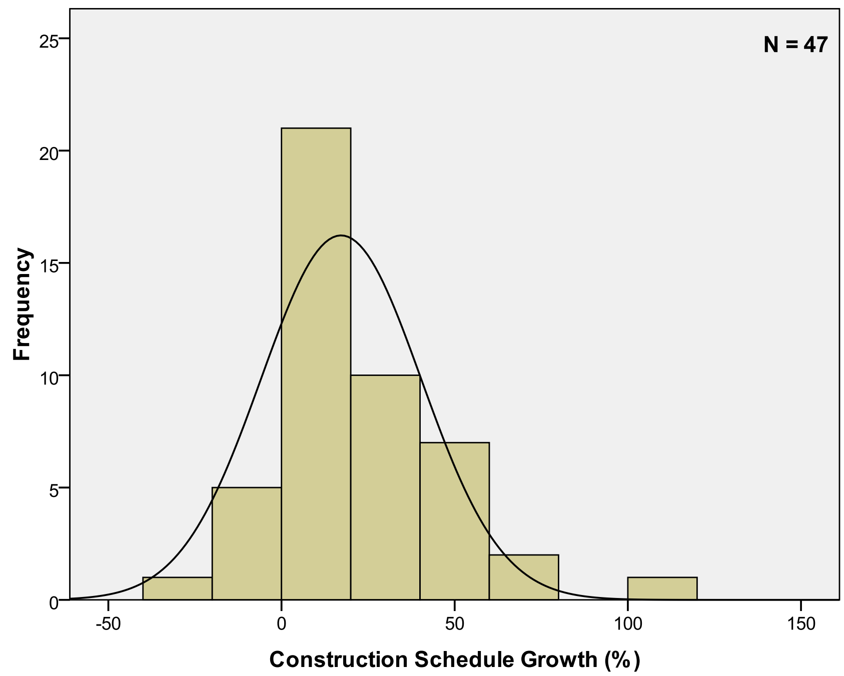

Figure B- 9. Histogram for construction schedule growth (%) of CCDPW road projects

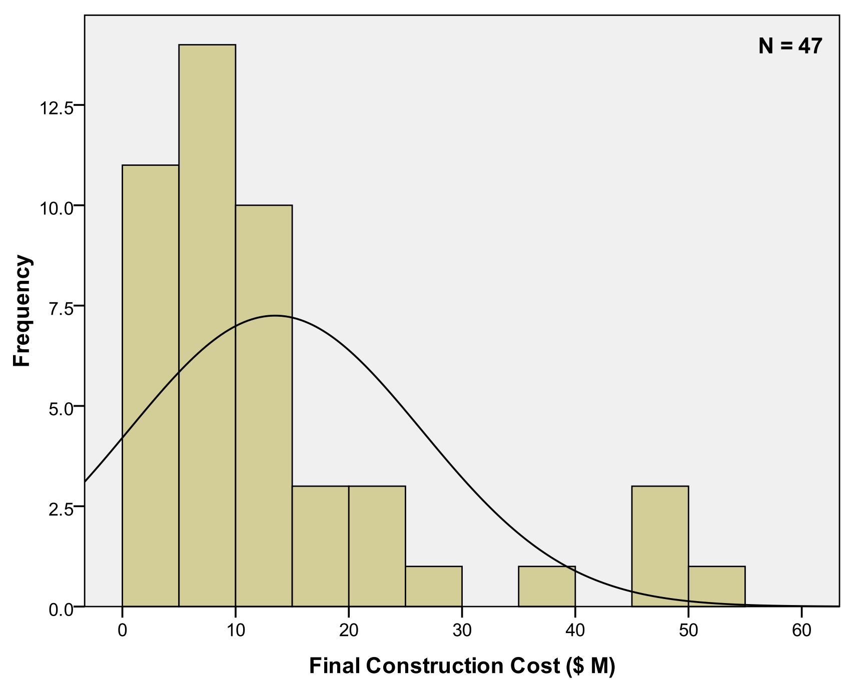

Figure B- 10. Histogram for final construction cost ($ million) of CCDPW road projects

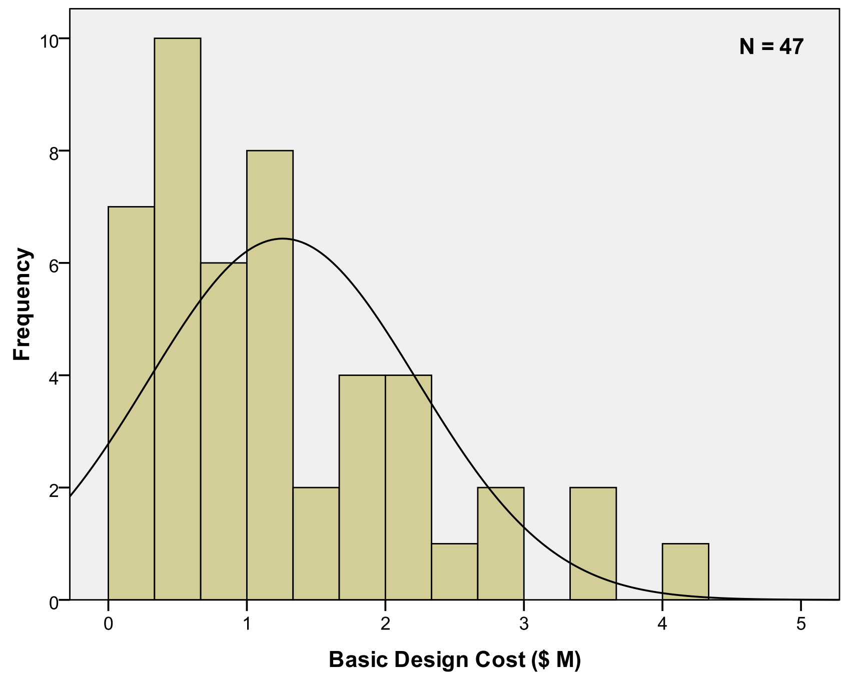

Figure B- 11. Histogram for basic design cost ($ million) of CCDPW road projects

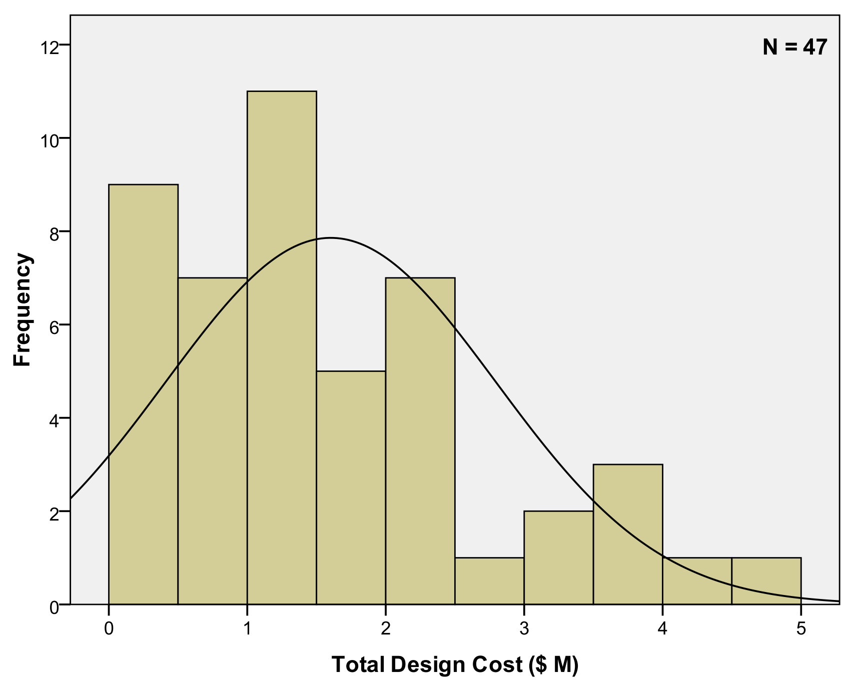

Figure B- 12. Histogram for total design cost ($ million) of CCDPW road projects

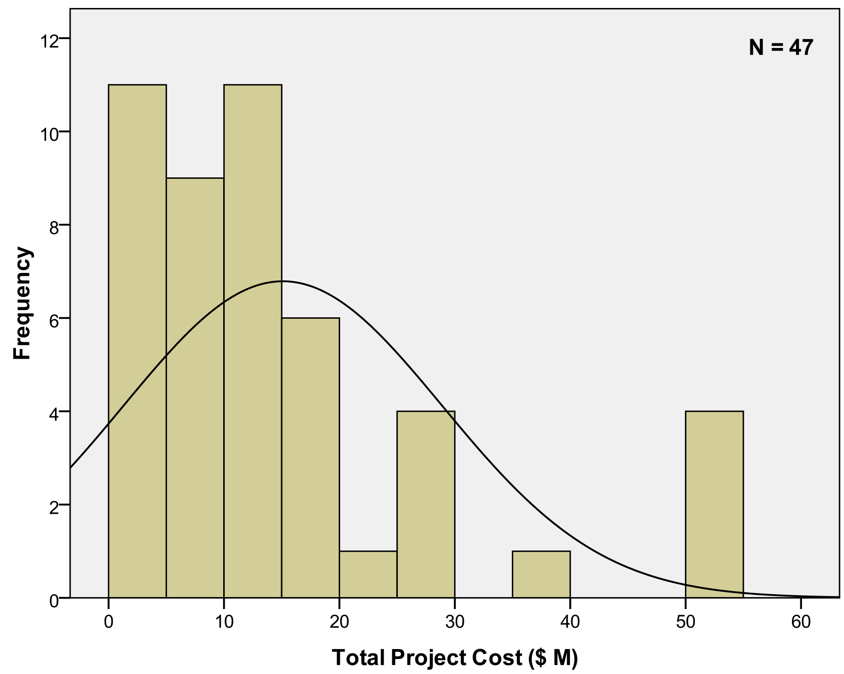

Figure B- 13. Histogram for total project cost ($ million) of CCDPW road projects

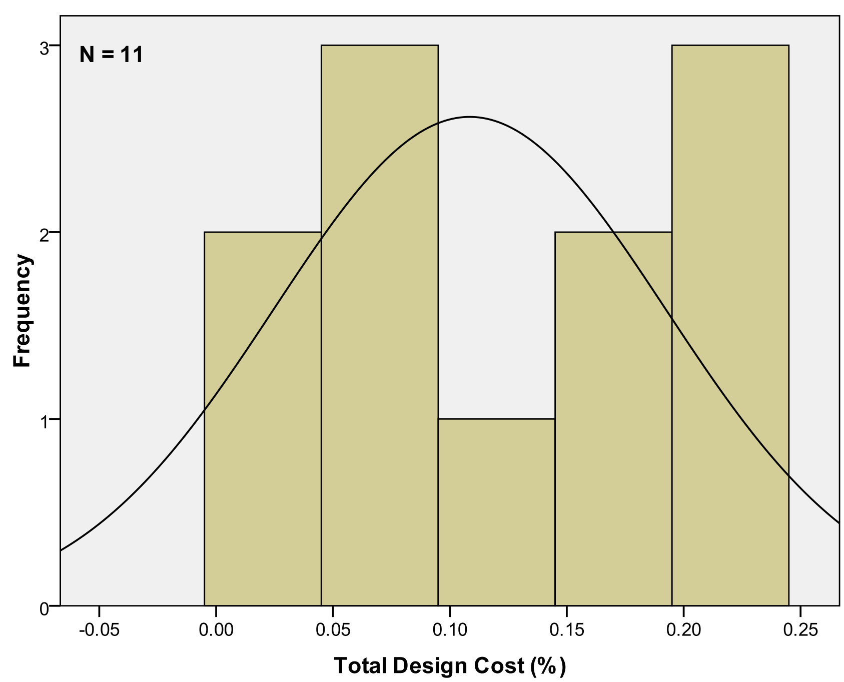

Figure B- 14. Histogram for total design cost (%) of CCDPW flood control projects

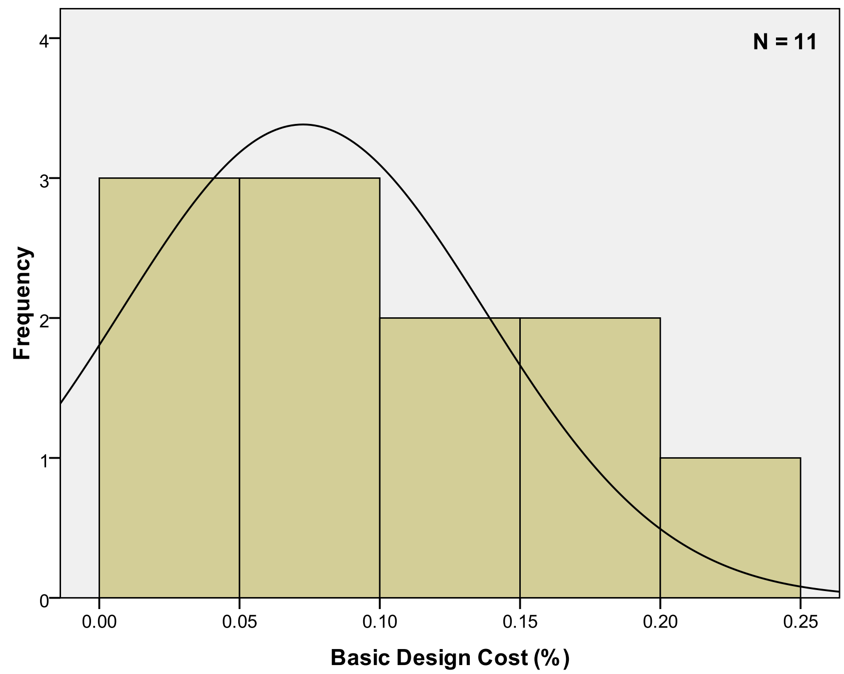

Figure B- 15. Histogram for basic design cost (%) of CCDPW flood control projects

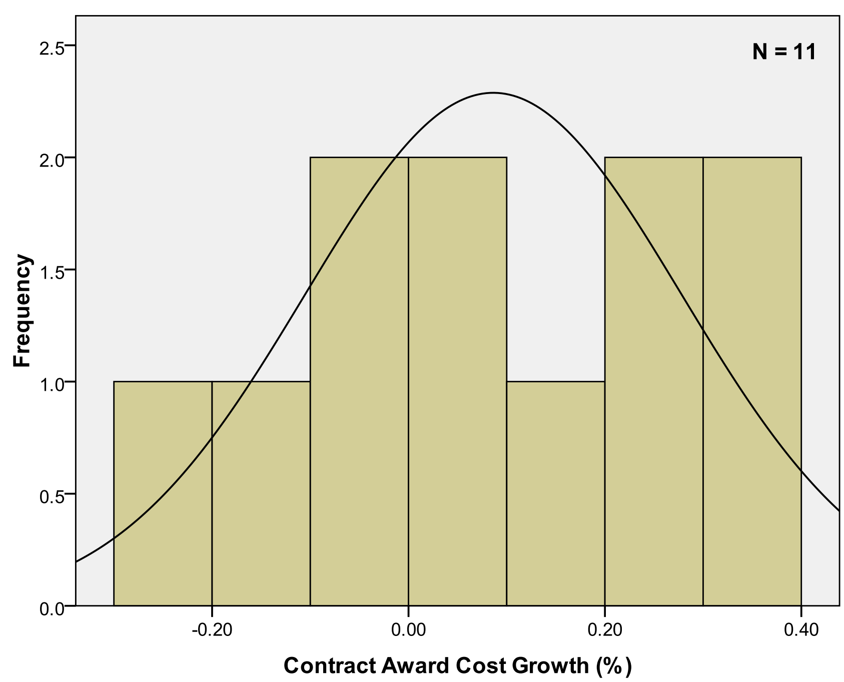

Figure B- 16. Histogram for contract award cost growth (%) of CCDPW flood control projects

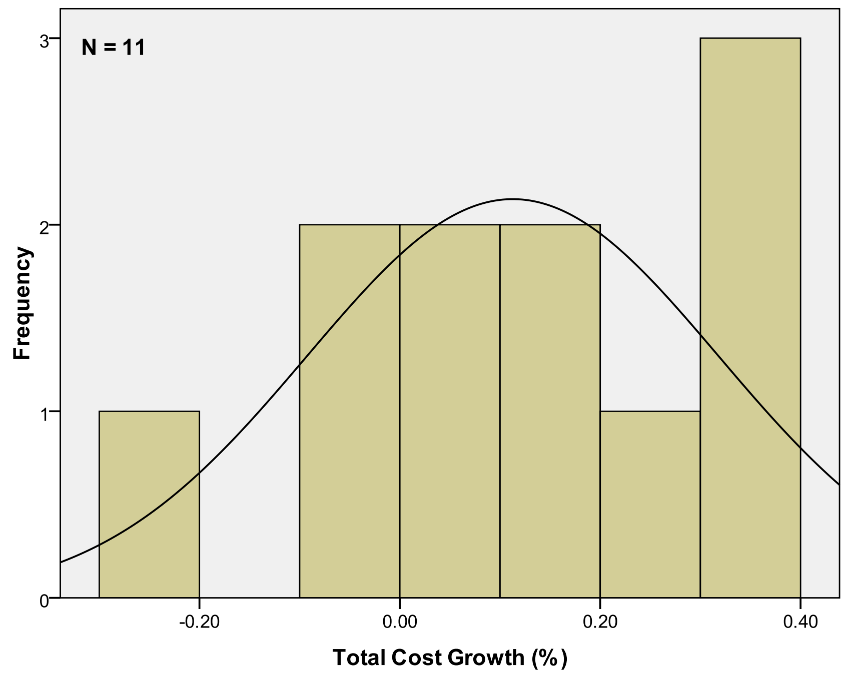

Figure B- 17. Histogram for total cost growth (%) of CCDPW flood control projects

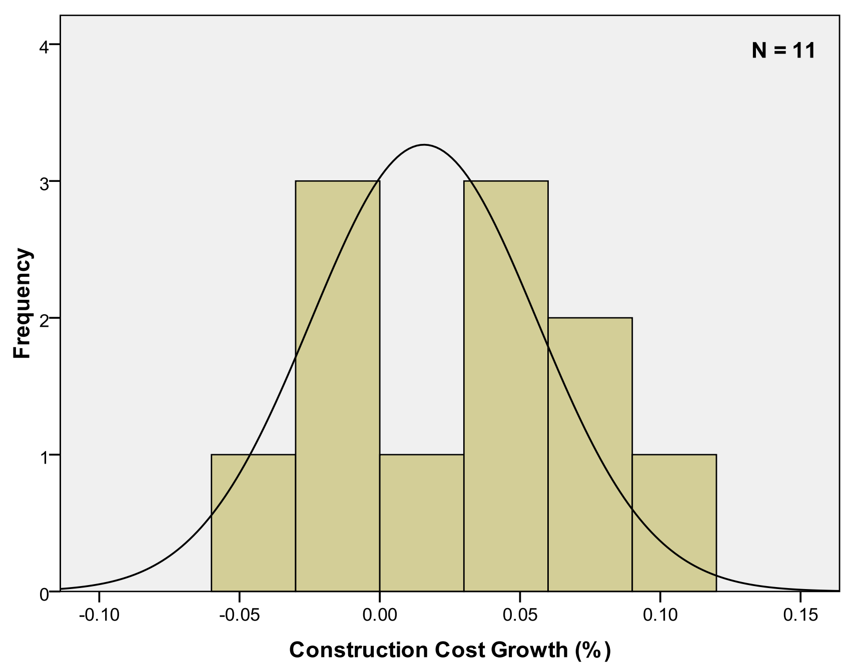

Figure B- 18. Histogram for construction cost growth (%) of CCDPW flood control projects

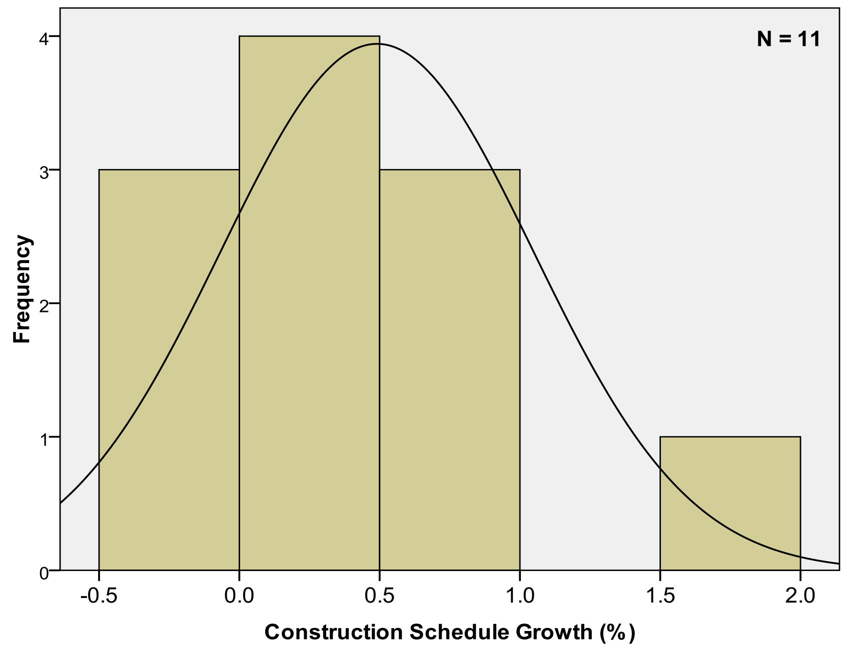

Figure B- 19. Histogram for construction schedule growth (%) of CCDPW flood control projects

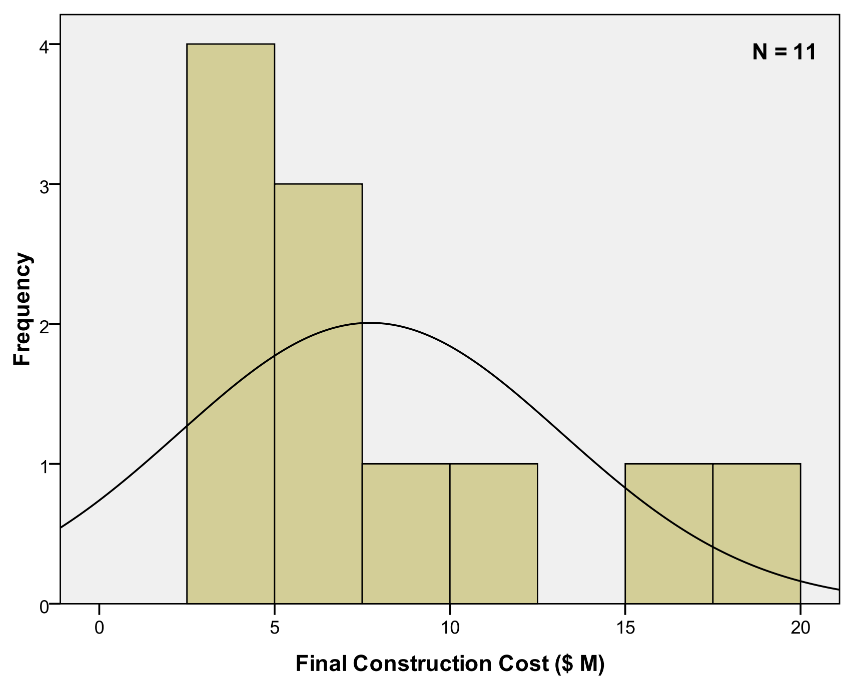

Figure B- 20. Histogram for final construction cost ($ M) of CCDPW flood control projects

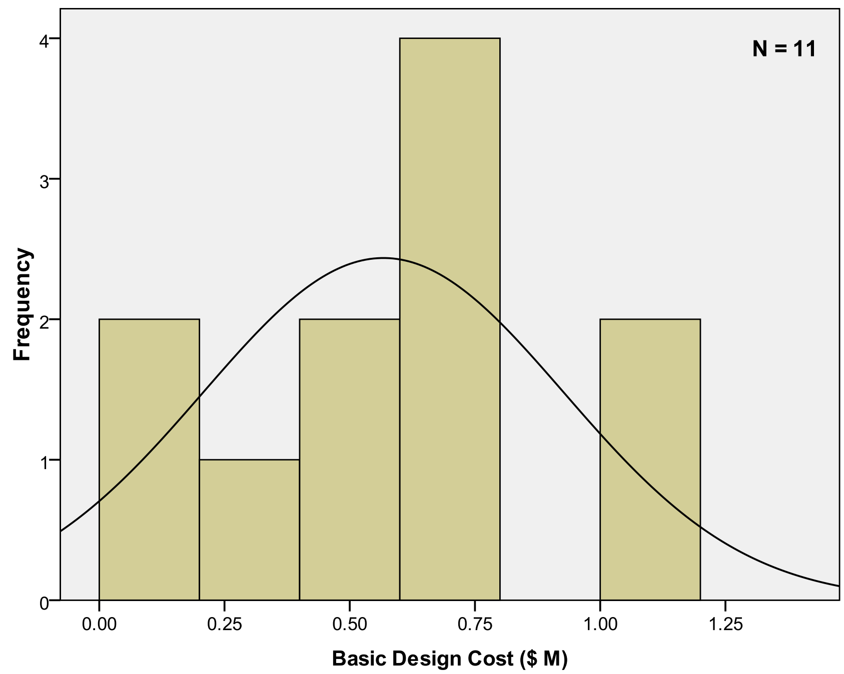

Figure B- 21. Histogram for basic design cost ($ M) of CCDPW flood control projects

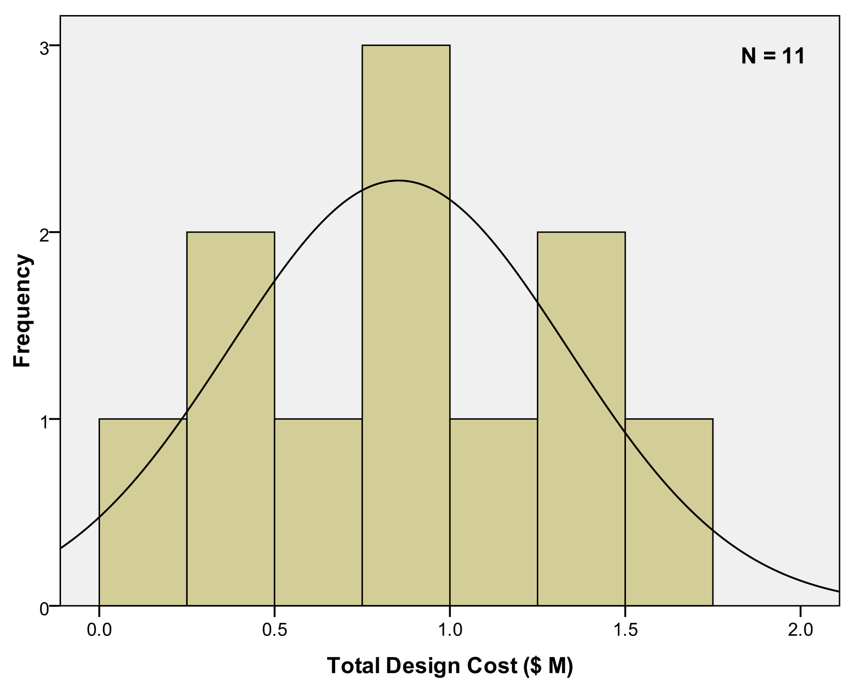

Figure B- 22. Histogram for total design cost ($ M) of CCDPW flood control projects

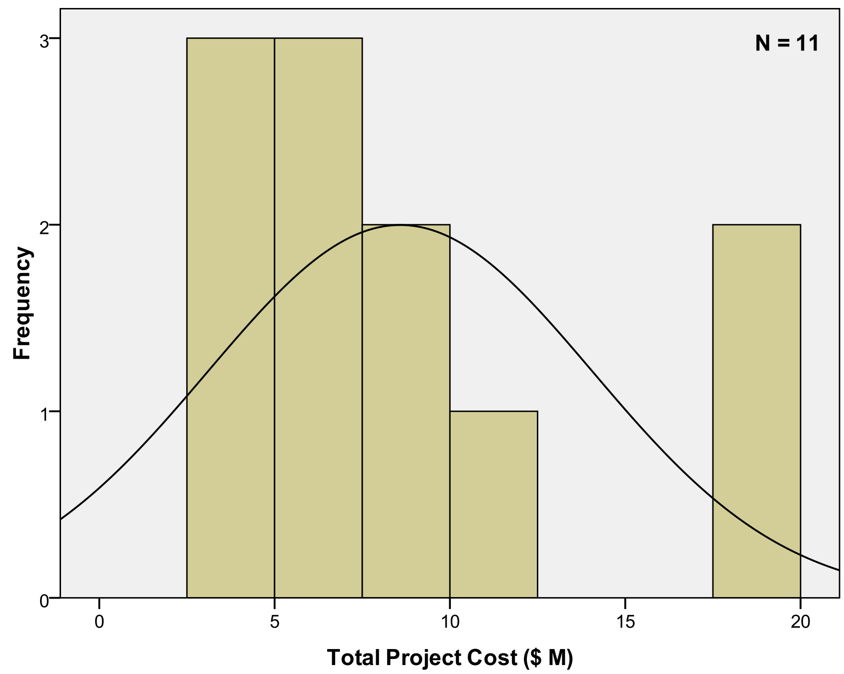

Figure B- 23. Histogram for total project cost ($ M) of CCDPW flood control projects

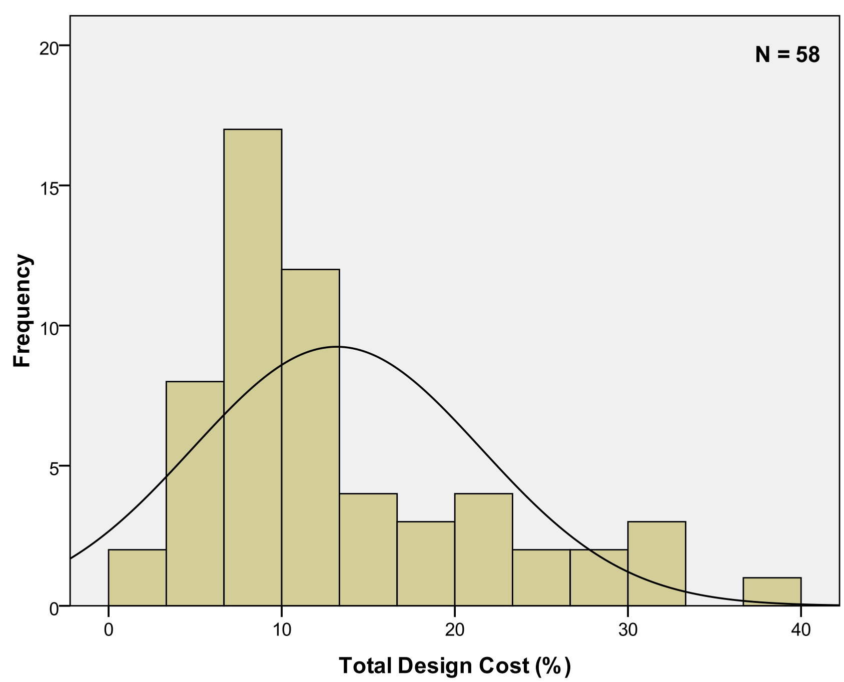

Figure B- 24. Histogram for total design cost (%) of CCDPW flood control and road projects

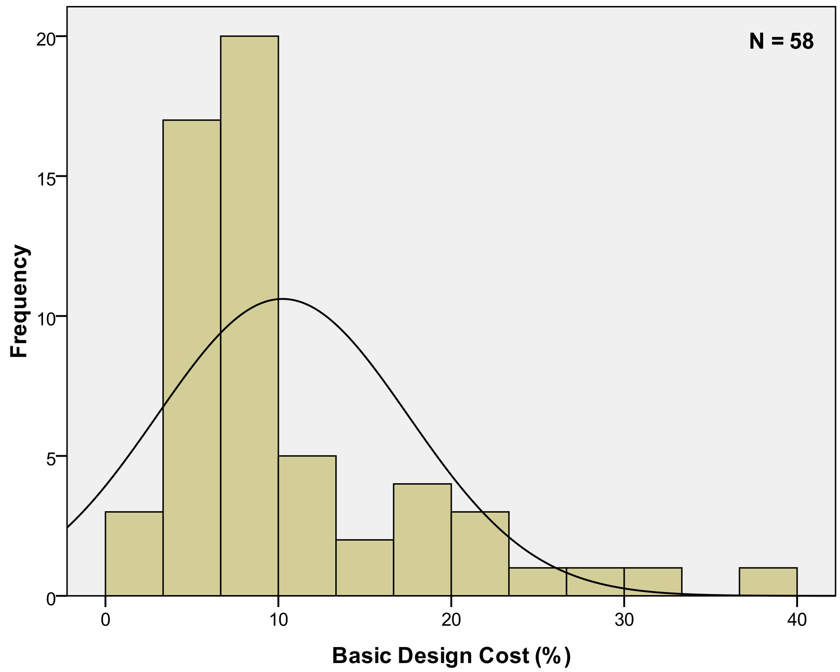

Figure B- 25. Histogram for basic design cost (%) of CCDPW flood control and road projects

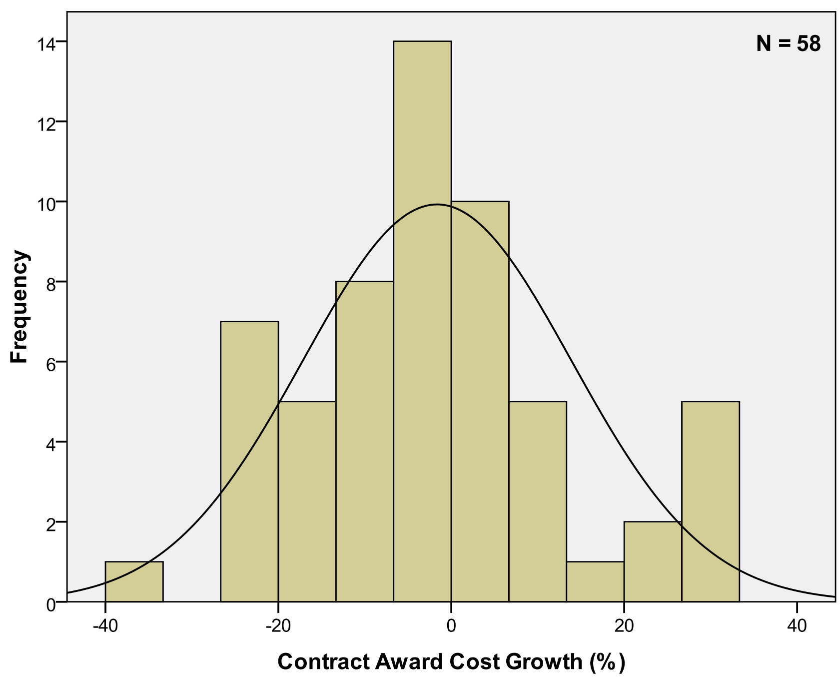

Figure B- 26. Histogram for contract award cost growth (%) of CCDPW flood control and road projects

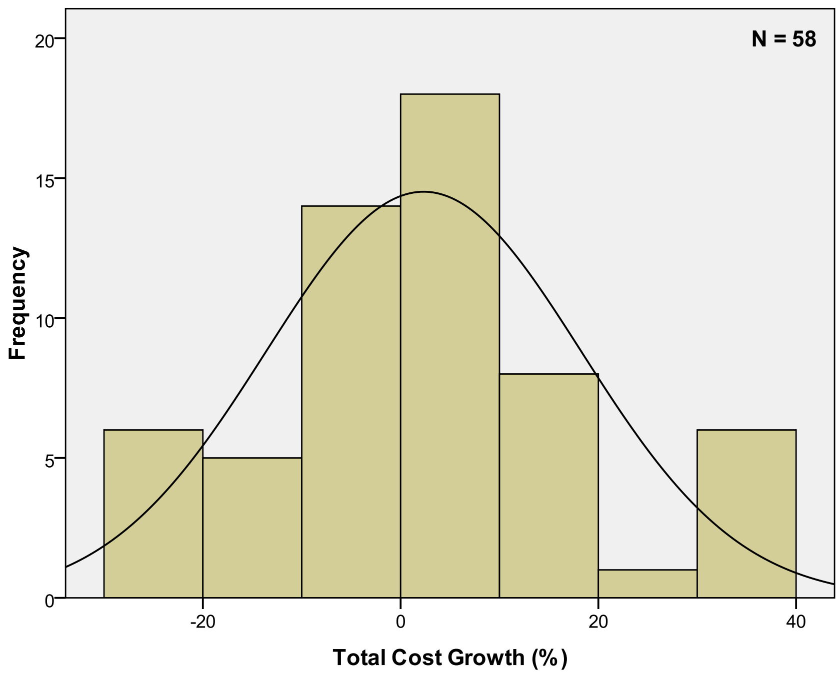

Figure B- 27. Histogram for total cost growth (%) of CCDPW flood control and road projects

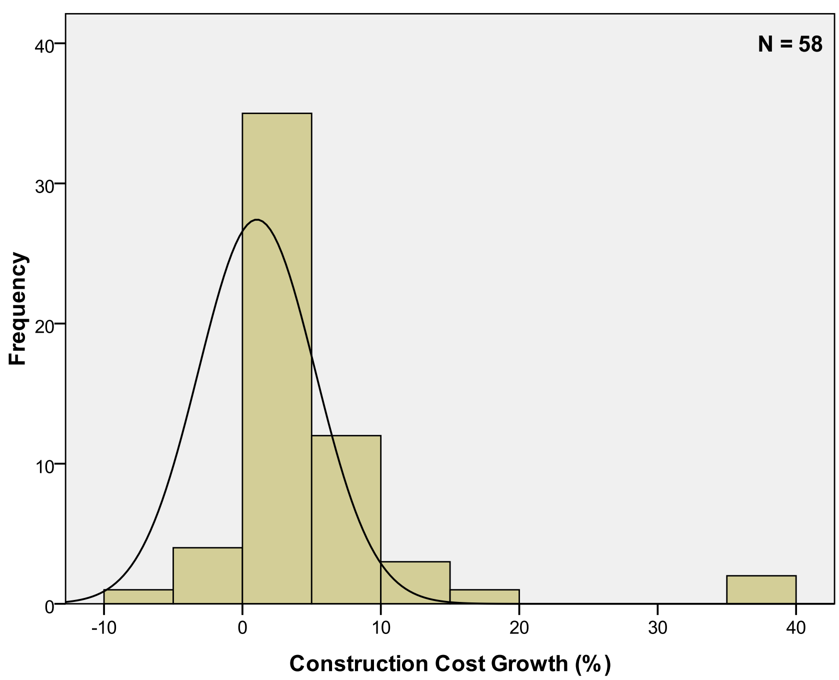

Figure B- 28. Histogram for construction cost growth (%) of CCDPW flood control and road projects

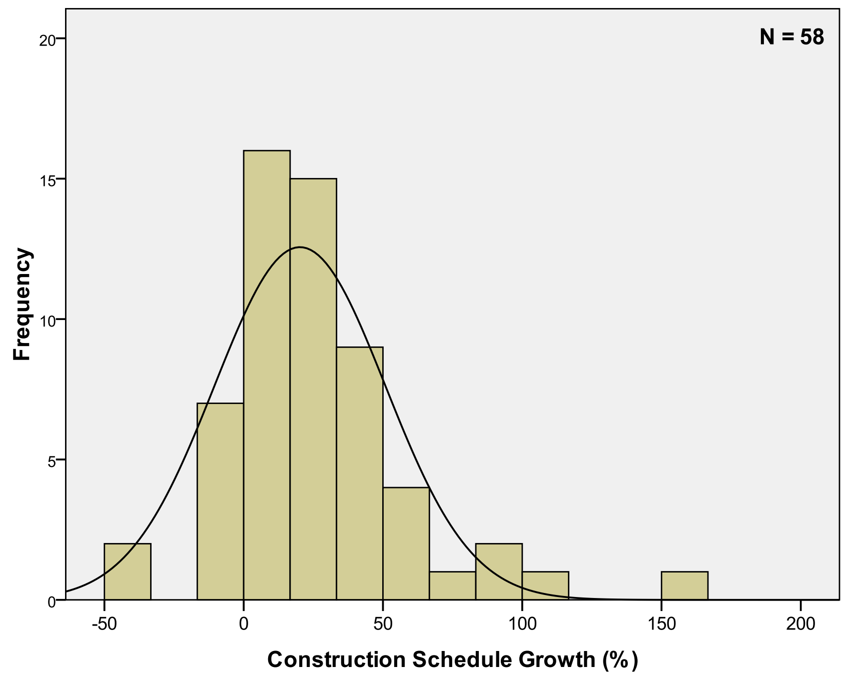

Figure B- 29. Histogram for construction schedule growth (%) of CCDPW flood control and road projects

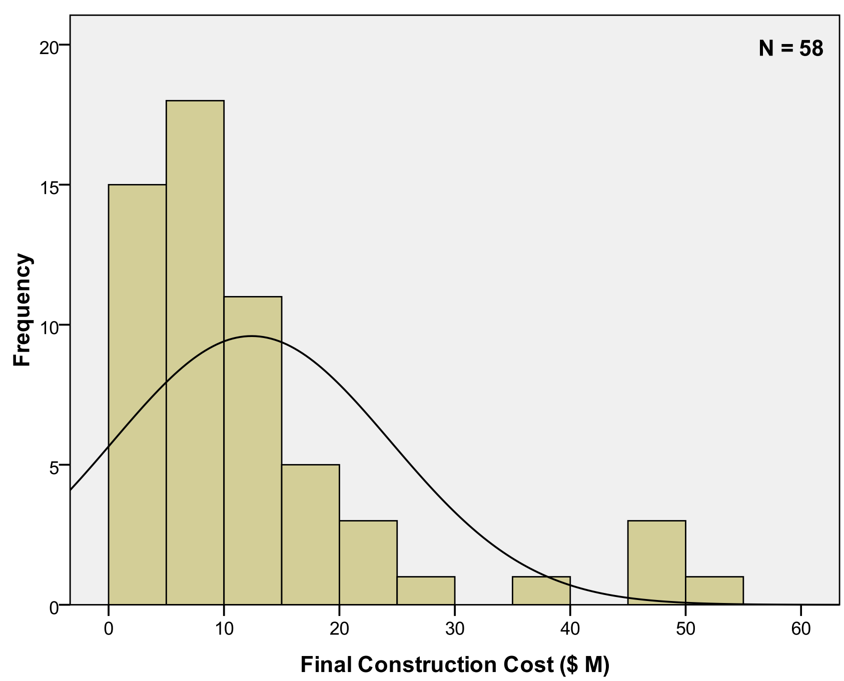

Figure B- 30. Histogram for final construction cost ($ M) of CCDPW flood control and road projects

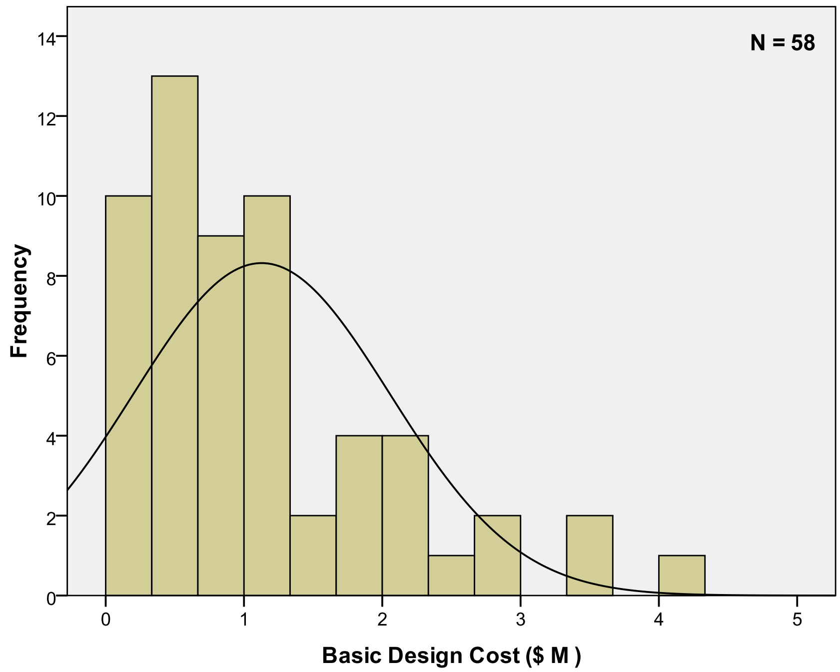

Figure B- 31. Histogram for basic design cost ($ M) of CCDPW flood control and road projects

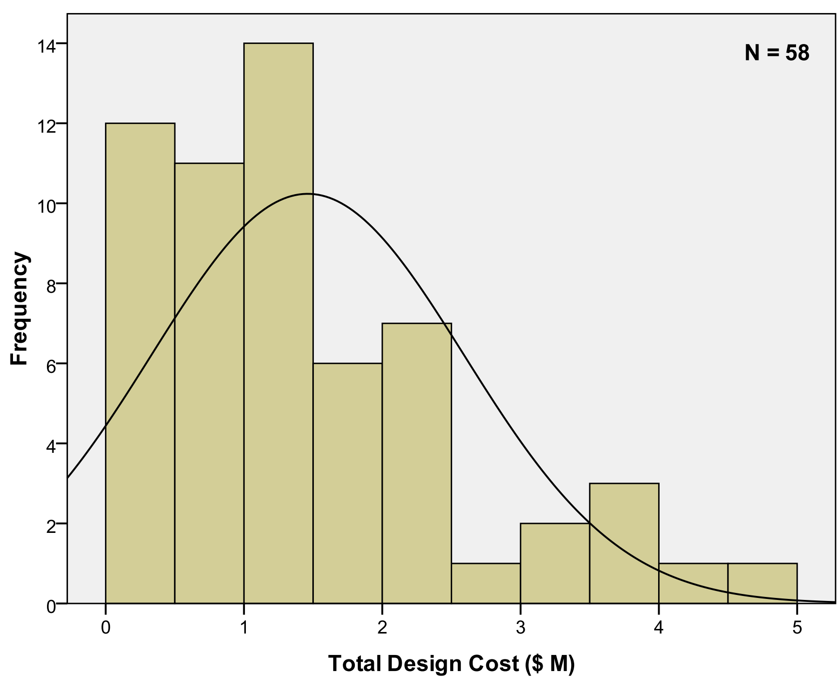

Figure B- 32. Histogram for total design cost ($ M) of CCDPW flood control and road projects

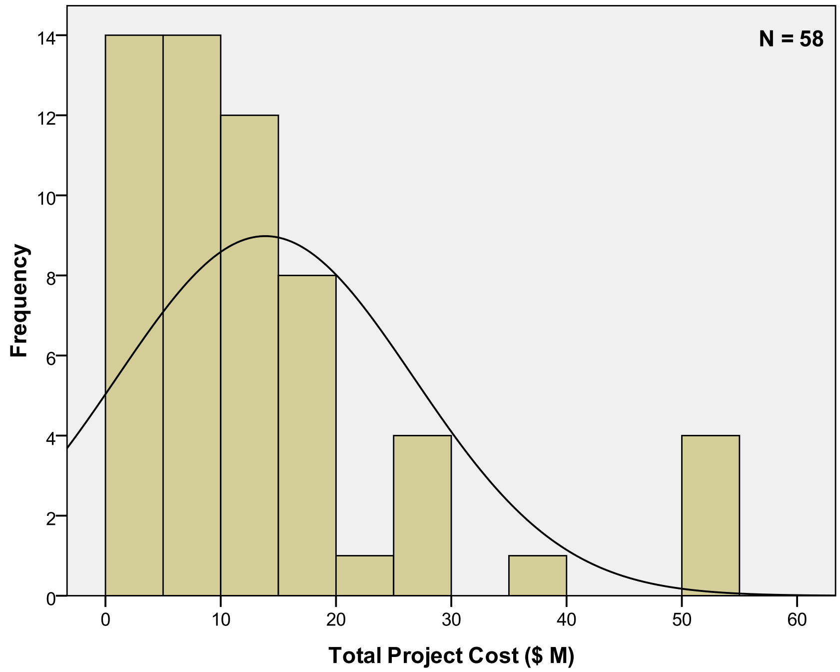

Figure B- 33. Histogram for total project cost ($ M) of CCDPW flood control and road projects

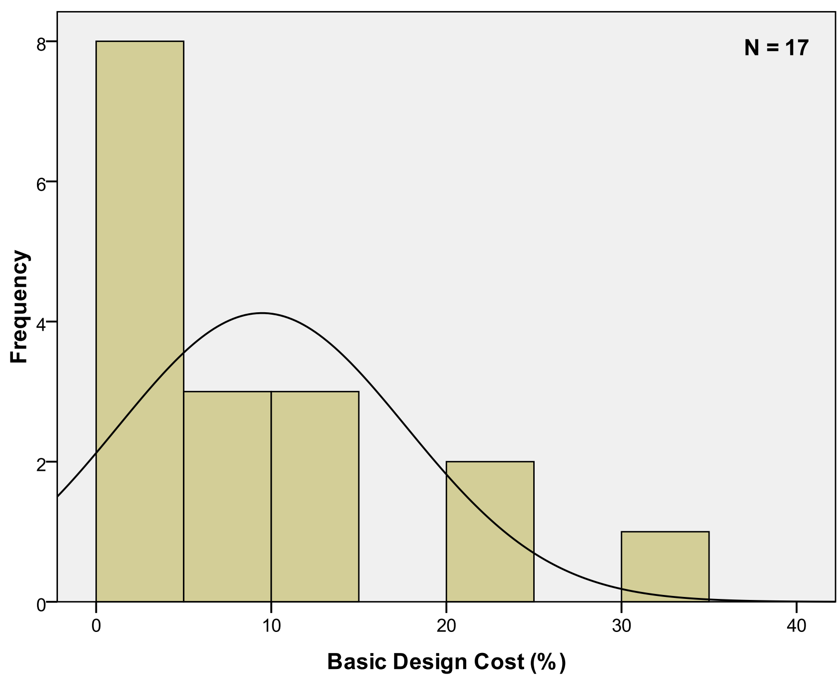

Figure B- 34. Histogram for basic design cost (%) of TXDOT road projects

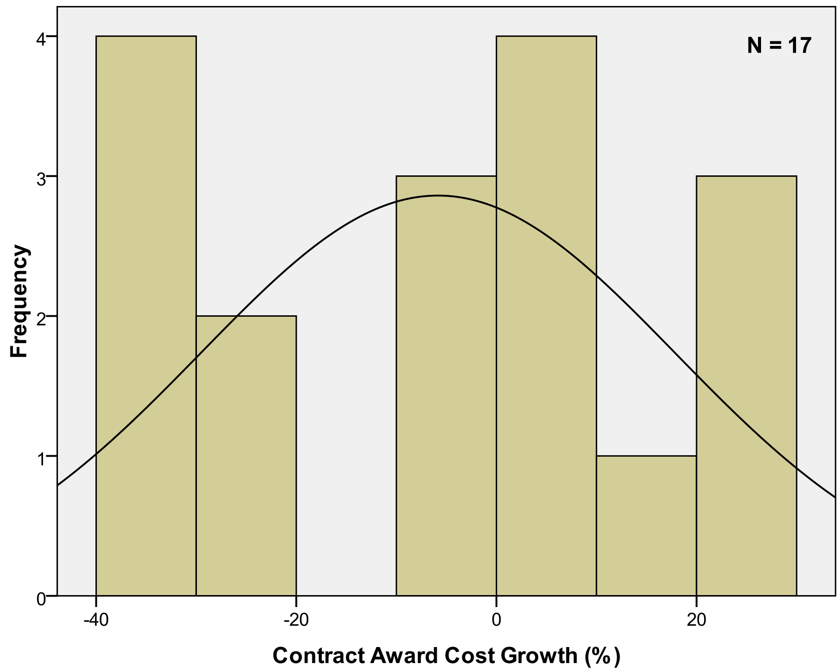

Figure B- 35. Histogram for contract award cost growth (%) of TXDOT road projects

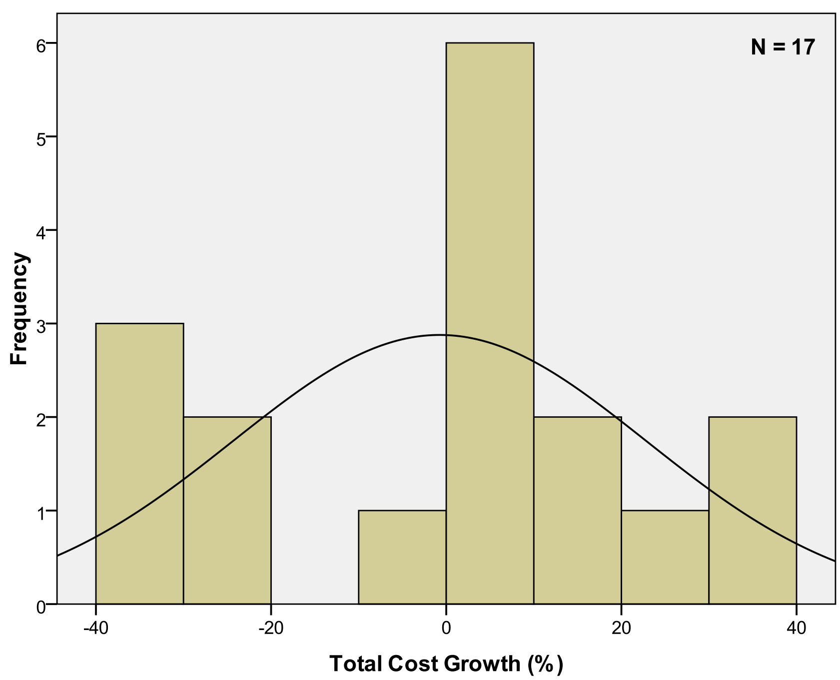

Figure B- 36. Histogram for total cost growth (%) of TXDOT road projects

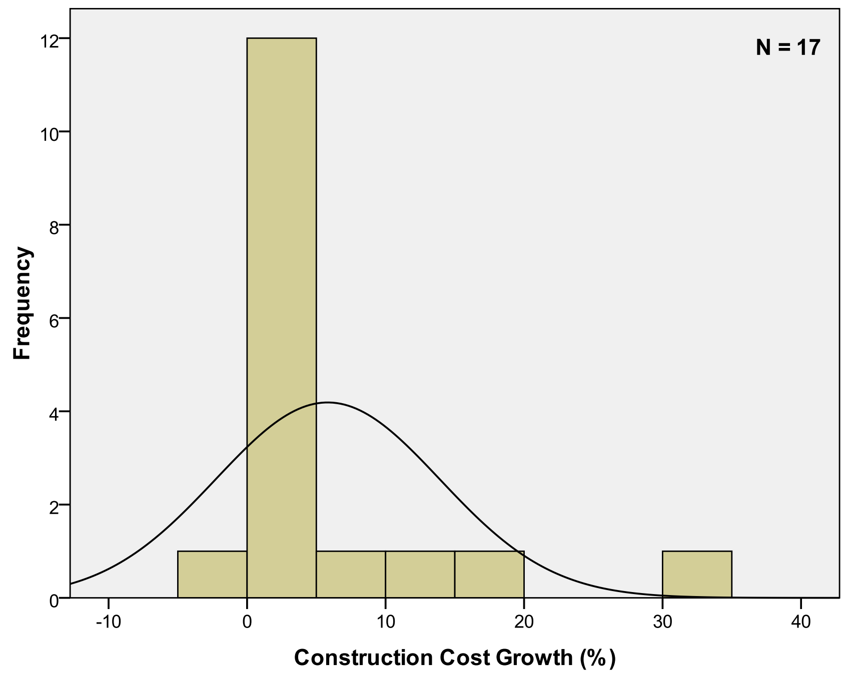

Figure B- 37. Histogram for construction cost growth (%) of TXDOT road projects

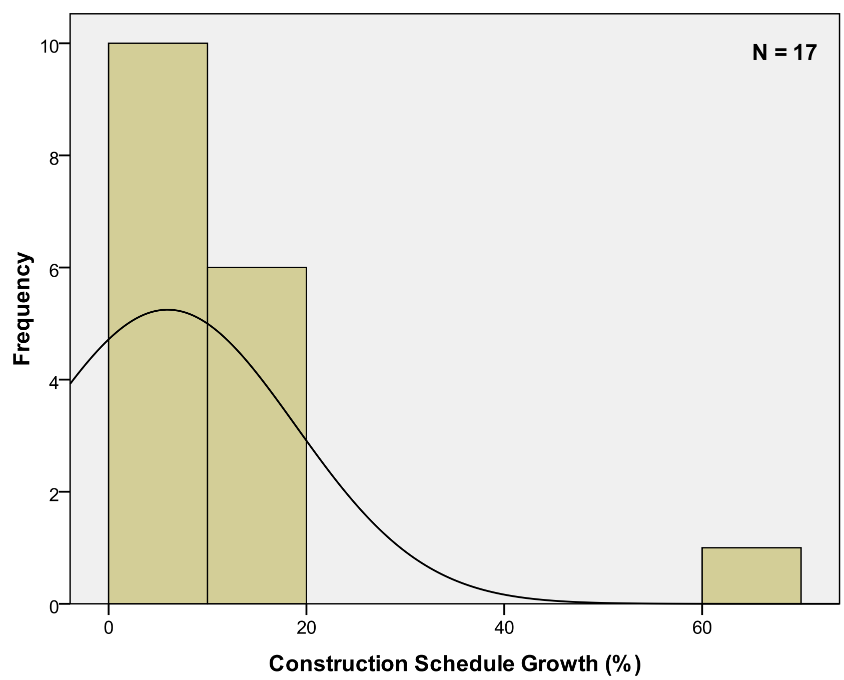

Figure B- 38. Histogram for construction schedule growth (%) of TXDOT road projects

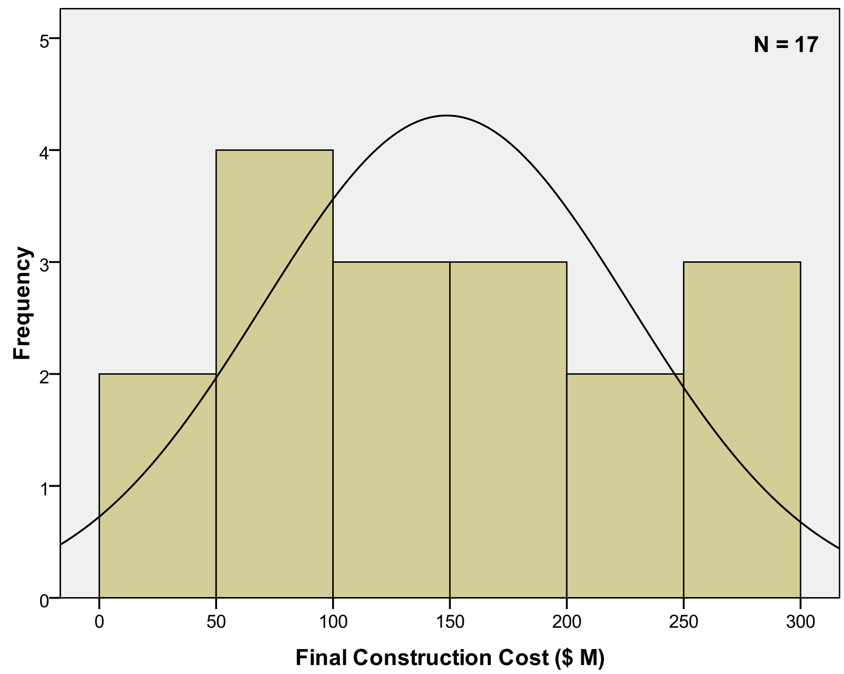

Figure B- 39. Histogram for final construction cost ($ M) of TXDOT road projects

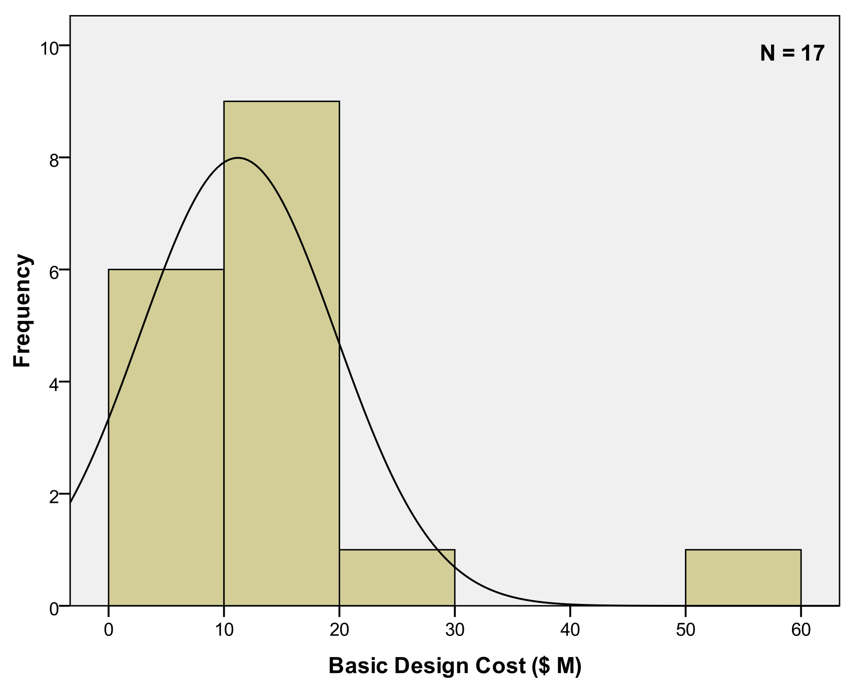

Figure B- 40. Histogram for basic design cost ($ M) of TXDOT road projects

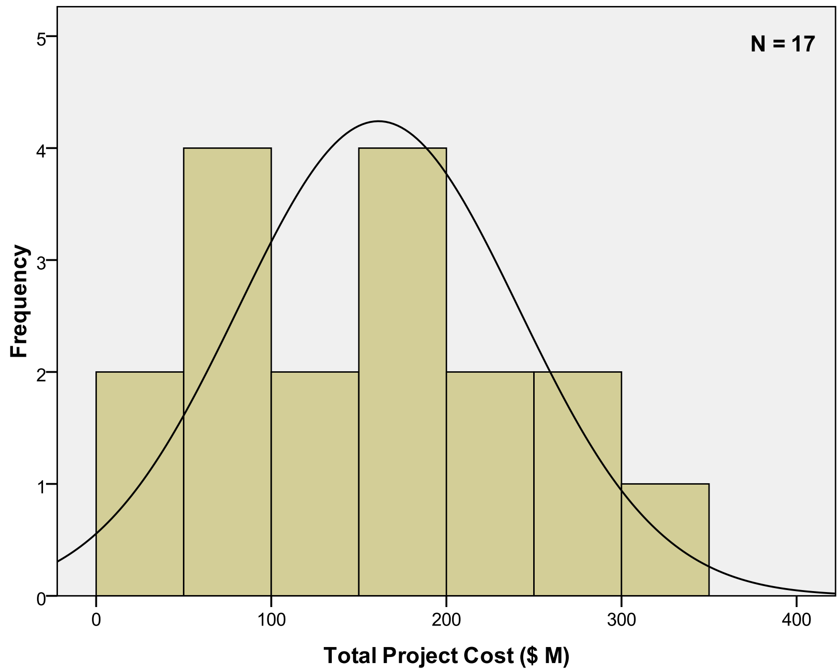

Figure B- 41. Histogram for total project cost ($ M) of TXDOT road projects

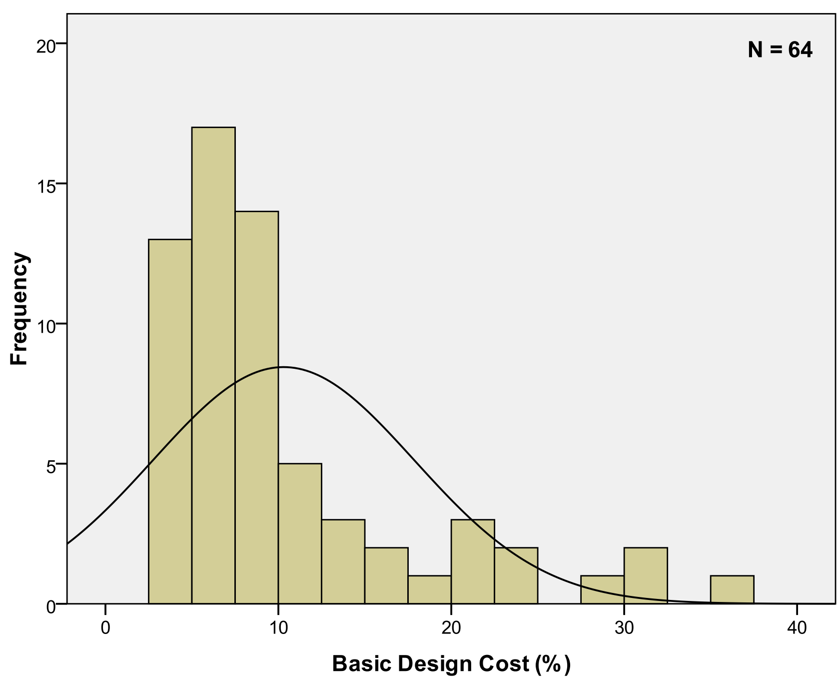

Figure B- 42. Histogram for basic design cost (%) of TXDOT and CCDPW road projects

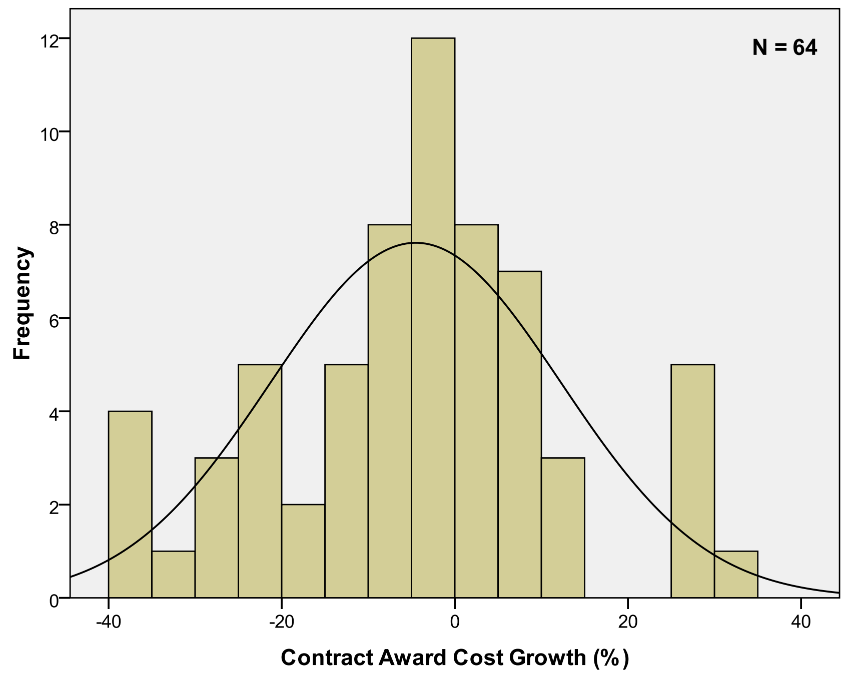

Figure B- 43. Histogram for contract award cost growth (%) of TXDOT and CCDPW road projects

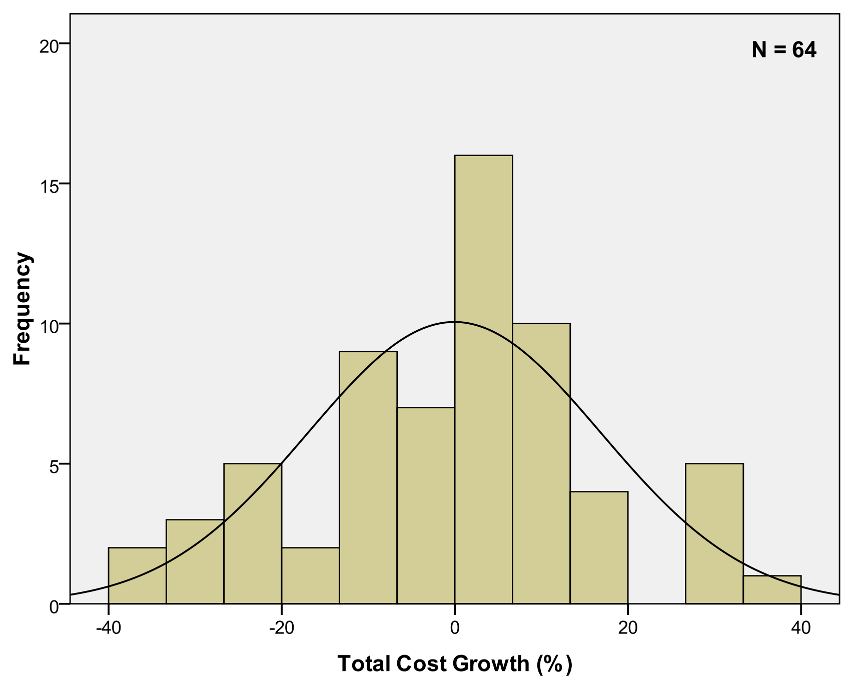

Figure B- 44. Histogram for total cost growth (%) of TXDOT and CCDPW road projects

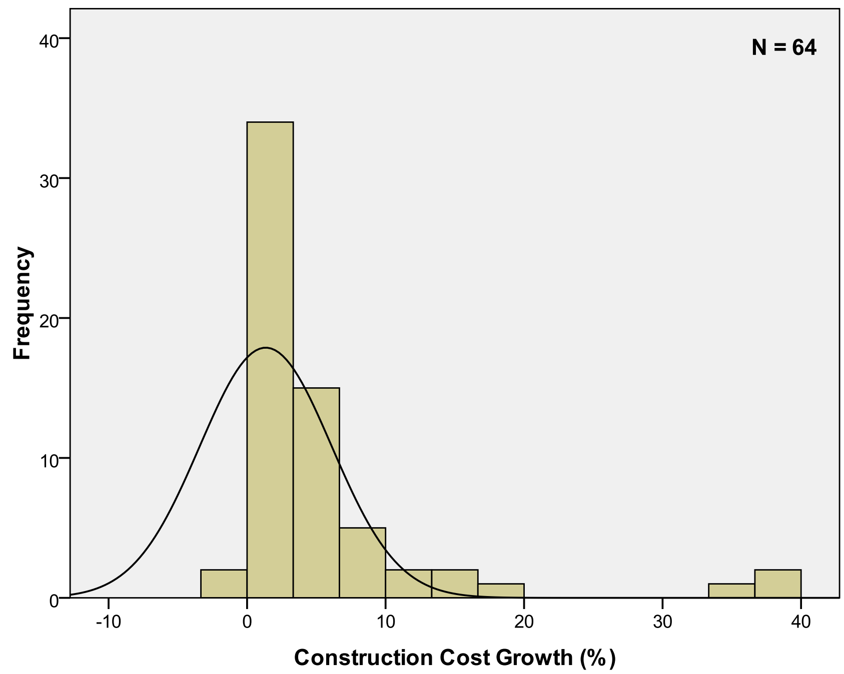

Figure B- 45. Histogram for construction cost growth (%) of TXDOT and CCDPW road projects

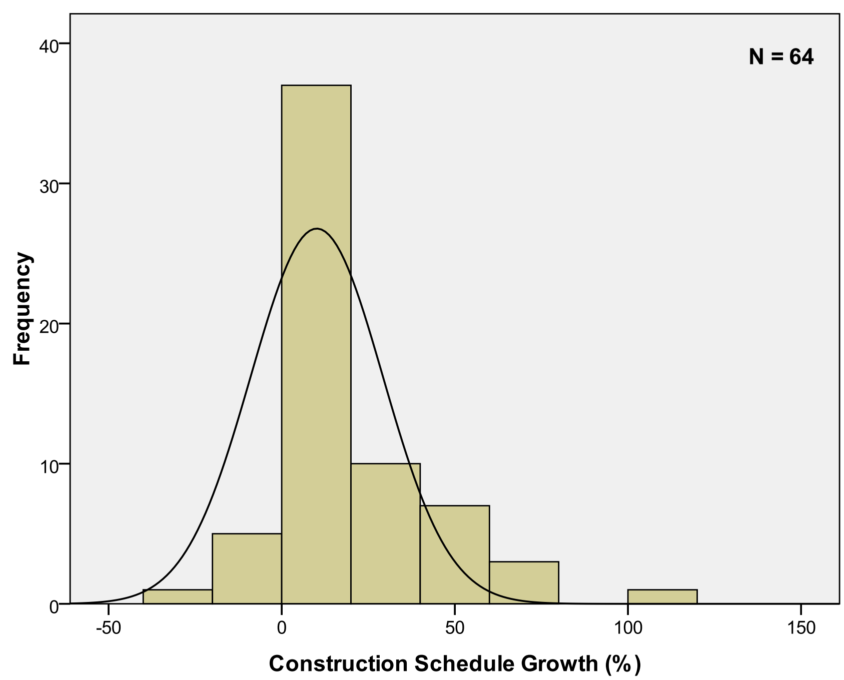

Figure B- 46. Histogram for construction schedule growth (%) of TXDOT and CCDPW road projects

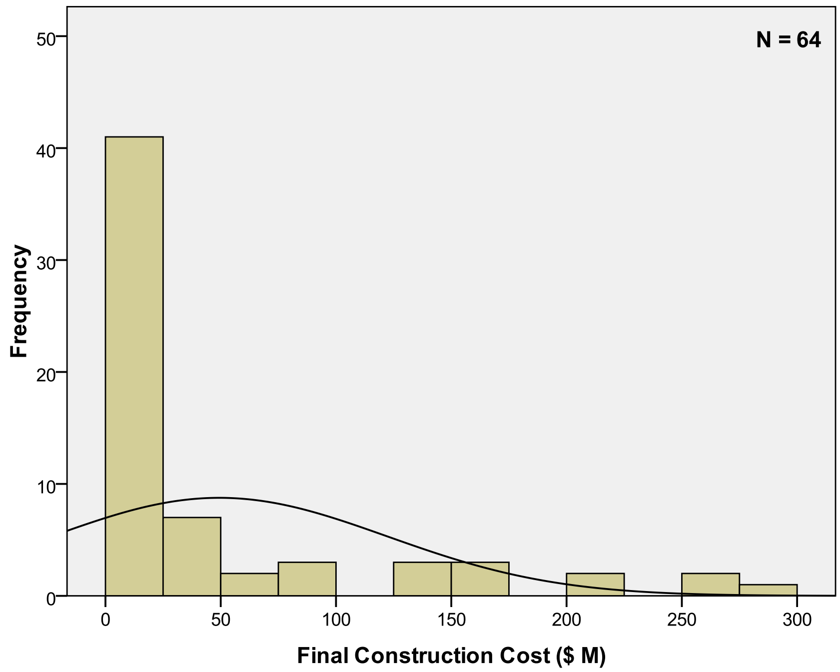

Figure B- 47. Histogram for final construction cost ($ M) of TXDOT and CCDPW road projects

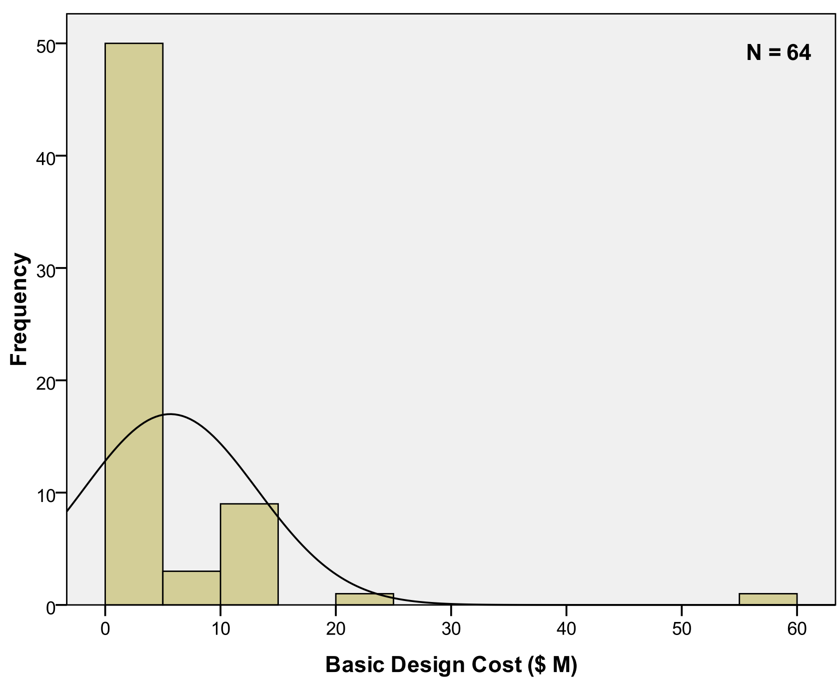

Figure B- 48. Histogram for basic design cost ($ M) of TXDOT and CCDPW road projects

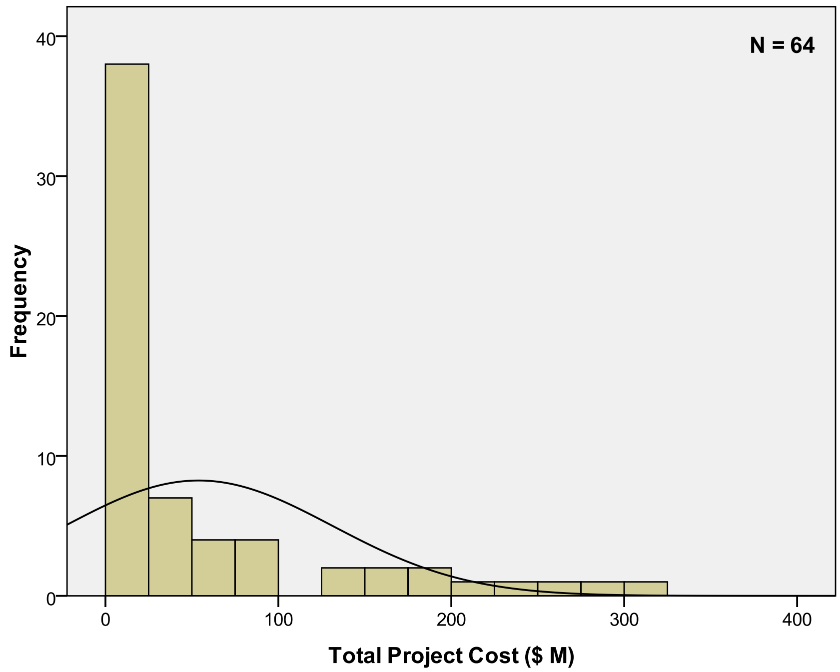

Figure B- 49. Histogram for total project cost ($ M) of TXDOT and CCDPW road projects

APPENDIX C

BOX PLOTS

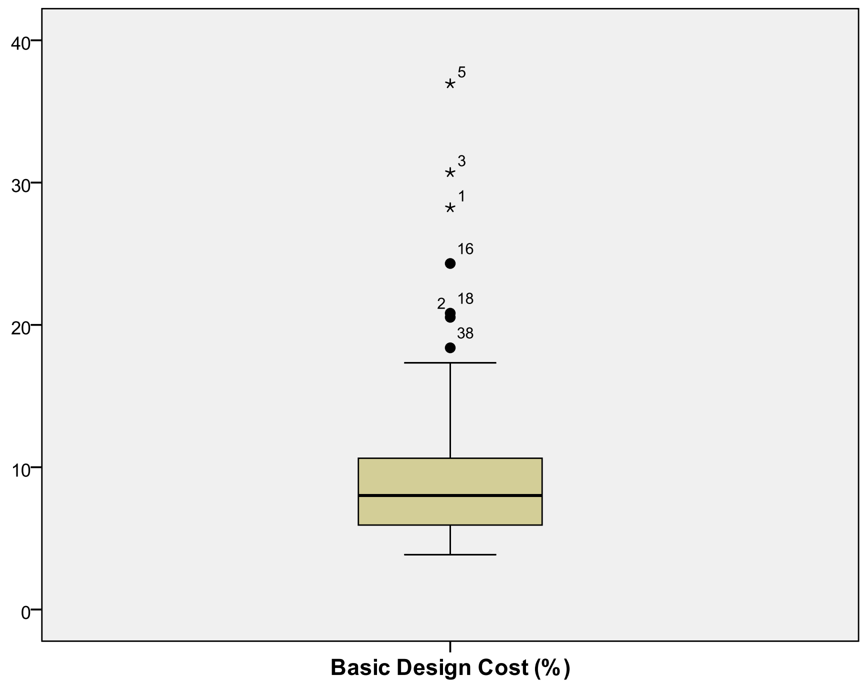

Figure C- 1. Box plot for basic design cost (%) of CCDPW road projects

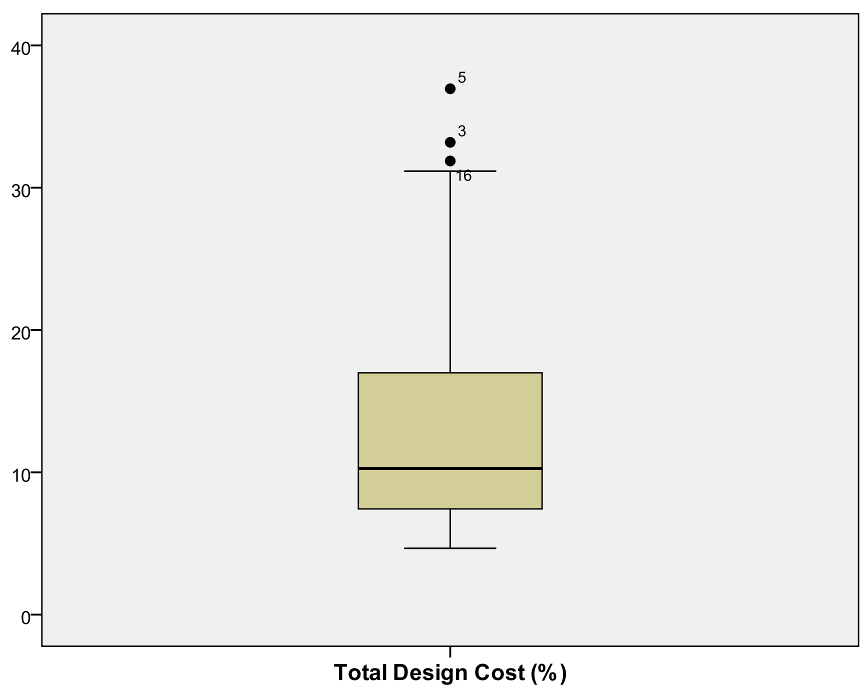

Figure C- 2. Box plot for total design cost (%) of CCDPW road projects

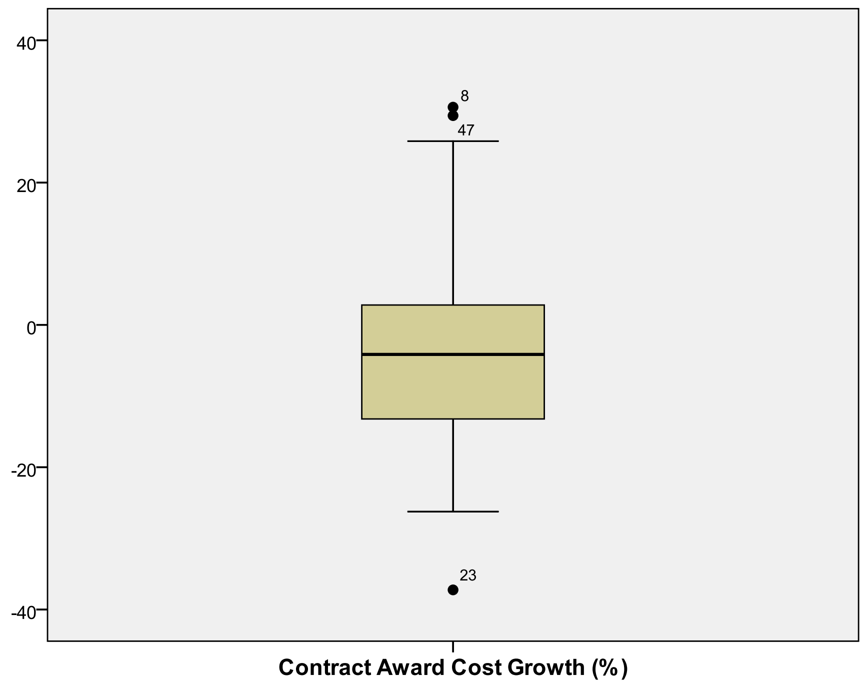

Figure C- 3. Box plot for contract award cost growth (%) of CCDPW road projects

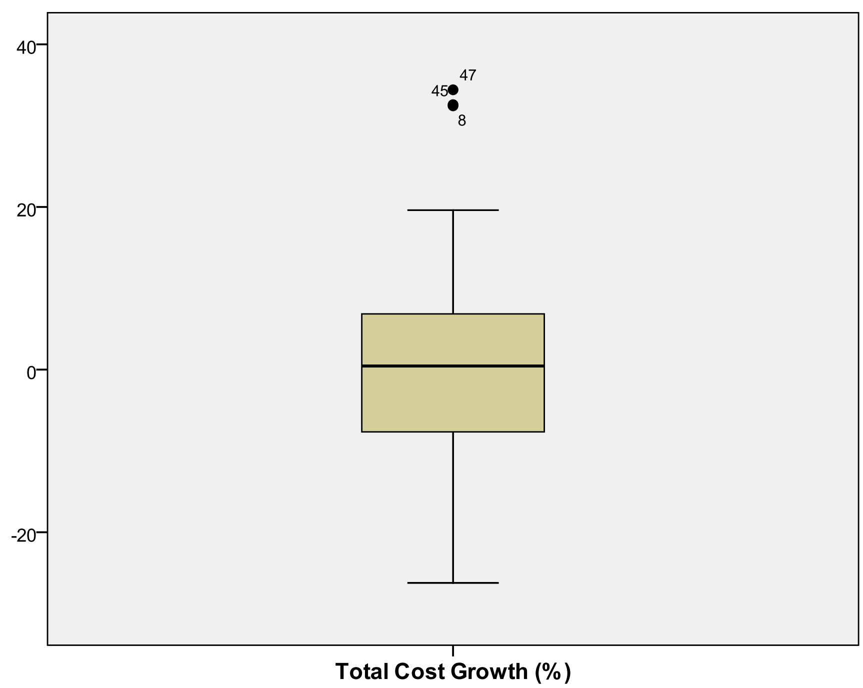

Figure C- 4. Box plot for total cost growth (%) of CCDPW road projects

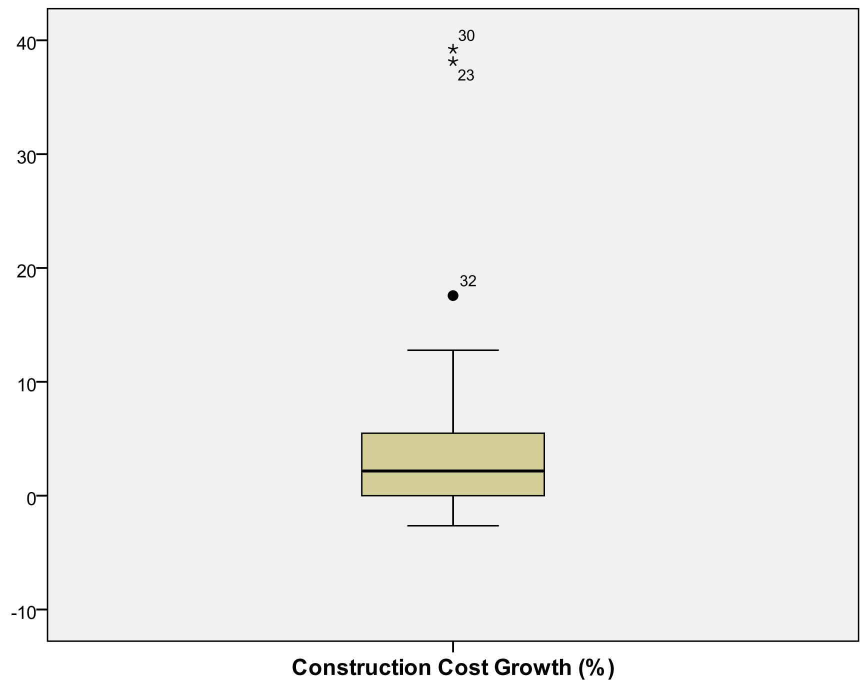

Figure C- 5. Box plot for construction cost growth (%) of CCDPW road projects

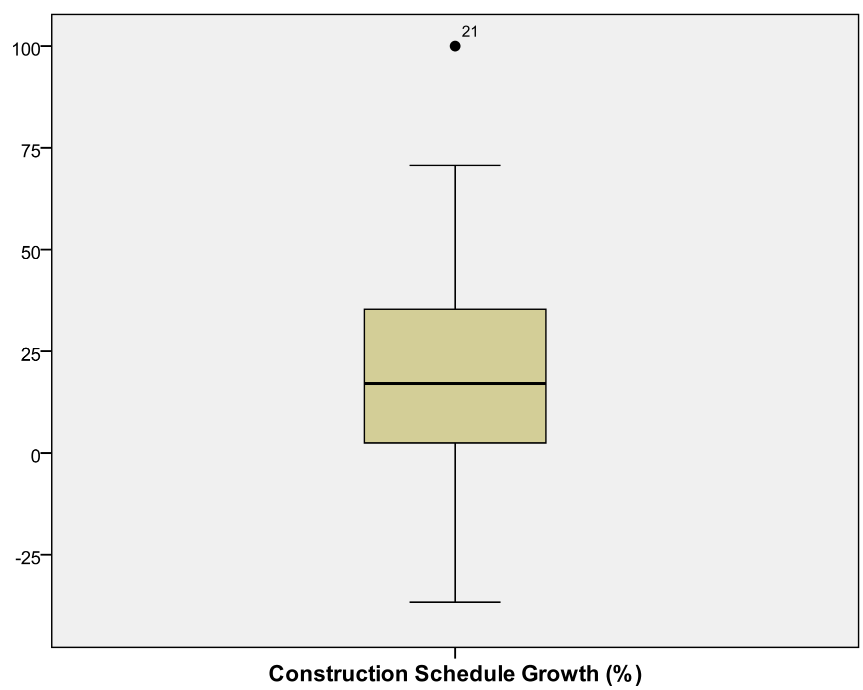

Figure C- 6. Box plot for construction schedule growth (%) of CCDPW road projects

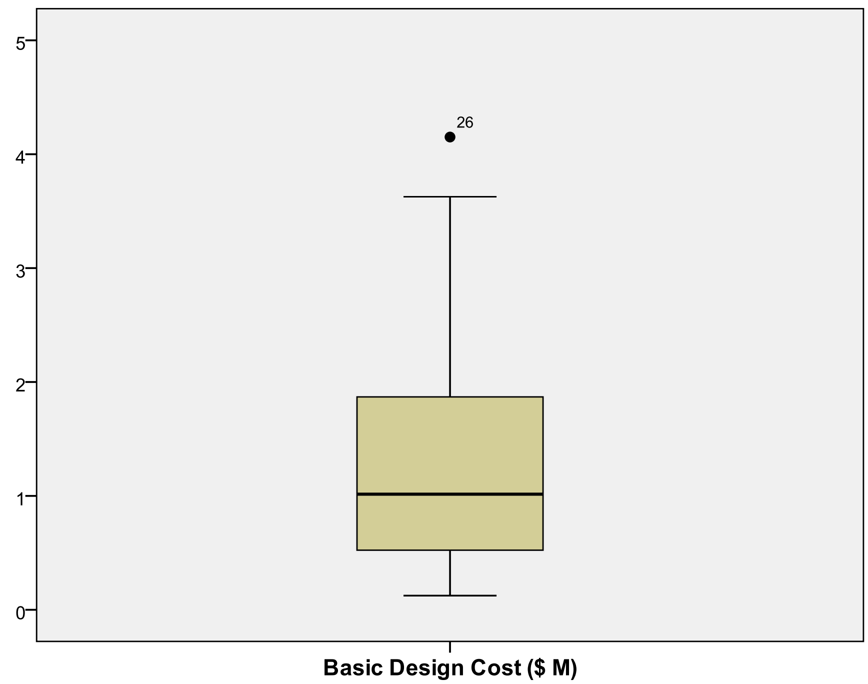

Figure C- 7. Box plot for basic design cost ($ million) of CCDPW road projects

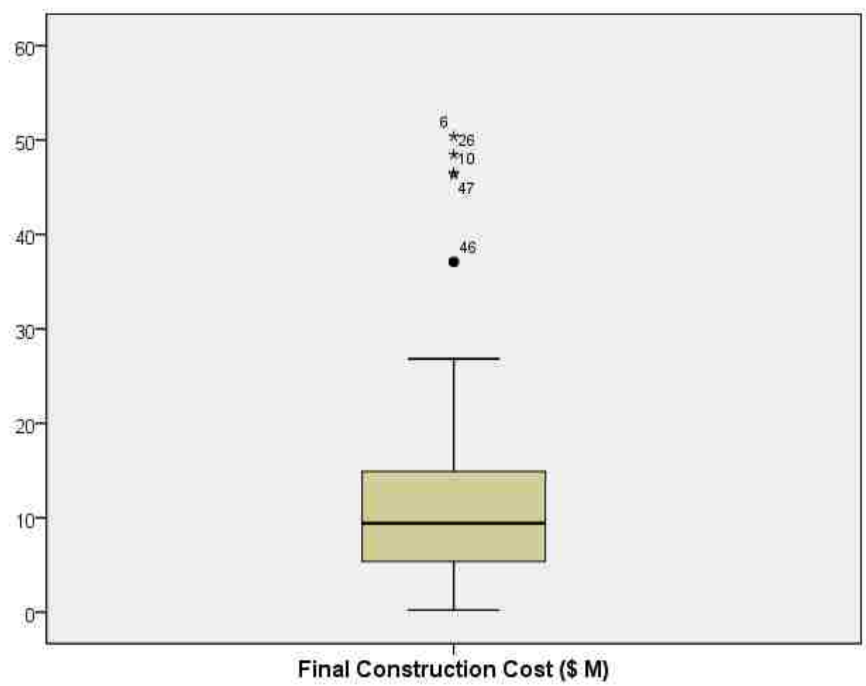

Figure C- 8. Box plot for basic design cost ($ million) of CCDPW road projects

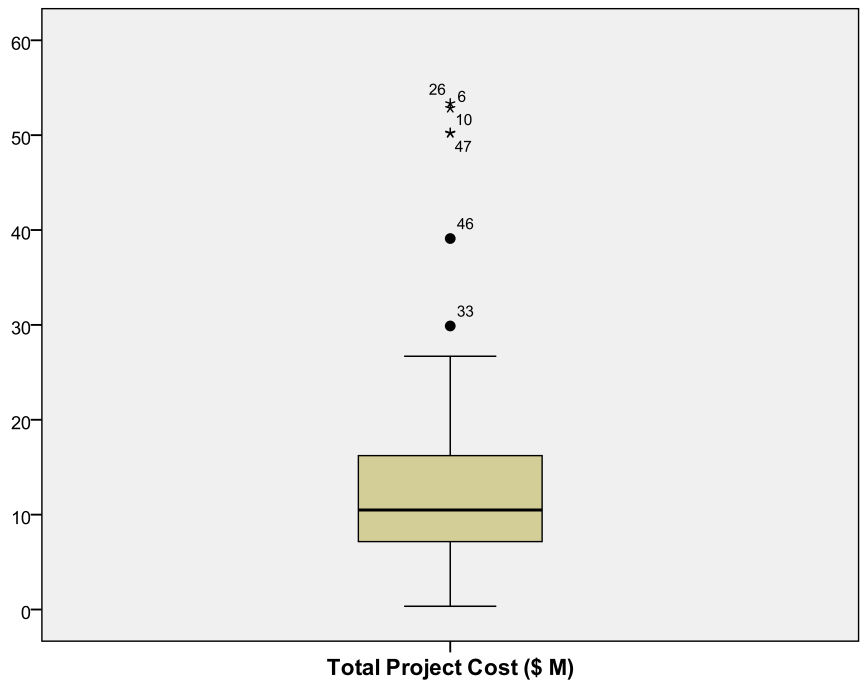

Figure C- 9. Box plot for total project cost ($ million) of CCDPW road projects

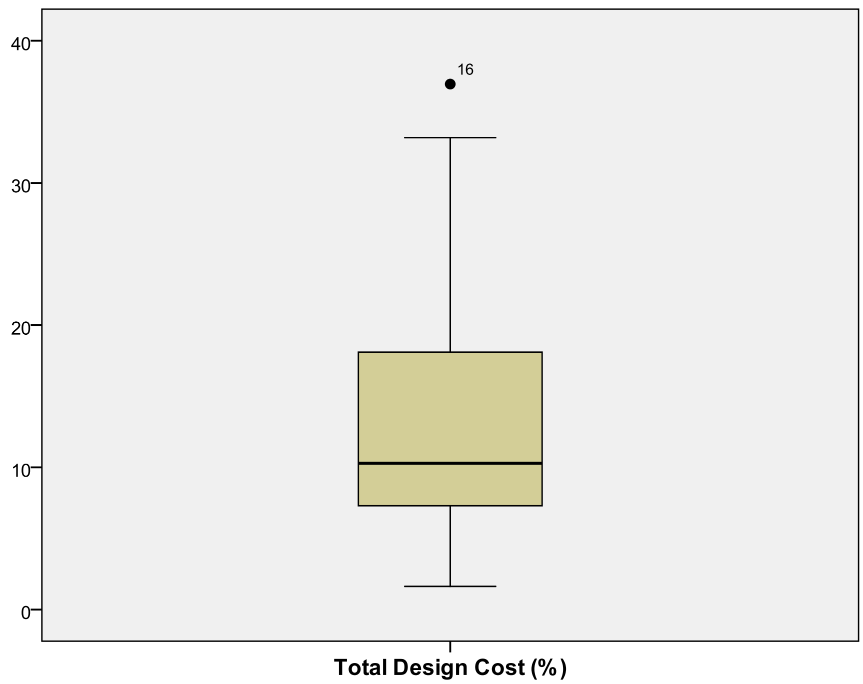

Figure C- 10. Box plot for total design cost (%) of CCDPW road and flood control projects

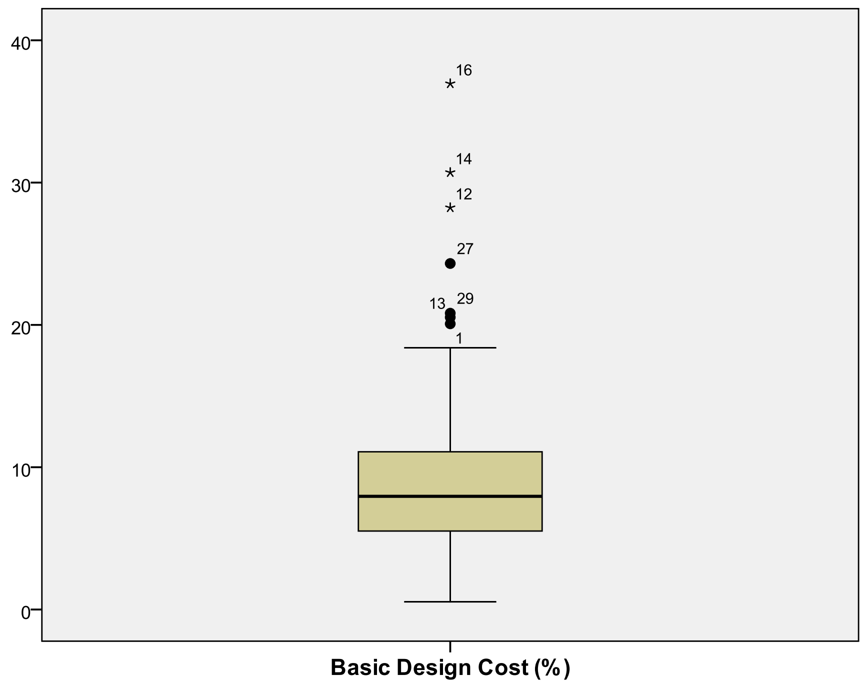

Figure C- 11. Box plot for basic design cost (%) of CCDPW road and flood control projects

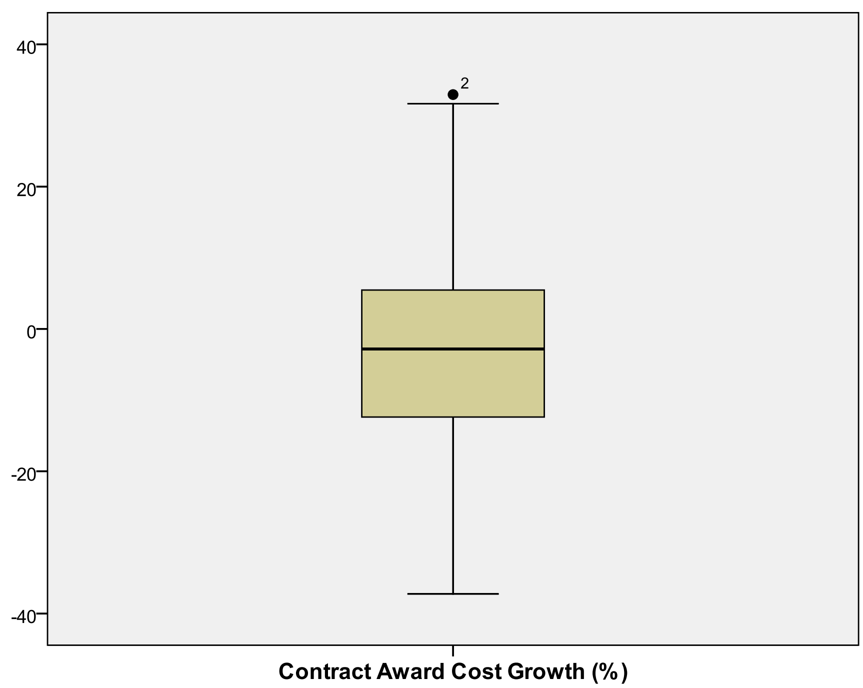

Figure C- 12. Box plot for contract award cost growth (%) of CCDPW road and flood control projects

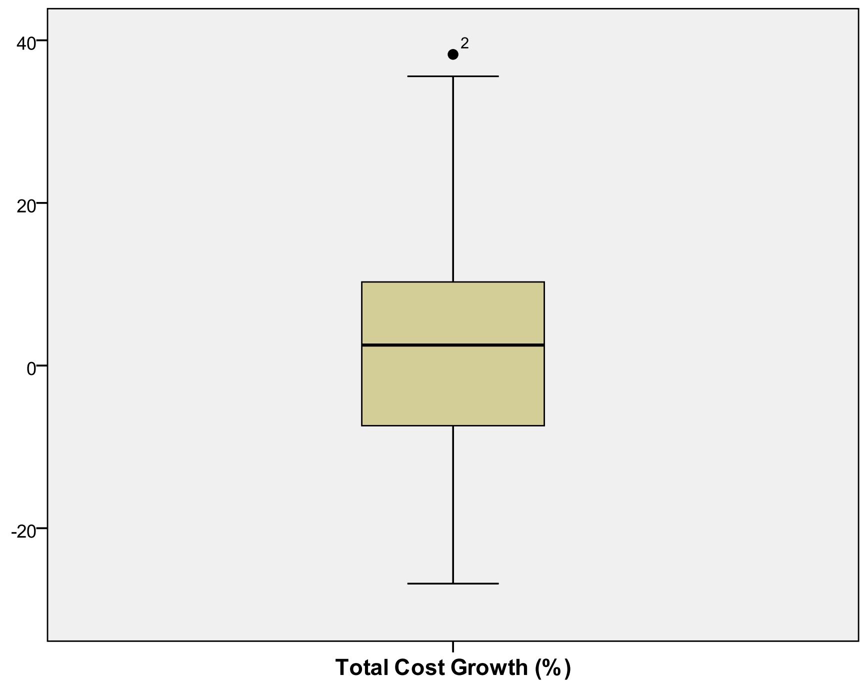

Figure C- 13. Box plot for total cost growth (%) of CCDPW road and flood control projects

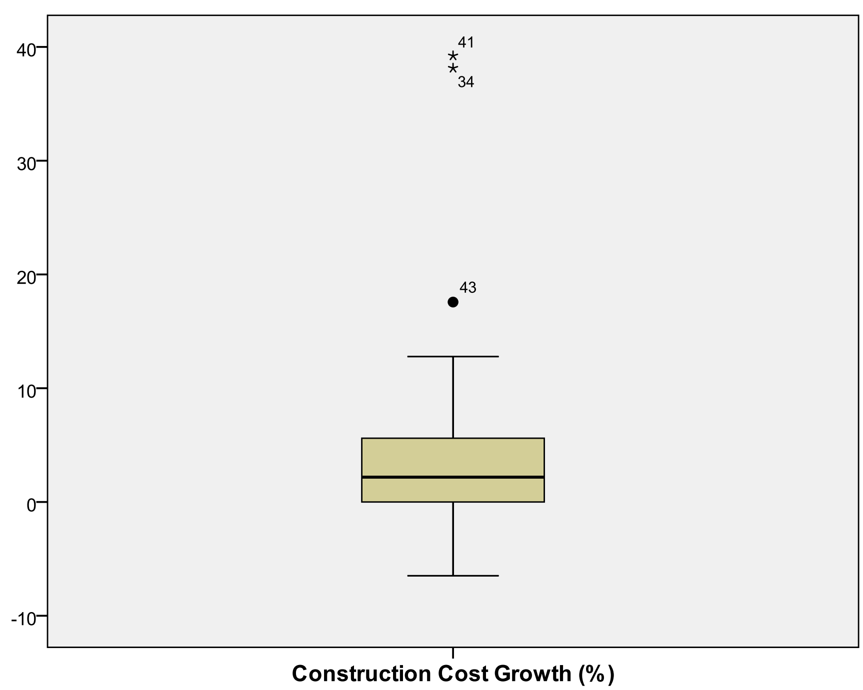

Figure C- 14. Box plot for construction cost growth (%) of CCDPW road and flood control projects

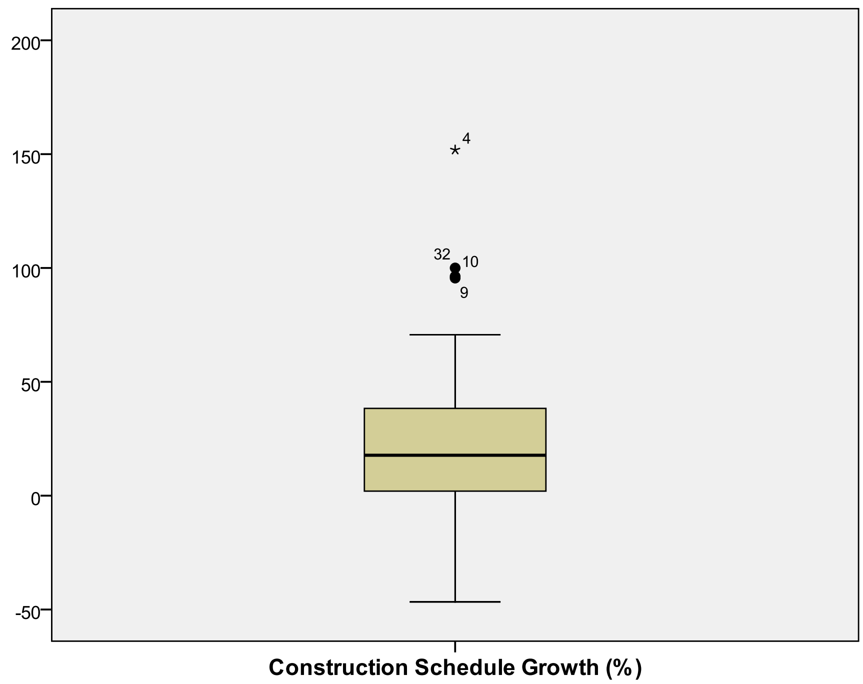

Figure C- 15. Box plot for construction schedule growth (%) of CCDPW road and flood control projects

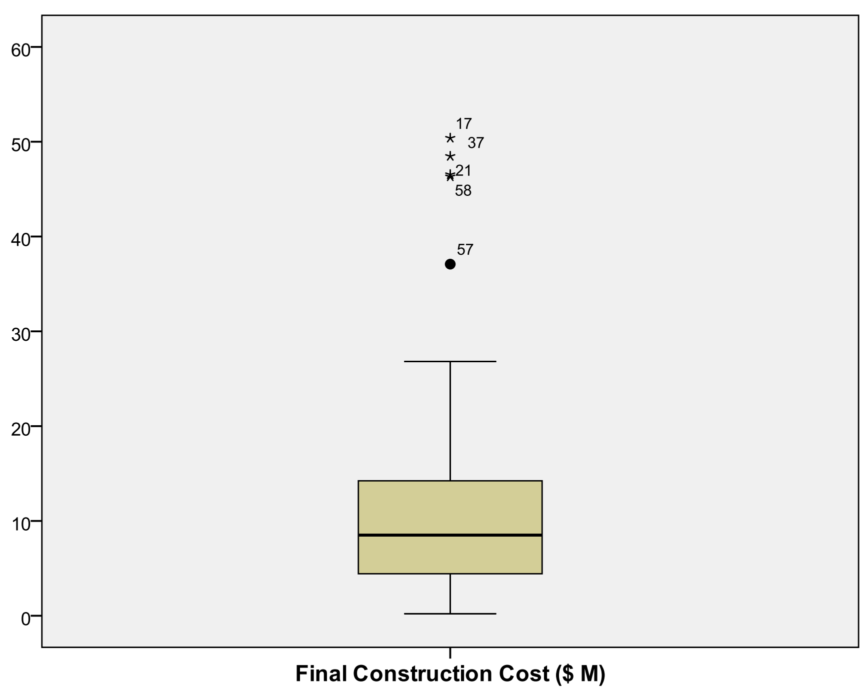

Figure C- 16. Box plot for final construction cost (%) of CCDPW road and flood control projects

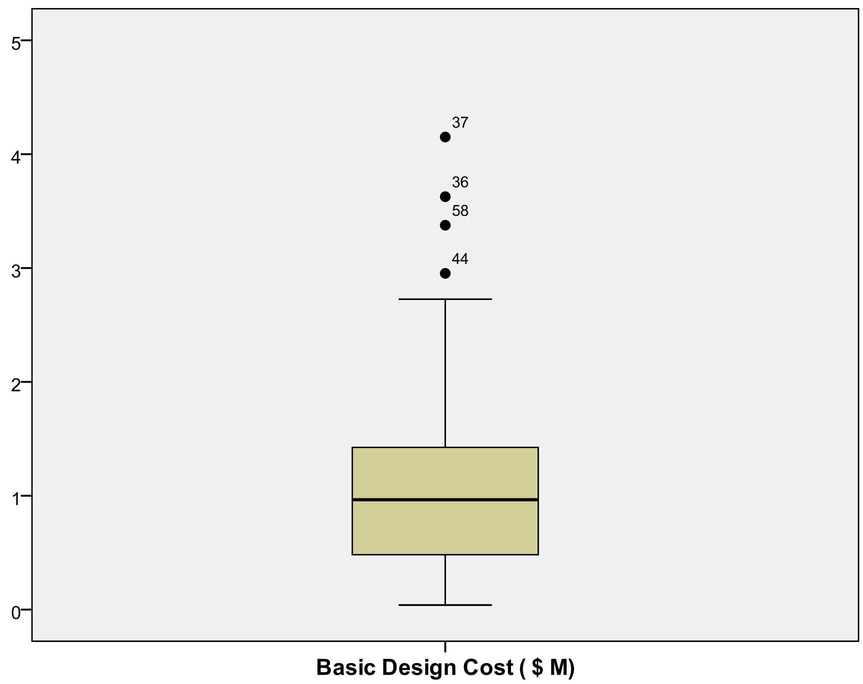

Figure C- 17. Box plot for basic design cost ($ million) of CCDPW road and flood control projects

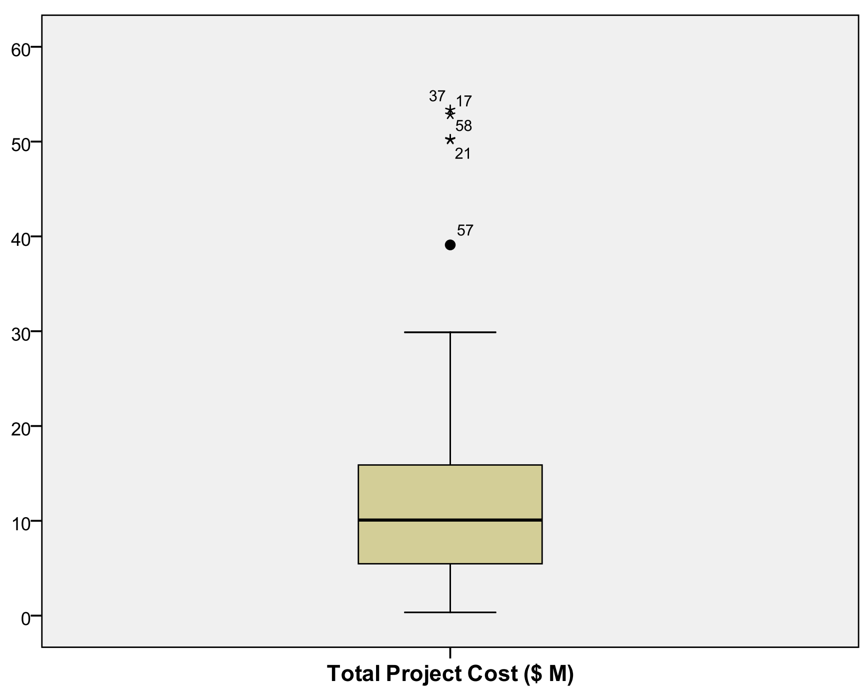

Figure C- 18. Box plot for total project cost ($ million) of CCDPW road and flood control projects

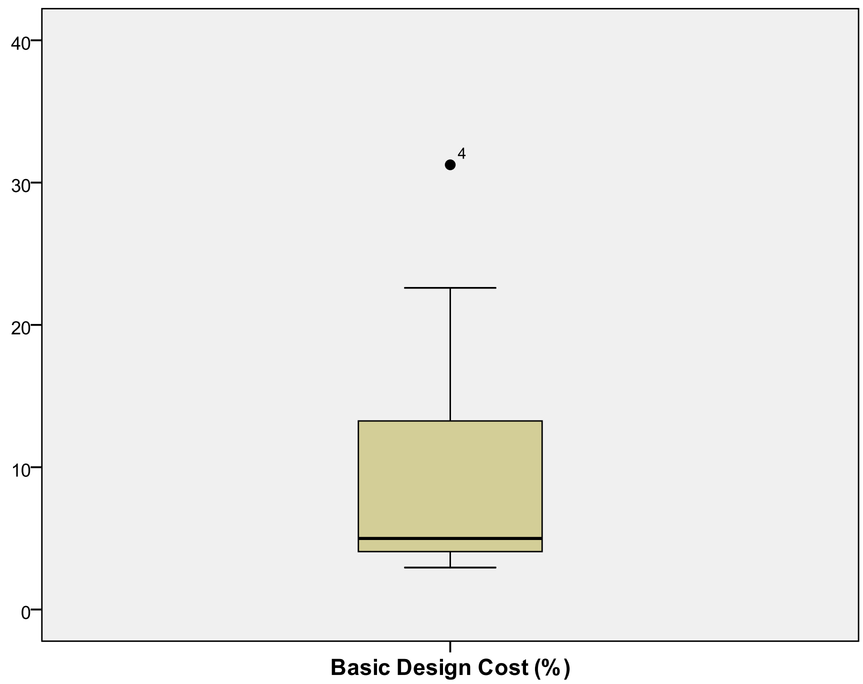

Figure C- 19. Box plot for basic design cost (%) of TXDOT road projects

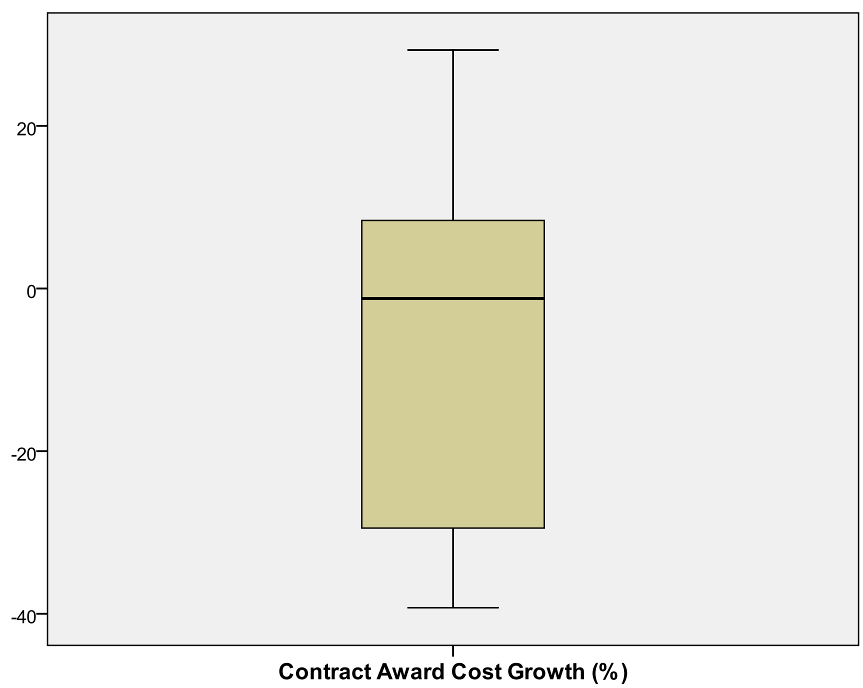

Figure C- 20. Box plot for contract award cost growth (%) of TXDOT road projects

Figure C- 21. Box plot for total cost growth (%) of TXDOT road projects

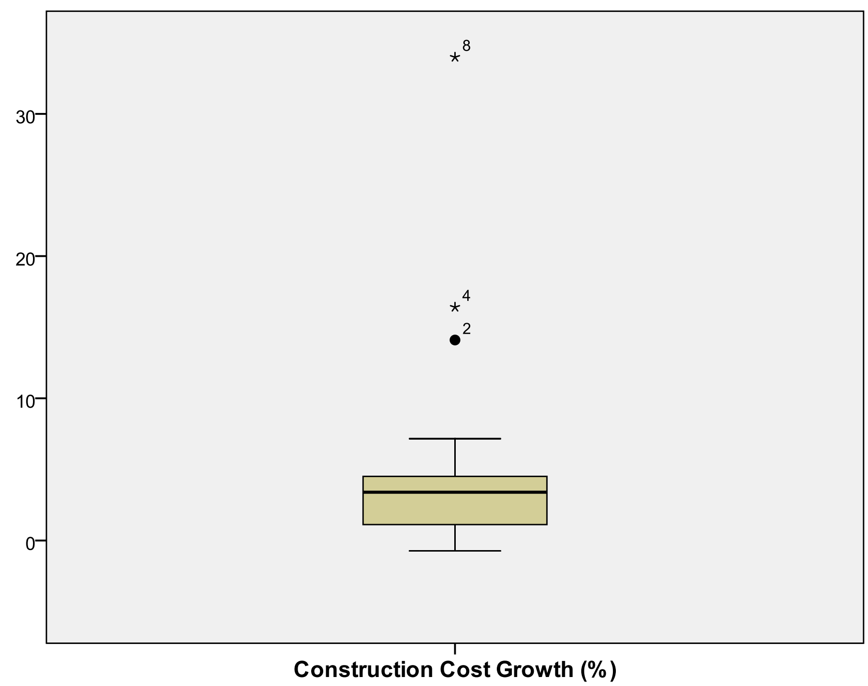

Figure C- 22. Box plot for construction cost growth (%) of TXDOT road projects

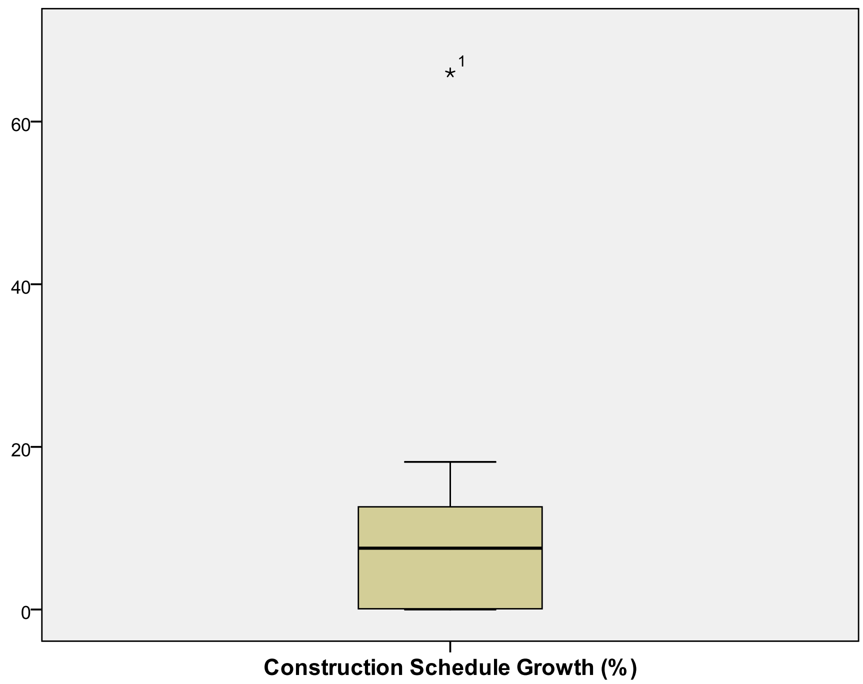

Figure C- 23. Box plot for construction schedule growth (%) of TXDOT road projects

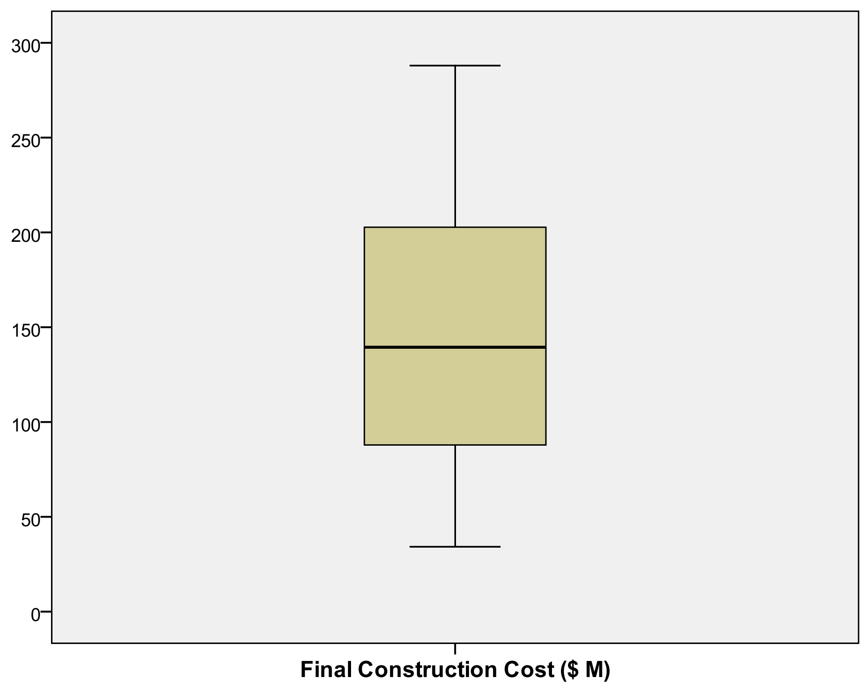

Figure C- 24. Box plot for final construction cost ($ million) of TXDOT road projects

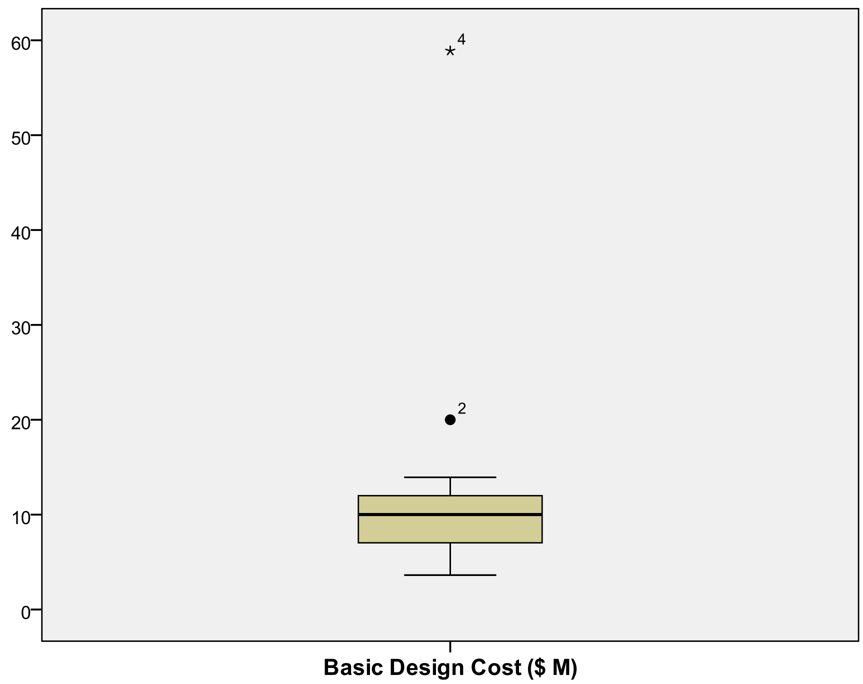

Figure C- 25. Box plot for basic design cost ($ million) of TXDOT road projects

Figure C- 26. Box plot for total project cost ($ million) of TXDOT road projects

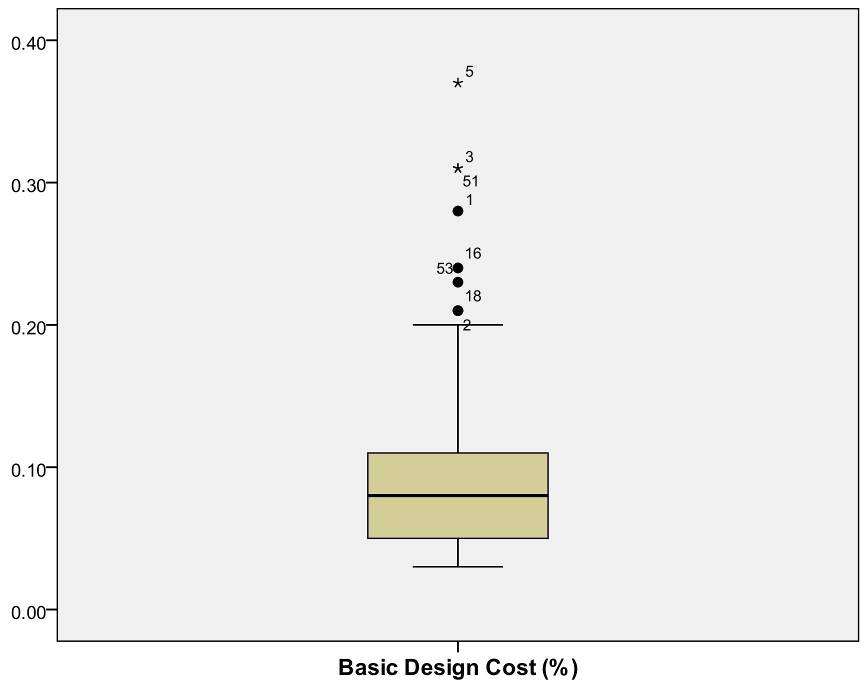

Figure C- 27. Box plot for basic design cost (%) of TXDOT and CCDPW road projects

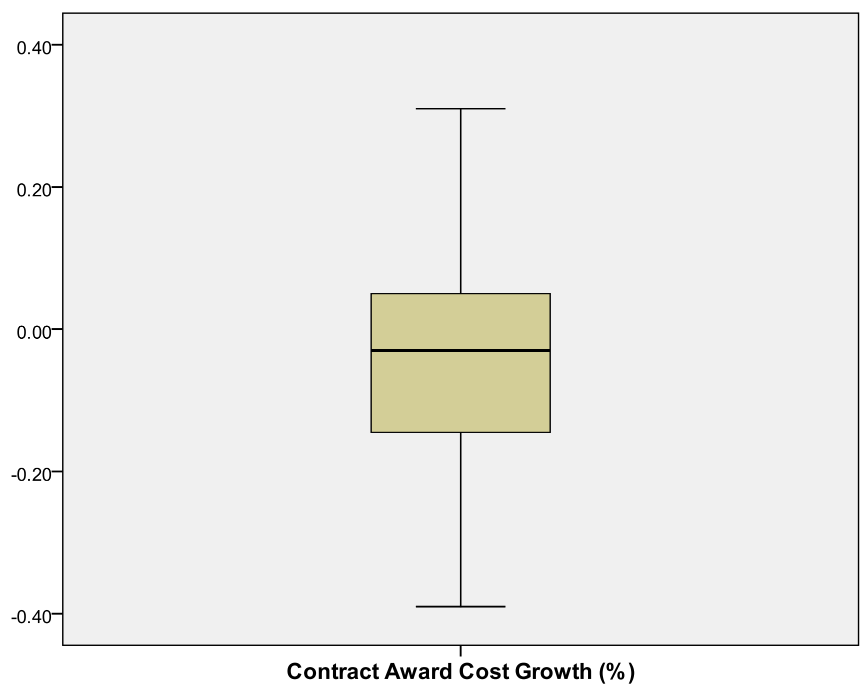

Figure C- 28. Box plot for contract award cost growth (%) of TXDOT and CCDPW road projects

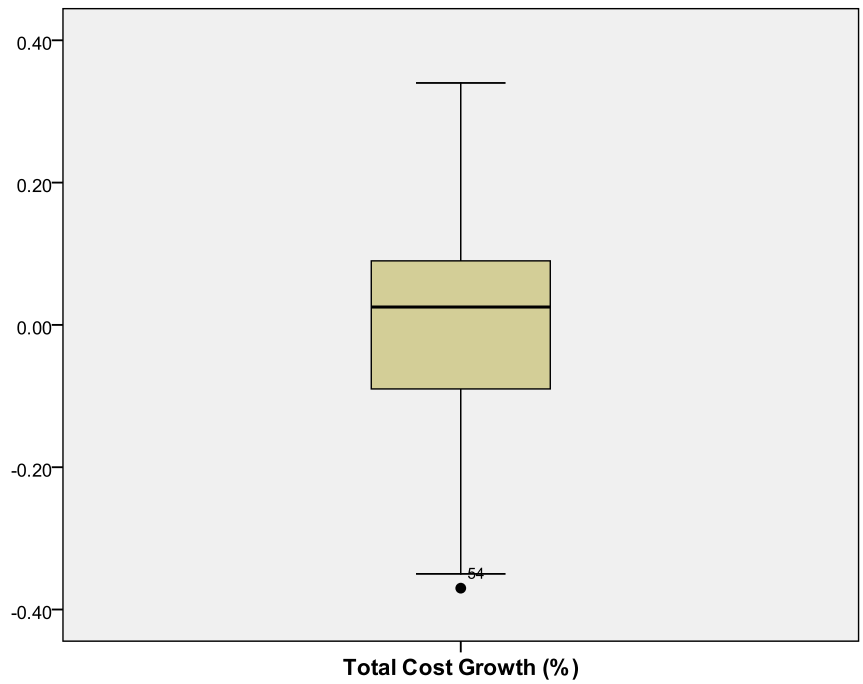

Figure C- 29. Box plot for total cost growth (%) of TXDOT and CCDPW road projects

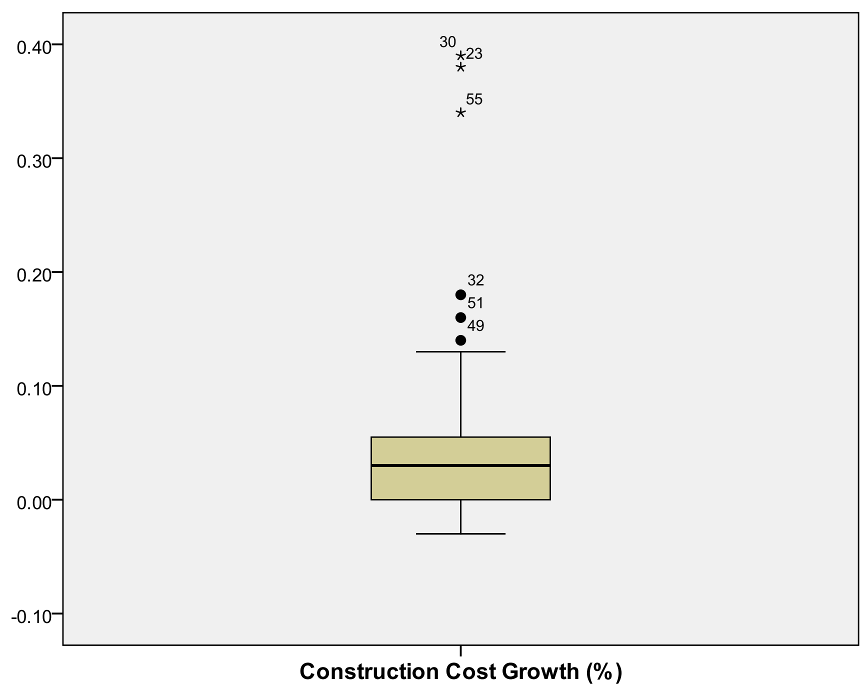

Figure C- 30. Box plot for construction cost growth (%) of TXDOT and CCDPW road projects

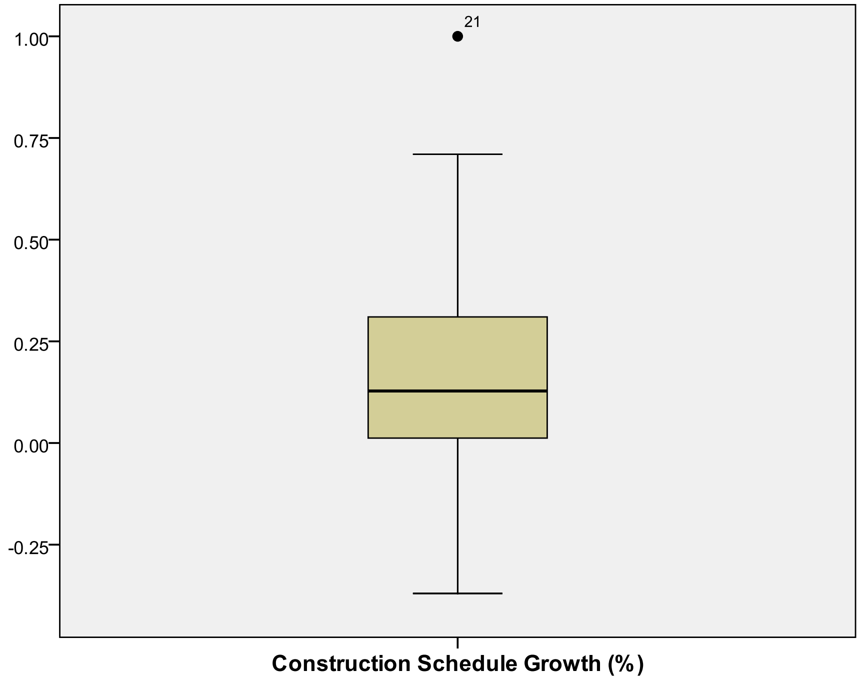

Figure C- 31. Box plot for construction schedule growth (%) of TXDOT and CCDPW road projects

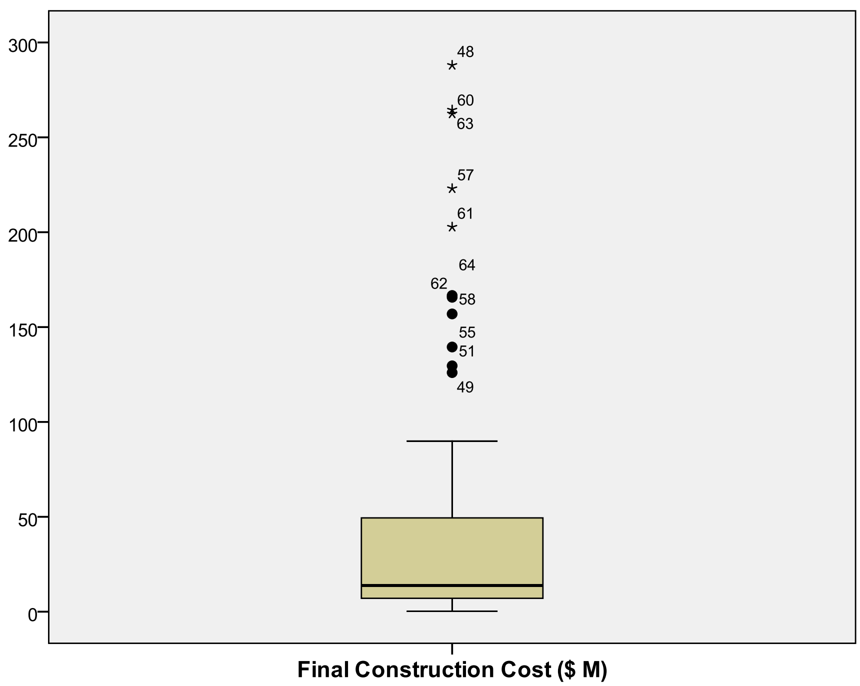

Figure C- 32. Box plot for final construction cost ($ million) of TXDOT and Clark County road projects

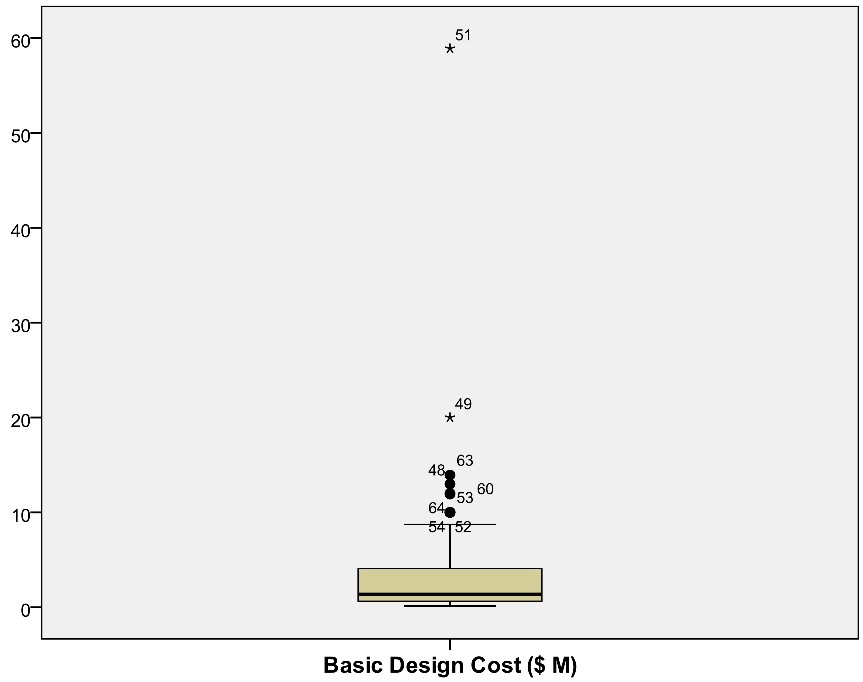

Figure C- 33. Box plot for basic design cost ($ million) of TXDOT and CCDPW road projects

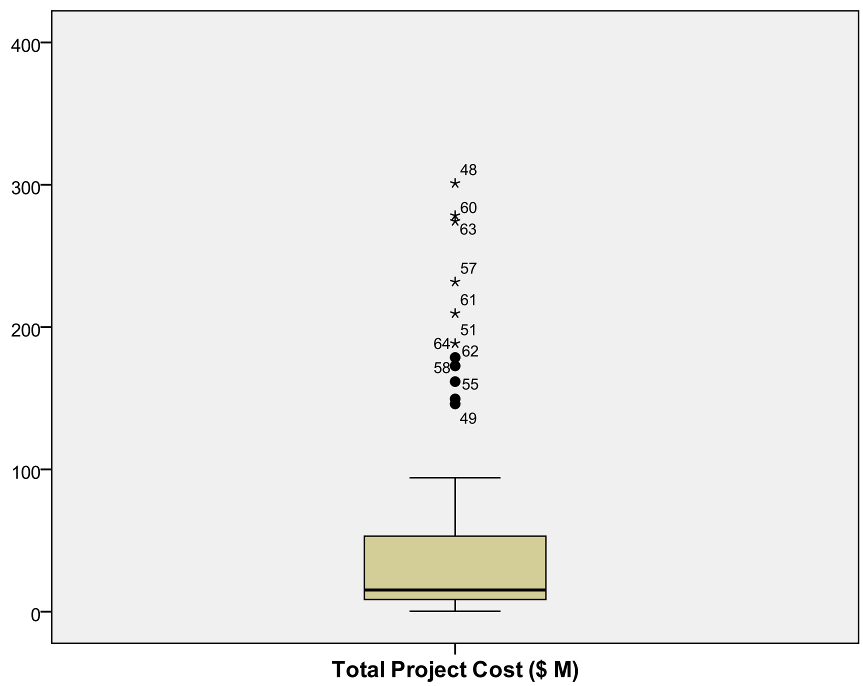

Figure C- 34. Box plot for total project cost ($ million) of TXDOT and CCDPW road projects

APPENDIX D

SCATTER PLOT BETWEEN INDEPENDENT AND DEPENDENT VARIABLES

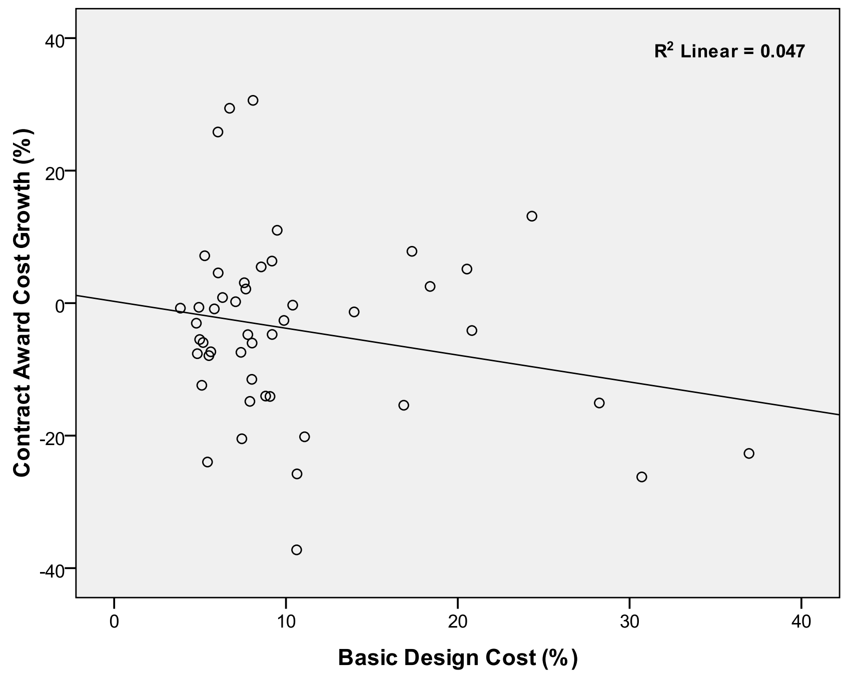

Figure D- 1. Scatter plot of basic design cost and contract award cost growth for CCDPW road projects

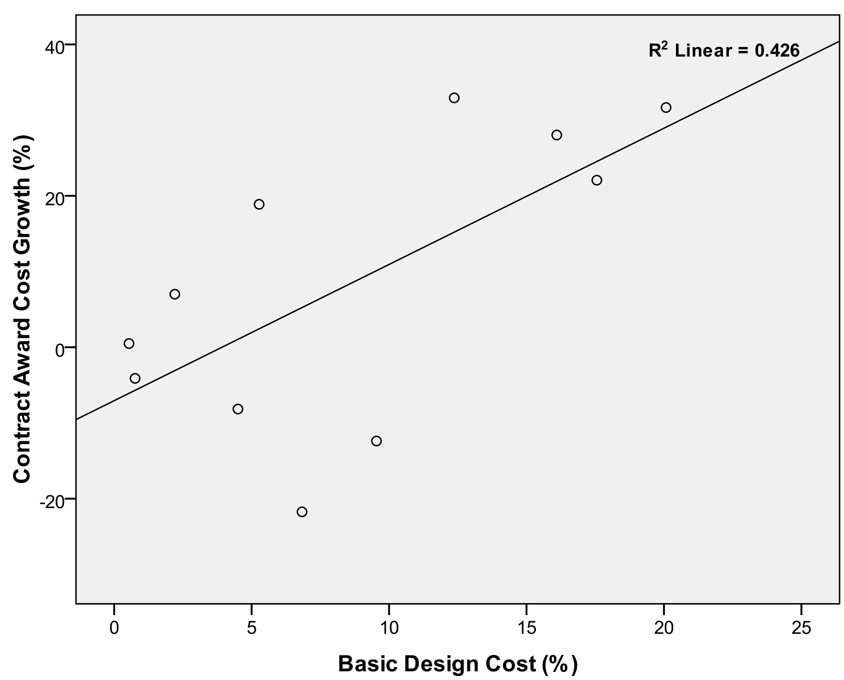

Figure D- 2. Scatter plot of basic design cost and contract award cost growth for CCDPW flood control projects

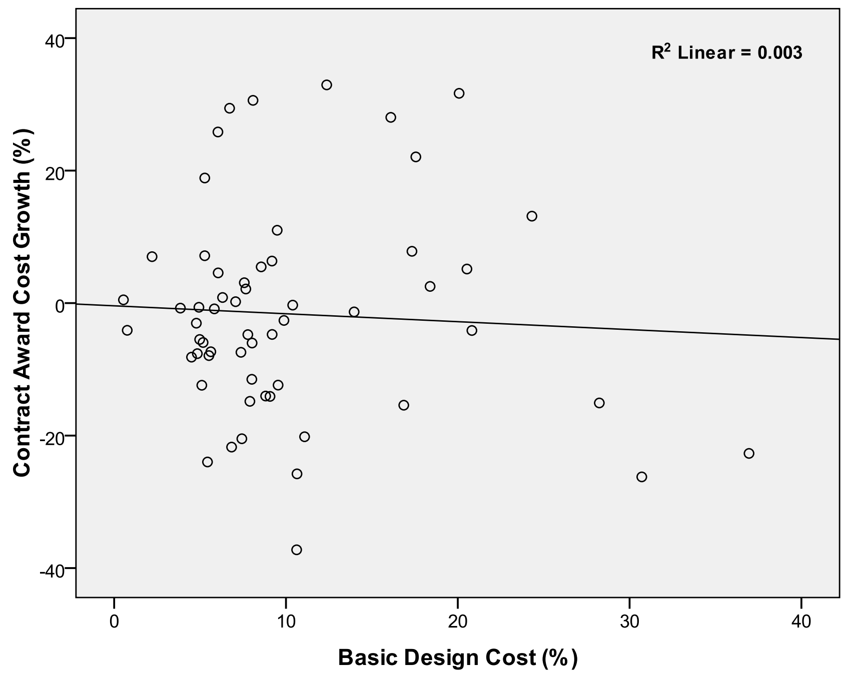

Figure D- 3. Scatter plot of basic design cost and contract award cost growth for CCDPW combined CCDPW road and flood control projects

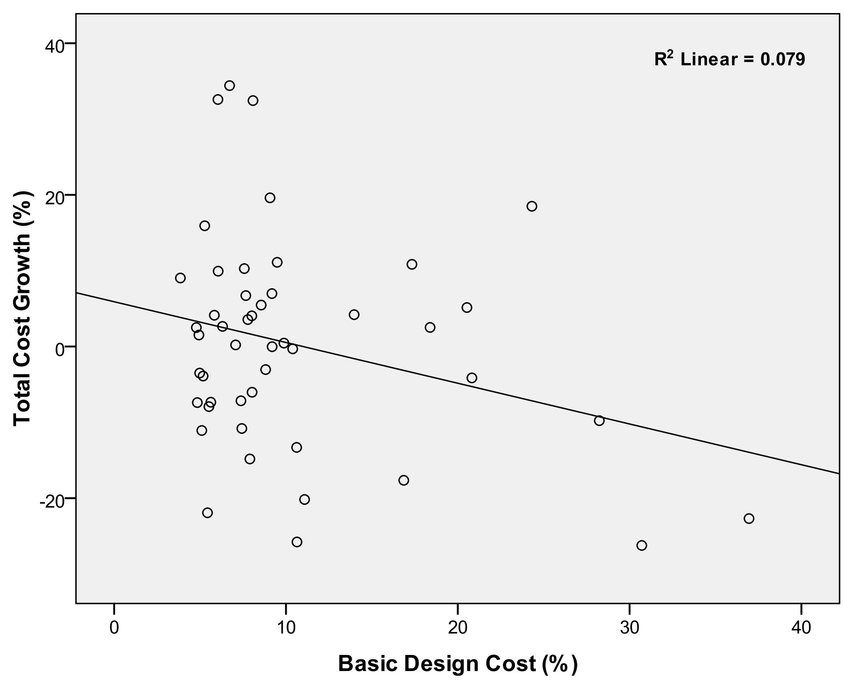

Figure D- 4. Scatter plot of basic design cost and total cost growth for CCDPW road projects

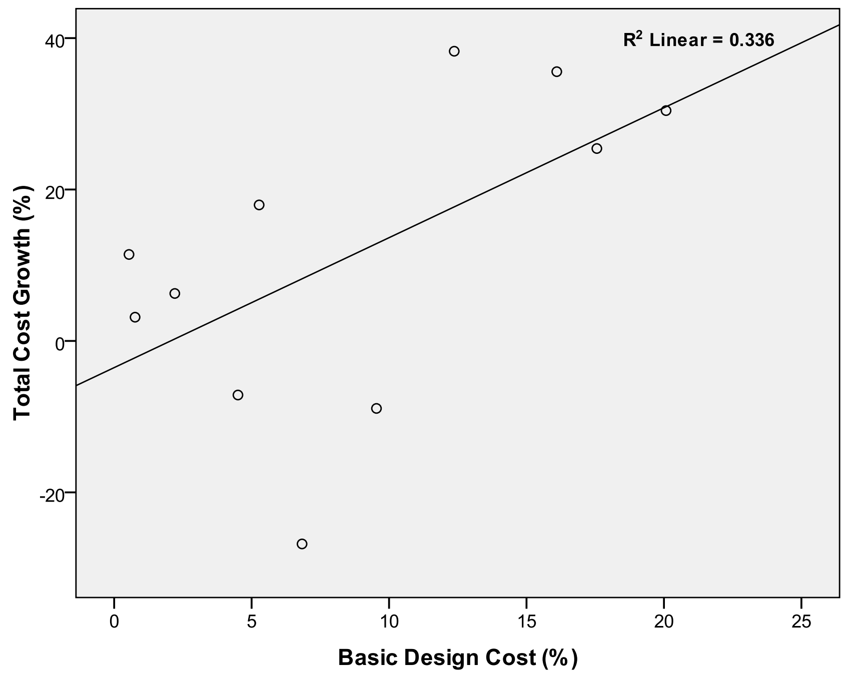

Figure D- 5. Scatter plot of basic design cost and total cost growth for CCDPW flood control projects

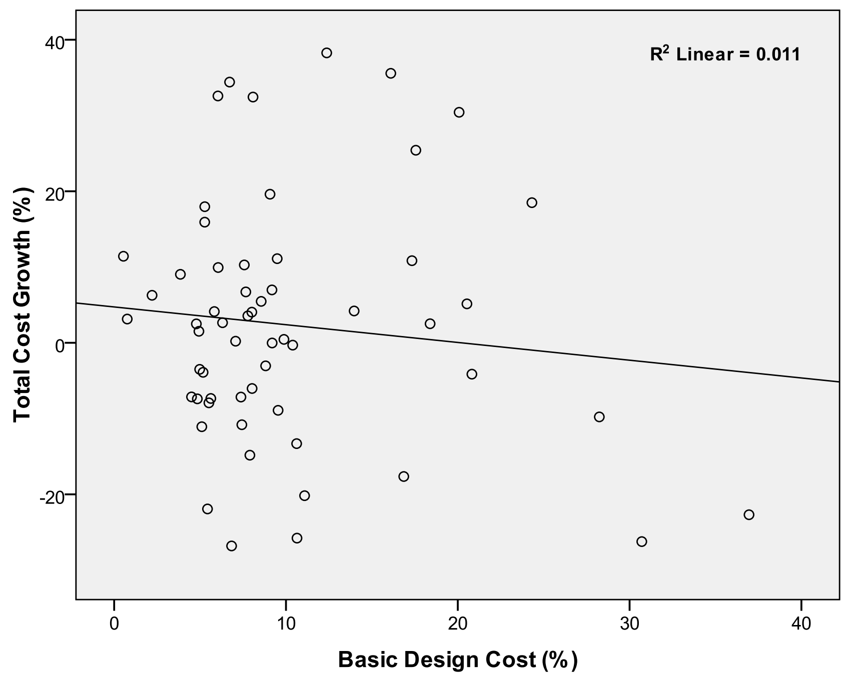

Figure D- 6. Scatter plot of basic design cost and total cost growth for CCDPW combined road and flood control projects

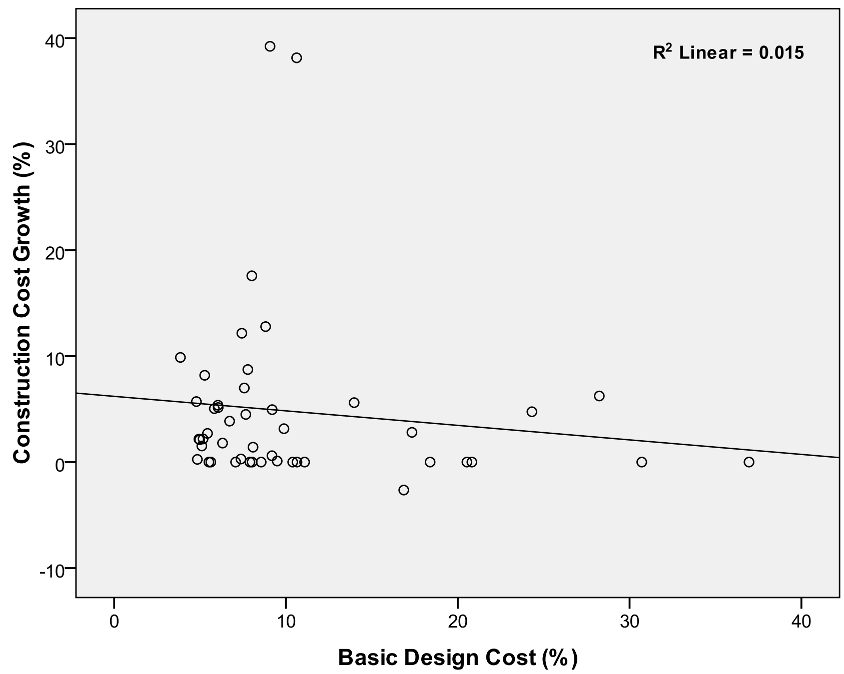

Figure D- 7. Scatter plot of basic design cost and construction cost growth of CCDPW road projects

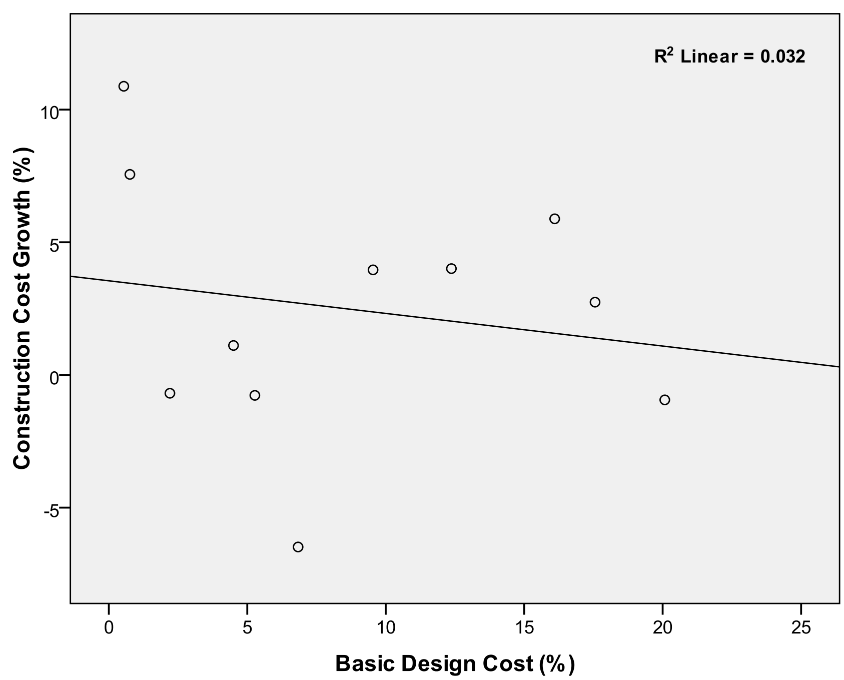

Figure D- 8. Scatter plot of basic design cost and construction cost growth of CCDPW flood control projects

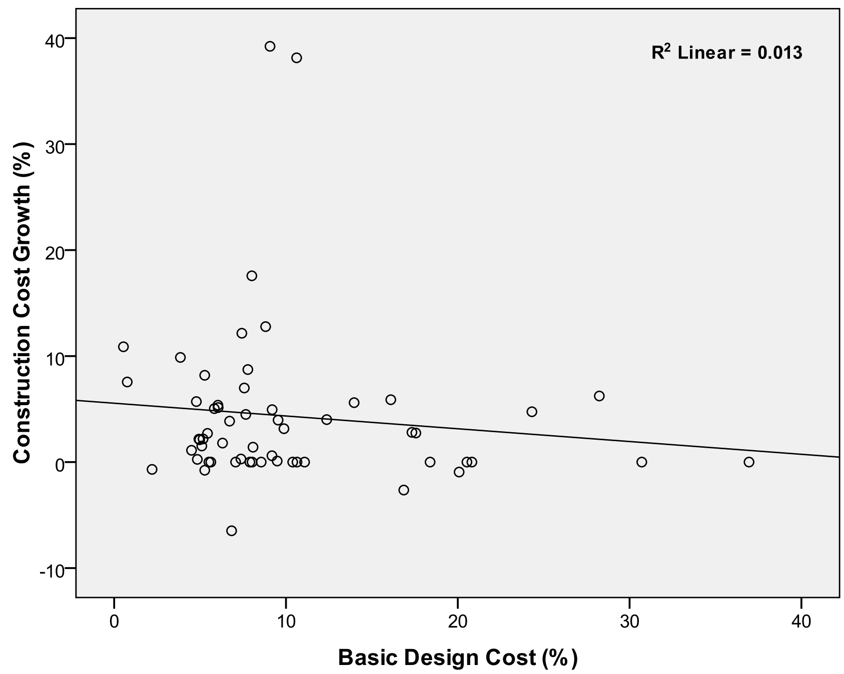

Figure D- 9. Scatter plot of basic design cost and construction cost growth of CCDPW combined road and flood control projects

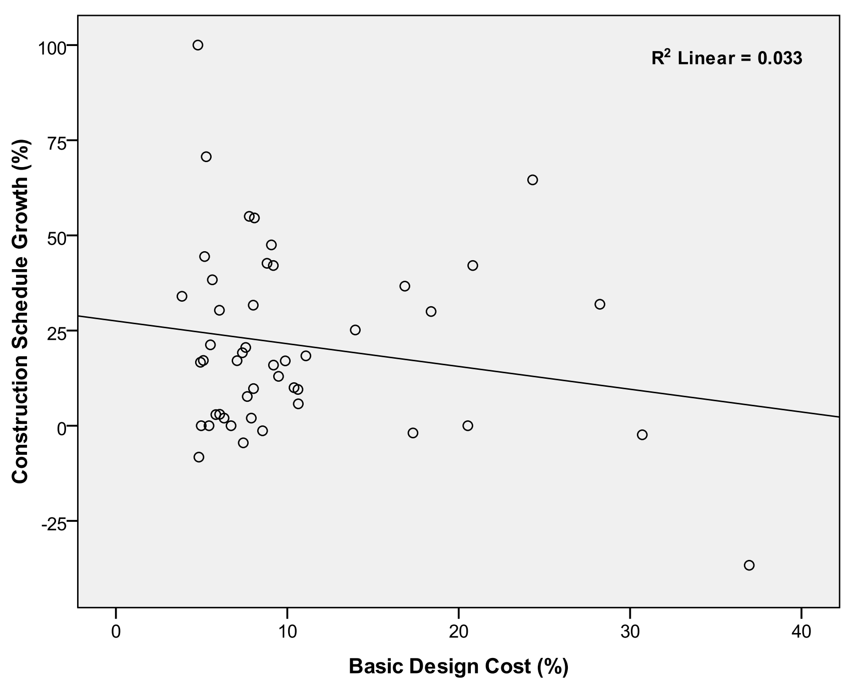

Figure D- 10. Scatter plot of basic design cost and construction schedule growth of CCDPW road projects

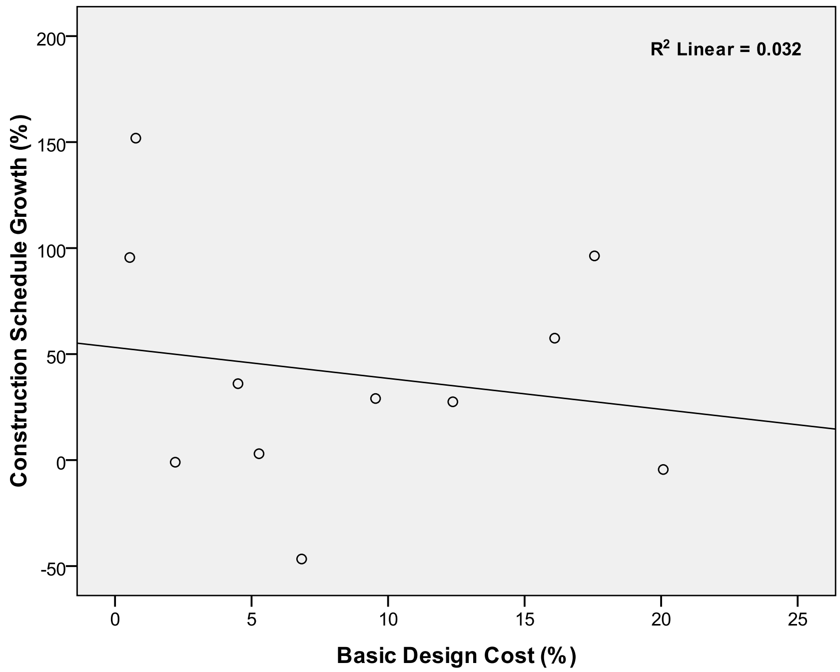

Figure D- 11. Scatter plot of basic design cost and construction schedule growth of CCDPW flood control projects

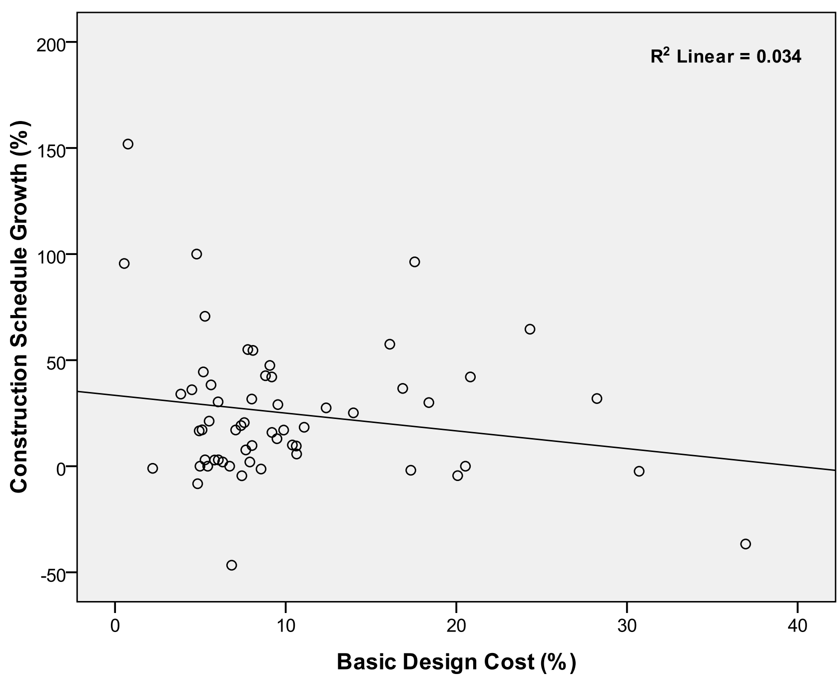

Figure D- 12. Scatter plot of basic design cost and construction schedule growth of CCDPW combined road and flood control projects

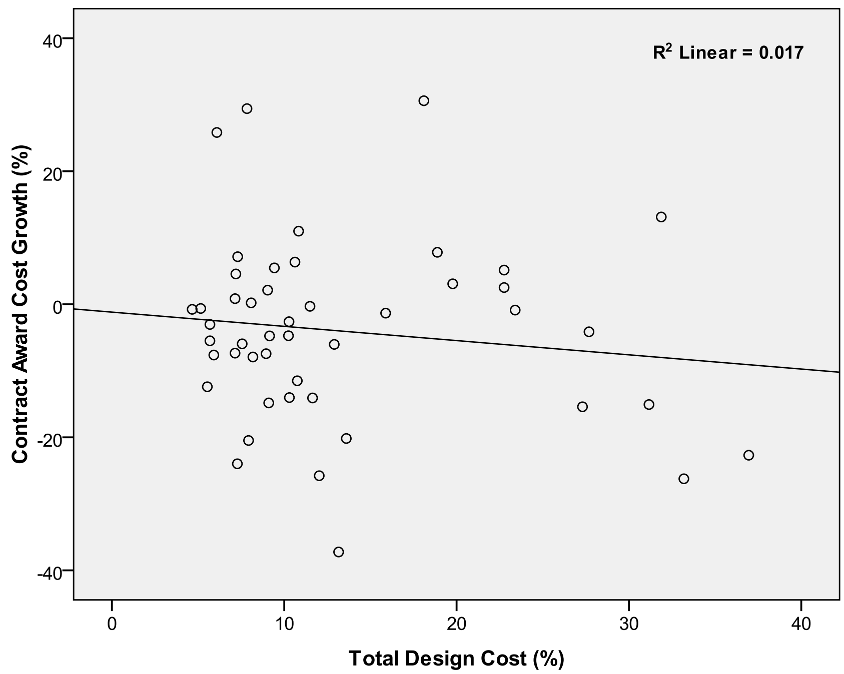

Figure D- 13. Scatter plot of total design cost and contract award cost growth of CCDPW road projects

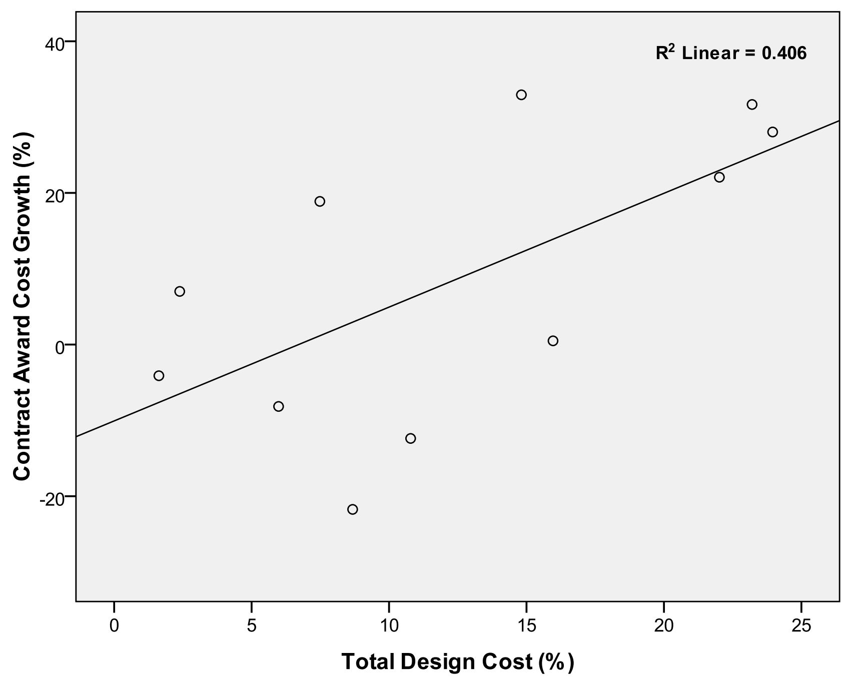

Figure D- 14. Scatter plot of total design cost and contract award cost growth of CCDPW flood control projects

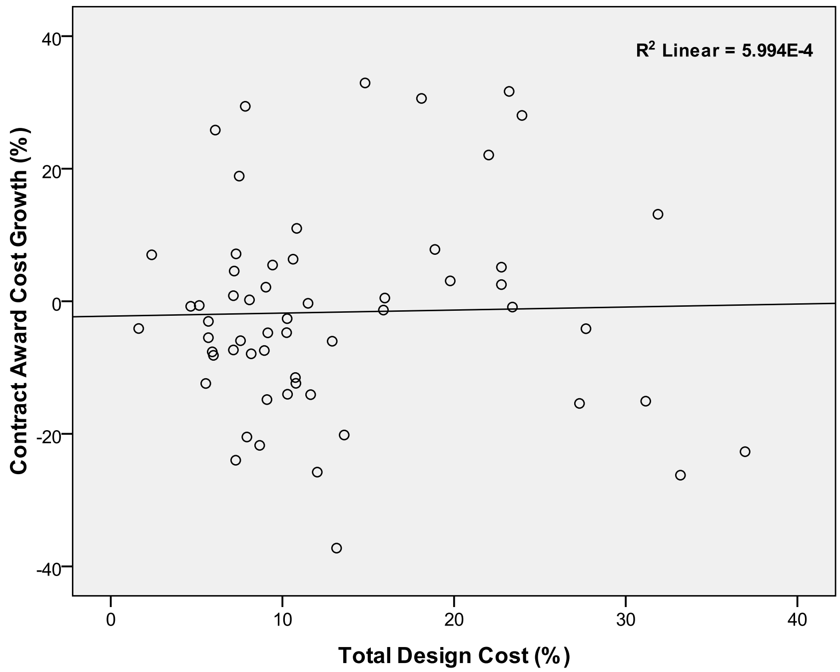

Figure D- 15. Scatter plot of total design cost and contract award cost growth of CCDPW combined road and flood control projects

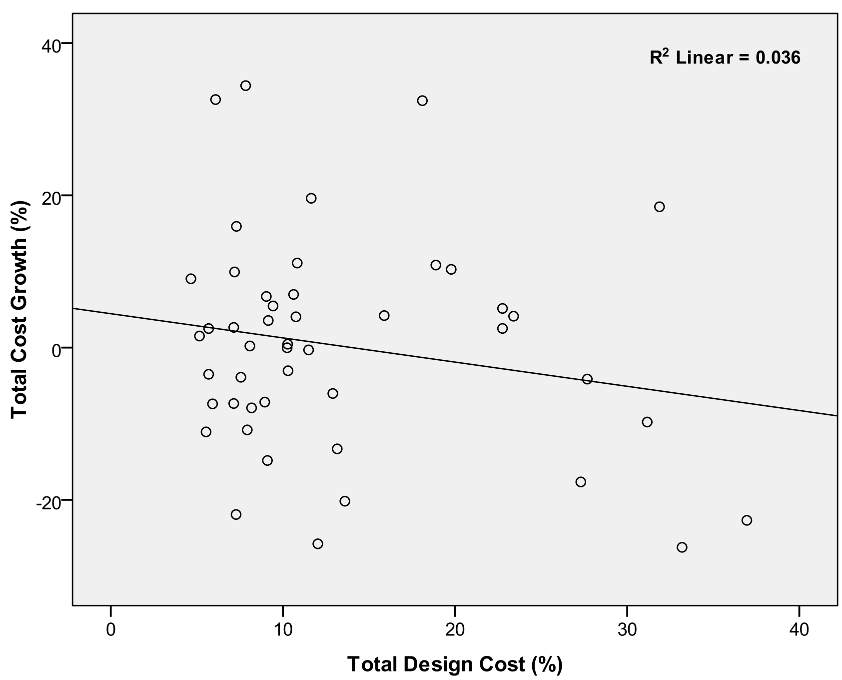

Figure D- 16. Scatter plot of total design cost and total cost growth of CCDPW road projects

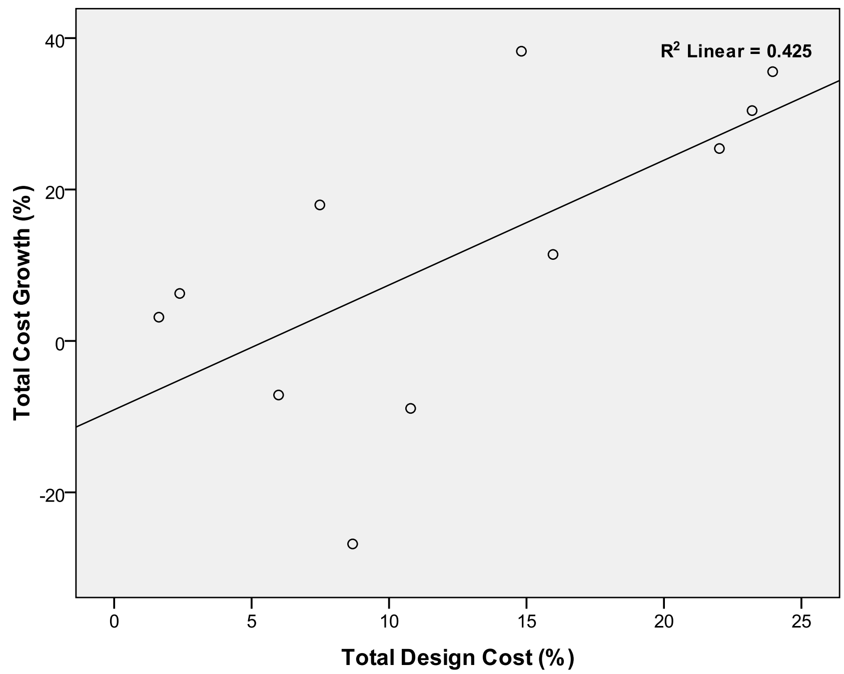

Figure D- 17. Scatter plot of total design cost and total cost growth of CCDPW flood control projects

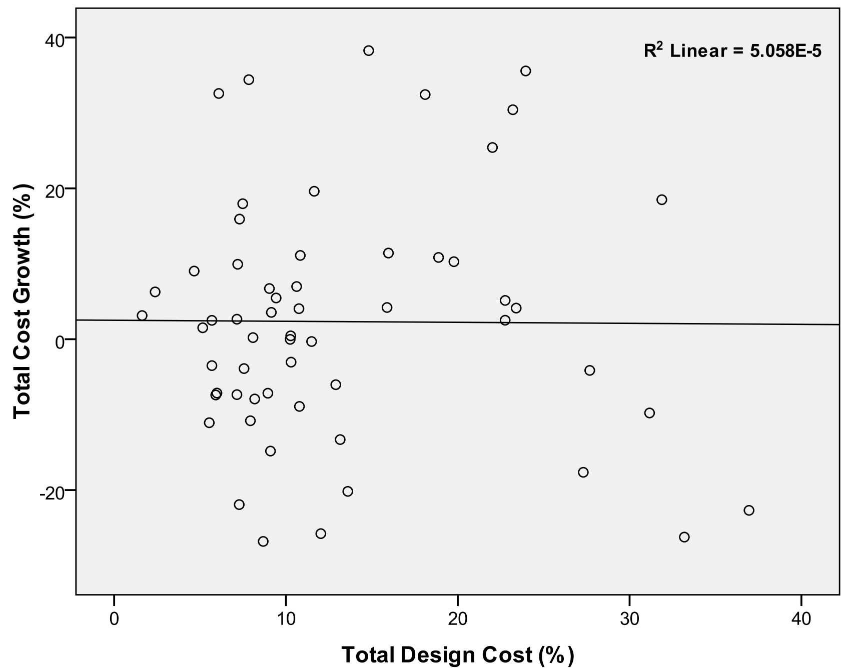

Figure D- 18. Scatter plot of total design cost and total cost growth of CCDPW combined road and flood control projects

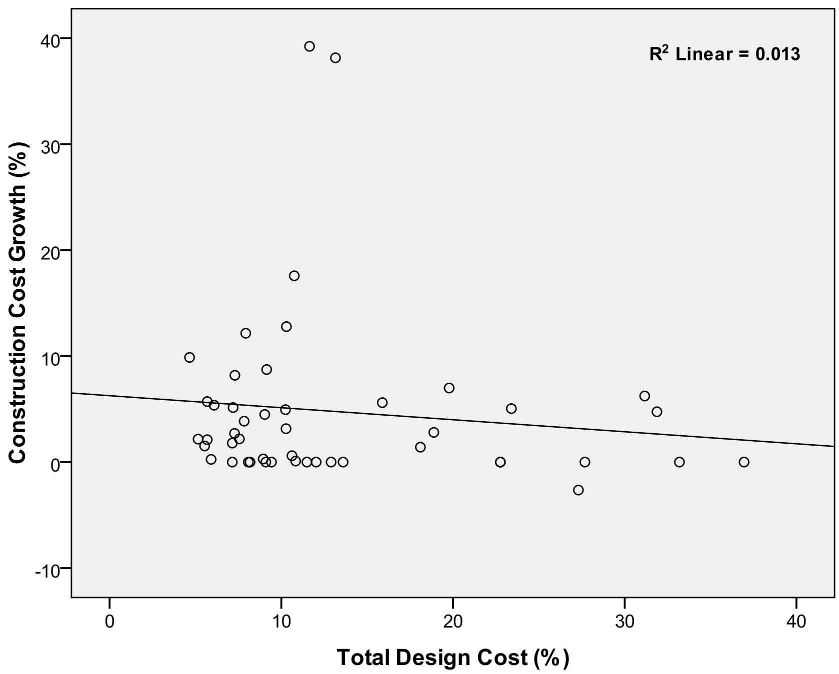

Figure D- 19. Scatter plot of total design cost and construction cost growth of CCDPW road projects

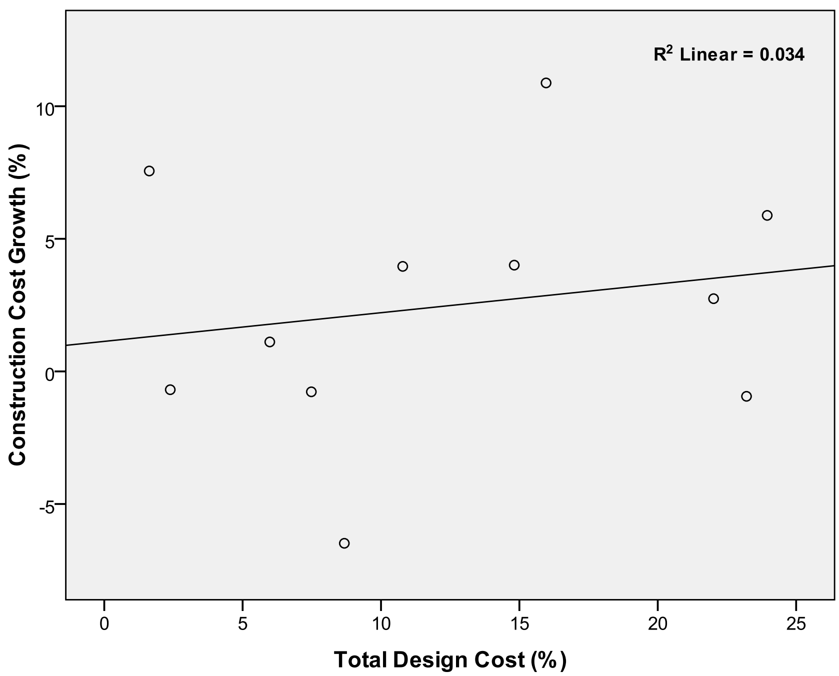

Figure D- 20. Scatter plot of total design cost and construction cost growth of CCDPW flood control projects

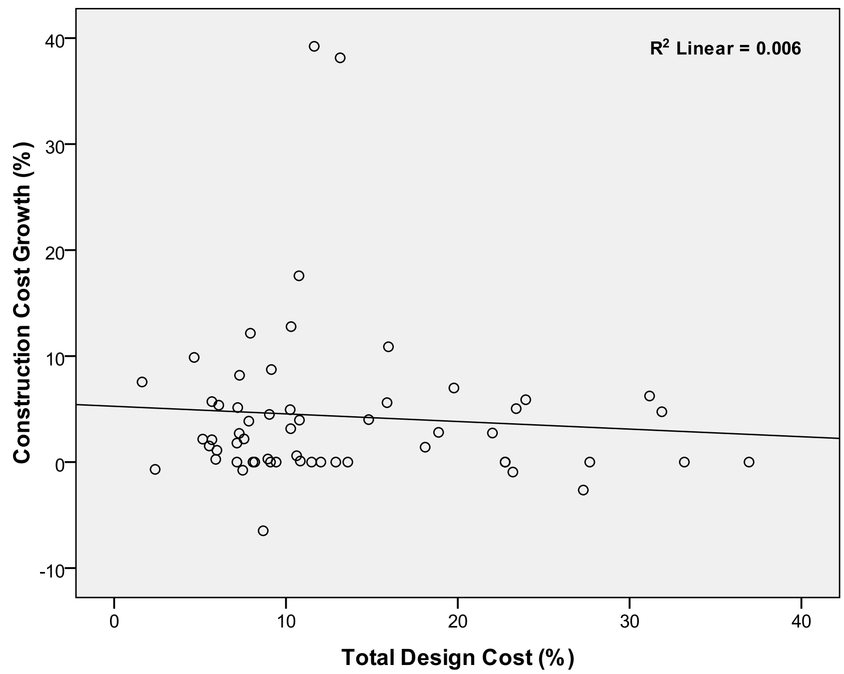

Figure D- 21. Scatter plot of total design cost and construction cost growth of CCDPW combined road and flood control projects

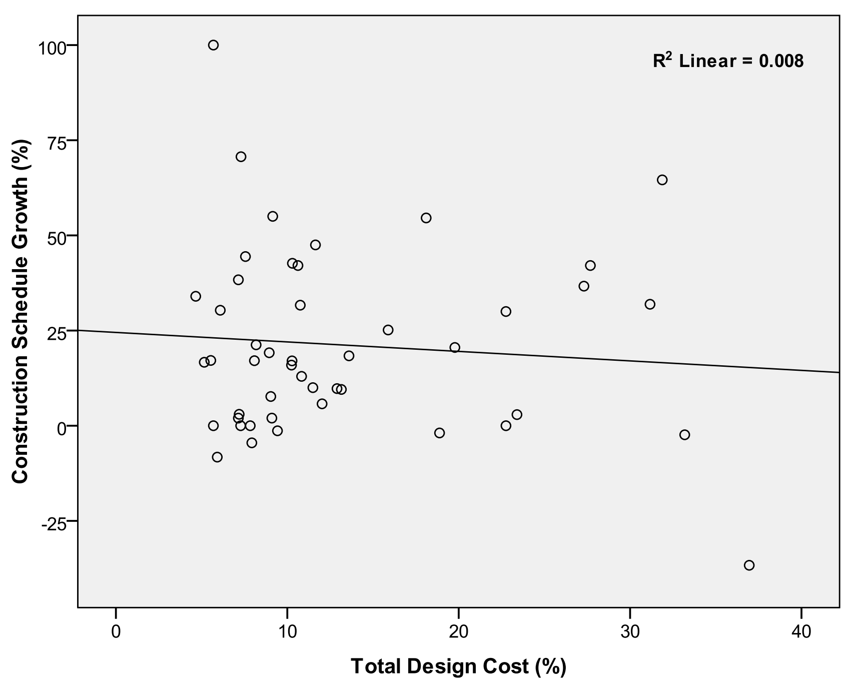

Figure D- 22. Scatter plot of total design cost and construction schedule growth of CCDPW combined road and flood control projects

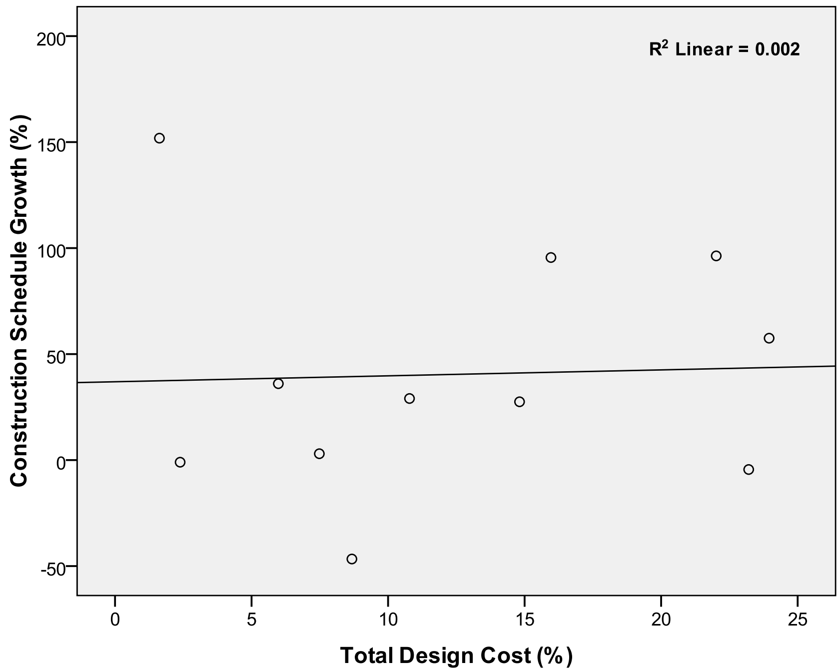

Figure D- 23. Scatter plot of total design cost and construction schedule growth of CCDPW flood control projects

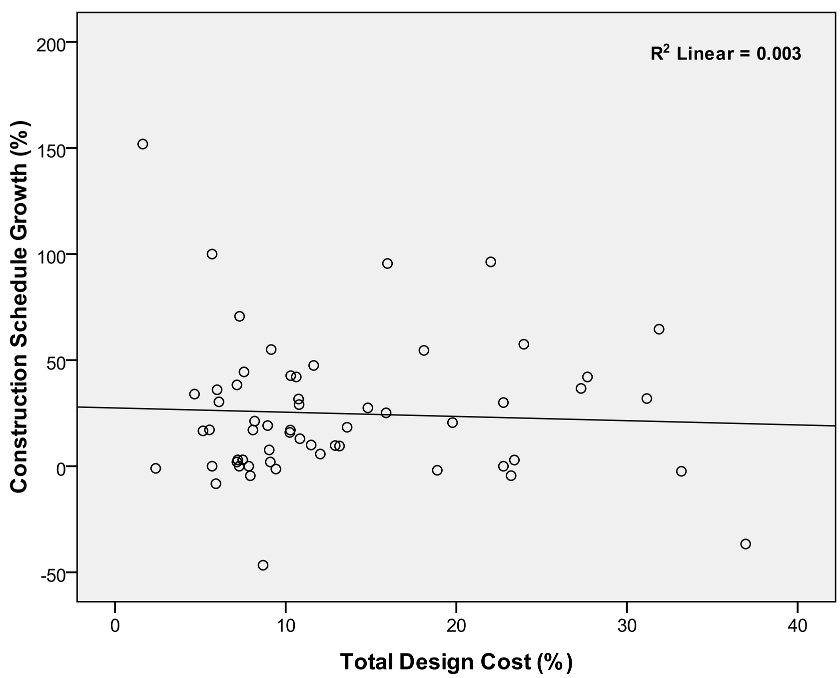

Figure D- 24. Scatter plot of total design cost and construction schedule growth of combined CCDPW road and flood control projects

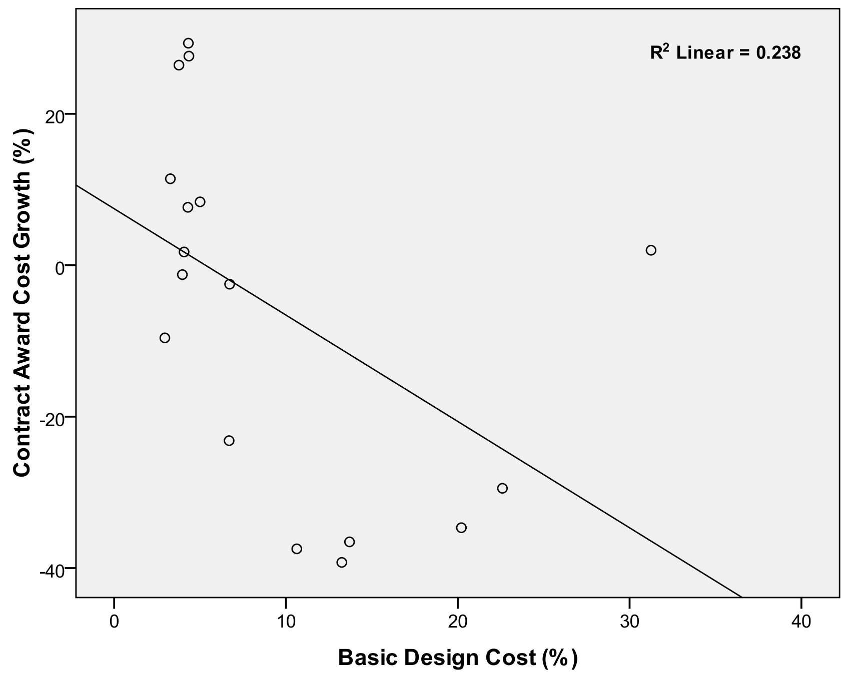

Figure D- 25. Scatter plot of basic design cost and contract award cost growth for TXDOT road projects

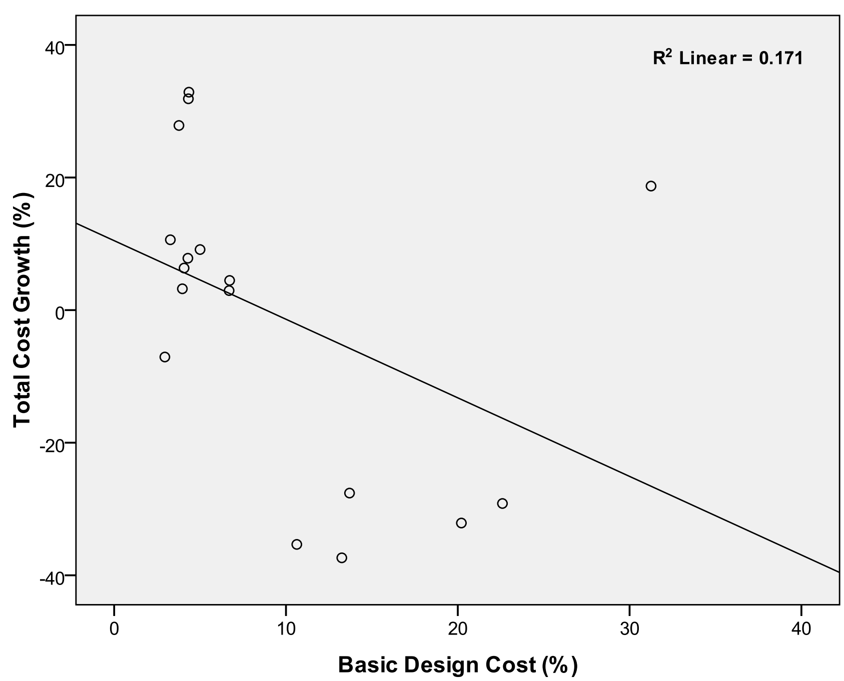

Figure D- 26. Scatter plot of basic design cost and total cost growth for TXDOT road projects

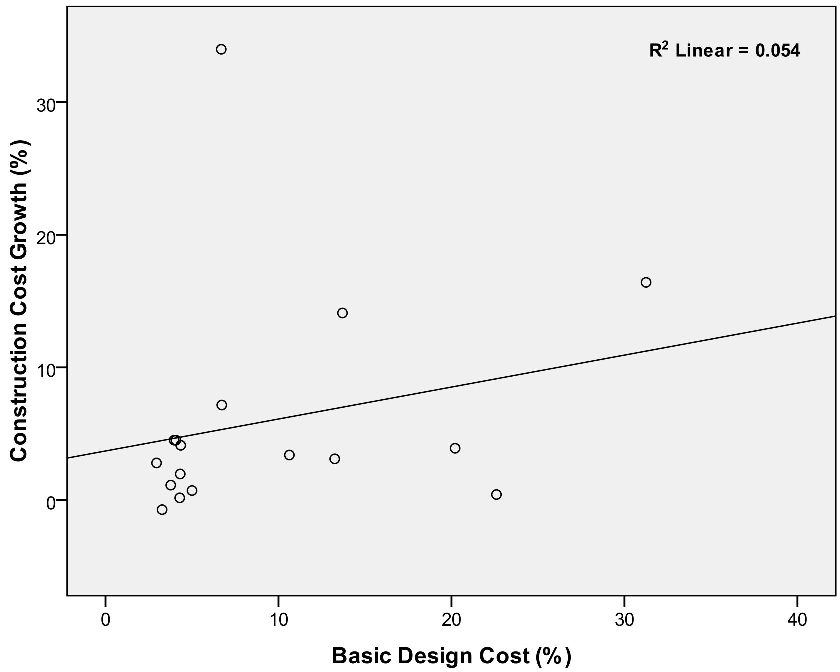

Figure D- 27. Scatter plot of basic design cost and construction cost growth for TXDOT road projects

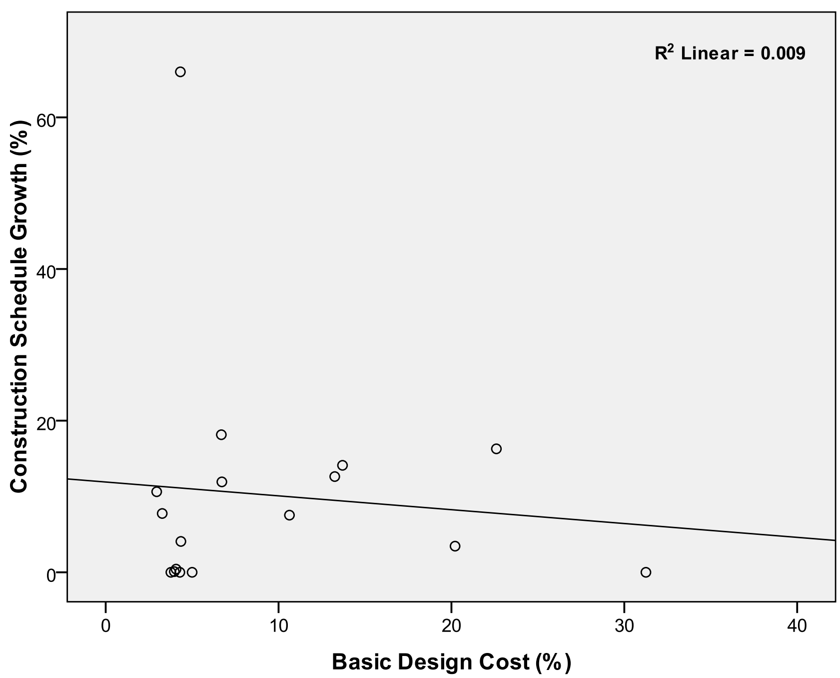

Figure D- 28. Scatter plot of basic design cost and construction schedule growth for TXDOT road projects

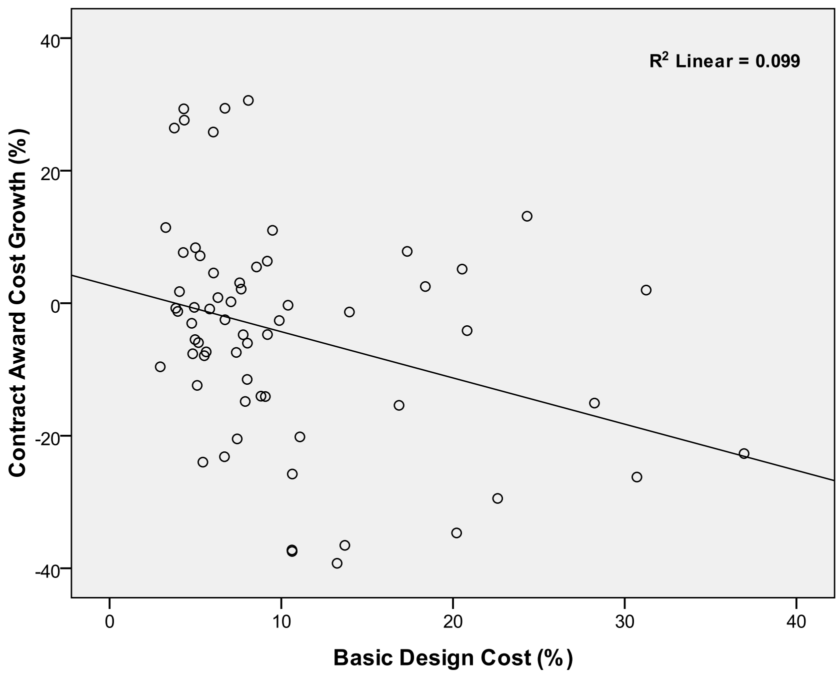

Figure D- 29. Scatter plot of basic design cost and contract award cost growth for CCDPW and TXDOT road projects

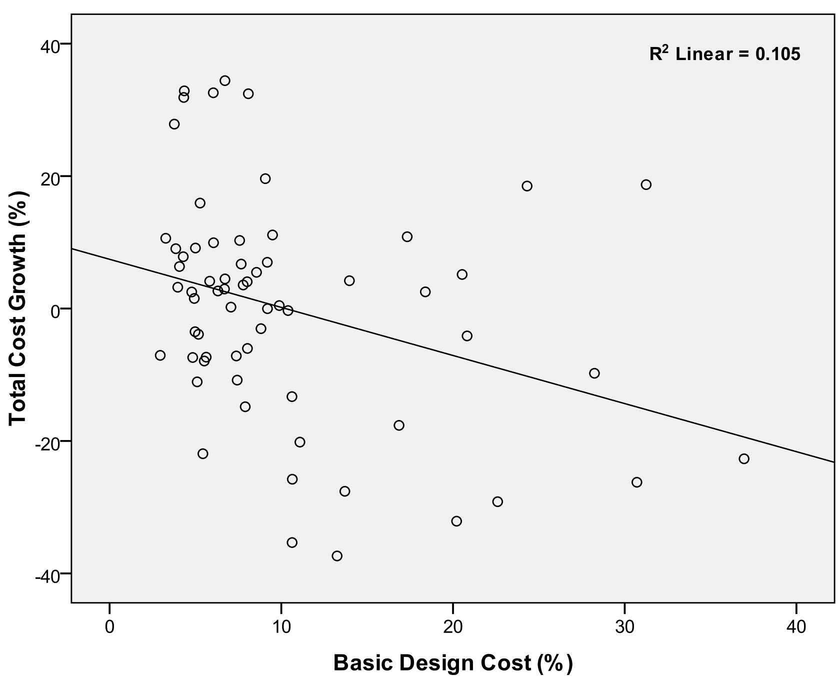

Figure D- 30. Scatter plot of basic design cost and total cost growth for CCDPW and TXDOT road projects

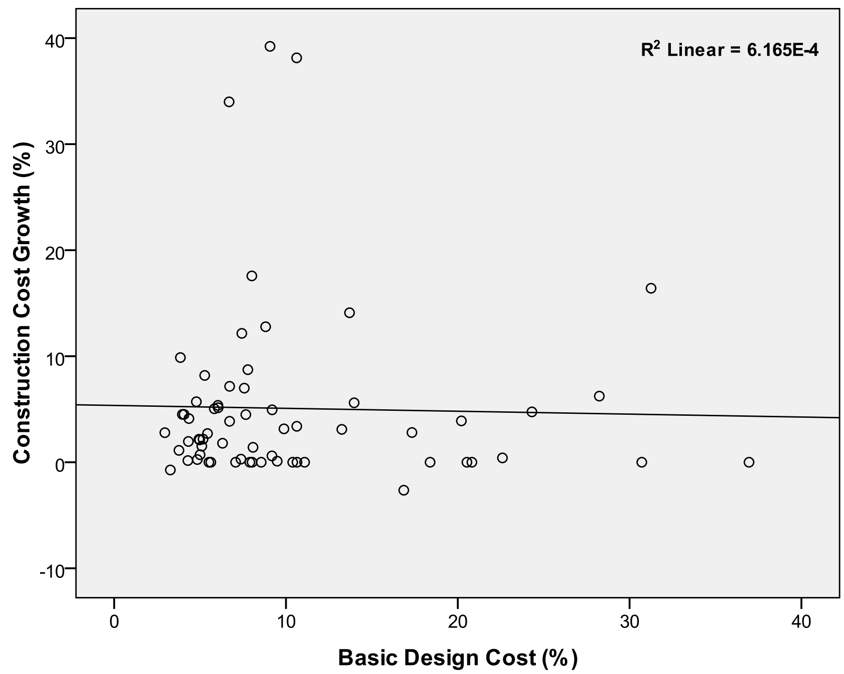

Figure D- 31. Scatter plot of basic design cost and construction cost growth for CCDPW and TXDOT road projects

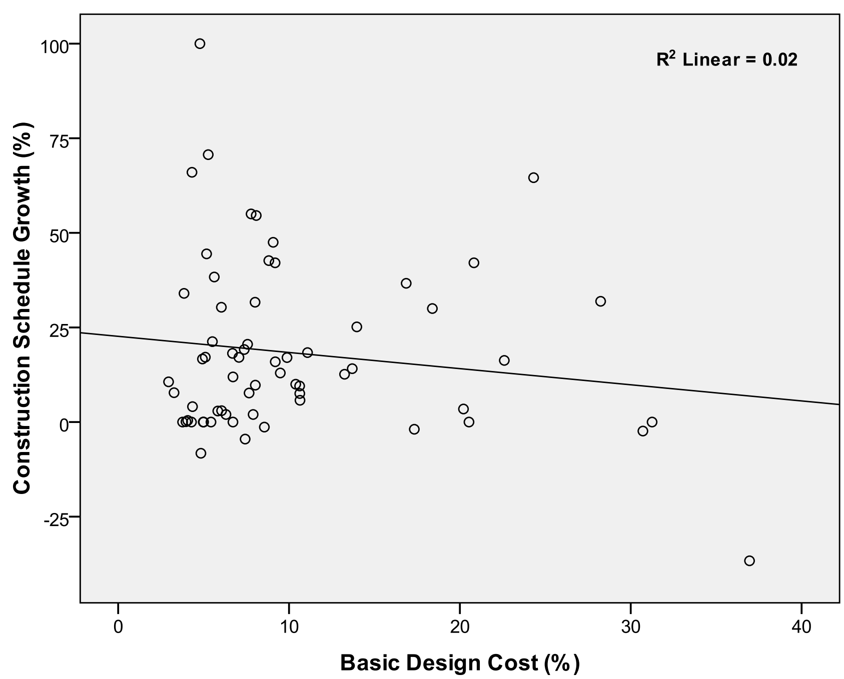

Figure D- 32. Scatter plot of basic design cost and construction schedule growth for CCDPW and TXDOT road projects

APPENDIX E

RESIDUAL PLOT WITH INDEPENDENT VARIABLES

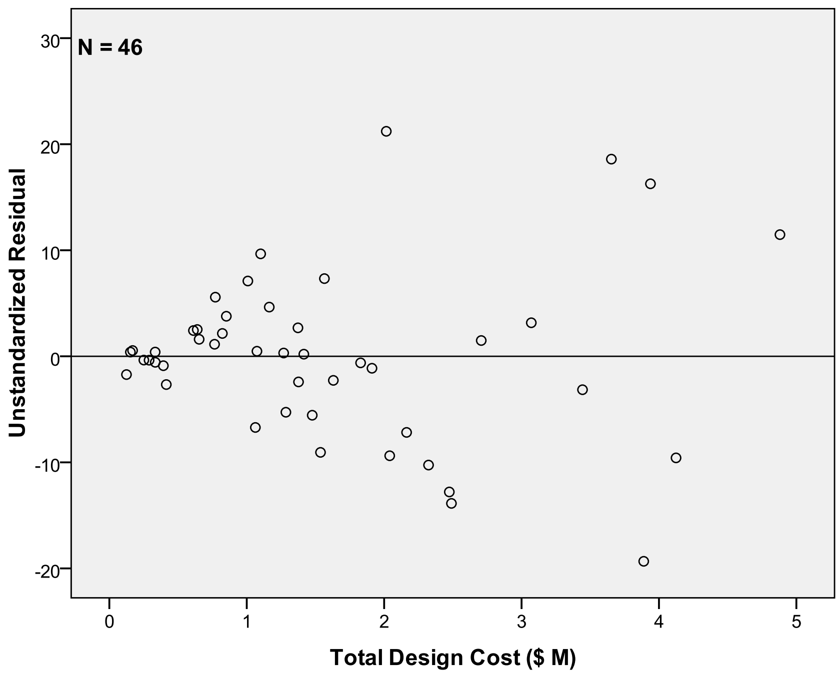

Figure E- 1. Unstandardized residual plot with total design cost ($ million) for CCDPW road projects

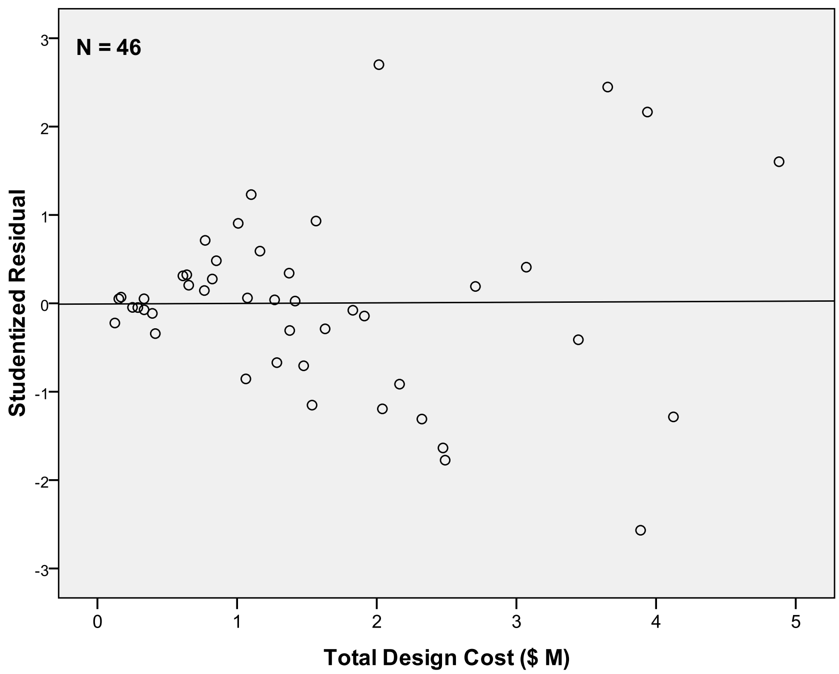

Figure E- 2. Studentized residual plot with total design cost ($ million) for CCDPW road projects

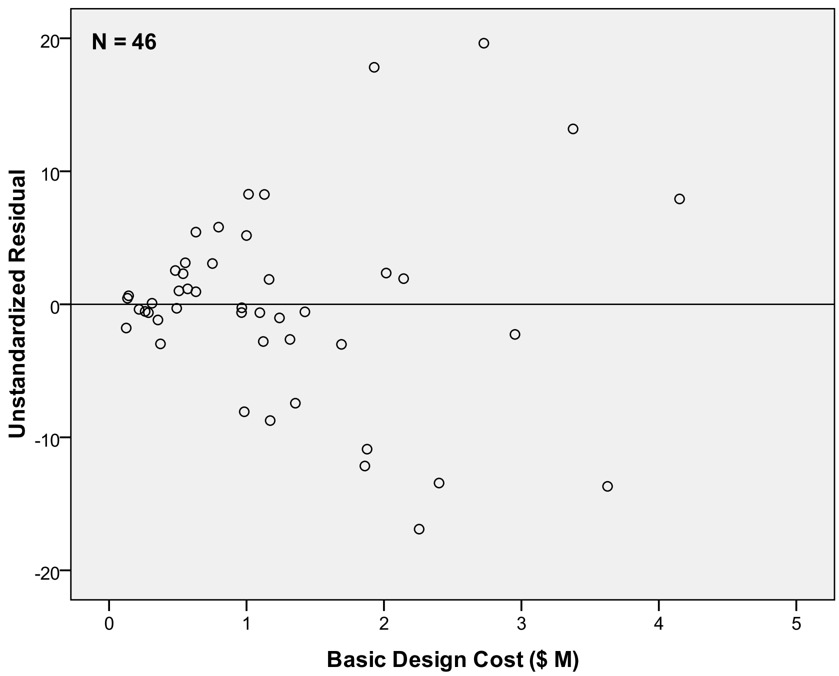

Figure E- 3. Unstandardized residual plot with basic design cost ($ million) for CCDPW road projects

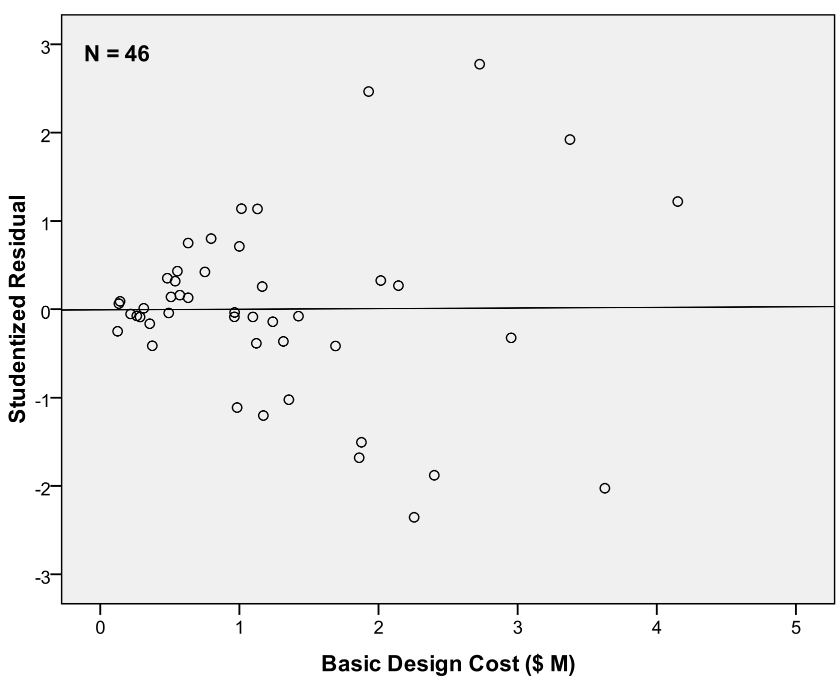

Figure E- 4. Studentized residual plot with basic design cost ($ million) for CCDPW road projects

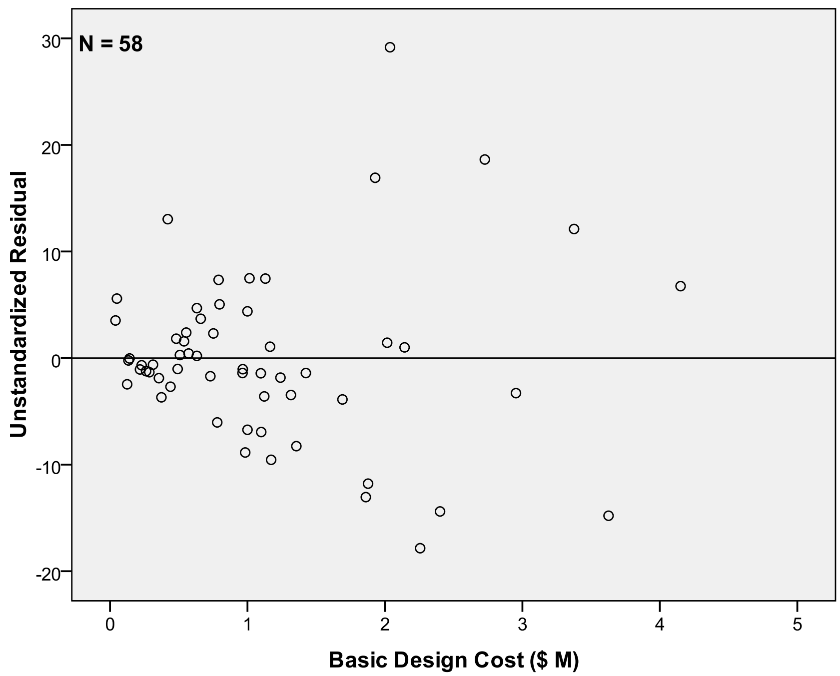

Figure E- 5. Unstandardized residual plot with basic design cost ($ million) for CCDPW road and flood control projects

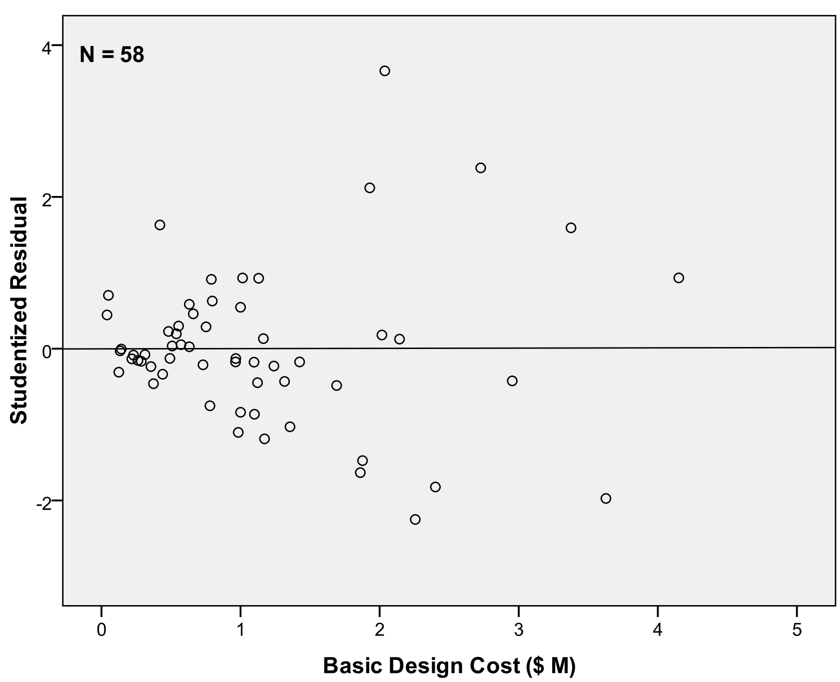

Figure E- 6. Studentized residual plot with basic design cost ($ million) for CCDPW road and flood control projects

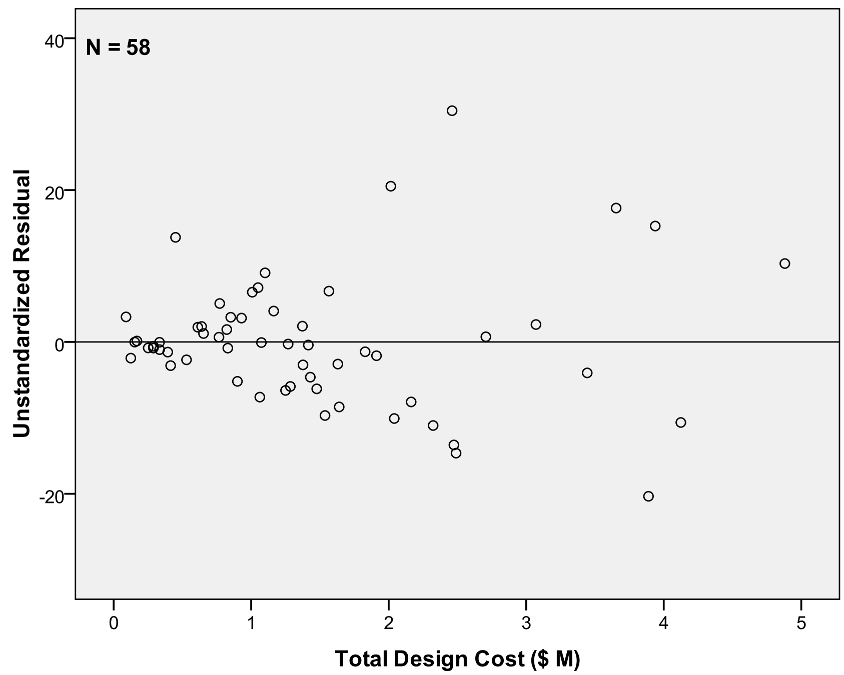

Figure E- 7. Unstandardized residual plot with total design cost ($ million) for CCDPW road and flood control projects

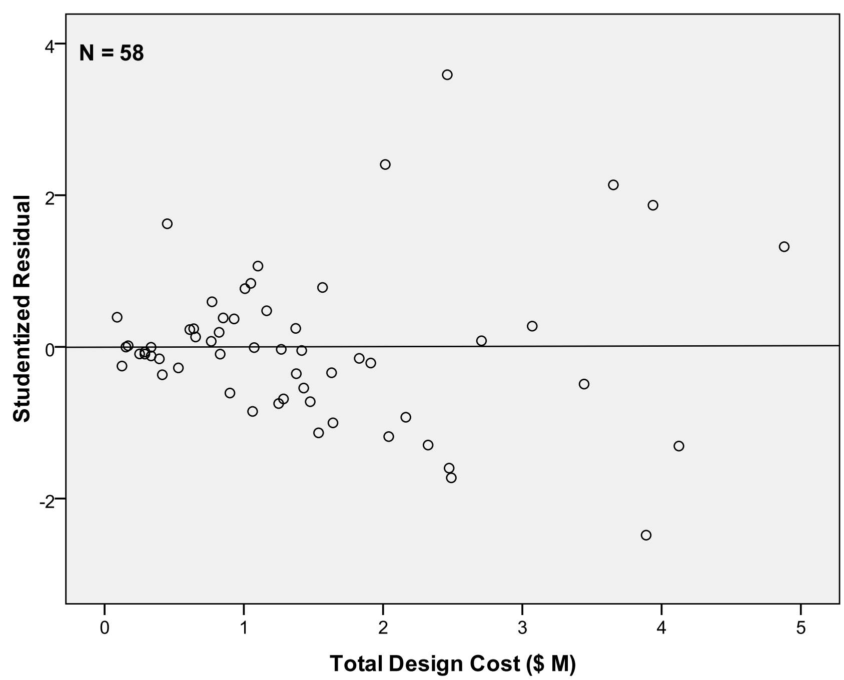

Figure E- 8. Studentized residual plot with total design cost ($ million) for CCDPW road and flood control projects

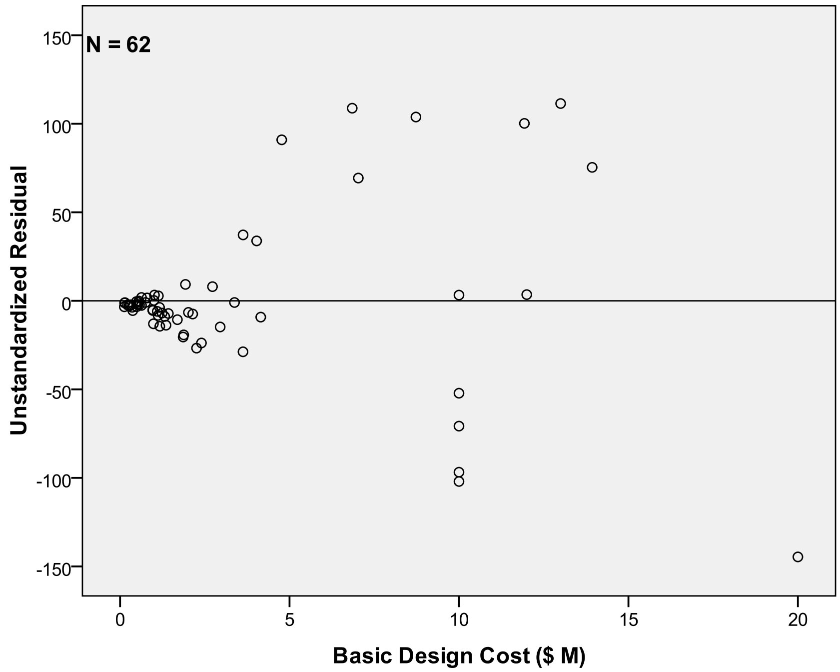

Figure E- 9. Unstandardized residual plot with basic design cost ($ million) for CCDPW and TXDOT road projects

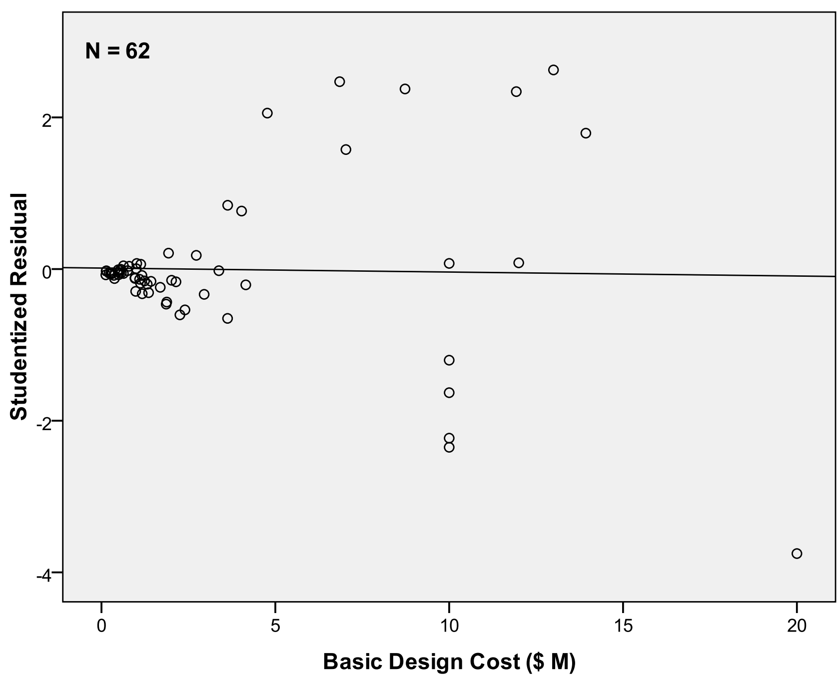

Figure E- 10. Studentized residual plot with basic design cost ($ million) for CCDPW and TXDOT road projects

APPENDIX F

RESIDUAL PLOT WITH PREDICTED VALUE

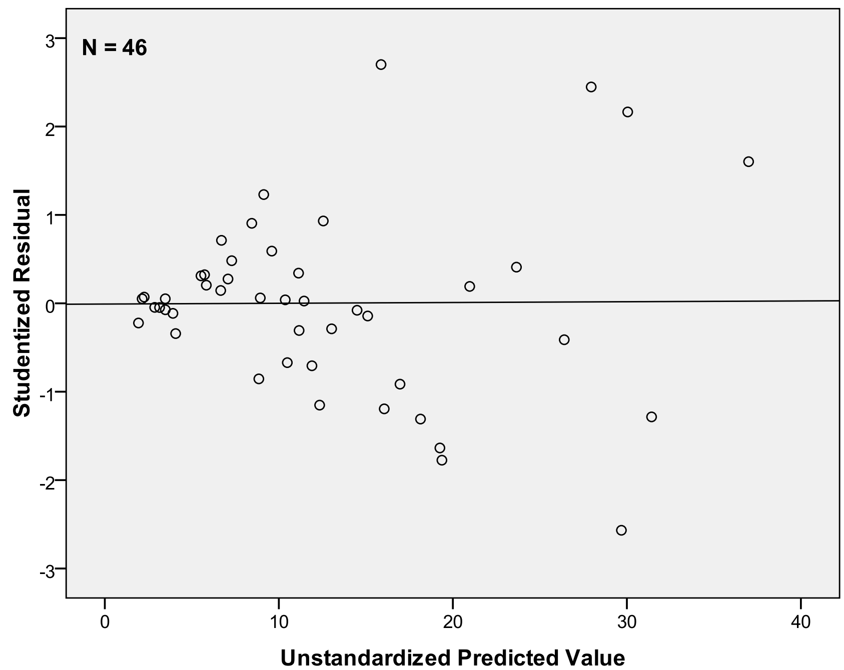

Figure F- 1. Residual plot with predicted value (for total design cost) for CCDPW road projects

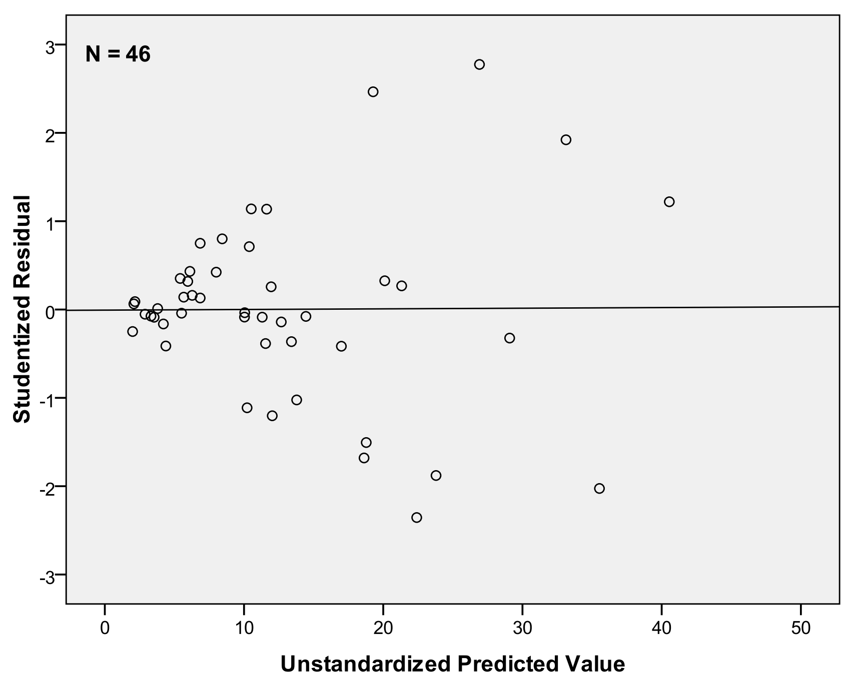

Figure F- 2. Residual plot with predicted value (for basic design cost) for CCDPW road projects

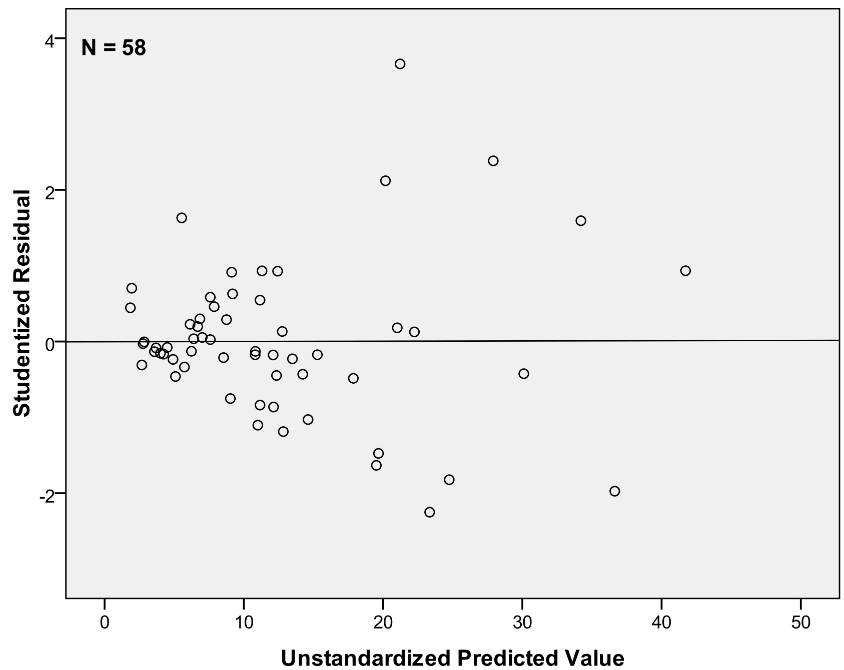

Figure F- 3. Residual plot with predicted value (for basic design cost) for CCDPW road and flood control projects

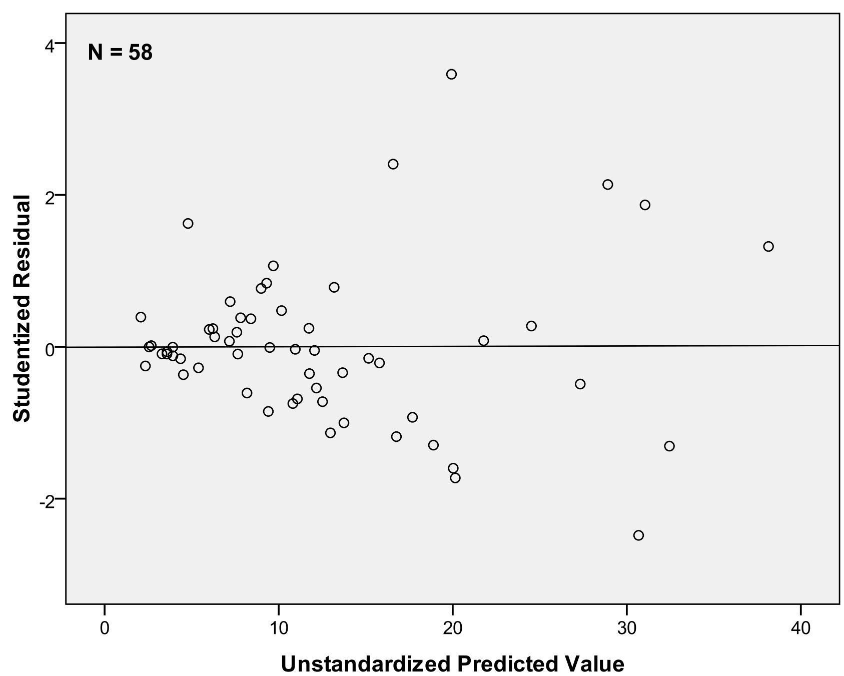

Figure F- 4. Residual plot with predicted value (for total design cost) for CCDPW road and flood control projects

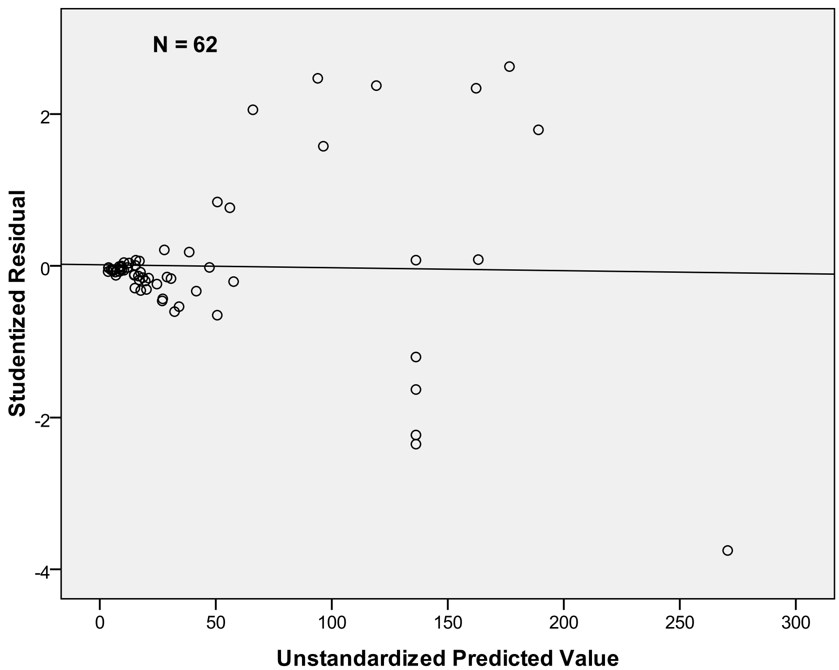

Figure F- 5. Residual plot with predicted value (for basic design cost) for CCDPW and TXDOT road projects

APPENDIX G

HISTOGRAM OF RESIDUALS

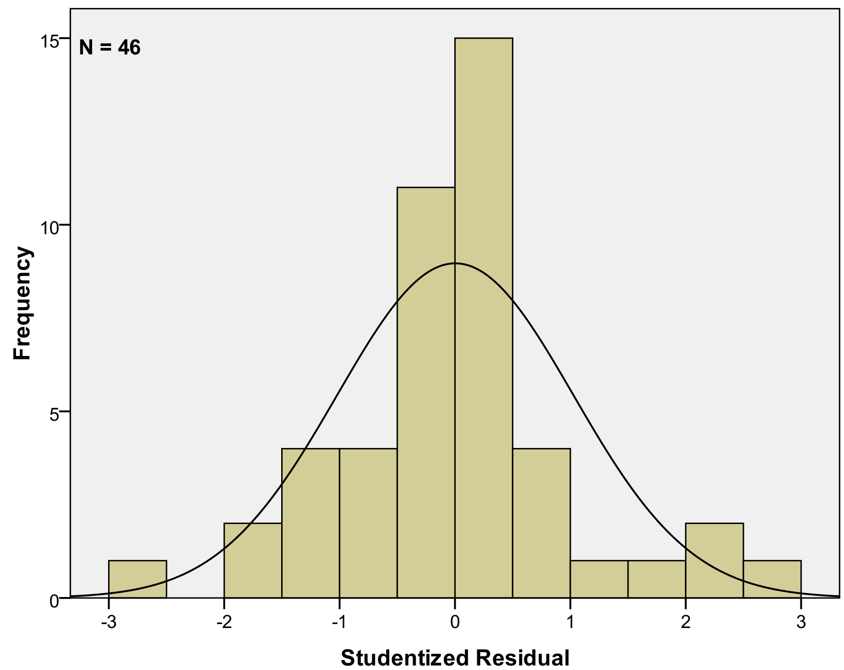

Figure G- 1. Histogram of the residuals (for total design cost) for CCDPW road projects

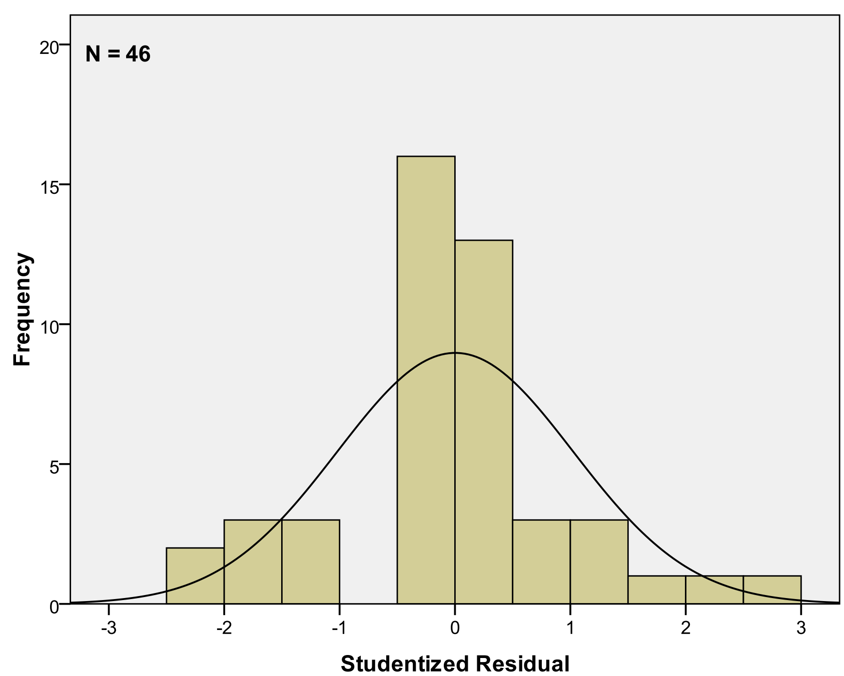

Figure G- 2. Histogram of the residuals (for basic design cost) for CCDPW road projects

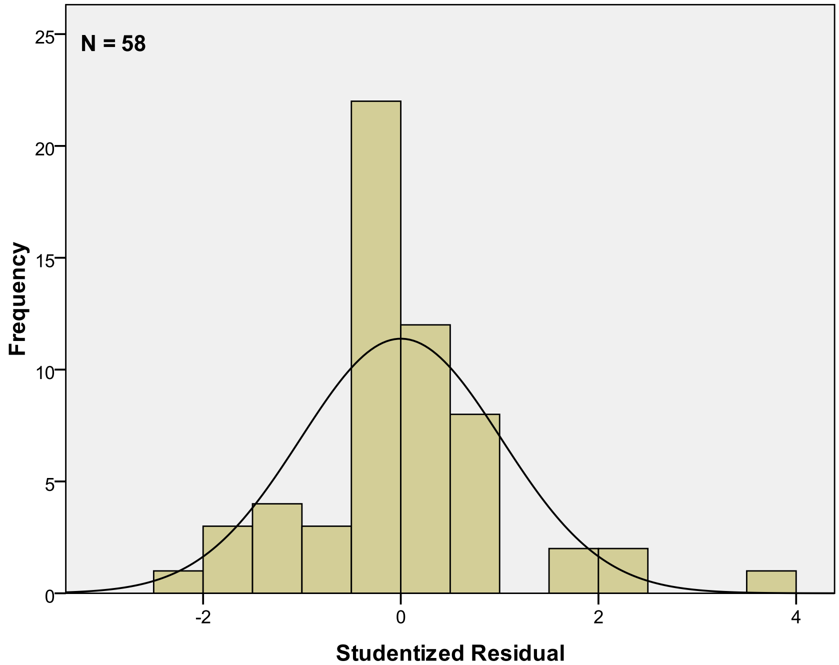

Figure G- 3. Histogram of the residuals (for basic design cost) for CCDPW road and flood control projects

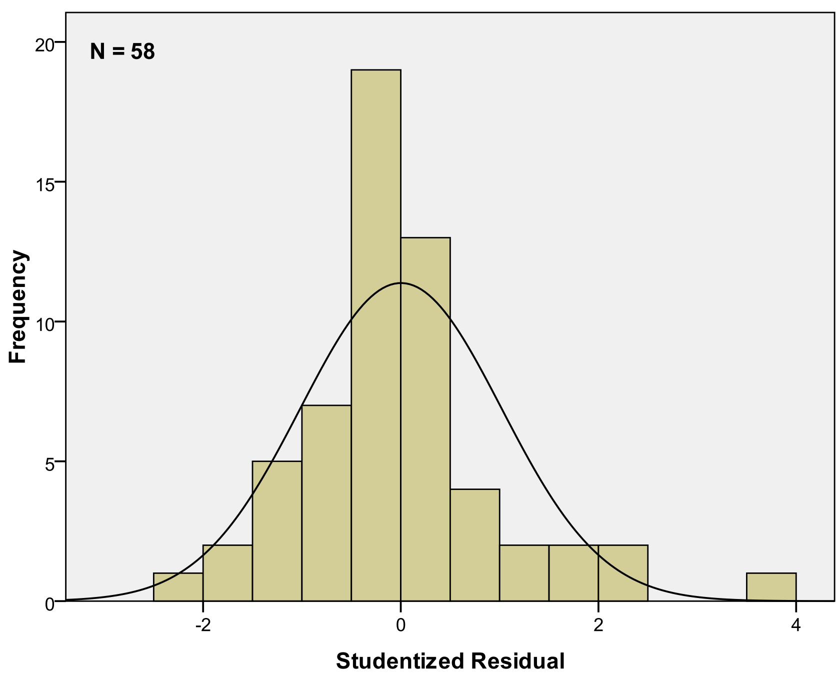

Figure G- 4. Histogram of the residuals (for total design cost) for CCDPW road and flood control projects

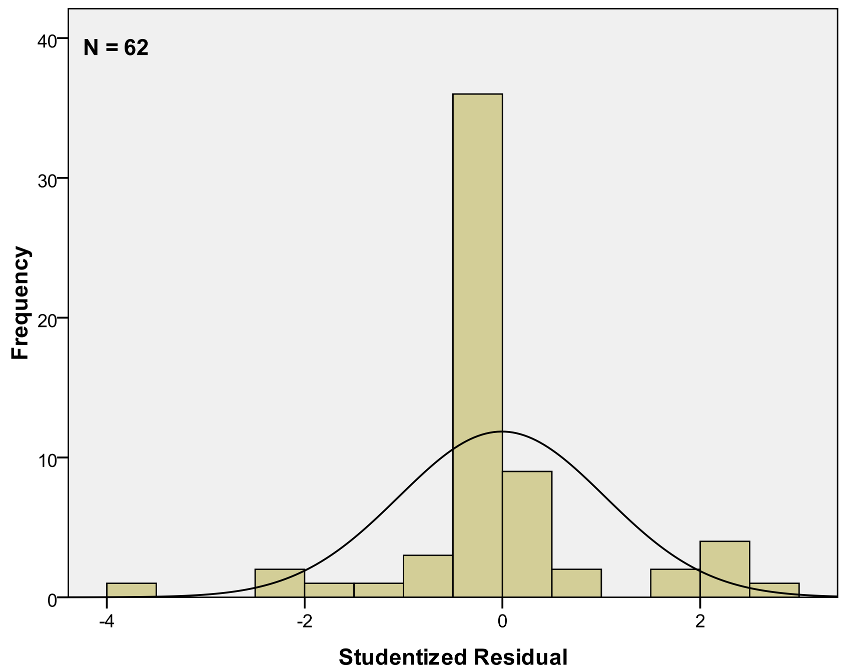

Figure G- 5. Histogram of the residuals (for basic design cost) for CCDPW and TXDOT road projects

APPENDIX H

PLOT FOR PREDICTED VALUES AGAINST ACTUAL VALUES

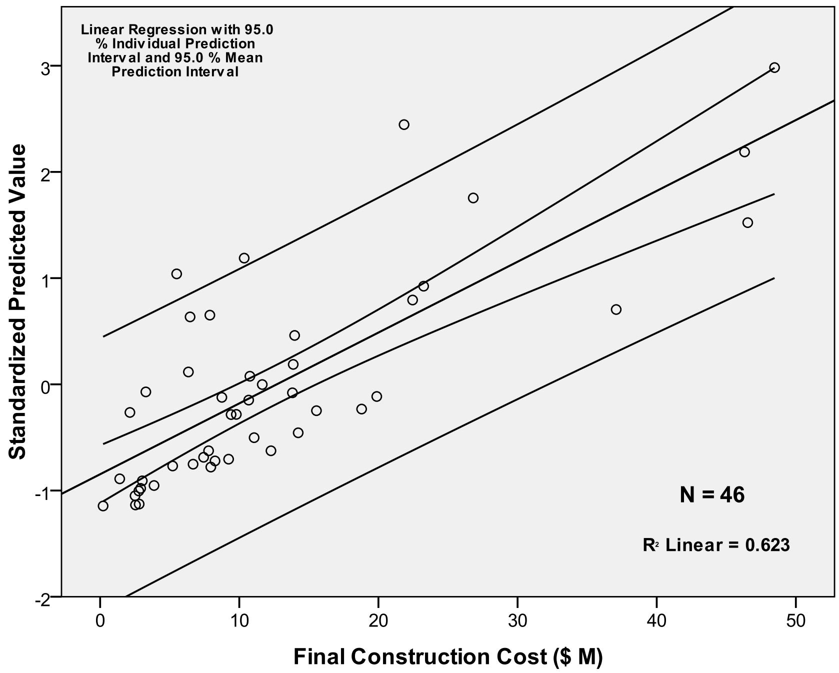

Figure H- 1. Standardized predicted values of final construction cost ($ M) for CCDPW road projects (considering basic design cost)

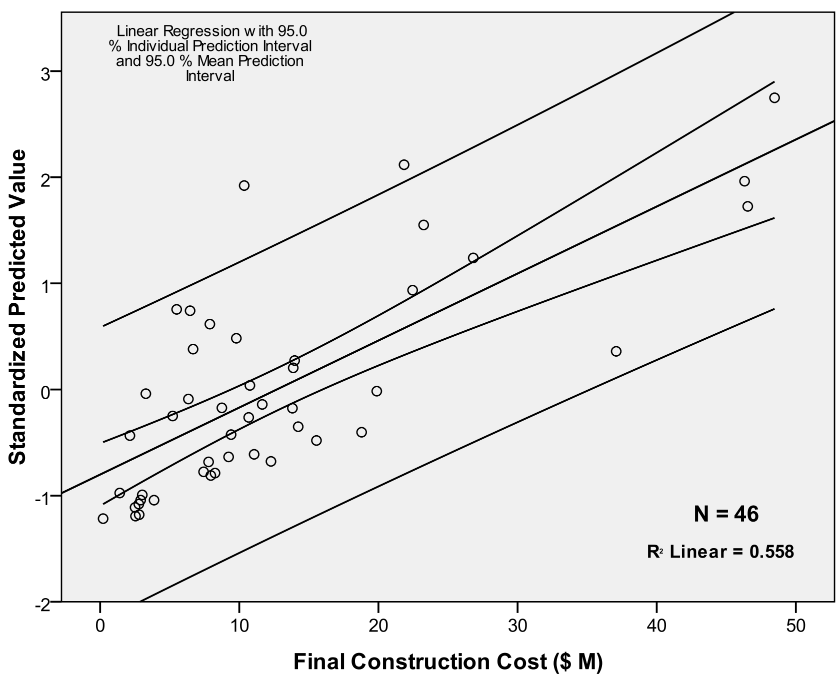

Figure H- 2. Standardized predicted values of final construction cost ($ M) for CCDPW road projects (considering total design cost)

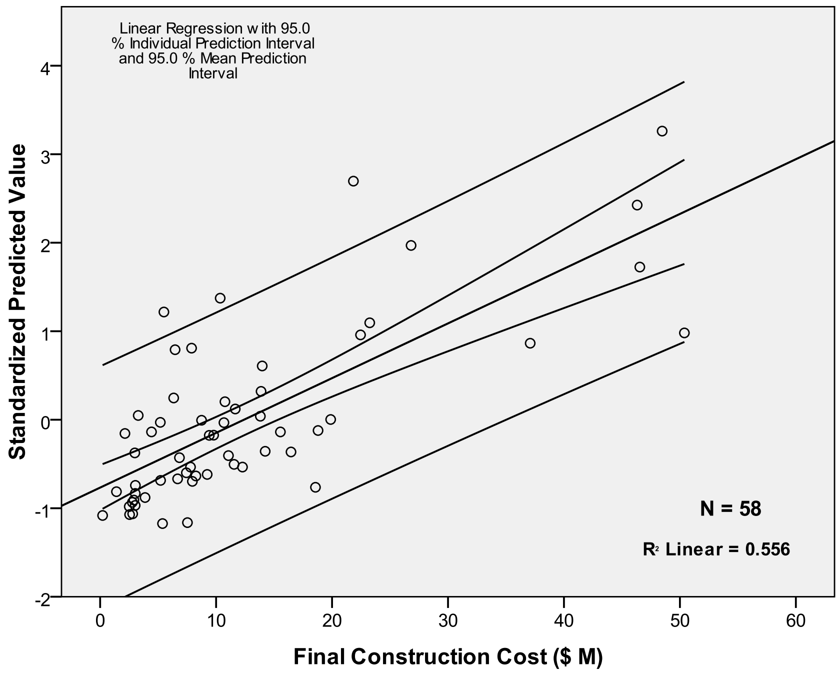

Figure H- 3. Standardized predicted values of final construction cost ($ M) for CCDPW road and flood control projects (considering basic design cost)

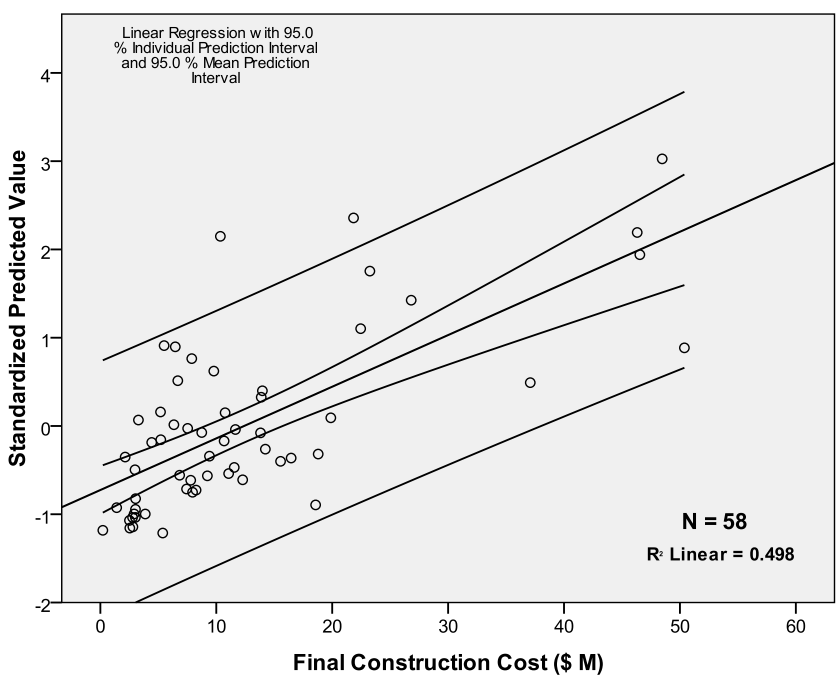

Figure H- 4. Standardized predicted values of final construction cost ($ M) for CCDPW road and flood control projects (considering total design cost)

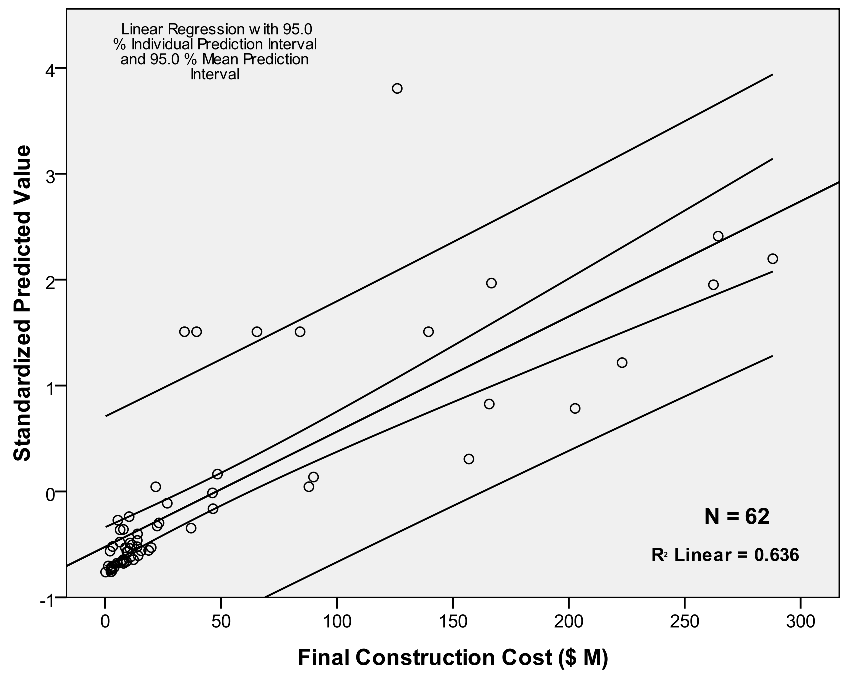

Figure H- 5. Standardized predicted values of final construction cost ($ M) for CCDPW and TXDOT road (considering basic design Cost)

APPENDIX I

RESIDUAL PLOT FOR YEARLY TIME SERIES MODEL

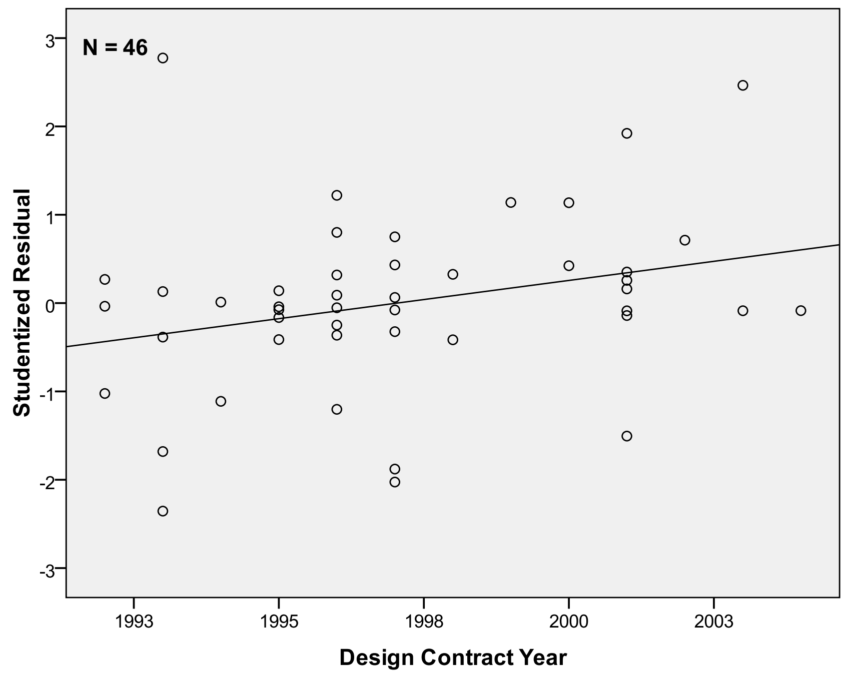

Figure I- 1. Residual plot for yearly design contract for CCDPW road projects

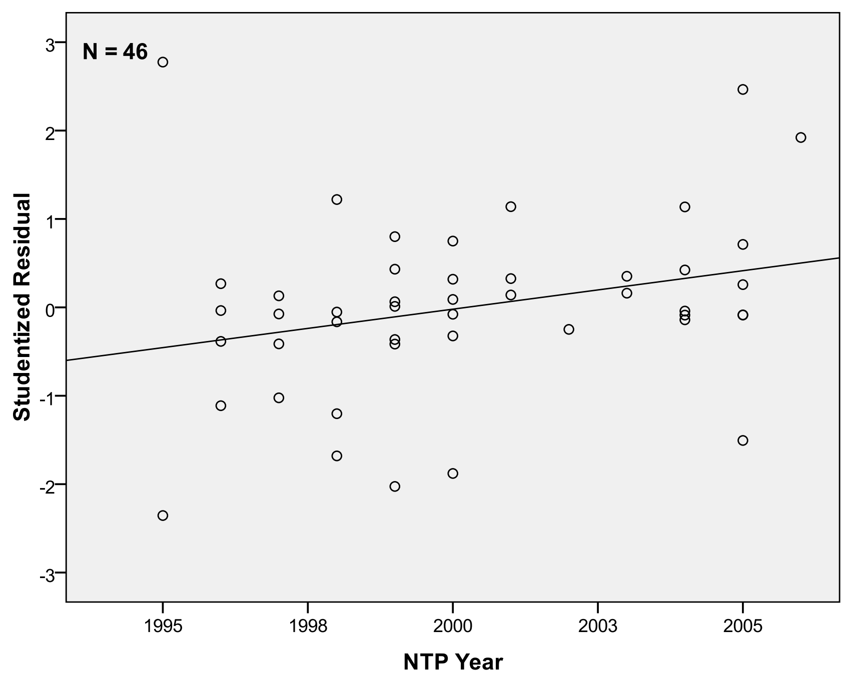

Figure I- 2. Residual plot for yearly NTP for CCDPW road projects

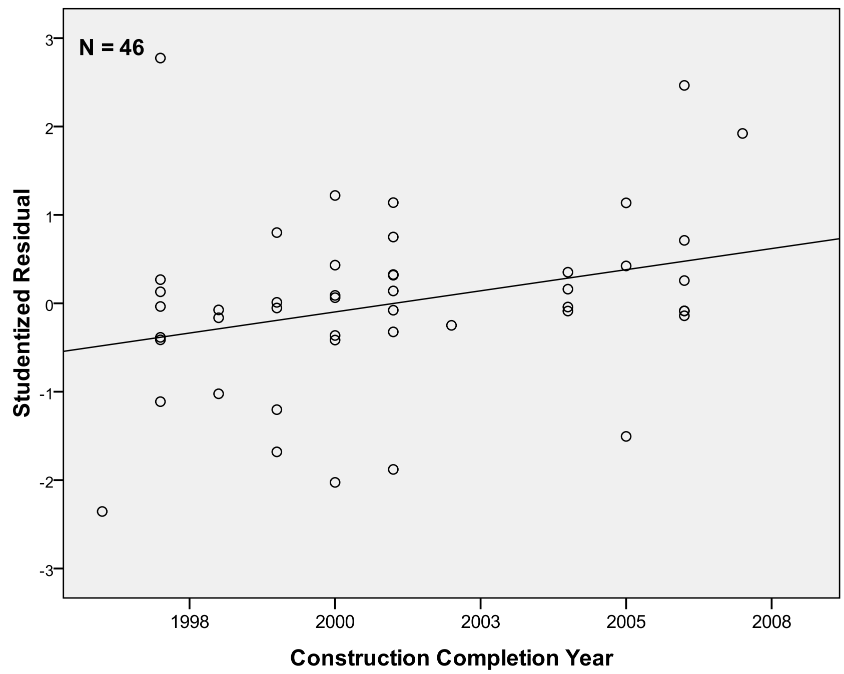

Figure I- 3. Residual plot for yearly construction completion for CCDPW road projects

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Shrestha, P.P. and **Mani, N.**, Impact of Mathematics and Physics Grade Point Average on Construction Management Undergraduate Students' Overall Grade, paper submitted to 4th International Multi-Conference on Engineering and Technological Innovation, Orlando, Florida, July, 2011.

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