QUANTIFYING CAUSES, SCHEDULE, AND COST IMPACTS OF CHANGE ORDERS: "IS ALTERNATIVE CONTRACTING REALLY EFFECTIVE?"

A Thesis

by

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ABSTRACT

The most professions who are engaged in the highway construction industry would commonly concur with an idea that the project cannot be delivered with no change. Regardless of considering different contract methods or what so ever, contract change orders (CCO) are yet inevitable due to unforeseen utility conflicts, unpredicted geology, and other unanticipated conditions. No matter of the project location and/or condition, the CCO negatively affects the project in aspects of project cost and schedule.

The main purpose of this study is to carefully examine the influences of change orders in infrastructure development projects in the schedule and cost aspects. The aim of this study starts with collecting Florida Department of Transportation's (FDOT) 9 years of solid data that contains abundant information of CCO in highway projects completed in the state of Florida. In addition to the data, it contains 2,990 infrastructure projects completed between 2002 and 2011, 43,000 change order types, 8 contract methods including conventional (D/B/B), Design-Build (D/B), Incentive/Disincentive (I/D), No Excuse Bonus, Lump Sum, etc., and 7 major types of projects. These detailed and vast data was utilized to evaluate each method's performances affecting projects on cost and schedule aspects by carrying quantitative analysis, such as graphs, box plots, etc. Lastly, the research hypothesis test, which utilized regression analyses, Q-Q plots, scatterplot matrixes, etc., was conducted to verify the data variation, normal distribution, equal variances, correlation, etc.

The research results reveal that the innovative methods perform better than conventional in aspects of saving project cost and time. In addition to the innovative methods, D/B is the most effective method that saves both cost and time of projects. I/D compresses project duration but often causes project cost overrun. And Lump Sum significantly saves the project cost but causes project schedule overrun. This study will help interstate transportation agencies with a proper guideline to choose an ideal delivery or contracting method for a project. By providing the information of each method's advantages and disadvantages, it is expected to significantly reduce the agencies' time and expenses required to deliver projects.

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1. INTRODUCTION

1.1 Background

In most construction projects, regardless of project sizes or locations, changes are inevitable. The changes are referred to any event that consequently causes a modification of the original contract in scope, schedule, and/or cost for both material and labor (Camlic et al. 2002). Modifying original contracts expectedly increases the contract value from 5 to 10% (Finke 1998). The United State Census Bureau (2013), however, announced that construction spending in 2013 exceeded $934 billion. Assuming that 5% of cost increase occurred, it means $46.7 billion has been wasted due to unforeseen change orders.

A number of professionals and researchers have developed their studies to identify factors of the changes which cause cost inefficiency and quantification of productivity loss (Ibbs et al. 2007). Overrun of cost for infrastructure projects has been issued as a common problem for transportation agencies. The interstate transportation agencies, therefore, are also researching for solutions to mitigate the negative change orders effects (Alavi and Tavares 2009).

1.2 Innovative Project Delivery and Contracting Strategies

Transportation project highly take possession of industrial construction. Which means small improvements can significantly save time to meet project completion timeline and cost for higher revenues (Hancher 1999). According to a research (Flyvbjerg et al. 2002) which sampled 258 U.S. infrastructure projects with values of

$90 billion, it revealed that the tunnels and bridges projects ended up with 34% higher actual costs than estimated costs, and road projects spent 20% more costs than estimated costs. 55% of Infrastructure projects delivered by Indiana Department of Transportation (INDOT) between 1996 and 2001 experienced cost overruns, and 12% of them had time delays with average of 115 days (Bordat et al. 2004). Such overrun of cost and time delay is one of major factors which cause private and public construction firms and transportation agencies suffering a serious deficit.

As a solution for reducing construction time and cost, as well as impacts to motorists, Minnesota Department of Transportation (MnDOT) stated that innovative contracting techniques have been effective (Minnesota Department of Transportation 2006). Through a survey conducted by Transportation Research Board, it revealed that 30 State Transportation Agencies (STAs) have used Alternative Contracting Methods (ACMs) to accelerate project completion. The ACMs have been implemented for a large numbers of roadway construction and infrastructure development projects throughout the state since 2000 (Minnesota Department of Transportation 2006). These non-traditional approaches for considering contracting methods have supported for rewarding performance to ideal and efficient contractors (Ellis et al. 2007).

1.2.1 Conventional Project Delivery

Conventional contracting method, which is referred as Design-Bid-Build (D/B/B) is the most traditional method of a construction project. Stakeholder or owner selects the Architect to complete the design documents and distributes the specific plan and design to General Contractors for bidding. On the bidding stage, the traditional

D/B/B's intend is to search a Contractor who bids the lowest cost for the project and award the contract to the lowest bidder (Ellis et al. 2007). From design to construction building stage, the Architect plays a critical role which makes administrative discretion and become a focal point of the entire communication ongoing between the Contractors and owner (Warner 2010). Although the D/B/B contracting method is effective to find the lowest bidder, it is not always the most effective method of project delivery (Hancher 1999).

1.2.2 Design-Build Project Delivery

Many STAs have practically used the alternative contracting methods to accelerate project completion, reduce cost, and ameliorate project quality and safety standard (Alavi and Tavares 2009). Each alternative contracting method has different and distinctive features. While considering a right type of the project contracting method, the type, size, and location of the project are critical factor for a successful project completion with shorten duration and reduced cost.

A+B bidding contract offers a specific cost rate per each day, which is referred to cost plus time. The main focus of A+B bidding is the lowest initial cost and reasonable duration. Due to its unique feature in linking cost with time, it is a very valuable tool to accelerate project completion. The A component is associated with the traditional unit-price construction bid, and the B component refers to the project duration, which is number of days initially required to complete the project (Alavi and Tavares 2009). According to AASHTO, the A+B method has been broadly used by approximately 27 states and Columbia District under Special Experimental Projects No.

14 provision (SEP-14) at FHWA (American Association of State Highway Transportation Officials 2011). The advantages of A+B bidding are as the followings:

- Incentives for contractors to shorten project duration;
- Prompt project completion; and
- Careful consideration for the A or time component.

Incentives and Disincentives bidding, known as I/D, is another contracting method that is more widely used in contracts. Incentives represent an award of extra payments for early project completion. Disincentives mean penalties for late finish of project, which is often known as liquidated damages.

No Excuse Bonus is another similar concept with I/D, which intends to shorten the project duration by awarding contractors a considerable bonus for project completion with a timely manner. Due to the substantial bonus, ordinary time extensions including weather issue and unforeseen conditions are not allowed for contractors under the No Excuse Bonus contract.

Each type of innovative contracting strategies is described below in Table 1.1. Lump sum is a valuable tool that reduces the contract administration costs for STAs, specifically in the project quantity verification and measurements. The lump sum contact is the simplest and most basic form of an agreement between an owner and contractor, which abbreviates the overall unit cost estimation and offers a bidding price for the whole project delivery. Therefore, it is the most ideal contract for an owner who has tight budget and lack of experience in construction industry by keeping the owner free of financial risks (Warner 2010).

Table 1.1 Innovative Contracting Strategies

Type	Objectives	Ideal Conditions
A+B	To provide contractor incentives for early project completions, thereby reduce traffic congestion in public.	Bridge constructions or rehabilitations, and urban reconstruction. (ideal for any types of projects that are required to be done in timely manner.
Incentive & Disincentives	To offer contractors an award of extra payments for early finished projects and charge penalties for late finished projects.	Urban reconstruction, local road rehabilitation, and highway reconstruction (ideal for any types of projects that are required to be accomplished within timely manner).
No Excuse Bonuses	To offer contractors substantial bonuses for early project completion without any ordinary time extensions.	Ideal for locations where have frequent weather issues to become free from time overrun risk.
Lump Sum	To reduce contract administration such as design, contract, and other documentation tasks.	Bike paths constructions, culvert extensions and resurfacing, road extension projects, and other small and simple projects.

1.2.3 Innovative Contracting Methods

According to innovative contracting summary organized by Mn/DOT, A+B showed effectiveness in reducing approximately 15% of contract time compared to the Mn/DOT's maximum bidding time allotment. Moreover, contractors who worked with A+B completed the project average 17% faster than originally contracted (MDOT 2006).

The California Department of Transportation, called as Caltrans, also formed an evaluation on A+B bidding practices. The evaluation stated that A+B projects (23.7%) had less amount of average cost growth percentage than other non-A+B projects (26.4%) including conventional projects (Ellis et al. 2007).

I/D contracts help STAs save on costs caused by drivers' delay by reducing construction time and contractors earn extra profits from receiving an incentive bonus (Plummer 1992). 58.6% of Caltrans' I/D projects were completed earlier than originally contracted schedule, while only 12 % of A+B and 32.4% of conventional project respectively reduced their project duration (Choi 2008).

No Excuse Bonus reduces construction time while improve coordination between project members such as owner, contractor, and subcontractors by adopting more innovative techniques and realistic bidding systems (Herbsman et al. 1995).

The Lump Sum contract, which is sometimes called as Drawings and Specific Contract, has the benefits as the followings (Naoum 1994):

- Specified final price in early stage, prior to the work commences;
- More opportunities to increase the profit by receiving incentives; and
- Early finished project by contractors due to risks of overruns in cost.

Design-Build contracting strategy has been implemented for number of the U.S. infrastructure improvement project in various states. Compared to traditional contracting method, Design-Bid-Build, D/B has been shown a remarkable performance in decreasing project time to completion and reducing cost growth (Reilly 2009). By D/B contracting technique implementation, moreover, there are more benefits identified as the followings (MDOT 2009):

- Highly promoted innovation;
- Reduced risk of claims; and
- Reduced or eliminated conflicts between design and actual conditions.

2. PROBLEMS AND RESEARCH SETTINGS

2.1 Gaps in Knowledge

Volumes of highway traffic in state of Florida have excessively increased. Thereby, Florida Department of Transportation (FDOT) is facing an ongoing need for infrastructure improvements, as well as, maintaining an aggressive highway work program (Ellis et al. 2007). During construction activity for the infrastructure improvement projects, capacity of highway gets obviously and significantly reduced, and it consequently causes motorists and adjacent businesses inconvenient and unexpected time wastes. In order to mitigate the negative impact of the infrastructure improvements and construction operations, the FDOT had continuously searched for a critical key which would accelerate project completion, improve project quality, and save project costs. As the result, the FDOT has been a leader in adopting alternative contracting methods: A+B, Incentive/Disincentive (I/D), Lump Sum, and No Excuse Bonus. (Ellis et al. 2007). Despite the FDOT's strong leadership and past experiences, only few researches in public have yet dimly studied for contracting or delivery strategies for infrastructure projects done in Florida. And such lack of precise and analytic research to clarify evaluation of alternative contracting methods has interrupted the FDOT from understanding of correlations between the contracting methods and change orders occurrences (COO).

2.1.1 Lack of Comprehensive Project Data

Yet, the effectiveness of alternative contracting and delivery methods is not clearly qualified to be commonly used for highway construction projects. Moreover, number of professions involved in construction industry advocates disadvantage of adopting the new methods. Lump Sum may reduce bid competition, increase likeness of disputes and claims, and require administrative efforts for compliance ensures for documentation (Molenaar, and Yakowenko 2007). Design-Build (D/B) favors larger construction firms over smaller firms in bid competition to enter into the contract award process by including non-price factors (Warner 2010). Cost-Plus-Time bidding (A+B) takes more time consuming to arrange adequate available staffing resources and require higher production and innovation to meet expectations of project completion and quality (Molenaar, and Yakowenko 2007).

2.1.2 Lack of Systematic Study on Aspect of Project Performance

Numbers of articles and projects have conducted on influences of change order impacts on general construction project delivering and contracting methods and direct effect on the outcome of the project. And only few articles studied different contracting techniques for highway projects to minimize negative impacts of change orders. Construction research area nowadays, however, there has not been any systematic study for the effects of each conventional and alternative contracting methods on the public construction industry for the possible outcomes (Smith 2008). Yet, no systematic studies have been seriously investigated to clarify impacts if I/D projects on change to project performances, specifically in costs and schedules (Choi 2008). The problem of not clearly identified impacts of the methods on project performances is not only limited to I/D but all other alternative contracting methods. Furthermore, there is no data researching past used contracting methods and their corresponding change order impacts on highway projects completed in the state of Florida within the last decade.

2.2 Research Objectives and Scopes

The point of departure for this study comes from a question: are alternative contracting strategies effective? The major goals of this project are twofold:

1. Quantify the major impact of Contract Change Orders (CCOs) on aspects of project performance; specifically causes, schedule and cost for this study.
2. Develop and test a prediction model that can be used to evaluate how CCO affects project schedule and cost.

To achieve these goals, this study proposes the following three-stage methodology:

- Stage 1: Project Delivery Comparison and Analysis: compare Design-Build (D/B) projects with the conventional delivery projects and analyze the impacts of CCOs in terms of schedule, cost, and causes.
- Stage 2: Project contracting comparison: compare the conventional contracting method with the alternative contracting methods: No Excuse Bonus (NEB), Lump sum, Incentive / Disincentive (I/D), and A+B.
- Stage 3: Evaluation.

These 3 portioned stages and tasks to achieve the objectives must include the followings:

- Determine and investigate the benefits in project performances, specifically shorten durations and reduced prices, from using alternative contracting methods instead of conventional;
- Investigate merit of alternative delivery method over conventional to meet or perform better than previously scheduled duration and estimated budget; and
- Certify qualification and authenticity of the quantitative model.

2.3 Research Methodologies

The scope of this research covers abundant change orders occurred in precedent Florida state highway projects. For the research procedure, the quantitative study of 2,990 infrastructure projects completed between the years 2002 to 2011 have been primarily implemented as the following orders:

1. Data collection: The project data, containing critical factors that are pertinent to change orders of precedent Florida state highway projects were collected.
2. Data classification: The data are classified into different groups sorted by contracting method, project type, and project scope.
3. Tendencies of Infrastructure Improvement Projects: Between the years 2002 and 2011, enormous projects had been developed using different contracting strategies and delivery methods. To evaluate different types of tendencies, this research examined the contracting strategy and project type that had been used by FODT during the period of 9 years.
4. Project Size Issues: Despite of possibility that alternative strategies are comparatively used less than conventional, it does not necessarily mean that

more cost were allocated to conventional strategy. Therefore, more accurate quantification of project size by contracting strategies needs to be analyzed.

5. Change Order Occurrences and Impacts: Often the frequency of change order occurrences varies on different contracting methods and project types. Moreover, the change order mostly causes performance impacts on cost and schedule of projects. Therefore, causes and impacts of change order need to be identified.
6. Schedule Modification Ratio: The ratio of modified schedule need to be identified by analyzing whether the project duration is advanced or delayed.
7. Cost Modification Ratio: The ratio of modified cost need to be identified by analyzing whether the project budget is increased or decrease.
8. Contract Modification Growth: The impacts of change order on entire project schedule and cost growth are identified by respectively conducting formulations for schedule and cost alteration.
9. Development of a Prediction Model for CCO: A prediction model for occurrences of change order is conducted at the end of this research.

2.4 Research Hypothesis

The motive of this study is to address a question: are alternative contracting strategies really effective? The hypothesis of this study is that alternative contracting and delivery methods actually benefit owners with project completion in reduced durations and saved costs. Prior to answering the question, having a firm literature review which supports in building a better understanding for the each alternative methods' specific terms and functions, stating the process of different project delivery methods, and defining a way to predict unforeseen change orders.

2.5 Expected Research Outcomes and Deliverables

Effectiveness of using the alternative contracting strategies, which is the major objective of this study, are anticipated to deliver some benefits to all members involved to the project. The benefits are expectedly and potentially to reduce costs for Construction Engineering and shorten duration to allow early project completion (Molenaar, and Yakowenko 2007). The actual benefits have been reported from diverse projects in different areas. There are numbers of infrastructure projects represents successful cases which are the Sydney North-side Tunnel Project (Henderson, 1999) and the United Kingdom Channel Tunnel Rail Link (Brierley and Hatem 2002).

Throughout researching and developing this study, more successful cases and alternative contracting and delivery methods with their corresponding effectiveness would be determined by performing a quantitative analysis. The quantitative analysis of vast data collection is the main part of this project. And the subsequent deliverables are as the followings:

1. A good quality of literature review regarding project delivery and contracting methods, causes of change orders, present uses of methods within the construction industry to build a better understanding;
2. Classification and analysis of project data by contracting and delivery methods, type of project, and scope; and

3. A qualified evaluation of each impact of conventional and alternative contracting method to projects in the past project performance in schedules and costs.

The deliverables obtained from the quantitative analysis are mandatory to proceed to next level of this study. The determination of the robustness of COO prediction model and accurate results of the research are the major purposes.

2.6 Contributions of the Research

The research result defines the effectiveness of innovative delivery and contracting methods in dealing with change orders. To consolidate contributions of this research, the following Table 2.1 below represents problems to be solved and tasks to be performed.

Table 2.1 Problems, Tasks, and Contribution

Problems	Tasks and Contributions
Lack of data handling change order impacts for Florida infrastructure development projects in cost and schedule	I. Collect data which includes useful information regarding past change order impacts on precedent infrastructure projects in Florida. II. Classify, study, and analyze the data to conduct a quantitative data analysis. Contribution: • Positive reinforcement in establishment of hypothesis for this project. • Judicious discernment for predicting change order influences on infrastructure project. • High quality of informative data to help for delivering infrastructure development projects in the future.

Table 2.1 Continued

Problems	Tasks and Contributions
Lack of research for divers outcomes caused by different contracting strategies	I. Compare the impact of alternative contracting strategies over the conventional strategy performances, schedule, and cost. Contribution: • Clarified ideas of different contracting strategies influencing project schedule and cost.
Lack of examination finding relationship between CCO magnitudes and schedule changes	I. Conduct scatterplots based linear regression model to predict schedule changes. II. Analyze correlation between the various factors, such as CCO frequency, cost, schedule, etc. Contribution: • Acquisition of accurate prediction of schedule change as a function of CCO.
Lack of study identifying factors causing change orders for Florida interstate infrastructure project	I. Identify causes of change orders occurred in the precedent infrastructure development projects. II. Classify the causes into different groups based on the project types. III. Examine the classified causes and list them in order by the frequency. Contribution: • Presupposition for major change orders that frequently occur during the project ongoing.

3. LITERATURE REVIEW

3.1 Study Needed for Delivery and Contracting Methods

Numbers of articles and projects have conducted studies regarding influences of change order impacts on general construction projects. And only few articles studied different contracting strategies for roadway projects to mitigate negative impacts of change orders. Yet, no project has studied in contracting or delivery strategies for infrastructure projects in Florida.

Prior to collecting data, however, it is mandatory to build a full of understanding in different types of contracting strategies along with their merits and demerits influencing the entire project processes. To build a better understanding in the contracting strategies, a good quality of literature review regarding project delivery methods, causes of change orders, contracting methods, etc. have been performed. Therefore, this literature review's proposed goals are threefold: (1) learn about Florida Department of Transportation's (FDOT) alternative (D/B) project delivery method. (2) build a better understanding and evaluate differences between conventional and alternative contracting strategies. (3) understand better about change order impacts on project performances, especially cost and schedule.

3.2 Project Delivery Method: Alternative versus Conventional

Between 1920s and 1930s, numerous research studies, which were mostly sponsored by the American Association of State Highway Officials (AASHTO), on construction materials and methods were performed to find significant results of their influences to entire construction project procedures (Serag et al. 2010). And the research outcomes were more than enough to stimulate construction professions' ardent interests. Starting of such enthusiastic research studies, discovering new effective alternative construction methods have been actively continued until nowadays construction industry. According to a national survey conducted by Gransberg and Senadheer (1999) over 15 DOTs, D/B was the alternative method which was the most highly qualified (Minnesota Department of Transportation 2009). Among the most national Department of Transportations (DOT), however, FDOT has been a leader and one of the first DOTs that adopted a Design-Build (D/B) contracting program since 1987 (Minnesota Department of Transportation 2006). Prior to adopting the new alternative contraction methods, traditional design-bid-build (D/B/B) contracting method was mainly performed to deliver the most highway construction projects (Minnesota Department of Transportation 2006). The main difference between D/B/B and D/B methods is omission of bid phase, and authority of the project delivery is solely awarded to a contractor, instead of collaborating with other parties including consultant, representative of owner, architect, etc. The better and more depth of understanding in differences between these delivery methods in contrasting respective characteristics and discovering their cons and pros are absolutely demanded in making evaluations on the methods. And the following articles listed below have been identified as references for the criteria.

3.3 Comparison of Alternative Contracting Methods with Conventional

The alternative contracting methods have been nationally utilized for various highway construction projects by DOTs and national contractors (Gransberg and

Sanjaya 1999). The Federal Highway Administration (FHWA) has approved several alternative contracting strategies for use on federal funded projects that differ from the traditional design-bid-build process (United States Bureau of the Census 2005). The alternative contracting methods comprise A+B, I/D, Lane Rental, Pay for performance, Lump sum, No excuse bonuses, etc. And research on analyzing and contrasting those alternative methods are broadly performed to pick out the outstanding contracting method and clarify the merits over replacing conventional contracting methods. According to Minnesota Department of Transportation's (MDOT) summary on innovative contracting executive, they have found the effectiveness of A+B, which is one of the alternative contracting techniques, in reducing construction time and impacts to motorists (Gransberg and Sanjaya 1999).

However, A+B is not the only contracting method which is effective in time savings. There are still many numbers of contracting methods are available to be evaluated or qualified by national DOTs.

3.4 Existing Studies: Impact of Change Orders

Change orders have been caused a negative impact on various aspects worsening construction productivity. (Flyvbjerg et al. 2002) And the loss of the productivity consequently leads the project to deadline overrun, over budget, and/or low quality issues. Engy, Amr, Linda, and Essam (2010) collected 16 FDOT projects with contract values from $10 to $25 million and conducted an interview with FDOT to clarify the major problems causing a contract price increase due to change orders. The interviewees are composed of resident Engineers and consultants who worked for FDOT from 9 districts (Alavi and Tavares 2009). With use of normality plot and the residual histogram based on the collected data, normal distribution assumption can be identified.

Throughout the experimentation, with use of additional collected data, equations, and the normal distribution assumption, the writers found key factors which can clarify the influences of change order on the contract price increases. The key factors are time, change order reasons, party involved in the project, whether rework and change order compensation required or not, and extension. Also, the overall results of the experimentation was enough to support the writers' hypothesis that the change order issued close to project completion causes an increase in the contract price (Alavi and Tavares 2009). The proposed acquirement obtained from reviewing of this article is to better understand how to effectively utilize the collected data to produce an excellent result and acquire some developed experimental methods which would strongly support the objectives and hypothesis of this study.

This project proposes to conduct a study which does not duplicate existing research for the following two reasons:

1. There is no data handling change order impacts on highway projects completed in the state of Florida.
2. Any significant research has not been conducted for Florida highway projects in change order growth issues, decision-support model for contracting strategy, and contrast for different delivery methods.

4. DATA COLLECTION AND ANALYSIS

4.1 Data Set

For traditional highway construction contracting method that is known design-bid-build, cost or lowest bid is the most critical criterion, which determines the winning bid (U.S. Department of Transportation). Despite of the low cost guaranteed biding processes, few innovative states started to search some alternative ways that can promptly complete projects and minimize traffic stagnation meanwhile construction works ongoing (Choi 2008). According to the record of Transportation Research Board, however, there was a struggle to have an innovation of contracting practices in the highway industry of 1991 (Transportation Research Board/National Research Council 1991). The concerns of adopting the innovative highway contracting methods were cost, risk in non-verified system, and resistance to change (2010).

Since the middle of 1990s, after conducting 5 years of studies, FHWA (Federal Highway Administration) has supported the use of innovative contracting methods to meet advanced quality, cost reduction, safety, and time saves (U.S. Department of Transportation). Consequently, FDOT has successfully delivered a major number of highway projects by uses of alternative contracting methods (Ellis et al. 2007), and about 67% of highway construction projects in Kentucky from 1999 to 2002 were performed with time-based I/D provisions, which is one of the alternative contracting methods (Choi 2008).

4.2 Data Collection

The quantitative study of 2,990 infrastructure improvement projects completed in Florida between 2002 and 2011 is a principal source of data for this research. Consulting the quantitative study supports this research to accomplish the goals in quantifying impacts of CCO and alternative contracting methods on aspects of project performance, particularly project schedule and cost. The ideal data collection is obtained by a help of FDOT, and the data contain abundant information of the infrastructure improvement projects. In addition to the content of data, it has more than enough useful sources applicable to this research. The followings are some examples of the sources:

- Description of each change order's contracting method - either Conventional or Alternatives;
- Contract numbers;
- Costs of each contract;
- Change order types: a list of the change orders classified into 10 different types;
- Project work types: 8 different types of project works;
- Classification of reasons: causes of the change order with detailed description;
- Change order date along with CO status – either approval or denial;
- Original contract amounts; and
- Adjusted original amount.

4.3 Data Classification

To acquire an accurate and bias free quantitative data analysis, the data need to be classified into different groups sorted by contracting method, project type and size. Within the data collection, seven project types and considerable points (Table 4.1) have been identified as the followings:

- The 3R infrastructure renewal projects: resurfacing, reconstruction, and interstate rehabilitation of existing highway;
- Bridge projects: Bridge repair and construction;
- Capacity added projects: the addition of lanes or expansion of existing lanes, it's often accompanied by resurfacing;
- New construction: newly building various infrastructure projects;
- Traffic operations: the addition of new equipment, traffic signal and operations;
- Miscellaneous construction: construction of bike paths and sidewalks; and
- Others: operations for maintenance, drainage construction, and unknown.

And the contracting methods have been identified as the followings:

- Cost plus time (A+B);
- No excuse bonus;
- Design/Bid (D/B);
- Incentive/Disincentive (I/D); and
- Conventional (D/B/B).

Table 4.1 Considerable Points of Project Data

	No.	Considered Points	Description
Project Summary	1	Contract ID Number	5 digit unique project ID
	2	District	
	3	Let Date	final bid date
	4	Project Work Type Description	13 different types
	5	Contracting Type	Innovative or Conventional
	6	Contractor Name	
	7	Contractor Vendor ID	
	8	Type of Contract Change Order	11 different types of CCO
Time	9	Original Contract Days	Planned schedule duration of project
	10	Work Begin Date	Actual working begin date
	11	Contract Change Order Days	Time adjustments due to CCO
	12	Present Contract Days	Equals 9+11
	13	Day Used	Actual project time spent to complete it
	14	Project Time Change	Equal 11/9
Cost	15	Original Contract Amount	Initial bid amount
	16	CCO Amount	All costs adjusted due to contract changes
	17	Present Contract Amount	Equals 15_16
	18	Final Project Cost	Final cost actually spent for the project
	19	Project Cost Change	Equals 18/16
	20	Work Orders	Different types of work orders

The data classification process (Figure 4.1) is needed to obtain unbiased and classified data. This data classifying process is formed in four steps, such as contracting strategies, project types, project sizes, and change order aspects.

Figure 4.1 Data Classification Model

This quantitative analysis is to identify how the alternative contracting and delivery methods effectively influence and deliver the impact in terms of schedule and cost. To achieve the goal, the data was proceeded as the followings two steps:

1. All the 2,990 projects were divided into their different contracting strategy; A+B, I/D, Lump Sum, No Excuse Bonus, or conventional (Figure 4.2).
2. The projects were classified by project type sizes as shown in Table 4.2. Some of the minor projects in project amount and number were then excluded.

Table 4.2 Project Types by Size Types

Type of Project	Small Size $0 to $10 million	Medium Size $10 to $50 million	Large Size $50 or more
Conventional	260	79	2
A+B Bidding	16	48	6
No Excuse Bonuses	17	32	13

Table 4.2 Continued

Type of Project	Small Size $0 to $10 million	Medium Size $10 to $50 million	Large Size $50 or more
I/D	15	26	8
Lane Rental	3	1	1
Liquidated Savings	3	2	1
Lump Sum	142	17	0
Design-Build	38	28	6

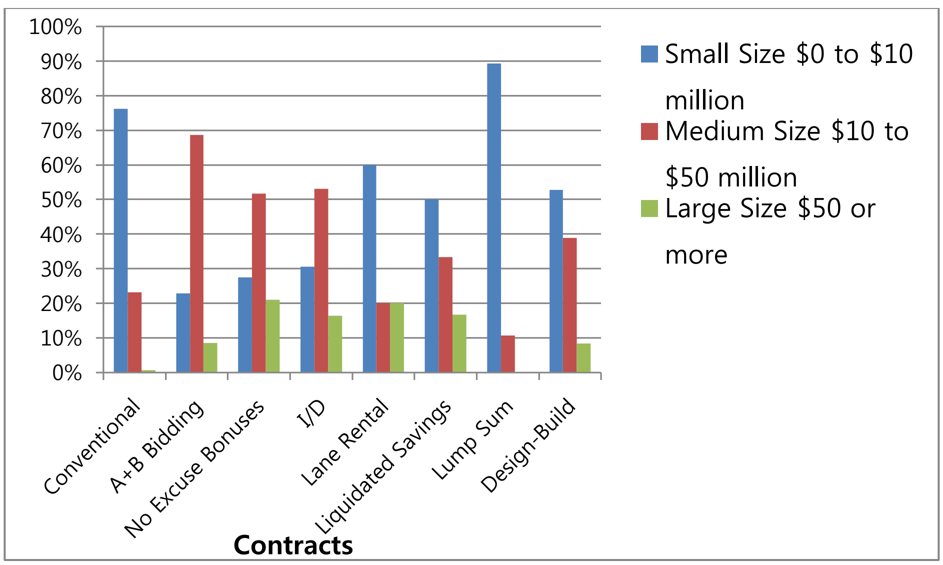

Figure 4.2 Project Size Portions versus Contract Types

4.4 Research Data Studied

4.4.1 Trend Analysis

Between 2002 and 2011, enormous projects had been developed using different contracting and delivery methods. The current tendency establishment (Figure 4.3) and cost allotment (Figure 4.4) of infrastructure improvement projects are shown blow.

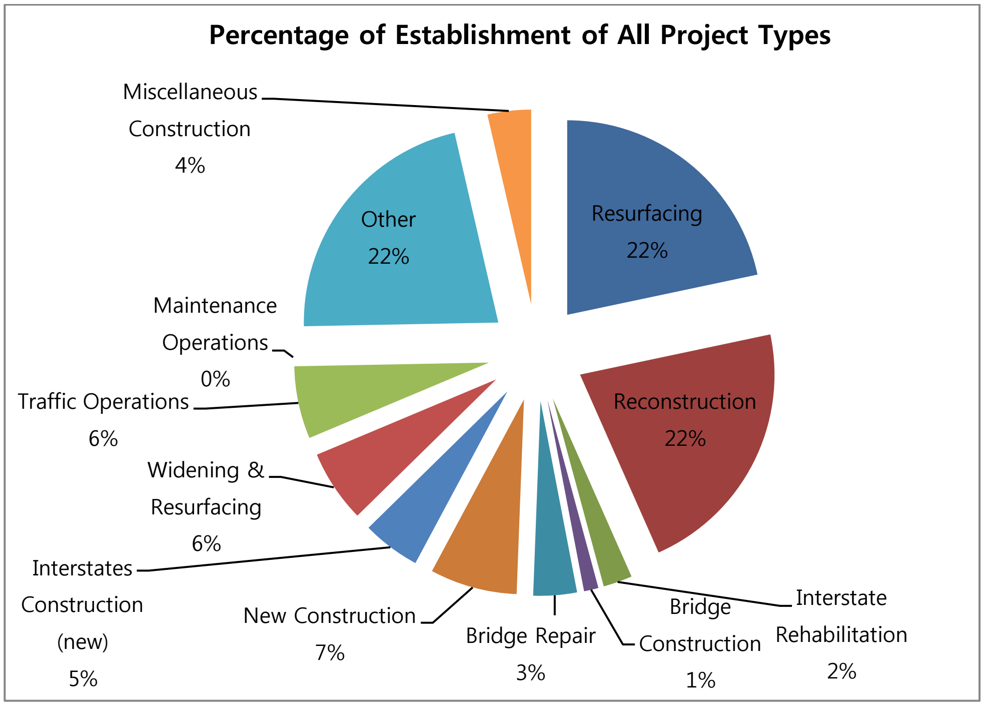

Figure 4.3 Trends of Infrastructure Projects' Establishment (2002 to 2011)

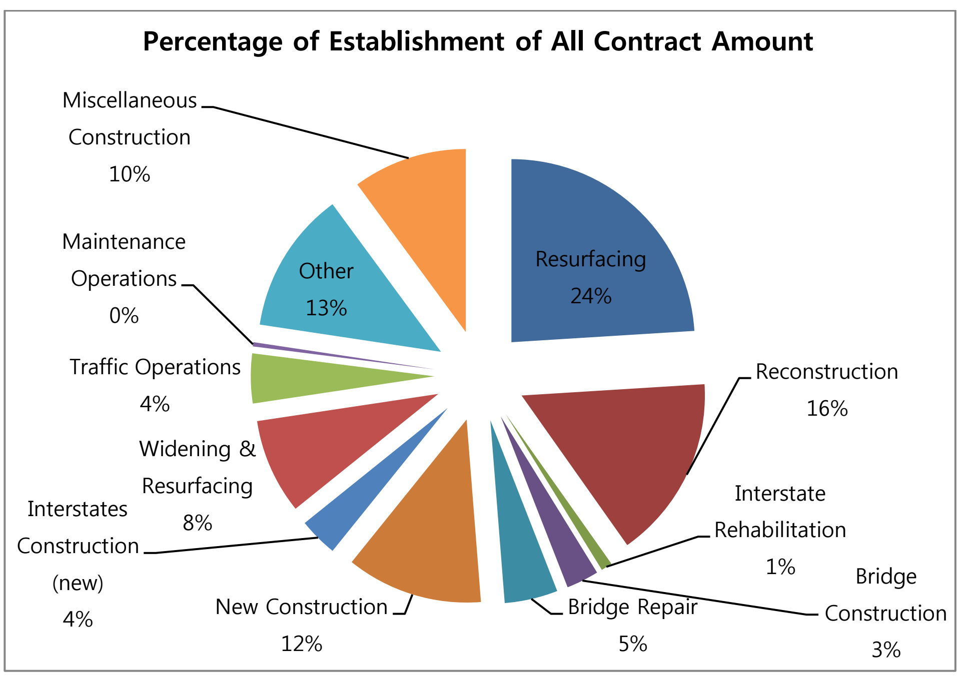

Figure 4.4 Trends of Infrastructure Projects' Cost Allotment (2002 to 2011)

Three major project types such as resurfacing, reconstruction, and new construction possess approximately 51% of all projects completed in Florida from 2002 to 2011. As focusing on the percentage of all contract amount allotment, the three project types mentioned above also dominate over half of the contract cost allotments, which is approximately 52%. These two different types of proportions tell that the three project types had larger projects in terms of number and cost.

Among those three major project types, however, the remarkable thing is that first two largest project types (44%) are involved with 3R construction: resurfacing, reconstruction, and rehabilitation (Figure 4.5). On the other hand, new construction type only represents 12% of entire projects. With the result of this research, the current tendency of infrastructure improvement projects has their intention of performing renewal of existing facilities instead of development and construction of new facilities.

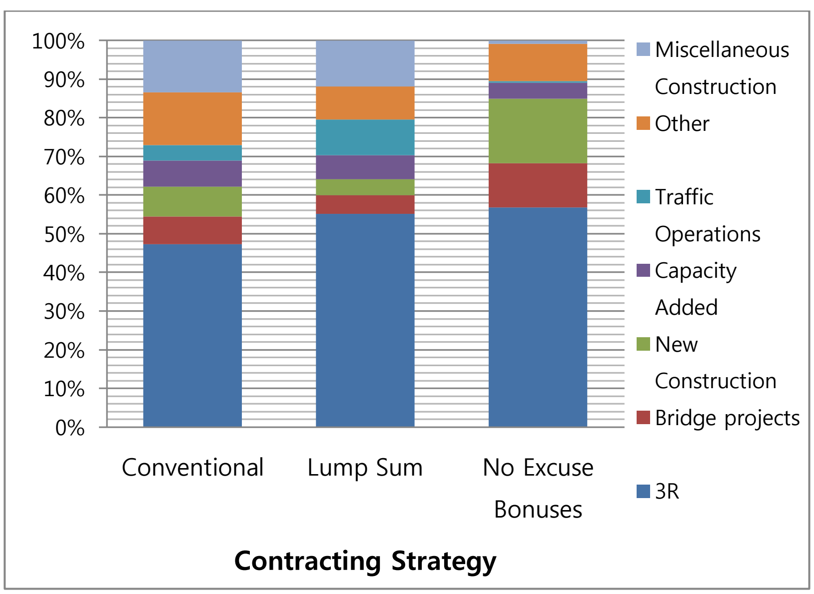

Figure 4.5 Adoption of Major 2 ACS versus Project Types

As shown in Figure 4.5, 3R projects are more likely involved with alternative contracting methods than conventional. The major purpose of 3R: resurfacing, restoration, or rehabilitation is to repair and develop current condition and life cycle of existing highways. Therefore, closing construction zone is inevitable, regardless of how many drivers are using the highway each day. Due to the existing lane closure, high volumes of traffic congestion occur on adjacent to the project sites, and early project completion would be highly demanded by the drivers. In order to minimize the inconvenient and inefficient situation, the number of the alternative contracting method adoptions has been increased due to its excellence in shortening project duration and mitigating the traffic congestion in public highway and local road.

4.4.2 Project Size Issues

The overall quantitative data analysis shows that conventional strategy has been preponderant over alternative strategies. Yet, however, it is unclear if more cost were allocated to conventional strategy. As much as the variances of project sizes, the cost allocated in each project varies as well. Under an assumption that only 30 percent of projects in the data completed using alternative strategies while rest 70 percent of the projects used conventional strategy. Apparently, it may look more cost was allocated in conventional strategies. However, if considerably large projects were delivered using alternative strategies and small projects with conventional, more cost may had been allocated in projects with alternative strategies. In the matter of fact, more accurate comparison of project size by each contracting strategy needs be accurately analyzed.

The pie chart demonstrates that alternative contracting methods take 52% of all the projects completed in Florida between year 2002 and 2011 (Figure 4.6). This number, which is more than half of overall project proportion, means that the uses of alternative contracting methods exceeds conventional due to their effectiveness and positive impacts in project performances for schedule and cost. When this percentage was compared to the total cost apportionment, however, the percentage of cost assigned to the alternative contracting strategies rose to approximately 69% (refer to Figure 4.7). This increased amount of cost allotment means that alternative contracting methods had been applied to larger projects.

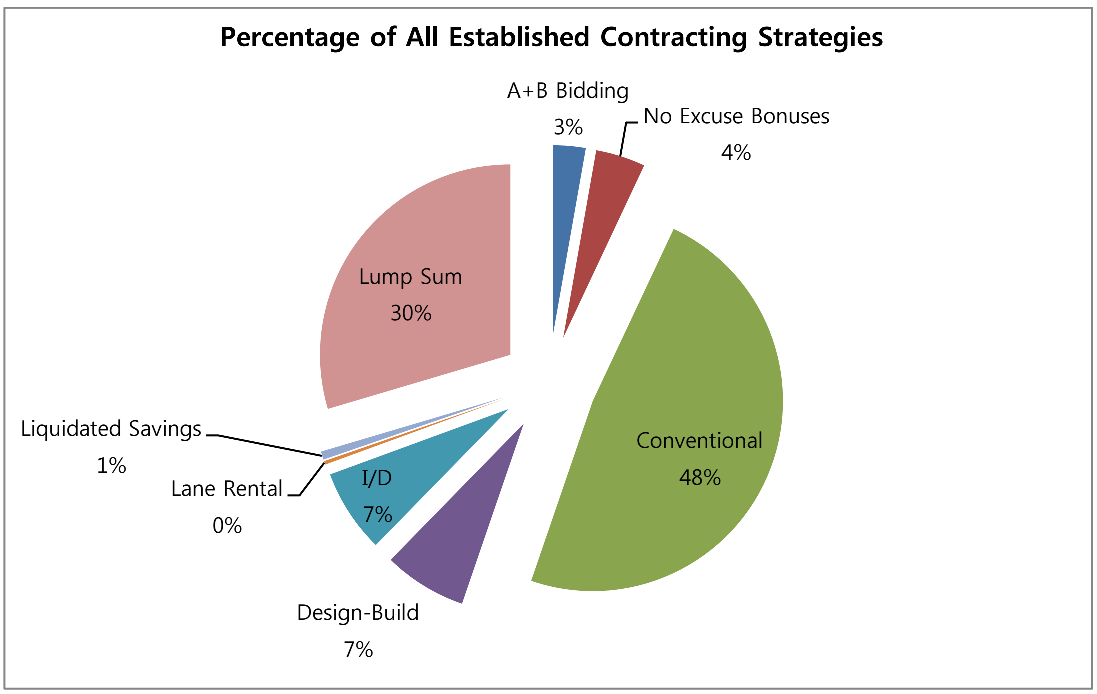

Figure 4.6 Proportion of Contracting Strategy Adoptions

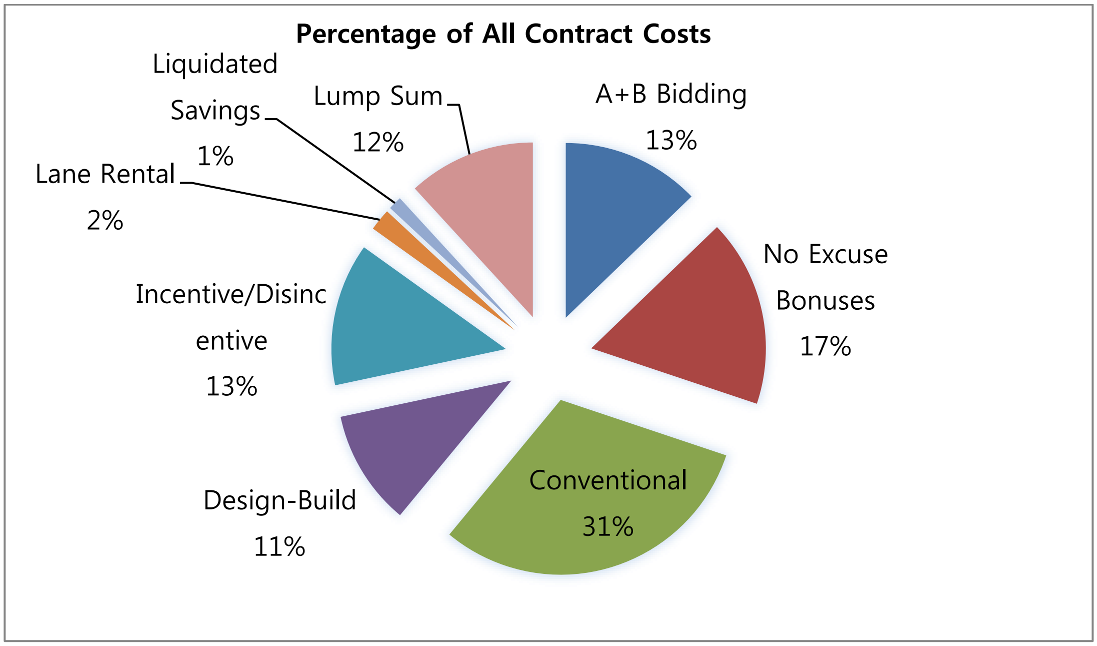

Figure 4.7 Proportions of Contract Costs

Figure 4.8 significantly shows that the larger project budgets had been invested in alternative contracting methods throughout the nine years of period. The average size on the original contract amount demonstrates important information about the distinctive characteristics of the alternative contracting methods.

The characteristics of each alternative project are as the followings:

- No Excuse Bonuses had the largest average project size in terms of the original contract amount, which is approximately $29.4 million. A+B Bidding and I/D respectively had $29.2 million and $19 million for average project sizes while conventional had only $5.2 million.

- No Excuse Bonuses was mainly applied for financially large sized projects, where no ordinary time extension is allowed to shorten the construction time or meet the originally scheduled time.
- New construction project had the largest project size, followed by bridge projects.

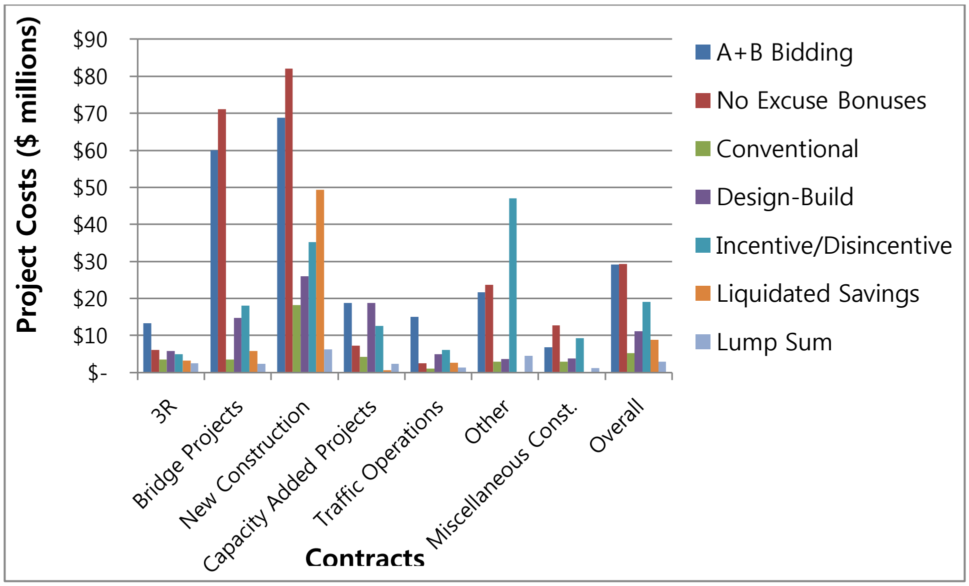

Figure 4.8 Average Project Size on the Original Contract Amount

4.4.3 Change Order Occurrences and Impacts

The frequency of change order occurrences often varies depending on the contracting strategy and project type. The change order occurrences are not unique while delivering construction projects, especially in large projects. In most cases, the change orders influence the projects on aspects of project performances, specifically schedule and cost. Therefore, it is very important to identify frequencies of change order occurrences on all different types of project and contracting strategy.

4.4.3.1 Reason for Change Order

Prior to identifying each different types of contract change order, a deep understanding about causes of the change orders primarily had to be done. 26 types of causes for change orders were contained in the data collection, such as weather related issues, defective materials, plan and specification modification, etc. The main purpose of using the FDOT's contract change order reason codes is to classify the Root Cause, Avoidability, Cost Recovery, Unilateral Payment Documents, Work Orders and Time Extensions in contract change tracking system (Camlic et al. 2002).

Frequencies of each contract change reason were classified into different contract types and shown in a simple form of graph (Figure 4.9). According to the data analysis, conventional contract had the most frequent change order reasons (approximately 14,163) followed by Lump Sum (app. 5,391) and No Excuse Bonuses (app. 3,242).

As mentioned before, the sum of cost proportion (30%), which was invested in Lump Sum and No Excuse Bonuses, were almost the same amount with Conventional (31%). When the frequencies of change order reasons were compared, however, the Conventional contracting strategy had almost two times of more numbers than sum of all Lump Sum and No Excuse Bonuses had. The result of comparison on contract change order frequencies is noteworthy to show how the Conventional contract is susceptible to unforeseen change orders. Among the all reasons of CCO within Conventional contracts, Weather related delays (49%) took the largest portion, which occurred 6,886 times (Table 4.3). On the other hand, however, innovative contracting strategies had significantly less change orders at all types of CCO. In the matter of fact, this result possibly means that those alternative contracting methods are comparatively adaptive and cope with unforeseen change orders.

Those CCO reasons can cause one or more of contract change orders. For example of Cost Savings Initiative, it correspondingly causes Supplement Agreement, which represents money and/or days granted for additional work (Ellis et al. 2007).

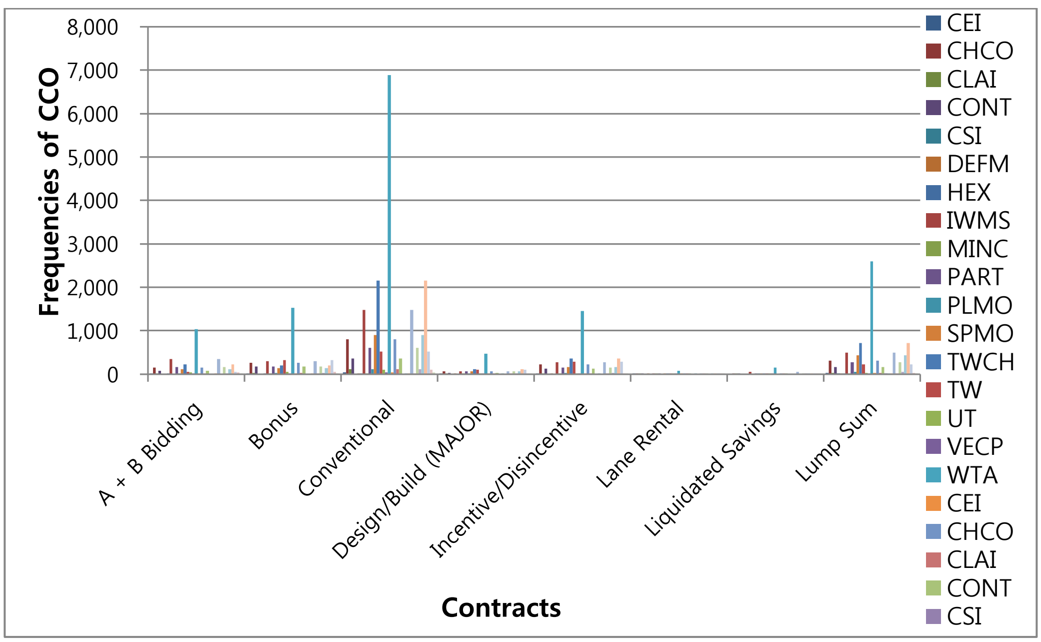

Figure 4.9 Frequencies of Contract Change Order versus Contracts

Table 4.3 Change Order Occurrence Types

CCO Type	A+B	Bonus	Conv.	D/B	I/D	Lane Rental	Liqui.	Lump Sum
CEI action/inaction	3	13	42	7	8	2	0	23
Changed conditions	146	262	801	59	219	12	17	315
Claims	20	25	112	15	19	4	1	32
Contingency SA	79	177	364	26	131	2	17	165
Cost Savings Initiative	0	0	0	0	0	0	0	1
Defective materials	0	0	17	1	1	1	0	3
Materials Shortage	2	3	4	0	0	0	0	6
Minor changes	350	302	1475	60	277	14	49	499
Partnering	0	2	18	2	1	1	0	7
Plans modification	167	175	603	63	151	6	18	272
Recovery due to weather	8	29	117	18	26	0	2	50
Specification modification	111	134	906	67	168	11	4	439
Time Extension For Holidays only	223	198	2153	115	354	3	3	713
Tropical Weather Related	58	322	521	103	281	18	12	231
Utility	38	55	108	11	13	1	2	33
Value engineering	9	20	36	2	8	2	18	155
Weather days - Weather letters only	1033	1525	6886	471	1450	82	155	2594

4.4.3.2 Types of Change Order

The change order claims that FDOT had to face were sorted into 11 categories as shown in the Table 4.4. Regardless of time when change order occurs, it is very difficult to quantify the level of impacts which may occur while delivering the project (Goodrum et al. 2010). Moreover, the impact of the change order often comes to the project as a disruption increasing cost of other unchanged works and causing change plans due to schedule conflict (Finke 1998).

Table 4.4 Change Order Types and Descriptions

Abbrev.	Change Order Types	Users
CN	Contingency Supplemental Agreement	Additional money granted for unexpected work.
CO	Changed Conditions	Something different than at the time of bidding.
EA	Time Extension Agreement	Days granted to complete the work.
HTEX	Holiday Time Extension	Days granted due to a holiday.
MPRT	Modifying Pay Item Participation	Used for changing participation on contract items that have already been paid. Administrative action only. Does not require outside approval.
SA	Supplemental Agreement	Additional money and/or days granted for specified additional work.
SPAD	Movement of Item Within Contract	Moving pay items from one financial project number to another. Administrative action only. Does not require outside approval.
SPEC	Work Order for Specification Change Only	Used to document any specification changes.
UN	Unilateral Sup. Agreement	Document used to pay our estimated value of a disputed claim.

Table 4.4 Continued

Abbrev.	Change Order Types	Users
WE	Weather Days Time Granted	When days are granted due to inclement weather.
WOTA	Contingency Work Order Time Adjustment	Days granted on the original contingency pay item or on a contingency SA.

From 2002 to 2011, the total contract change order was only 3.5%. As mentioned earlier, approximately 2,990 projects were delivered during the period, and the sum of overall actual project costs were $13.7 billion values. In other words, such small percentage of contract change order, which was less than 5%, consequently caused substantial impacts in cost of $428.3 million.

The change orders issued during the periods were mainly fallen into 4 categories, which are Supplemental Agreement (SA), Time Extension Agreement (EA), Contingency Work Time Adjustment (WOTA), and Unilateral Supplemental Agreement (UN). These 4 change order types represented more than 99% of all change order occurrences (Figure 4.10).

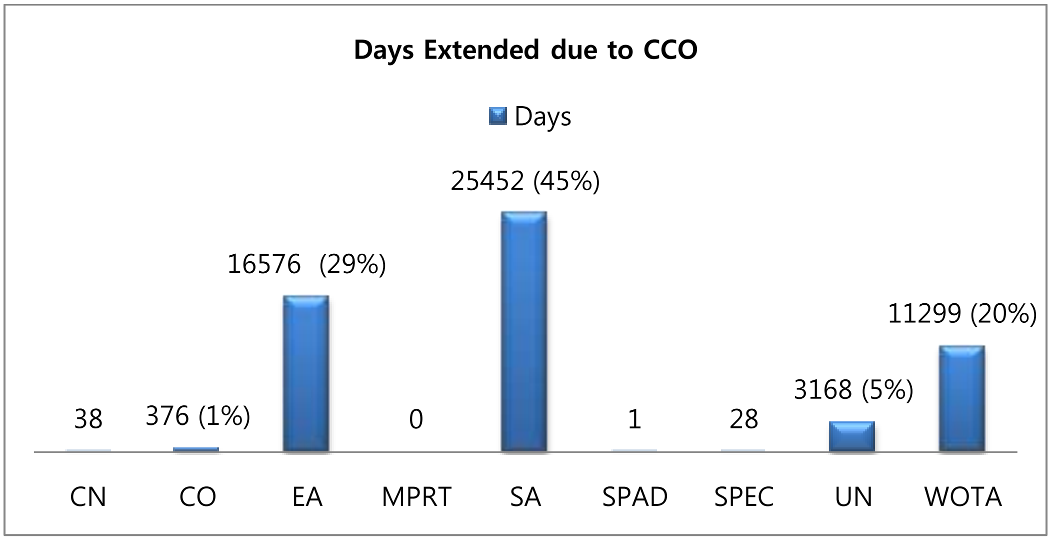

Figure 4.10 Impact of CCO on Project Schedule

4.5 Performance Evaluations

4.5.1 Schedule Performance Ratio

In most cases, the change order influence in project schedule changes. Therefore, a schedule performance ratio, which was impacted by change orders, is mandatory to analyze the ratio of the schedule changes. Throughout getting the ratio of schedule changes, it defines if actual final completion time is whether advanced or delayed by calculation of utilizing the original contract time and final contract time.

$$\text{Schedule Performance Ratio} = \frac{[\textit{final contract time - original (and amended) contract time}]}{[\textit{original (and amended) contract time}]}$$

When a negative valued outcome is given at the end of the calculation, it implies that the project was accomplished prior to meeting the originally scheduled day. A positive value, on the other hand, implies that the project duration was extended and completed later than the original schedule. Other than either negative or positive numbers, there is one more possible option for an outcome, which is zero implying that the project was completed right on time as originally scheduled.

This performance indicator in schedule would help on quantifying the schedule performance on a project by comparing the original contract duration versus amended contract duration. The main objective of utilizing the schedule performance ratio is to examine whether the adoption of the innovative contracting methods exactly influence the actual project duration. Throughout the process of calculating the schedule change ratio, differences in project performance between conventional and alternative contracting methods were clearly identified.

4.5.2 Cost Performance Ratio

The cost performance ratio is another performance indicator to evaluate the level of growth in project cost. The amount of cost decreased or increased was identified with uses of the following formula:

$$\text{Cost Performance Ratio} = \frac{[\textit{final contract amount - original (and amended) contract amount}]}{[\textit{original (an amended) contract amount}]}$$

This performance indicator in cost helps to analyze the ratio of cost differences between the final project cost and the original contract amount. As the same as the rule of the schedule change ratio, each numeric outcome such as negative, positive, or zero, represents either early, late, or on time finished project completion.

4.5.3 Contract Cost Change Growth

The contract cost change growth is another performance indicator that analyzes the change order impacts on a project schedule and cost growth. Since the margin of amount of cost and schedule changes can extremely vary on project size, however, each project will be grouped into three different project sizes (small, medium, and large) prior to applying the cost change growth performance indicator.

$$\text{Contract Cost Change Growth} = \frac{\textit{[contract change order amount (\$)]}}{\textit{[original contract amount (\$)]}}$$

$$\text{Contract Schedule Change Growth} = \frac{\textit{[contract change order extensions (number of days)]}}{\textit{[original contract time (number of days)]}}$$

The impacts of change order on entire project schedule and cost growth were identified by respectively conducting formulations for schedule and cost alteration.

4.6 Summary of Data Analysis

Throughout the process of data classification depicted above, corresponding discoveries of data analysis were found as the followings:

- 3R (3 Roadway projects – Resurfacing, Restoration, and Rehabilitation), Reconstruction, and New construction represented 64% of all amount invested by FDOT during the 9 years, from 2002 to 2011 (Figure 4.4).
- Conventional contracts were mostly composed of small sized projects (up to $10 million) which represent more than three forth (approximately 76.2%) of the overall projects. However, sum of medium and large sized projects of the

Innovative contracts approximately represented 69% of the total project portions (Table 4.2).

- Majority of A+B Bidding contracted projects were between $10 million and $50 million (Table 4.2 & Figure 4.2).
- According to the original project cost allotment, the projects involved with 3R took the largest portion of all infrastructure improvement projects (Figure 4.3).
- More percentage of overall 3R projects were delivered by the Innovative contracts.
- Although conventional projects represented almost the half (48%) of all contracting strategy adoptions, only 31% of all project costs were assigned to conventional project (Figure 4.5 and 4.6).
- No Excuse Bonuses and I/D contracts were the first two largest contract strategies sizes according to their original contract amount (Figure 4.7).

5. IMPACT OF INNOVATIVE CONTRACTS ON PROJECT SCHEDULE

5.1 Alternative Contracting Strategies

The ultimate goal of implementing innovative contracting methods is to promote accelerated project completion. In order to achieve the accelerated project completion, reduced cost in overall aspects, and assured safety and quality of project, majority of STAs searched for an innovative method (Transportation Research Board 2008). Throughout the national states of the U.S., innovative contracting techniques have broadly been implemented on various projects including infrastructure development projects since year 2000 (Minnesota Department of Transportation 2006). Just like large numbers of STAs has rapidly adopted alternative contracting methods, the effects of innovative contracting techniques in shortening construction time and reducing project costs were precisely verified.

Despite of the existing studies and findings about alternative contracting methods, further evaluations were mandatory to confirm the positive effects by analyzing the data collection of FDOT. Therefore, each innovatively contracted project was compared with traditionally contracted projects to meet the demand of qualified evaluations. To have a clear and bias free evaluation of project performance in schedule, a one-way ANOVA analysis was considered as a methodology, which was contemporarily used with post-hoc tests.

The purpose of the overall procedures is to form two types of evaluations:

1. Quantitative analysis: comparative statistical data analysis of each innovative

projects and conventional projects in influencing the actual project duration.

2. Quantitative evaluation: evaluation for advantages and disadvantages of each innovative contract implementation in shortening the project duration.

5.2 Effectiveness on Schedule of Project

In order to find out the impact of innovative contracting strategies differed from conventional, calculation for schedule change ratio was performed as shown in Table 5.1. The ultimate purpose of getting the schedule changing ratio is to examine early or late finish of project that were contracted by different types of method. In this case, the outcome with positive number represents completion of the project was delayed than original schedule, and negative means early finish. Since comparing different sizes of projects can cause biased results, as explained in part of above, the projects were sorted out to 3 different groups which are corresponding to the project sizes, small, medium, or large.

As it shown in the Table 5.1, each average of overall schedule change ratio had positive number and indicated that all the different contracts completed the projects later than originally scheduled. Since Florida is located in tropical area with extremely high amount of annual precipitation, there were more frequent chances to have change orders involved in weather issues. Despite the delayed completion date, however, there were few noteworthy results as the followings:

- Among the all contract types, I/D showed the best project performance in schedule, regardless of project sizes.
- Within the small sized projects, I/D projects were completed 3.7 times faster than

conventionally contracted projects, 8.5 times faster than Lane Rental, and 2.3 times earlier than No Excuse Bonuses.

- Other than Lane Rental, all types of contracts showed better schedule performance than conventional.

In addition to the schedule change ration for Lane Rental projects (Table 5.1), however, they had only 9 projects available for the entire projects, which was equivalent to 0.3% of total numbers (2,988) of projects. In other words, only those 9 projects represented all the ratios of lane rental projects, and the number was quite not enough to become an average. Due to the fact, only the lane rental projects showed higher rate than conventional. This condition may need to be applied to Liquidated Savings as well since it had only 21 projects, which is approximately 0.7% of the total portion of projects (Figure 4.6). Therefore, both lane rental and liquidated savings contracts should be assumed as an exception to avoid biased data.

Table 5.1 Average of Schedule Change Ratio versus Contract Types

SCHEDULE CHANGE RATIO (SCR)			
Type of Contract	SMALL SIZE	MEDIUM SIZE	LARGE SIZE
A+B Bidding	0.23	0.25	0.18
No Excuse Bonuses	0.13	0.06	0.11
Conventional	0.22	0.36	0.21
Design-Build	0.14	0.25	0.24
Incentive/Disincentive	0.06	0.06	0.08
Lane Rental	0.51	1.01	0.41
Liquidated Savings	0.16	0.13	0.01
Lump Sum	0.14	0.24	-

Unlike the Schedule Change Ratio which was calculated by using final contract time and original contract time, Amended Schedule Change Ratio that is, as shown in Table 5.2, utilized amended contract time instead original. Since the amended schedule change ratio reflects the time adjustments after contract change occurrences, the amended contract time is very an important source for analyzing how the schedule of each contracts appropriately adapts to the newly changed circumstances.

The result of the amended schedule change ratio implies that I/D projects in medium size again performed the best in aspect of schedule control. Among the small and large sized projects, Liquidated Savings showed the best performances. However, as it mentioned earlier, the liquidated savings projects are not a reliable due to their comparatively and significantly less numbers of projects.

Table 5.2 Average of Amended Schedule Change Ratio versus Contract Types

AMENDED SCHEDULE CHANGE RATIO (SCR)			
Type of Contract	SMALL SIZE	MEDIUM SIZE	LARGE SIZE
A+B Bidding	-0.05	-0.06	-0.06
No Excuse Bonuses	-0.07	-0.09	-0.02
Conventional	-0.04	0.05	-0.02
Design-Build	-0.04	0.00	-0.02
Incentive/Disincentive	-0.12	-0.11	-0.06
Lane Rental	0.03	0.03	0.00
Liquidated Savings	-0.13	-0.01	-0.10
Lump Sum	-0.07	-0.05	0.00

Figure 5.1 depicts how each contracts responded to change orders. Throughout the bar graph, it shows that I/D projects were completed average of only 7% behind the

original schedule, while almost of other contract projects floundered with highly overdue project completion. For instance, conventional, Design-Build, and A+B Bidding projects respectively experienced the construction time growth by 26%, 21%, and 22%. Such tendencies of schedule performance, however, continued to amended contract time as well. While I/D projects were shortening the project duration by 10%, other contracts such as conventional, D/B, and Lump Sum ended up compressing the project time by below 5% (Figure 5.1).

This quantitative analysis implies the excellence of I/D and deficiency of conventional contracts in schedule performance. Within the most investigation, I/D projects showed up to 73% better schedule performances than other types of contract in adapting to any change order and mitigating corresponding impacts. On the other hand, however, all other innovative contracting strategies showed better performance than conventional at least 15.3%.

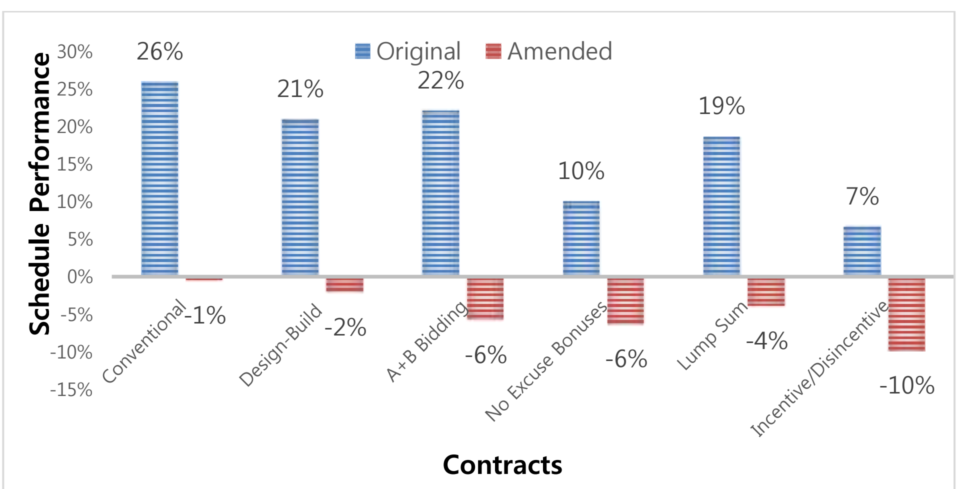

Figure 5.1 Schedule Performance Ratios versus Contracts

Figure 5.2 shows schedule performance ratios of each contracts depicted in box plots. And Table 5.3 lists numbers of corresponding quartiles of the contracts. Throughout these two types of informative forms, 5 divisional numbers can be found, which are minimum, lower quartile (25%), median (50%), upper quartile (75%), and maximum .

The lines in the middle of each box plot represent the median of Schedule performance ratio (Figure 5.2). This median of box plots, however, showed the same tendency of what were found in previous section via averages of (amended) schedule change ratio and schedule performance shown in Table 5.1 and 5.2 and Figure 5.1. According to the analysis on the median, I/D showed the best performance in schedule control. Moreover, the distribution of I/D's the each schedule performance rates showed a center concentrated form with minimal deviation. On the other hand, conventional contracts showed excessive variances in the distribution of overall projects for both original and amended schedule performance ratios. The deviation between maximum and minimum original schedule performance ratios was 5.2 and 3.78 for amended.

As shown in the Figure 5.2 and Table 5.3, conventional contracts had the largest number of outlier projects. Since the outlier projects are commonly critical factors influencing the result of the schedule performance, further steps are necessary to testify the research hypothesis. To develop the research quality and verify the study result precision, a one-way ANOVA analysis was conducted in diverse phases, which can be found at the end of this section.

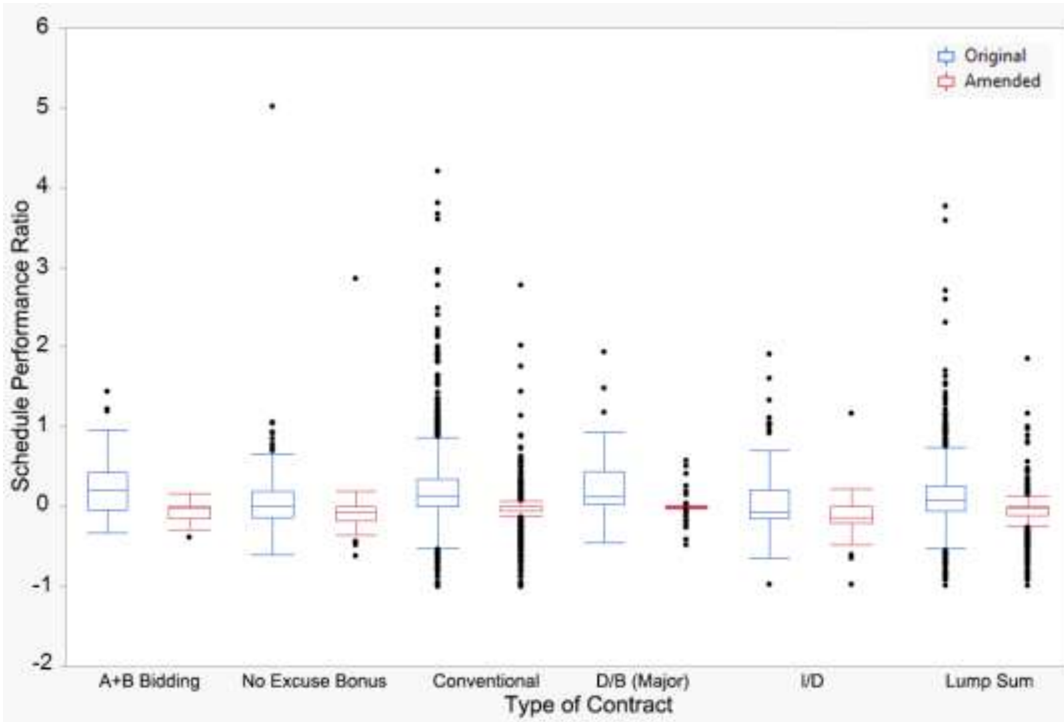

Figure 5.2 Schedule Performance Box Plots versus Contracts

Table 5.3 Quantiles of Contracts

Quantiles										
Level	Minimum		25%		Median		75%		Maximum	
	Ori	Ame	Ori	Ame	Ori	Ame	Ori	Ame	Ori	Ame
A+B BIDDING	-0.3	-0.4	-0.1	-0.2	0.2	-0.1	0.4	0	1.4	0.2
NO EXCUSE BONUS	-0.6	-0.6	-0.1	-0.2	0.1	-0.1	0.2	0	5.0	2.9
CONVENT.	-1	-1	0	-0.1	0.1	0	0.4	0	4.2	2.8
D/B (Major)	-0.5	-0.5	0.1	-0.1	0.1	0	0.5	0	2.0	0.6
INCENTIVE/ DISINCENTIVE	-1.0	-1.0	-0.2	-0.2	-0.1	-0.1	0.2	0	1.9	1.2
LUMP SUM	-1.0	-1.0	-0.1	-0.1	0.1	-0.1	0.3	0	5.3	1.9

5.3 Schedule Performance versus Project Type

Depending on each type of project, the schedule performance of both conventional and innovative contracting methods can vary. Therefore, more and deeper research was conducted to examine how the contracts effectively impacted on schedule performance on different project types.

5.3.1 3R Projects

3R projects are mostly involved with roadway maintenance and construction, which include resurfacing, reconstruction, and rehabilitation. During the 9-year period, 3R projects took the largest part of the overall project allocations that were 46% of all project establishments and 41% of all project cost allotments. Such great portion means that development and recondition of the existing roadway instead of reconstruction were turned into the major tendency for the highway projects in Florida.

Figure 5.3 shows the average schedule performance of each contract that was implemented for the overall 3R projects between 2002 and 2011. The overall outcome was slightly different with the result shown in Figure 5.1. I/D projects overran only 3% behind the original schedule while conventional projects were 28% overdue for originally scheduled completion. After the original schedule was amended, the conventional projects shortened the project completion but failed to complete the project prior to meeting its deadline. It is worthy enough to note that all innovative contracting methods successfully reduced 3R projects to finish the project earlier. In addition to the impacts on schedule performance, all contracts, except conventional, completed the projects from 5% to 9% sooner than their original completion date.

Throughout the research based analysis, the findings were identified as the followings:

- Among the overall 3R projects completed between 2002 and 2011, conventional contracting method (28%) had the highest amount of schedule overruns while I/D contract (3%) had the least (Figure 5.3).
- Among the all contract types, I/D was the only the contract which had a single digit numbered percentage in project overrun ratio.
- Conventional projects had the highest standard deviation with largest number of outlier projects (Figure 5.4)
- I/D projects had lowest median in schedule performance ratio for both original and amended schedule (Figure 5.4).

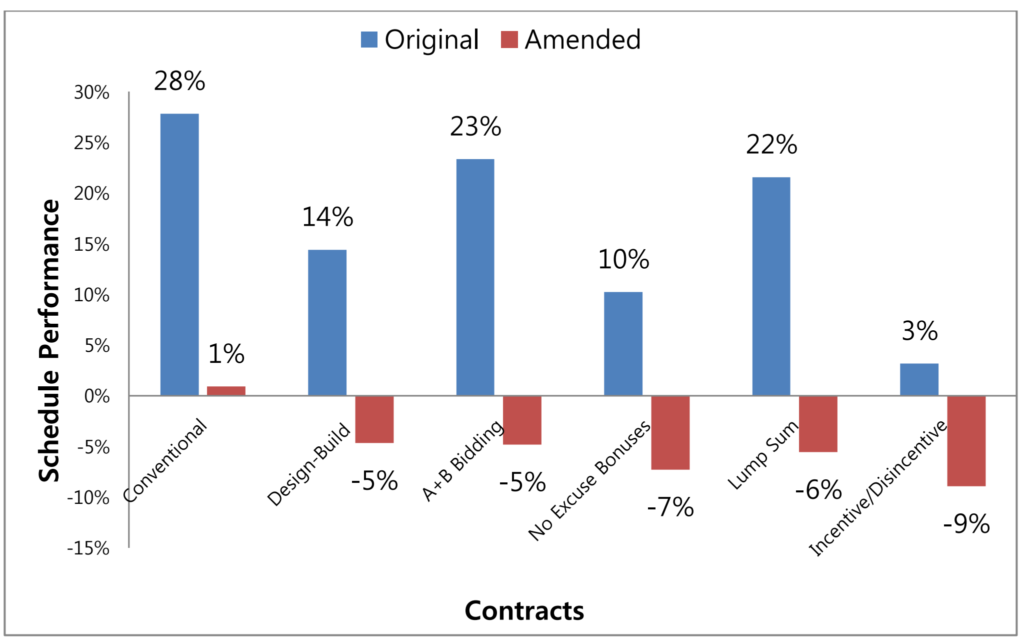

Figure 5.3 Schedule Performance Ratios of 3R versus Contracts

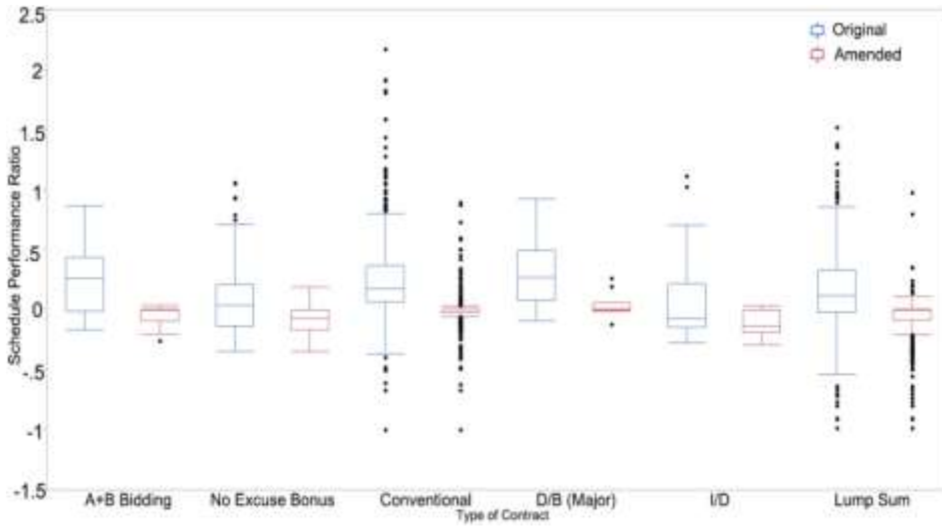

Figure 5.4 Schedule Performance Box Plots of 3R versus Contracts

5.3.2 Capacity-added Projects

The research involved with capacity-added projects on schedule performance ratio of each contracting methods (Figure 5.5) and corresponding box plots (Figure 5.6) are shown as below.

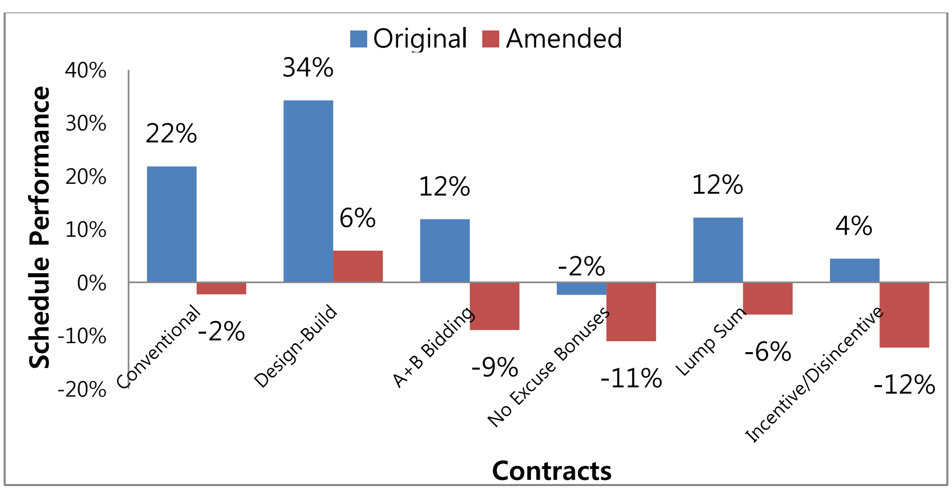

Figure 5.5 Schedule Performance Ratios of Capacity-added versus Contracts

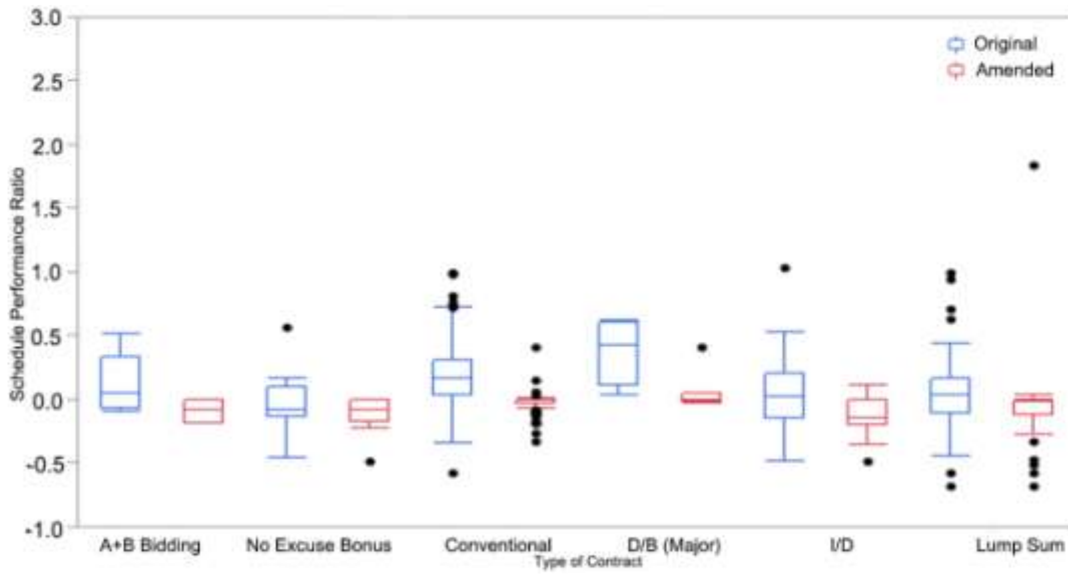

Figure 5.6 Schedule Performance Box Plots of Capacity-added versus Contracts

5.3.3 New Construction Projects

New construction projects took the second largest portion of the overall projects, which was approximately 7% of all project establishments and 12% of all project cost allotments. Due to the tendency of developing and repairing the existing roadways, the new construction project proportion had comparatively small quantity of the overall project allotment.

Analyzing new construction data for average of schedule performance ratio revealed that I/D projects had only 2% schedule overrun, while 36% of conventional projects were completed later of schedule as shown in Figure 5.7. Just similar to other results found in previous data analysis of schedule performance ratios, conventional projects again showed the dullest performance in schedule control aspect. Although the most innovative contracting methods successfully adapted to amended schedule and effectively performed excellent work in completing projects ahead the schedule, conventional again failed to meet the schedule.

The value outlier (3.67) with the largest numerical deviation was found among the conventional projects (Figure 5.8). Furthermore, conventional projects had comparatively a lot more outliers than the rest of contract types.

Findings associated with this analysis on the new construction projects were identified as the followings:

- On the new construction projects, A+B projects showed a significant improvement in original and amended schedule performances, when it was compared to 3R projects. A+B contract had 23% of schedule overrun for the 3R projects and only 11% for the new construction projects (Figure 5.7).
- The longest schedule overrun project with schedule performance ratio of 3.67 was found among the conventional projects.
- I/D projects showed a remarkable time saving impact based on amended contract time, which completed 23% earlier than the schedule.
- Conventional projects had a considerable problem with schedule performance such as delay.

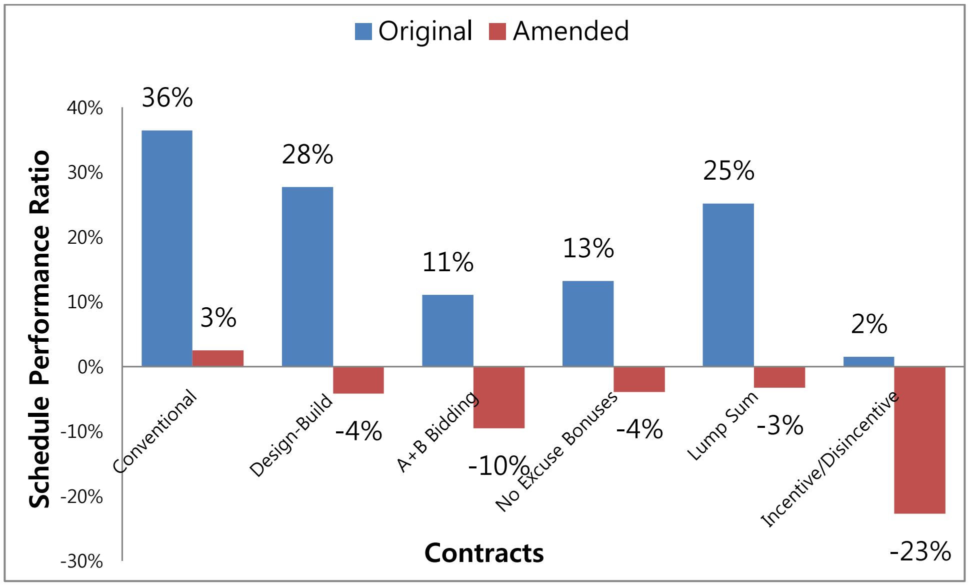

Figure 5.7 Schedule Performance Ratios of New Const. versus Contracts

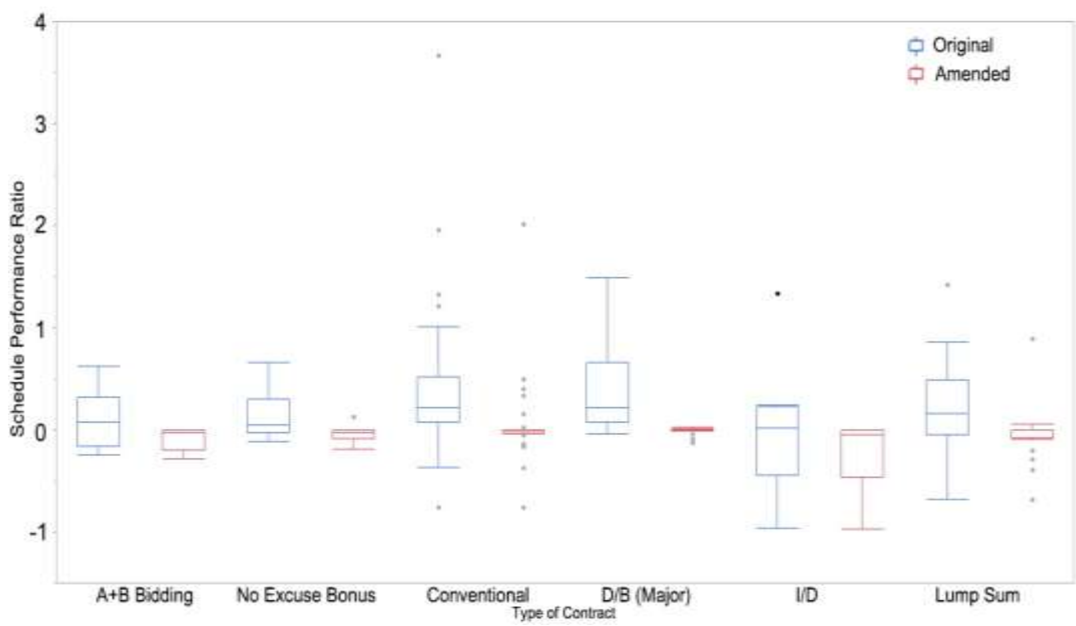

Figure 5.8 Schedule Performance Box Plots of New Const. versus Contracts

5.3.4 Bridge Construction Projects

The research involved with bridge projects on schedule performance ratio of each contracting methods (Figure 5.9) and corresponding box plots (Figure 5.10) are shown as below.

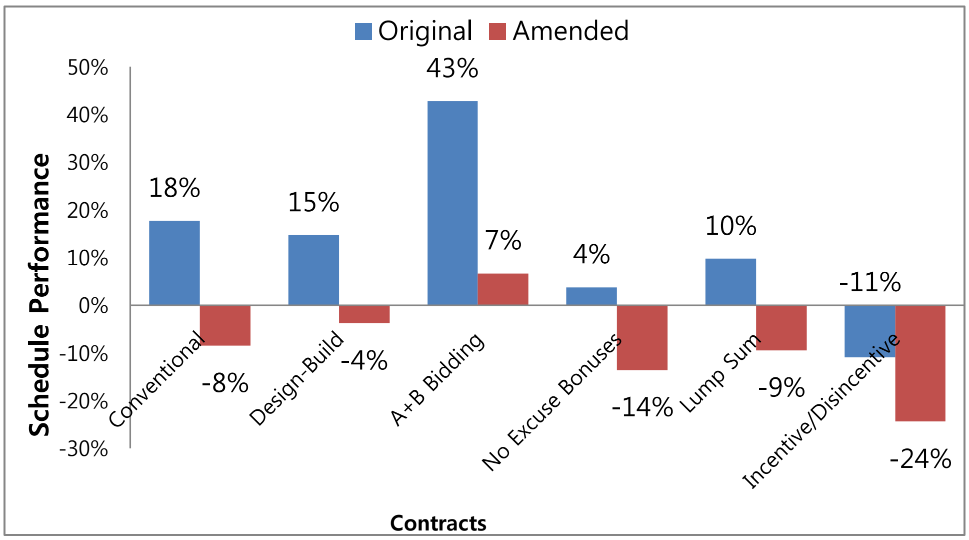

Figure 5.9 Schedule Performance Ratios of Bridge Const. versus Contracts

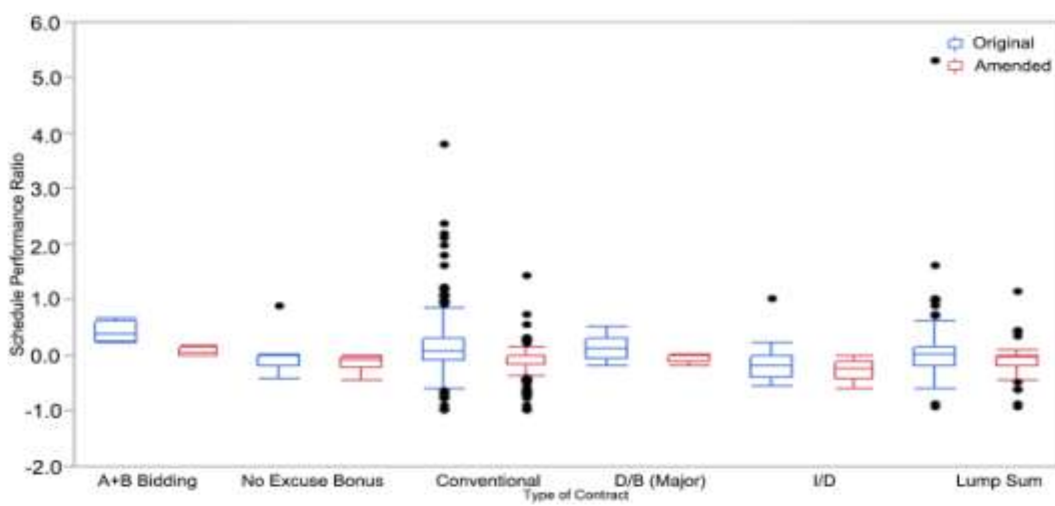

Figure 5.10 Schedule Performance Box Plots of Bridge Const. versus Contracts

5.3.5 Other Projects

A group of other projects is commonly composed of some minor and low budgeted projects such as drainage improvements, electrical upgrades, minor landscape improvement, barrier installations, etc. This type of projects represents 22% of all project establishments and 13% of all project cost allotments. Due to the reason that the low budgeted projects were mostly involved with the group of other projects, cost allotments were a bit more than only half of its project establishment.

Like the previous analysis, I/D projects showed the project schedule compression with an outstanding schedule performance. However, A+B projects considerably had the highest delay in schedule performance ratio followed by conventional projects. According to Figure 5.11 and 5.12, A+B projects did not meet their scheduled deadline but had schedule overrun by 31%. This ratio was remarkably higher than other contract types that were from 8% to 20%.

The findings emerged from the analysis of other projects are as the followings:

- I/D projects showed the most outstanding reduction in project duration among the all contract types.
- A+B projects had the highest delay ratio in analysis of schedule performance ratio for other projects.
- The highest degree of schedule performance ratio’s decentralization was identified on conventional projects followed by lump sum projects.

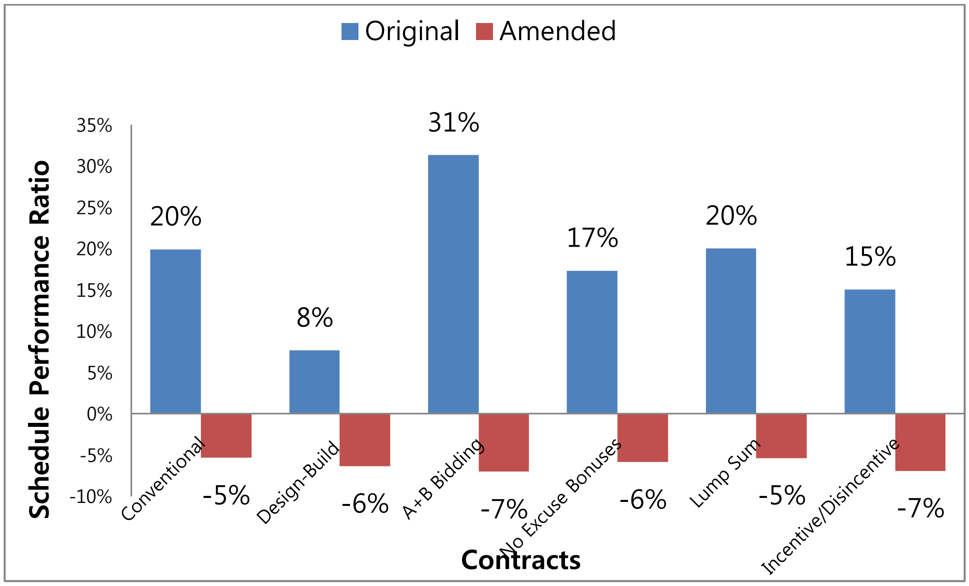

Figure 5.11 Schedule Performance Ratios of Other Projects versus Contracts

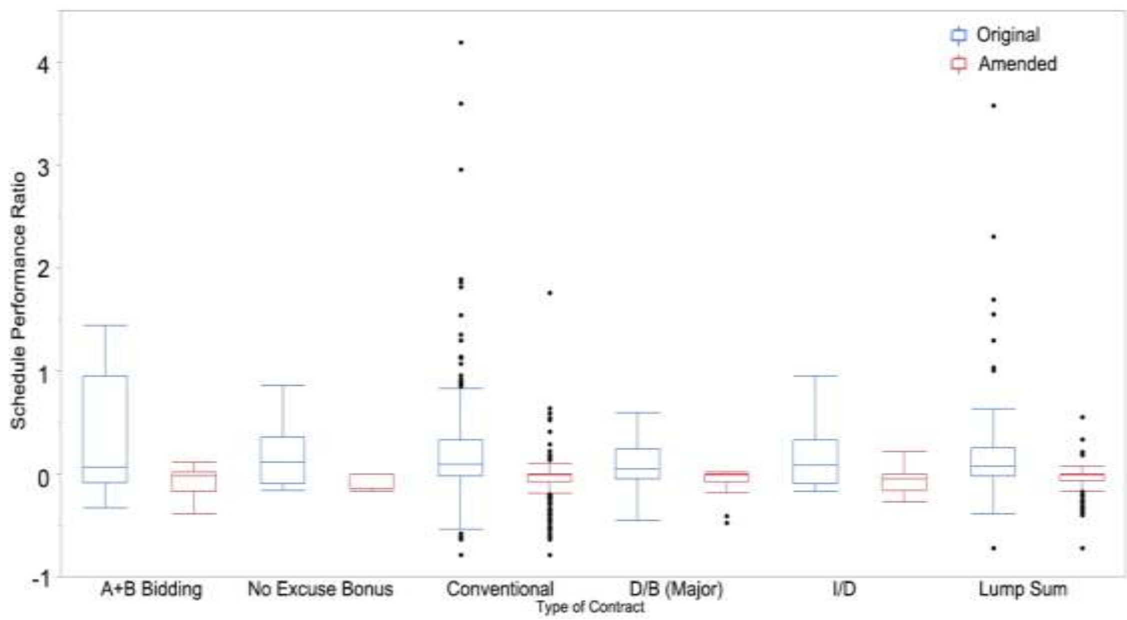

Figure 5.12 Schedule Performance Box Plots of Other Projects versus Contracts

5.4 Research Hypothesis Test

5.4.1 Setting Research Hypothesis

The quantitative analysis of Schedule performance ratio indicated two things:

1. Innovative contracting strategies effectively performed better for project performance in schedule.
2. I/D projects were the most effective among the all contracting strategies in accelerating the project completion.

In order to substantiate the findings, a one-way ANOVA analysis was conducted. The implementation of the analysis enabled the test on the research hypotheses that are listed as followings:

- I/D contracting is a critical method that shortens project schedules.
- I/D contracting is the most effective method that accelerates project completions among the all contracting methods.
- The innovative contracting methods significantly reduces project durations below the levels performed by the conventional methods.

5.4.2 Checking Research Assumptions before Testing

The variance for one-way analysis can be qualified only if there are any significant differences identified between three or more independent groups with no relation (Laerd Statistics 2013). To conduct a qualified one-way ANOVA analysis, independence of each project, variance homogeneity, and normality must be satisfied for the following reasons:

- To verify that each group of homogeneous contracting project have the same variances;
- To confirm the normal distribution of the test variable; and
- To test the normal distribution on the test variance.

To test normal distribution of the data, quantile-quantile plot (Q-Q plots) was primarily implemented, which is commonly used by statisticians. A statistics software producing company called Analyse-it (2013) stated that the data with the ideal normal distribution would form a straight line by connecting dots or points.

Lastly the independence of projects can be assumed by making sure that there was not any correlation between the projects. Even if some projects were delivered by the same material and construction process, the projects can never get correlated due to different location and time. It means that each project is given different externalities, such as site condition, weather, etc., that affect the overall project completions. The research assumption check is available below.

5.4.3 Interpretation of Test Results

In order to analyze the test results, Table 5.4 provides a brief summary of schedule performance for each contract type. According to the table, I/D has the lowest number for mean and standard deviation. In other words, I/D projects were accomplished ahead schedule and have the lowest variability in schedule performance.

Table 5.4 Summary of Average Schedule Performances

Type of Contracts	Number	Mean	St. Devi.	Std. Error	Lower 95%	Up. 95%
A+B	83	0.238147	0.363774	0.04971	0.1407	0.33561
No Excuse Bonus	126	0.111307	0.536987	0.04034	0.0322	0.19041
Conventional	1442	0.224223	0.463719	0.01193	0.2008	0.24761
D/B	81	0.246721	0.37535	0.05032	0.1481	0.34538
I/D	212	0.056948	0.32225	0.0311	-0.004	0.11793
Lump Sum	884	0.139603	0.455277	0.01523	0.1097	0.16947

5.5 Summary of Impact of Innovative Contracting Methods on Schedule

Major goal for this section was to examine the schedule change ratio of each contract, and investigate the innovative contacting methods are really effective in schedule performance. Based on the quantitative analysis and study, the overall alternative contracts showed better performance in schedule control than conventional. A+B contract, however, had the highest delay ratio for small size projects that were belong to a group of other. Such phenomenon can be inferred that small projects with low cost incentives are not attractive to contractors. Therefore, schedule compression would not have been effectively done through the project procedures.

6. IMPLICATION OF CHANGE ORDERS AND OCCURRENCE TIMING

6.1 Change Order and Timing

Unforeseen change orders commonly occur in the most construction projects. Therefore, the contingency funds are often prepared to backup the unforeseen change orders. The reserved amount for contingency refers to the money retained for payment of mandatory and change order occurrence after award of construction contract (Chen and Francis 2000). Many studies have put efforts in finding and providing innovative method to estimate the amount for contingency funding (Cook 2006). Despite of such various research efforts, yet no significant predictive model for contingency amount is developed. Therefore, assigning the money to deal with contingency is based solely on experience and intuition (Zayed et al. 2009). In other words, the contingency amount is measured upon the expectation of frequencies of change order occurrence.

The purpose of the overall procedures within this section is to form two types of evaluations:

1. Comparative analysis: respective comparisons of each different type of delivery and contracting methods in contingency amount allocation; and
2. Quantitative evaluation: correlation of the contingency amount with schedule and cost performances of each delivery and contracting methods.

6.2 Phase I: Project Delivery Comparison

Since large portion of change orders are not predictable, there are only few considerable factors to estimate the contingency amount of each project. In this research, two things were considered as the major factors, which are Schedule Impact of Change (SIC) and Cost Impact of Change (CIC) of change orders.

The study in this section examines how much contingency amount were allocated for each delivery method and finds correlation of the contingency amount with final cost and schedule changes. Based on the research hypothesis, relatively more schedule and cost overruns are expected for the projects, which had a large amount of contingency allocation.

6.2.1 Impact of Change Order on Schedule for Delivery Method

In terms of avoidable time percent, it refers to the total days extended from the original contract days for all contract changes. Those extended durations of projects, which could have been evitable, were expressed as a percentage of the original contract amount. The equation for calculating the SIC of original days is as the following:

$$\text{SIC} = \frac{\textit{(days added due to change orders)}}{\textit{(original days)}}$$

Figure 6.1 shows the SIC ratio of overall projects. As shown below, average of more than 22% of conventional projects had overrun days, which could have been evitable, while D/B projects had only 15%. In other words, the conventional comparatively had more impacts in schedule from the change order and had higher ratio of schedule overrun consequently. The SIC ratio of each project type did not show much difference with the result of overall projects. The range of SIC ratio for conventional projects was between 0.18 to 0.36 and 0.8 to 0.28 for D/B projects. The new construction project had the highest SIC ratio for both conventional (0.36) and D/B

(0.28). The reason of more days added on both delivery types is that the new construction are more impacted by change orders compared to rest type of projects. The deviation of the new construction projects, furthermore, showed higher portion of variances despite of relatively less number of projects.

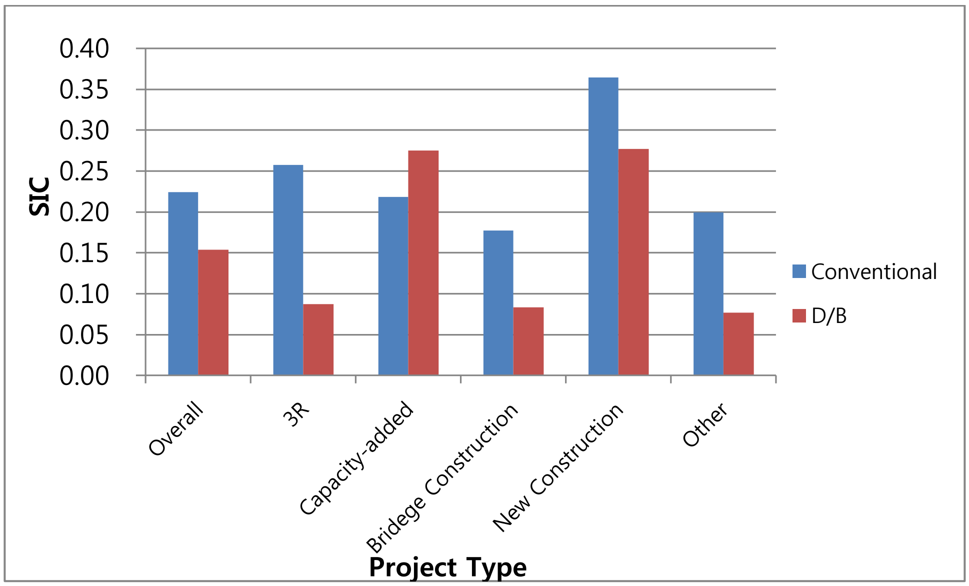

Figure 6.1 SIC Ratios of Construction Projects versus Delivery Projects

To see if D/B projects were more effective in shortening the duration of projects, box plot of schedule performance ratio for overall project types was formed as shown Figure 6.1. According to the box plot results (Figure 6.2), D/B projects had significantly lower ratio in median (-1.54) than the median (-1.42) for conventional projects. Therefore, it suggests that D/B delivery method is more critical in reducing project time.

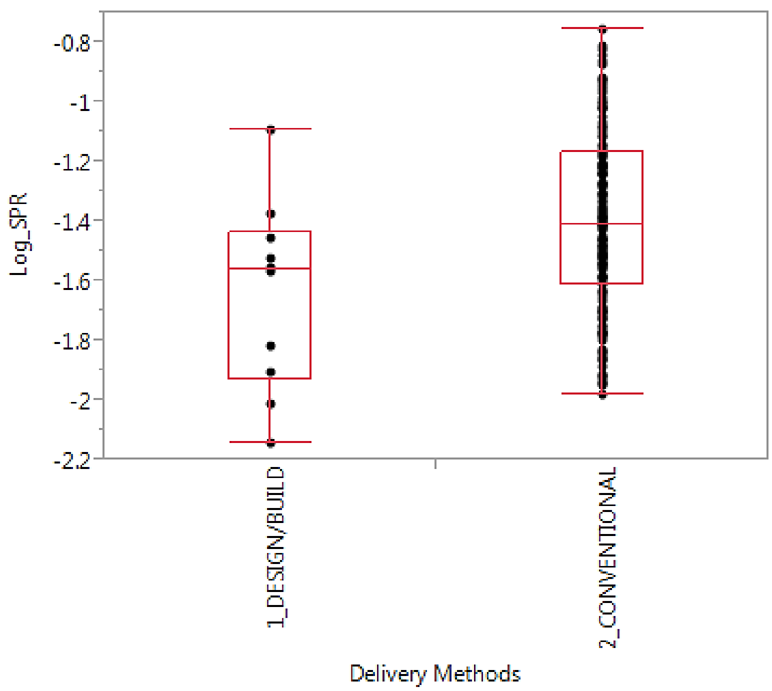

Figure 6.2 Box Plots of Schedule Performance Ratio on Overall Projects

To perform a further exploration, t-test was conducted and analyzed as a part of research progress. As shown in the Table 6.1, it was conducted to assume if conventional delivery method was more effective in schedule control. Since both probabilities (Prob > |t| and Prob > t) were lower than 5%, while reversed probability (Prob < t) was more than 95%, the t-test revealed that D/B method performed better than conventional to reduce project duration.

Table 6.1 Schedule Performance Ratio Check

t-Test			
Conventional - D/B			
Assuming unequal variances			
Difference	0.243573	t Ratio	2.352291
Std Err Dif	0.103547	DF	9.871232
Upper CL Dif	0.474699	Prob > ltl	0.0408*
Lower CL Dif	0.012447	Prob < t	0.0204*
Confidence	0.95	Prob > t	0.9796

6.2.2 Impact of Change Order on Cost for Delivery Method

The CIC of change orders represents a rough estimation to predict impact of change order on project performance in cost aspect. The equation for calculating the CIC of change orders is as the following:

$$\text{CIC (\$)} = \frac{\textit{(dollar amount of change orders)}}{\textit{(adjusted original amount)}}$$

Comparing to conventional projects, D/B project had lower amount in the ratio for CIC. As shown in Figure 6.3, average of the overall D/B projects were 0.401 while conventional projects had 0.527 for the ratio. As shown in the result, the conventional projects had 31% more increase in project cost compared to the conventional projects. This analysis showed that the D/B projects were less affected by change order in cost than conventional. Even in the box plot analysis in Figure 6.4, D/B projects had lower mean and less standard deviation. While the range of conventional projects was placed between 0.01 and 0.38, D/B projects had the range between 0.01 and 0.33. The conventional projects had not only wider range in data set but also more number of outliers.

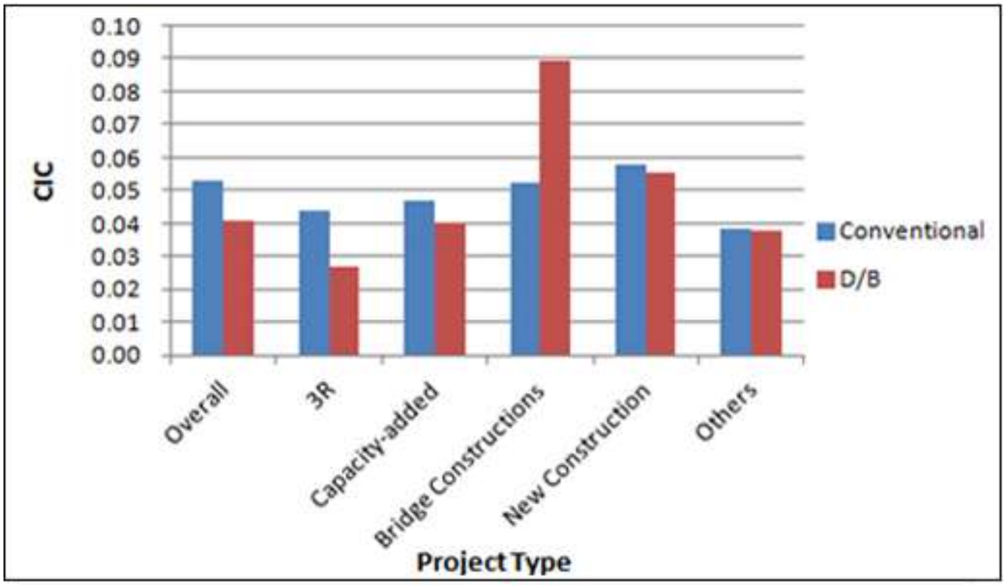

Figure 6.3 CIC Ratios versus Project Types

Major types of infrastructure projects showed a similar trend in CIC ratios with the analysis of overall projects. Most of conventional projects, except bridge projects, had the higher number in CIC, statistical range, and outlier. Unlike other infrastructure projects, such as 3R - road projects, new construction, and other, the bridge projects that was completed with D/B delivery method had 0.0896 for ratio of CIC, while conventional had only 0.0524. In other words, D/B projects had 71% more in the ratio of CIC than conventional.

In many cases, however, bridge projects are associated with emergency program that is required to complete the projects promptly as possible. Since bride is what connecting place to place and preventing a place from isolation, bridge project requires the fastest project delivery method to accelerate project completion and saving cost consecutively. As the matter of fact, D/B is the ideal delivery method for bridge projects.

Despite the fact, however, FDOT implemented D/B delivery method only 20 times for the bridge projects, while 217 bridge projects were delivered by conventional delivery method. Furthermore, 14 out of 20 bridge projects with D/B delivery method were delivered lately between 2008 and 2011 even though conventional method was actively implemented from 2002 to 2011.

To check both mean and median costs of overall conventional and D/B projects, box plots of cost performance ratio for overall project types were formed as shown in Figure 6.4. And it showed that D/B projects had significantly lower median with less variances compared to conventional. In other words, D/B projects were completed with relatively lower cost impacts from change orders.

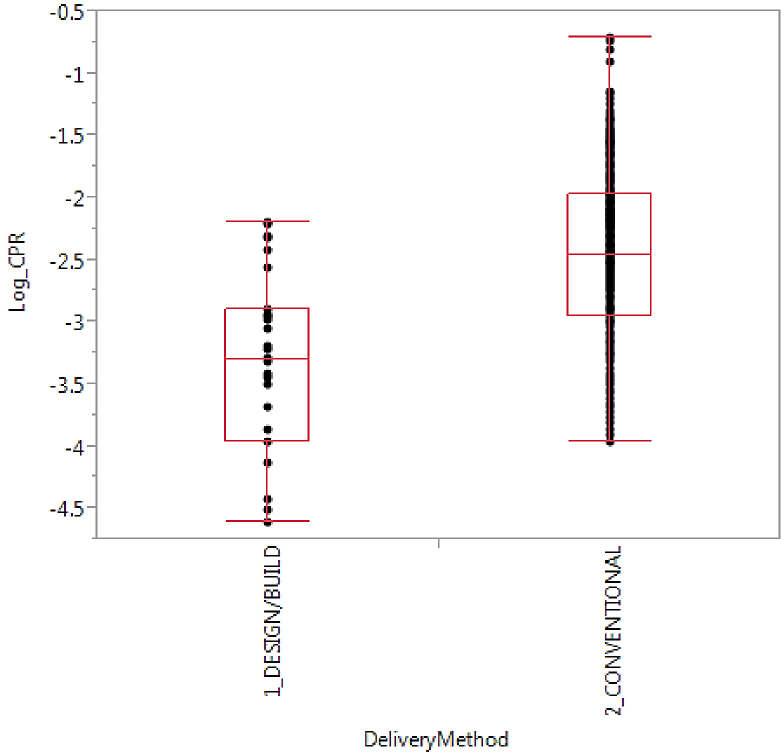

Figure 6.4 Box Plots of Overall Project CPR versus Delivery Types

The t-test was implemented as below (Table 6.2) to verify the findings and analysis regarding project costs. The result was pretty much the same as the t-test conducted previously. According to the t-test result, the assumption insisting that conventional was more effective in saving project costs was an erroneous supposition. On the other hand, however, D/B was more effective in reducing project costs.

Table 6.2 Cost Performance Ratio Check

t-Test			
Conventional - D/B			
Assuming unequal variances			
Difference	0.87187	t Ratio	6.532627
Std Err Dif	0.13346	DF	33.34541
Upper CL Dif	1.1433	Prob > ltl	<.0001*
Lower CL Dif	0.60044	Prob < t	<.0001*
Confidence	0.95	Prob > t	1.0000

6.2.3 Occurrence, Timing, and Implication of Delivering Change Order

Figure 6.5 depicted the frequency of change order versus each delivery method's timing in a quarter terms. In addition to the quarter terms, smaller number quarter represents that the change order occurred in early stage and larger number for late change order timing. The trend showed that both conventional and D/B projects had more than 60% of change orders behind the half portion of project completion.

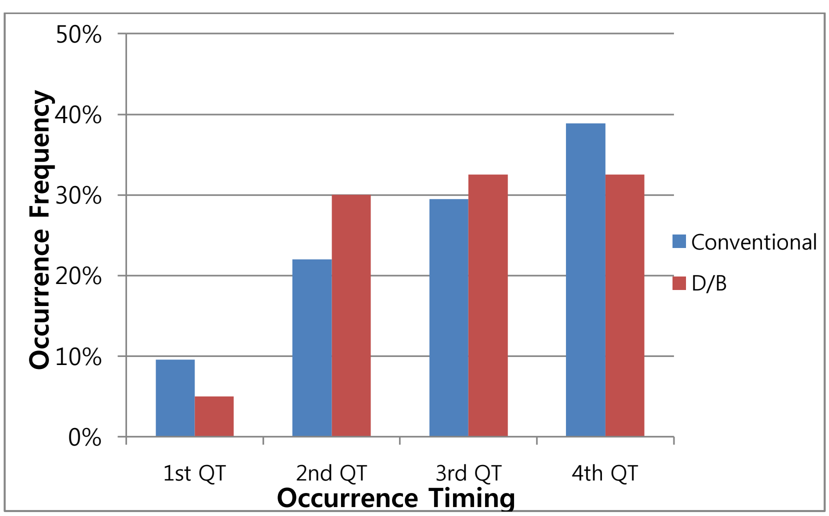

Figure 6.5 Change Order Frequency versus Timing of Delivery Methods

Timing of change order occurrences is another critical factor that causes impact on project performances in schedule and cost specifically. It is commonly known that lately occurred change orders cause more negative impacts to project cost as much as closing to the project completion date. Prior examine and study more about the relationship of change order occurrence and timing with project performances in cost, the data was set by finding each project's maximum change order amount and its corresponding change order timing. Thereby, the most critical timing in aspect of cost growth for each project was clearly identified.

6.3 Phase II: Project Contracting Comparison

6.3.1 Impact of Change Order on Schedule for Contracting Method

According to the quantitative analysis, shown in Figure 6.6, A+B projects had the largest SIC ratio (0.24), while the mean of those 4 innovative contracting methods was 0.138 and 0.11 for mean. The ratio of A+B project was approximately 4 times bigger than I/D project, which was the lowest SIC ratio (0.06). The result on SIC ratio revealed that I/D contracting method had an excellent control in reducing the unnecessary time wastes caused by change orders. On the other hand, A+B showed the worst schedule control on change orders among the all contracting methods.

Lump sum projects had the widest range from -0.98 to 5.33 with a significant number of outliers, while A+B had a range between -0.33 and 1.44 (Figure 6.7). The highest mean was identified in A+B (0.24) and I/D for the lowest mean value.

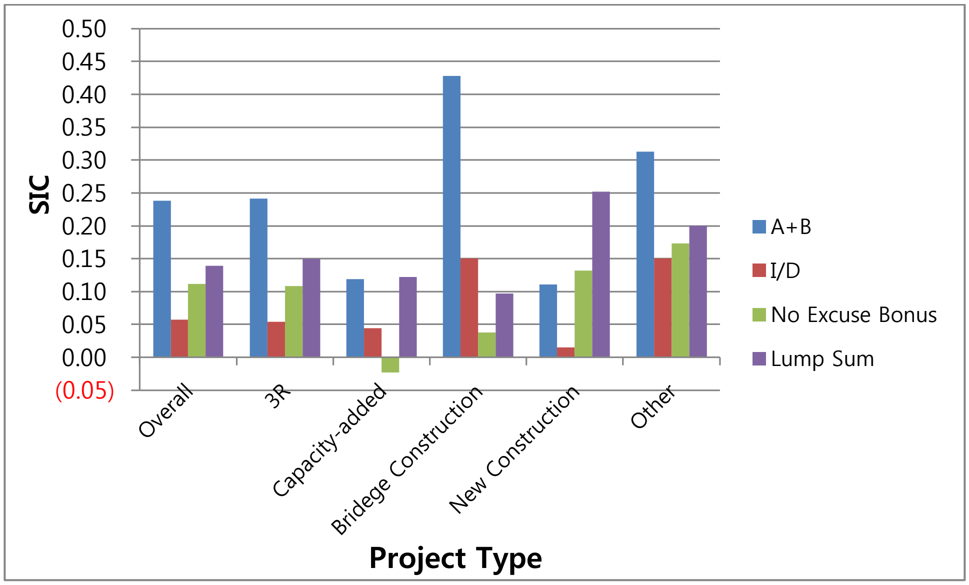

Figure 6.6 SIC Ratios versus Project Types

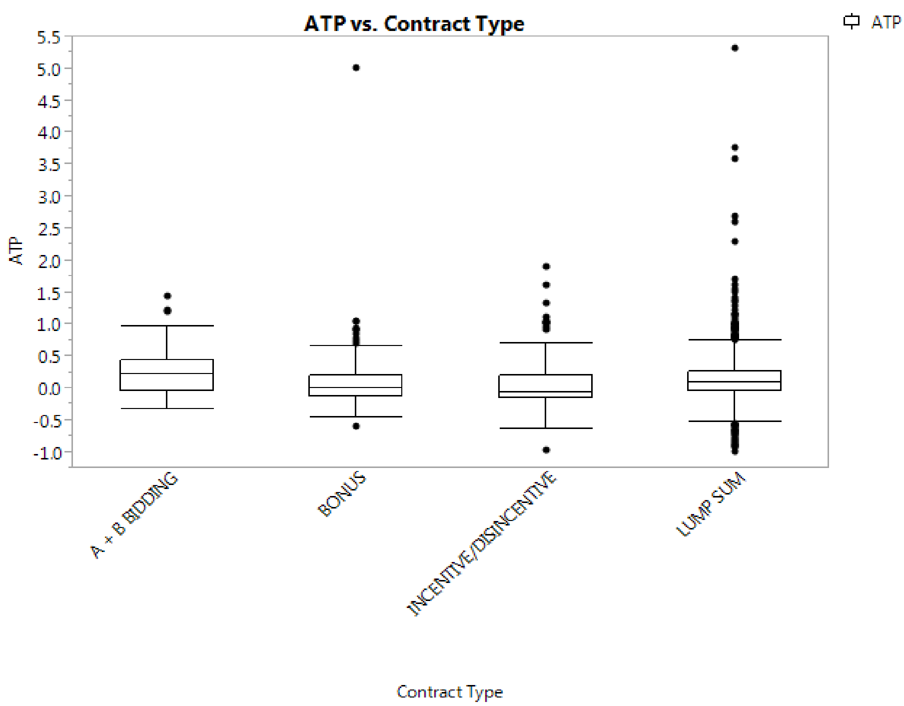

Figure 6.7 Box Plots of SIC versus Contract Types

3R and other type of projects had a similar trend with the SIC ratio of overall projects (Figure 6.6). Bridge and new construction projects, however, showed some impressive distinction that differs from other types of projects. The SIC ratio of the bridge projects associated with I/D contract was only 0.001 (or 0.1%) and 0.02 (or 2%) for new construction. Such lower SIC ratio of I/D contract, however, does not mean its excellence in controlling schedule.

As mentioned earlier, bridge projects are commonly considered as an emergency project that is required to be delivered as promptly as possible. According to Choi (2008), I/D bridge projects had a severe tradeoff between construction time and cost due to urgent needs to complete the projects as soon as possible. Moreover, I/D contracts often led bridge projects to severe cost growth for reducing project duration. Therefore, lump sum contract is more seriously considered for the major bridge projects instead of I/D or other contracting types. In fact, there were only 14 cases of I/D contracts associated with bridge projects, while lump sum contracts had 84 times.

6.3.2 Impact of Change Order on Cost for Contracting Method

As shown in Figure 6.8, lump sum had the lowest average of CIC (0.027), while no excuse bonus (0.052) had the highest CIC followed by A+B (0.05). According to the box plots (Figure 6.9) of the all contract types, lump sum contracts had the highest outliers that were 1.0 and 0.998, and without those two outliers, however, the average of SIC ratio even drops down to 0.023.

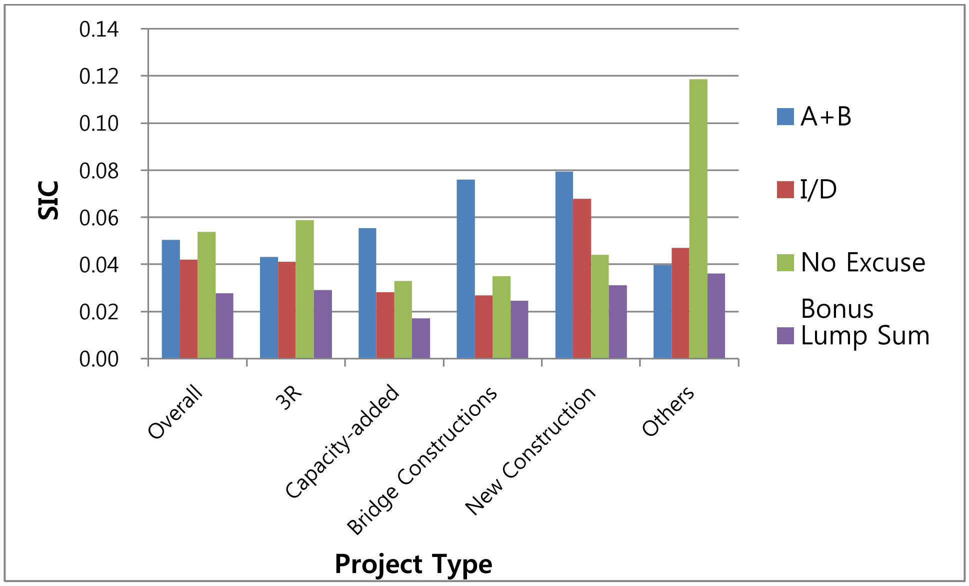

Figure 6.8 CIC of Overall Project versus Contract Types

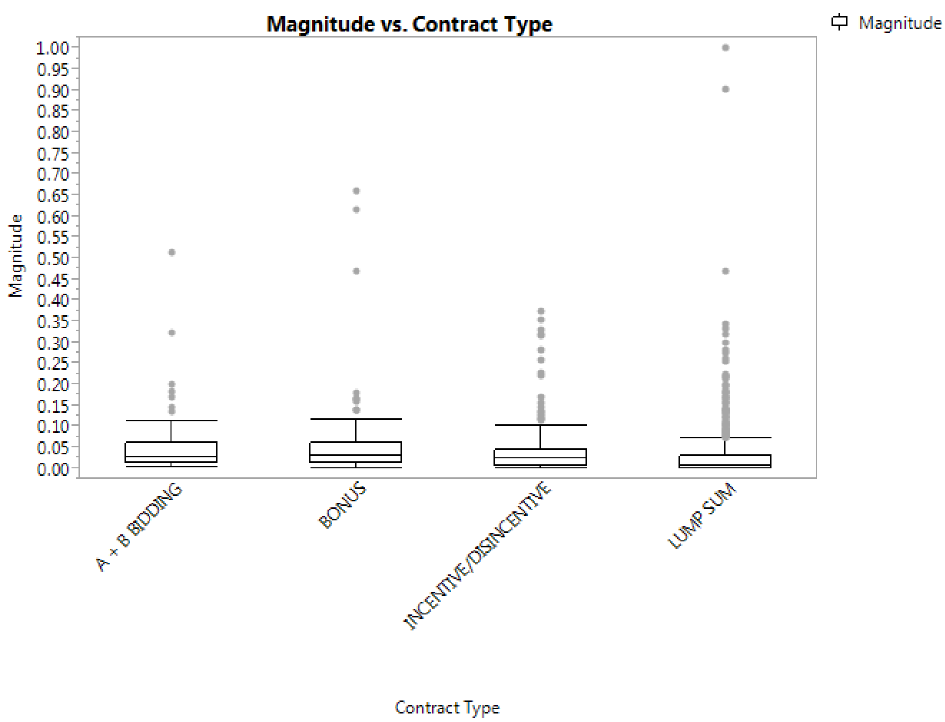

Figure 6.9 CIC Box Plots of Overall Projects versus Contract Types

6.3.3 Occurrence, Timing, and Implication of Contracting Change Order

The timing of change order frequency showed the same trend of the delivery methods (Figure 6.10). As the projects getting closer to completion, the frequency of change orders increased, and more than 70% of change orders occurred after the end of second quarter term.

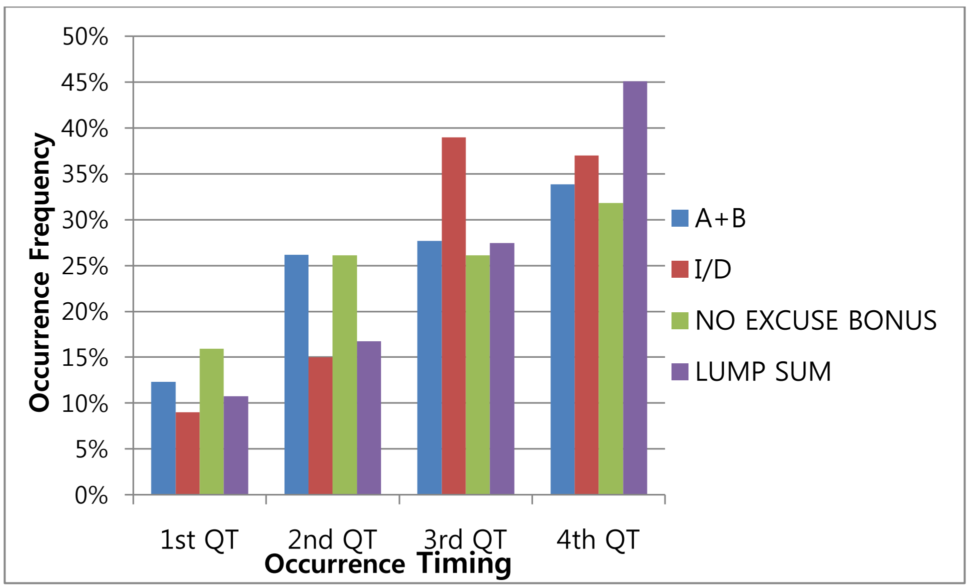

Figure 6.10 Change Order Frequencies versus Timing of Delivery Methods

6.4 Research Hypothesis Verification

6.4.1 Design of Research Hypothesis

Based on the analysis conducted in this section, the result of the analysis revealed three things as the followings:

1. Innovative delivery method, D/B, were more effective than conventional in reducing construction time and project cost.

2. Among the all contracting methods, I/D projects were more effective than other contracting projects in accelerating project completion.
3. A+B had the least ratio for cost overrun and contingency amount allotment but did not show any better schedule performance.

As the same as prior research case, a one-way ANOVA analysis was conducted to test the following research hypotheses:

- Contingency amount of both delivery and contract methods, except lump sum, is correlated with project cost and schedule.

6.4.2 Verification for Assumptions

6.4.2.1 Delivery Methods versus Schedule

To test the variation of assumptions, Q-Q plot was primarily conducted to test normality of the data. The first trial of the normality test, however, did not satisfy the test expectation and came and revealed that the data was not normally distributed (Figure 6.11). Therefore, log transformation was applied to the data in order to examine the data distribution wisely.

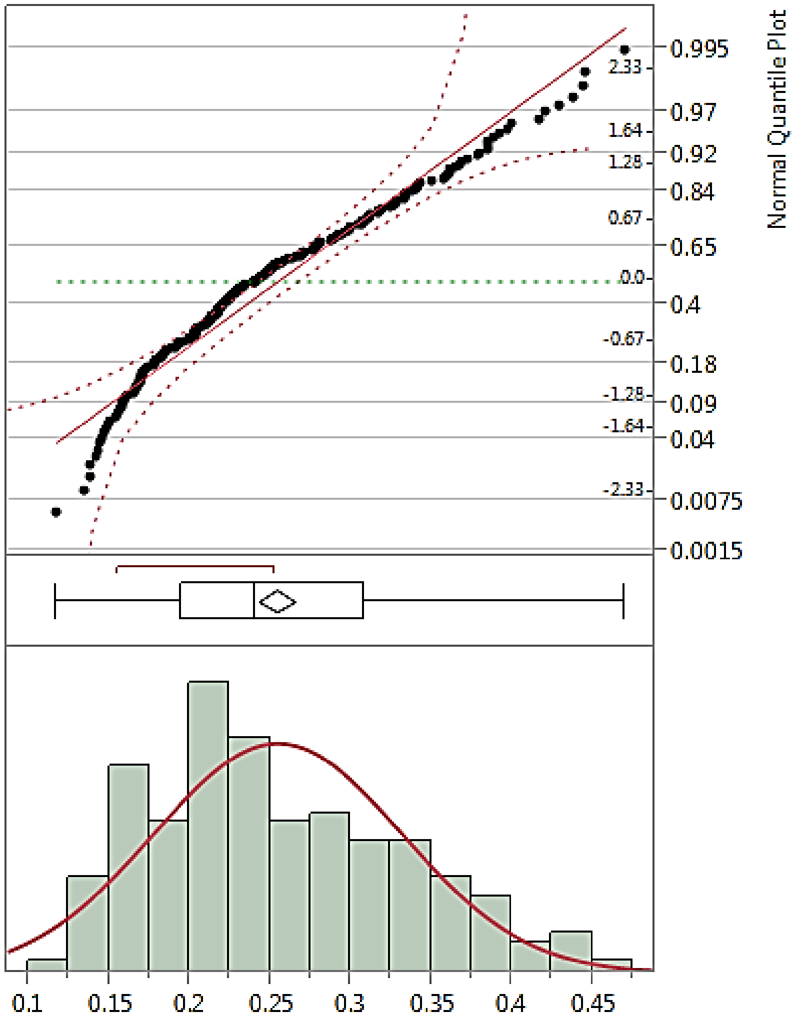

Figure 6.11 Histogram and Q-Q Plot of Schedule Per. for Delivery Methods

After the log transformation, Figure 6.12 showed the normal distribution, which formed closing to a straight line with bell-shaped graphs. Based on the information obtained from the Q-Q plot, histogram, and box plot with median, the normality of data was proved. The result of variance tests with histogram and Q-Q plot of contingency amount is shown in Figure 6.12. The straight line formed in the Q-Q plot represents bias free results and satisfies the normal distribution of the test variable. Moreover, it is suitable to assume that the most of projects within the data collection are independent since each project was delivered in different location and time. Therefore, each project was given different externalities (ex. weather, site condition, tec.) that affect the overall project completion.

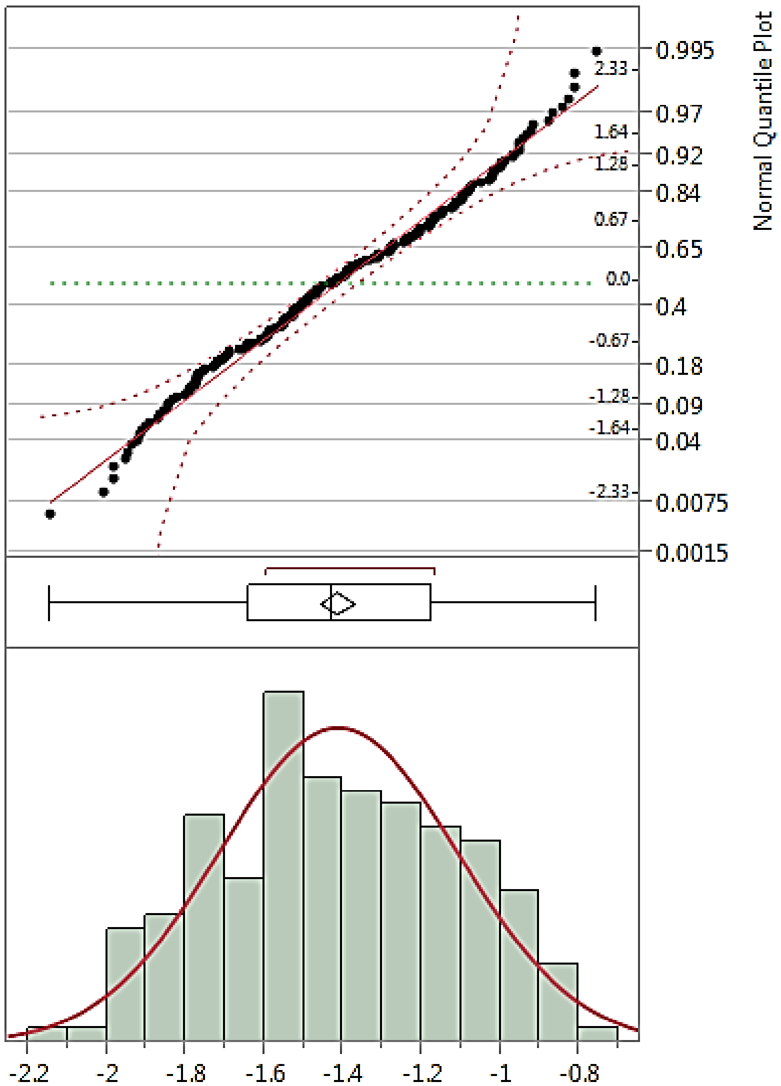

Figure 6.12 Transformed Histogram and Q-Q Plot of Schedule Performance

To develop the normality test and form a robust result, goodness of fit test was performed under an assumption that the data was normally distributed (Table 6.3). Since the p-value was more than 5% (0.0568), the assumption could not be rejected. In other words, the data used for the SIC ratio passed the normality test.

Table 6.3 Goodness of Fit Test for Schedule Performance Ratios

Goodness-of-Fit Test	
Shapiro-Wilk W Test	
W	**Prob < W**
0.986167	0.0568
Note: Ho= The data is from the Normal distribution. Small p-values reject Ho.	

Levene's F test was implemented to test the assumption of equal variance as shown in Figure 6.13 and Table 6.4. Since the F-ratio of Levene's F test (p=0.84) was 0.04, it suggests that the null hypothesis of equal variance would not be rejected. And it means that the similar variances are met as assumed. Other than the Levene's F test, however, other tests, such as standard deviation, Welch's test etc., supports the homogeneity of variances.

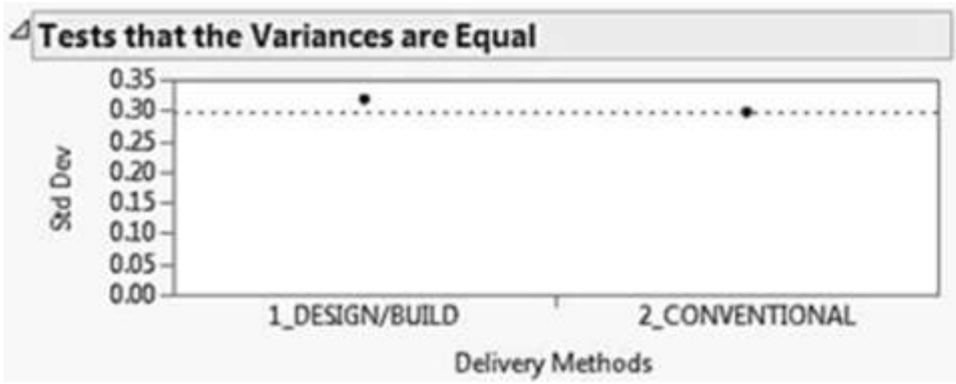

Figure 6.13 Equal Variances Test of Delivery Methods in Schedule

Table 6.4 Homogeneity Test of Scheduler Performance for Delivery Projects

Level	Count	Std Dev	Mean Abs Dif to Mean	Mean Abs Dif to Mean
Design/Build	10	0.319959	0.2592414	0.244122
Conventional	182	0.296999	0.2485411	0.2484026
O'Brien[.5]	0.2052	1	190	0.651
Brown-Forsythe	0.0064	1	190	0.9363
Levene	0.0415	1	190	0.8388
Bartlett	0.0959	1	.	0.7568
F Test 2-sided	1.1606	9	180	0.6459
Welch's Test				
Welch ANOVA testing Means Equal, allowing Std Deviation Not Equal				
F Ratio	DF Num	DF Den	Prob > F	
5.5333				
t Test				
2.3523				

Lastly, a scatterplot, which was formed with the standardized residuals versus the predicted values of the dependent variable, was conducted to detect heteroscedasticity (Figure 6.14). Since the residuals within the scatterplot (Figure 6.15) are randomly and evenly distributed without any visual patterns, it suggests that there is not any significant evidence of heteroscedasticity in the proposed models.

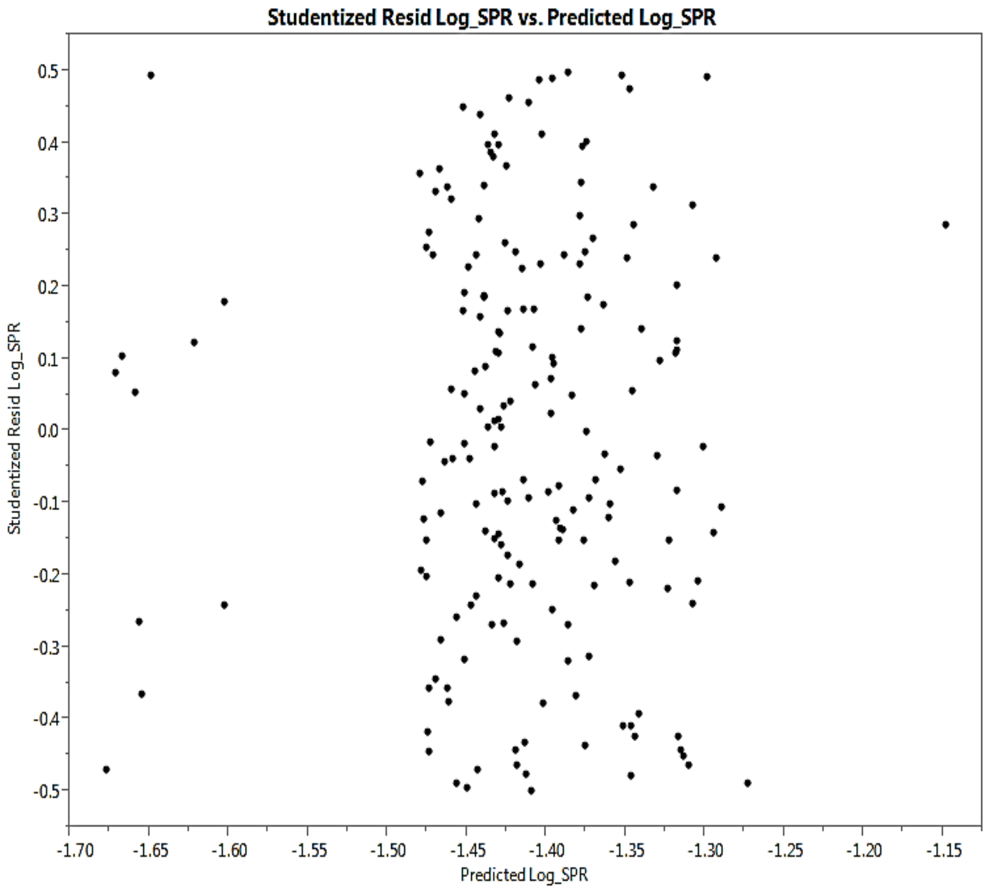

Figure 6.14 Scatterplot of Schedule Performance Ratios for Delivery Methods

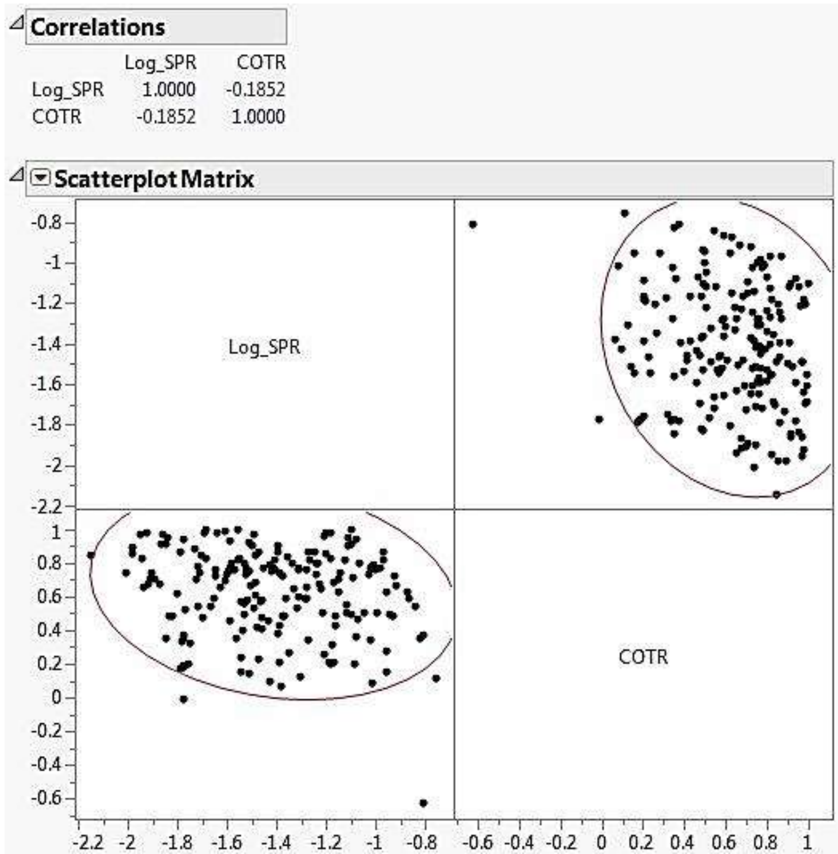

Figure 6.15 Correlation Test of Schedule for Delivery Methods

In order to examine how late change orders affected project performance in the aspect of schedule (Figure 6.16), a regression model for each delivery method was respectively implemented. The overall result of the regression model for schedule indicated that lately occurred change orders affected projects relatively less in schedule extension. Since the projects that were closer to their completions had significantly less tasks left, they were not affected by change orders, compared to rest of projects having a lot more tasks to be accomplished. In most of the cases, change orders, especially plan modification, unforeseen project site condition, ect., occurred in early stages consecutively causes other types of change orders and delay of project finish consequently. Moreover, the major cases of infrastructure projects are related to horizon construction, unlike general construction which is more involved with vertical construction. The horizon construction has comparatively simpler construction process than vertical construction in dealing with multi-stories, complicated utility lines, and so on. Based on the research study and quantitative analysis, rather than late change orders, early change orders seriously impacted the project durations in most cases of projects, and D/B (-1.7) performed better in accelerating project completion and reducing project time than conventional (-1.5). Also variance analysis for schedule performances (Table 6.5) and parameter estimates (Table 6.6) of delivery projects can be seen blow.

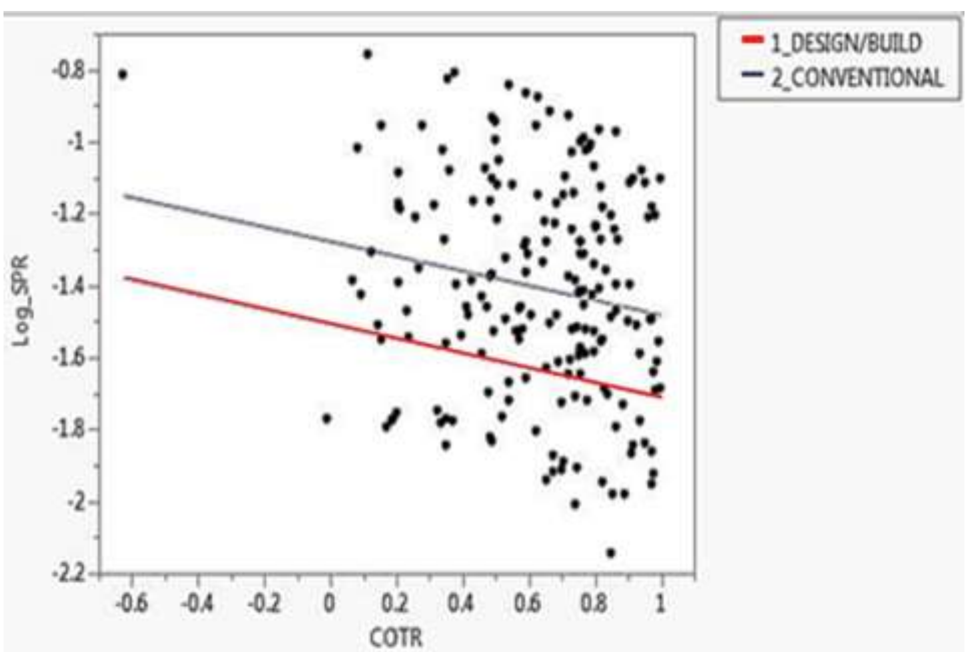

Figure 6.16 Schedule Performance Ratios versus COTR for Delivery Methods

Table 6.5 Analysis of Variance of Schedule Performances for Delivery Projects

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	2	1.091332	0.545666	6.3046
Error	189	16.35809	0.086551	**Prob > F**
C. Total	191	17.44942		0.0022*

The following is a Regression equation for D/B projects:

- Log (SPR) = $\beta_0 + \beta_1 \, _{COTR} + \beta_2 I_0$

Table 6.6 Parameter Estimates of Delivery Projects in Schedule Performance

Parameter Estimates					
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob > ltl**	**VIF**
Intercept	-1.38993	0.07229	-19.23	<.0001*	.
COTR	-0.20384	0.08245	-2.47	0.0143*	1.0040791
Delivery Method: Design/Build	-0.11424	0.04788	-2.39	0.0180*	10.004079

Based on the information observed in Table 6.6, D/B method performed better in the project cost control than conventional method, as much as the ratio of -0.11. And the equation for each project was come out as the followings:

- D/B delivery method: Log (SPR) = -1.39 - 0.204 COTR - 0.114 I_0
- Conventional delivery method: Log (SPR) = -1.39 - 0.204 COTR

The quality of prediction is determined by predicted error sum of square (PRESS) via comparing each observed response (Choi et al. 2012). The PRESS and sum of square error (SSE) are mandatory elements that compose ESC model. And the ESC model ratio for the proposed model was 1.036 (PRESS/SSE=16.939/16.35) by given information in Table 6.7. This outcome supports that the proposed model is robust.

Table 6.7 Validation Check for Schedule Ratio of Delivery Methods

Press	
Press	**Press RMSE**
16.93938613	0.29702857

6.4.2.2 Delivery Methods versus Cost

Conducting a Q-Q plot for normality check on cost caused the same problem as the same as the case of schedule. Therefore, log transformation was performed, and the result of Q-Q plot was come out as shown in Figure 6.17. It showed a perfect normal distribution by satisfying critical factors such as straightly lined forms of plots and bell shaped histogram matching with the median in the box plot. Therefore, the normality of data was clearly verified.

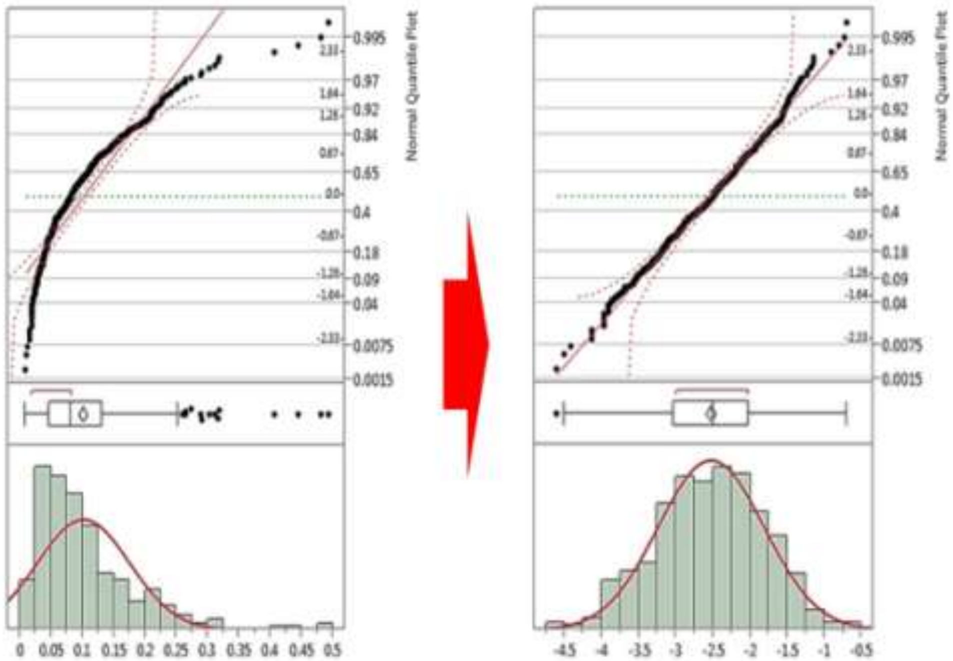

Figure 6.17 Histogram and Q-Q Plot of Cost Per. for Delivery Methods

Goodness-of-fit test (Table 6.8) was again conducted to examine the normal distribution of the data. The null hypothesis is that the data was not normally distributed. As the result, however, the *p*-value was more than 5% (0.1795), which means that the assumption never would be rejected. Therefore, the verification of normal distribution of data is clearly met.

Table 6.8 Goodness of Fit Test for Cost Performance Ratios

Goodness-of-Fit Test	
Shapiro-Wilk W Test	
W	**Prob < W**
0.994767	0.1795
Note: Ho= The data is from the Normal distribution. Small p-values reject Ho.	

According to Levene's F test (p=0.70) which was 0.15, it reveals that the null hypothesis of equal variance would not be rejected, and the similar variances are qualified (Figure 6.18). Moreover, the Welch's test in Table 6.9 supports that means are equal to each other since the p-value is less than 5%.

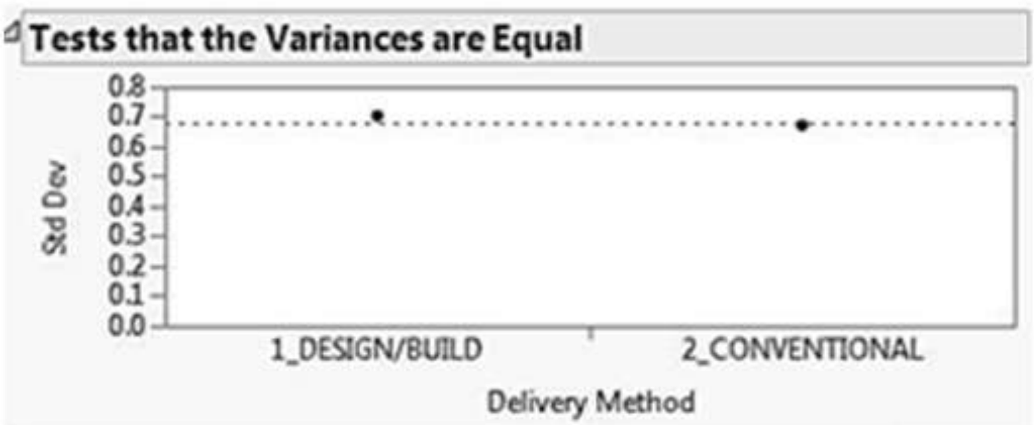

Figure 6.18 Equal Variances Test of Delivery Methods in Cost

Table 6.9 Homogeneity Test of Cost Performance for Delivery Projects

Level	**Count**	**Std Dev**	**Mean Abs Dif to Mean**	**Mean Abs Dif to Mean**
Design/Build	30	0.705865	0.5789389	0.5777606
Conventional	379	0.675645	0.5506203	0.5505812
Test	**F Ratio**	**DF Num**	**DF Den**	**p-Value**
O'Brien[.5]	0.1563	1	407	0.6928
Brown-Forsythe	0.1345	1	407	0.714
Levene	0.1462	1	407	0.7023
Test	**F Ratio**	**DF Num**	**DF Den**	**p-Value**
Bartlett	0.1045	1	.	0.7464
F Test 2-sided	1.0915	29	378	0.6874

Table 6.9 Continued

Welch Test			
Welch ANOVA testing Means Equal, allowing Std Deviation Not Equal			
F Ratio	DF Num	DF Den	Prob > F
42.6752	1	33.345	<.0001*
t Test			
6.5326			

Last step is to detect deteroscedasticity by implementing scatterplot (Figure 6.19) and check if there is any pattern within the scatterplot (Figure 6.20). Within the scatter plot, there was not any significant pattern or shape detected, and the residuals were randomly distributed within the given area. Therefore, the scatter plot result suggests that no evidence of heteroscedasticity was found for the proposed models.

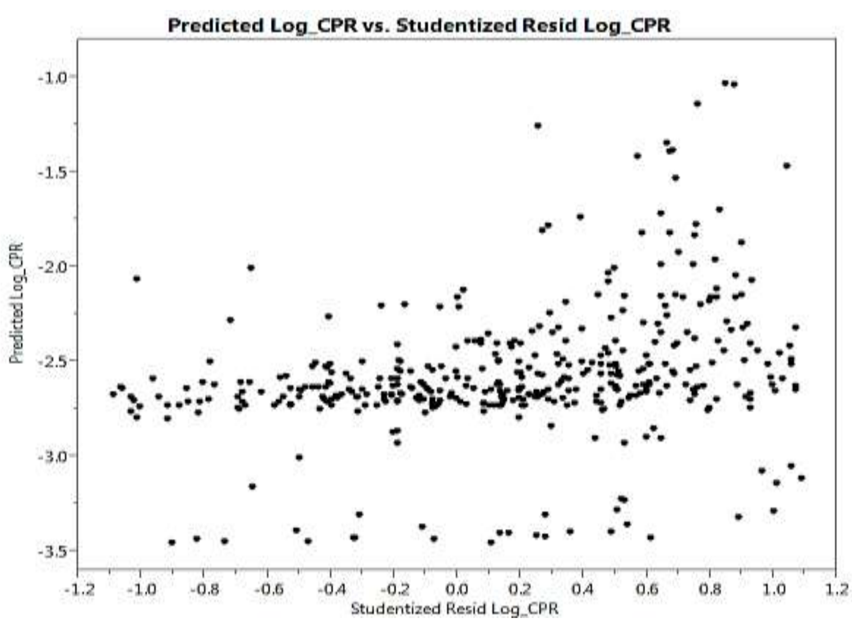

Figure 6.19 Scatterplot of Cost Performance Ratios for Delivery Methods

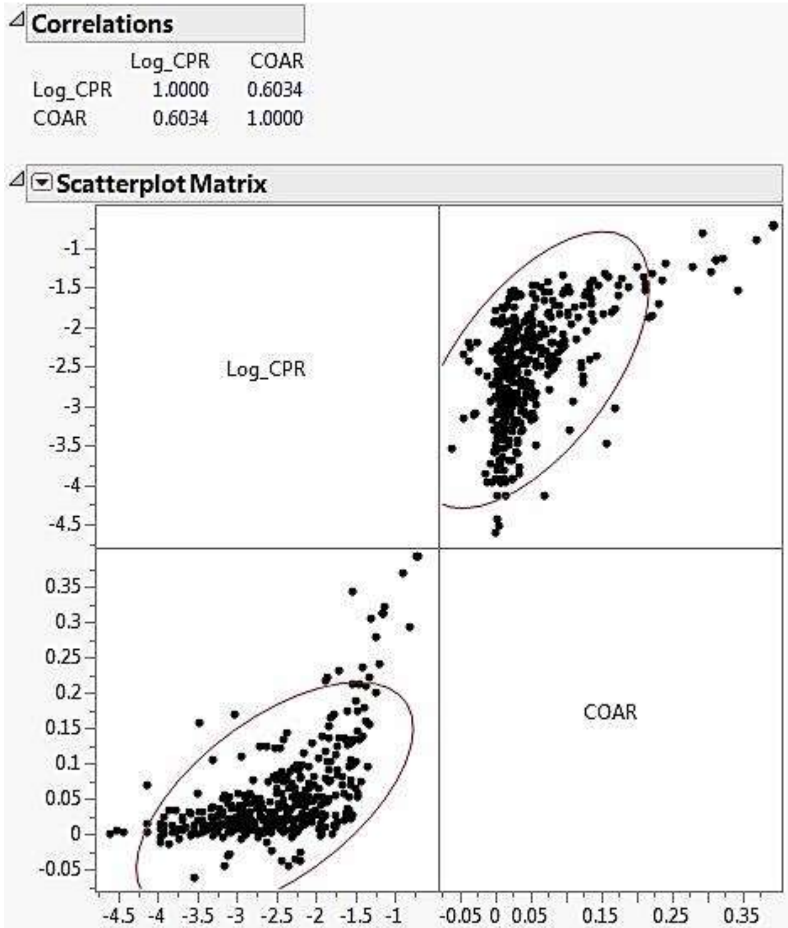

Figure 6.20 Correlation Test of Cost for Delivery Methods

Figure 6.21 and Table 6.10 depict the regression model for cost performances versus change order amount ratio of the delivery methods. The regression model revealed that change order amount ratio (COAR) was increased as the cost performance ratio increased. Also, tells that D/B (-1.5) projects were more effective in saving costs compared to conventional (-0.5).

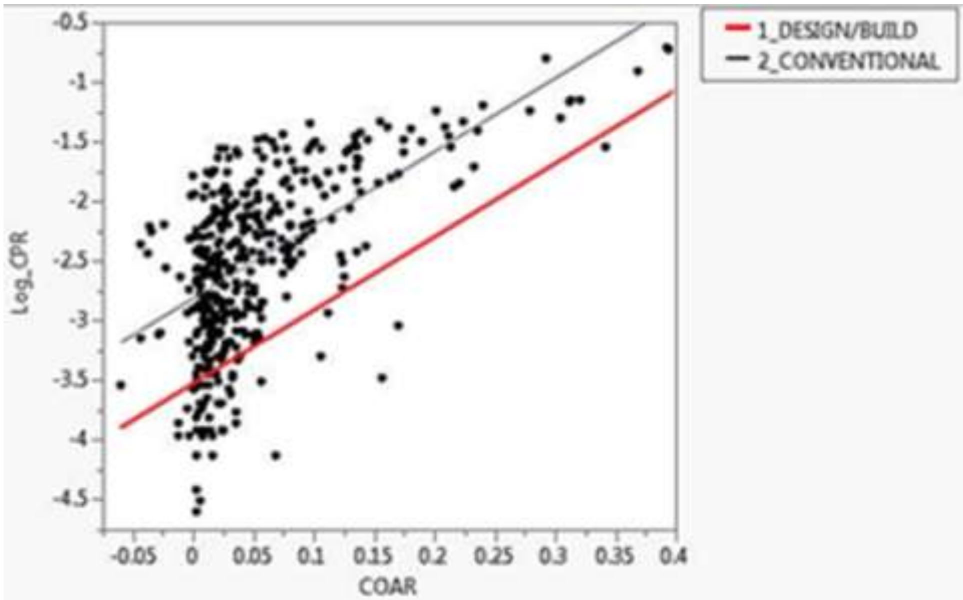

Figure 6.21 Cost Performance Ratios versus COAR for Delivery Methods

Table 6.10 Analysis of Variance of Cost Performances for Delivery Projects

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	2	90.05808	45.029	154.8272
Error	406	118.0787	0.2908	**Prob > F**
C. Total	408	208.1367		<.0001*

The following is a Regression equation for conventional projects:

- Log (SPR) = $\beta_0 + \beta_1\,_{COAR} + \beta_2 I_0$

In Table 6.11, parameter estimates of delivery projects in cost performance was conducted to find critical differences between methods.

Table 6.11 Parameter Estimates of Delivery Projects in Cost Performance

Parameter Estimates					
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob > ltl**	**VIF**
Intercept	-3.16167	0.053771	-58.8	<.0001*	.
COTR	6.147583	0.399333	15.39	<.0001*	1.0093139
Delivery Method: D/B	-0.35995	0.051379	-7.01	<.0001*	1.0093139

Based on the information observed in Table 6.11 and 6.12, D/B method performed better in the project cost control than conventional method, as much as the ratio of -0.36. And the equation for each project was come out as the followings:

- D/B delivery method: Log (SPR) = -3.16 + 6.15 COAR - 0.36 I_0
- Conventional delivery method: Log (SPR) = -3.16 + 6.15 COAR

Table 6.12 Validation Check for Cost Ratio of Delivery Methods

Press	
Press	**Press RMSE**
119.8221882	0.54126129

The ESC model ratio for the proposed model was 1.02 (PRESS/SSE = 119.82/118.07) based on the information obtained from the Table 6.12. Therefore it suggests that the proposed model is robust enough.

6.4.2.3 Contracting Methods versus Schedule

The log transferred Q-Q plot (Figure 6.22), which stands for normality test, shows a straight line of normal distributional form with a reasonable bell shaped histogram. Therefore, it suggests the data is normally distributed.

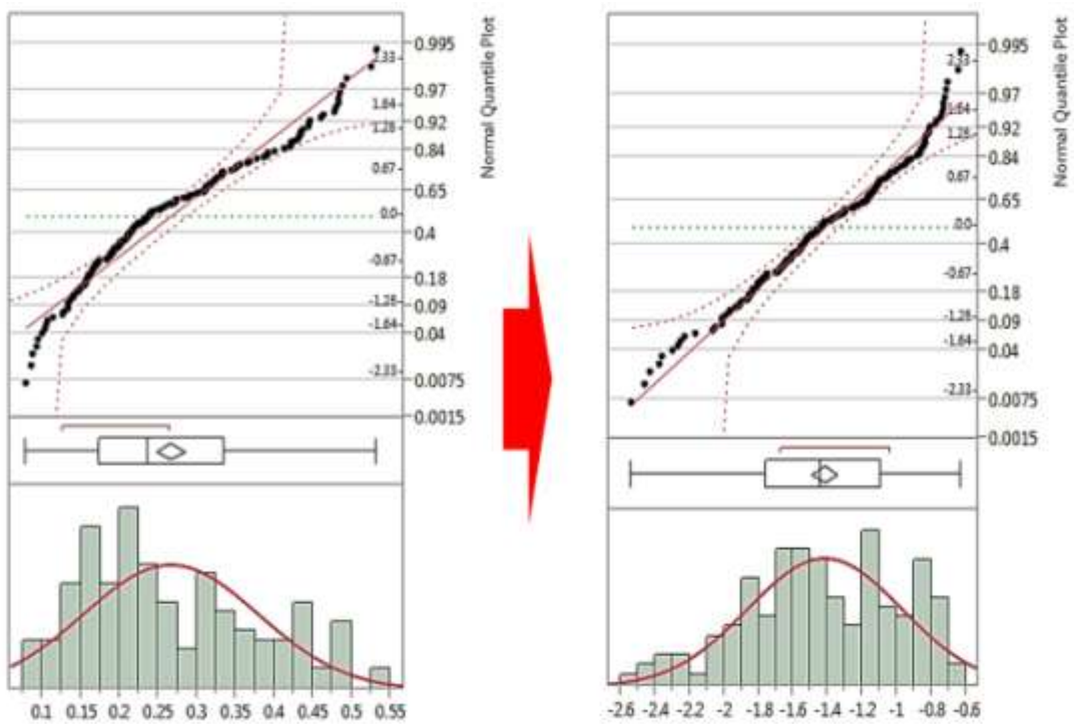

Figure 6.22 Histogram and Q-Q Plot of Schedule Per. for Contracting Methods

Standard deviation of overall data was laid +/- 0.7 (Figure 6.23). Also, Levene's F test (*p*=0.89) in Table 6.13 was 2.22, which means that there is no difference identified between the variances in the population of data, and the equal variances of data were verified. Lastly, Welch's test proved the equal means of each project type since the *p*-value (<.0001*) was less than 5%.

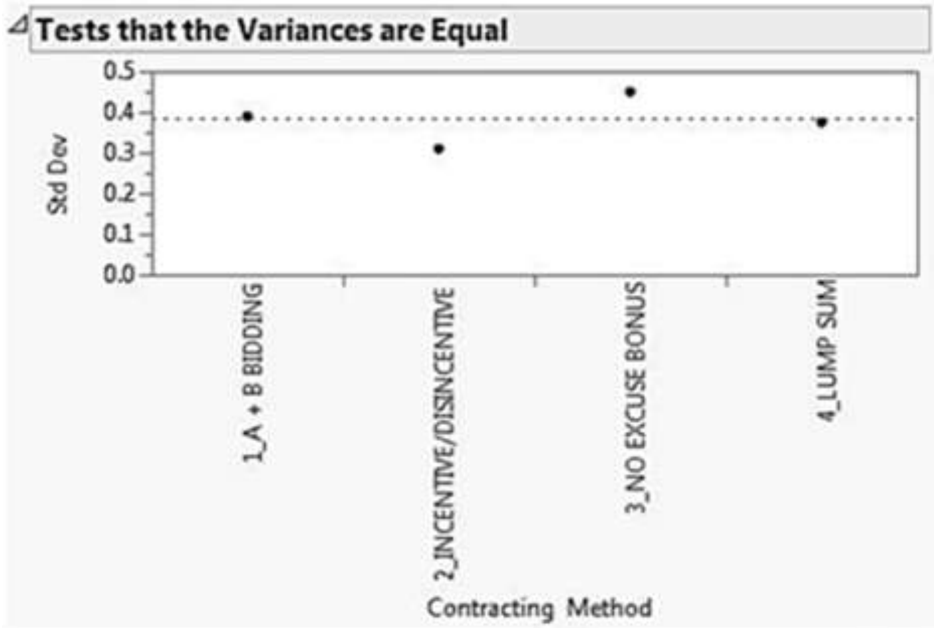

Figure 6.23 Equal Variances Test of Contracting Methods in Schedule

Table 6.13 Homogeneity Test of Schedule Performance for Contracting Projects

Level	Count	Std Dev	Mean Abs Dif to Mean	Mean Abs Dif to Mean
A+B Bidding	23	0.390405	0.3307946	0.32914
I/D	17	0.312044	0.2518517	0.25179
No Excuse Bonus	24	0.450406	0.331879	0.39494
Conventional	86	0.377223	0.3320448	0.33165
Test	**F Ratio**	**DF Num**	**DF Den**	**p-Value**
O'Brien[.5]	2.1071	3	146	0.1019
Brown-Forsythe	1.8996	3	146	0.1322
Levene	2.216	3	146	0.0888
Bartlett	0.843	3	.	0.4701

Welch's Test			
Welch ANOVA testing Means Equal, allowing Std Deviation Not Equal			
F Ratio	DF Num	DF Den	Prob > F
16.401	3	44.229	<.0001*

As the final phase of homogeneity test (Figure 6.25), scatterplot was implemented as below. Within the scatterplot in Figure 6.24, no significant patter was found, and each residual was randomly distributed within the area. Based on the homogeneity verification tests above, it suggests that no evidence was found, which supports the heteroscedasticity of the proposed models.

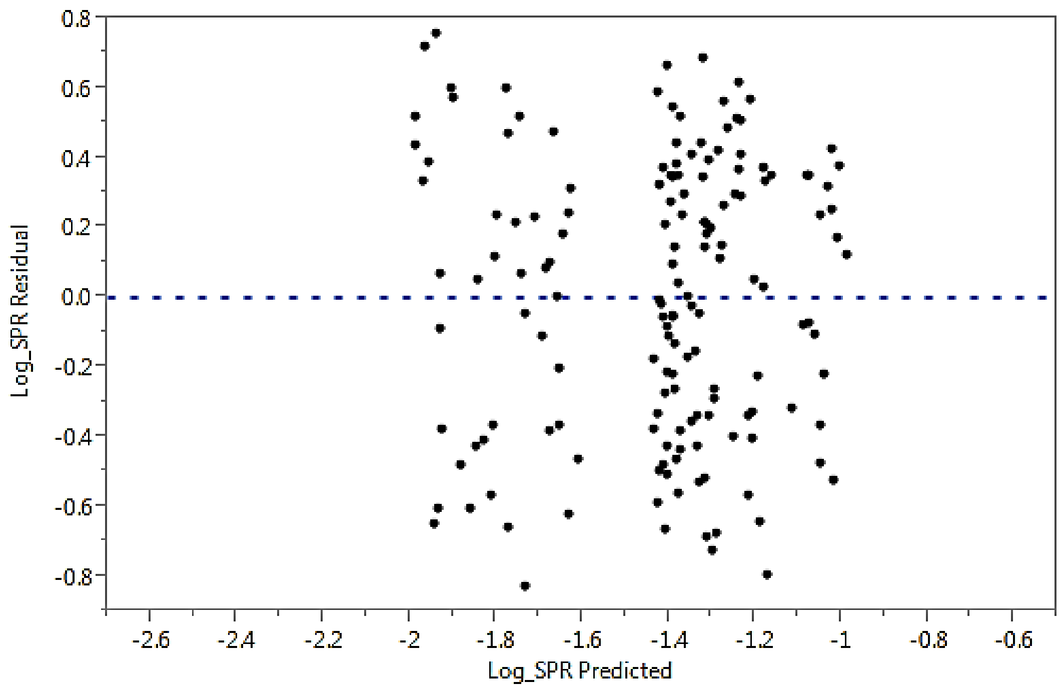

Figure 6.24 Scatterplot of Schedule Performance Ratios for Contracting Methods

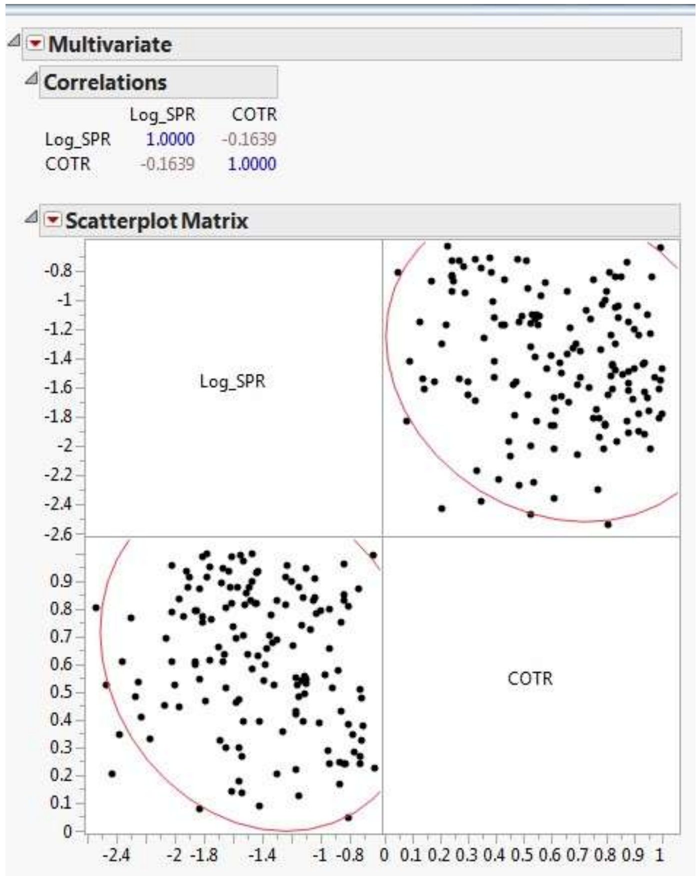

Figure 6.25 Correlation Test of Schedule for Contracting Methods

Figure 6.26 represents the regression model for change order timing ratio (COTR) versus schedule performance of each contracting method. As the slot of lines shows, COTR increased as the cost performance ratio decreased. According to the outcome of Figure 6.26 and Table 6.14, A+B showed worst performance and best schedule performance for no excuse bonus projects, followed by I/D projects.

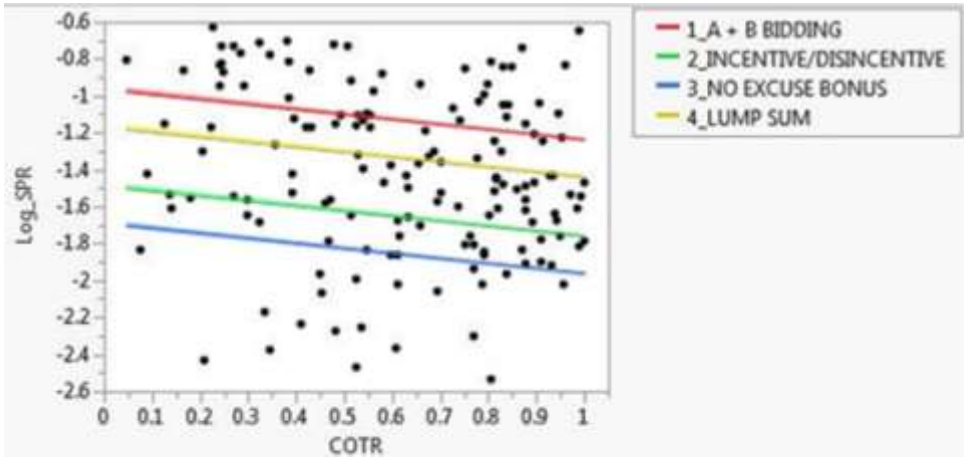

Figure 6.26 Schedule Performance Ratio versus COTR for Contracting Methods

Table 6.14 Analysis of Variance of Schedule Performances for Contracting Projects

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	4	8.801834	2.20046	15.191
Error	145	21.003643	0.14485	**Prob > F**
C. Total	149	29.805477		<.0001*

Based on the information observed Table 6.15 and 6.16, No excuse bonus was identified the best performing schedule control among the all contracting methods, followed by I/D, Lump Sum, and A+B in order. And the equation for the projects came out as the following:

- Log (SPR) = $\beta_0 + \beta_1\ _{COTR} + \beta_2 I_1 + \beta_3 I_2 + \beta_4 I_3$

Table 6.15 Parameter Estimates of Contracting Projects in Schedule Performance

Parameter Estimates					
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob > ltl**	**VIF**
Intercept	-1.325	0.085	-15.52	<.0001*	.
COTR	-0.2698	0.126	-2.15	0.0333*	1.0330496
Method: A+B	0.3629	0.681	5.33	<.0001*	2.6513354
Method: I/D	-0.161	0.086	-2.12	0.0356*	2.8355325
Method: No Excuse Bonus	-0.361	0.0667	-5.41	<0.001*	2.5898987

- Log (SPR) = -1.39 – 0.27 COTR + $0.36I_1 - 0.16\ I_2 - 0.36\ I_3$

Table 6.16 Validation Check for Schedule Ratio of Contracting Methods

Press	
Press	**Press RMSE**
22.578650429	0.38797466

The ESC model ratio for the proposed model was 1.07 (PRESS/SSE = 22.58/21.004) based on the information obtained from the Table 6.16. Therefore it suggests that the proposed model is robust enough.

6.4.2.4 Contracting Methods versus Cost

The log transferred Q-Q plot (Figure 6.27), which stands for normality test, shows a straight line of normal distributional form with a reasonable bell shaped histogram. Therefore, it suggests the data is normally distributed.

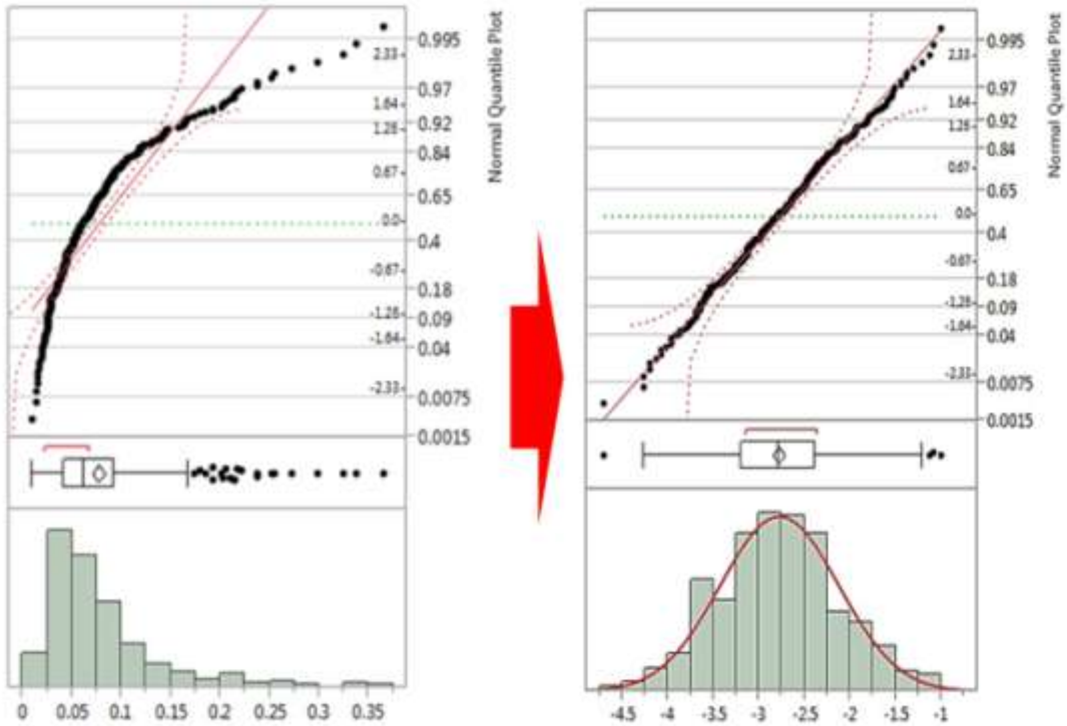

Figure 6.27 Histogram and Q-Q Plot of Cost Per. for Contracting Methods

Standard deviation of overall data was laid +/- 0.8 (Figure 6.28). Also, Levene's F test (*p*=0.11) in Table 6.17 was 2.0, which means that there is no difference identified between the variances in the population of data, and the equal variances of data were verified. Lastly, Welch's test proved the equal means of each project type since the *p*-value (<.02) was less than 5%.

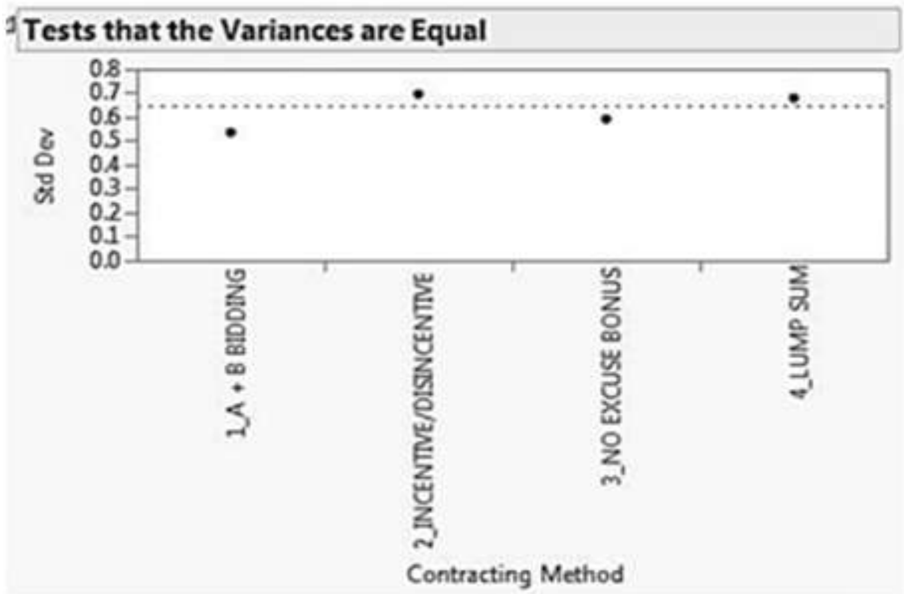

Figure 6.28 Equal Variances Test of Contracting Methods in Cost

Table 6.17 Homogeneity Test of Cost Performance for Contracting Projects

Level	**Count**	**Std Dev**	**Mean Abs Dif to Mean**	**Mean Abs Dif to Mean**
A+B Bidding	40	0.533033	0.3779335	0.3779335
I/D	57	0.697164	0.5501608	0.5439794
No Excuse Bonus	60	0.589577	0.4954875	0.4926338
Conventional	167	0.676612	0.5366068	0.5352306
Test	**F Ratio**	**DF Num**	**DF Den**	**p-Value**
O'Brien[.5]	1.4695	3	320	0.2228
Brown-Forsythe	1.8414	3	320	0.1395
Levene	2.0007	3	320	0.1138
Bartlett	1.6149	3	.	0.1835

Welch's Test			
Welch ANOVA testing Means Equal, allowing Std Deviation Not Equal			
F Ratio	DF Num	DF Den	Prob > F
2.0125	3	117.63	0.01159

For finalize the homogeneity test, scatterplot (Figure 6.29 and Figure 6.30) was implemented as below. Within the scatter plot, no significant patter was found, and each residual was randomly distributed within the area. Based on the homogeneity verification tests above, it suggests that no evidence was found, which supports the heteroscedasticity of the proposed models.

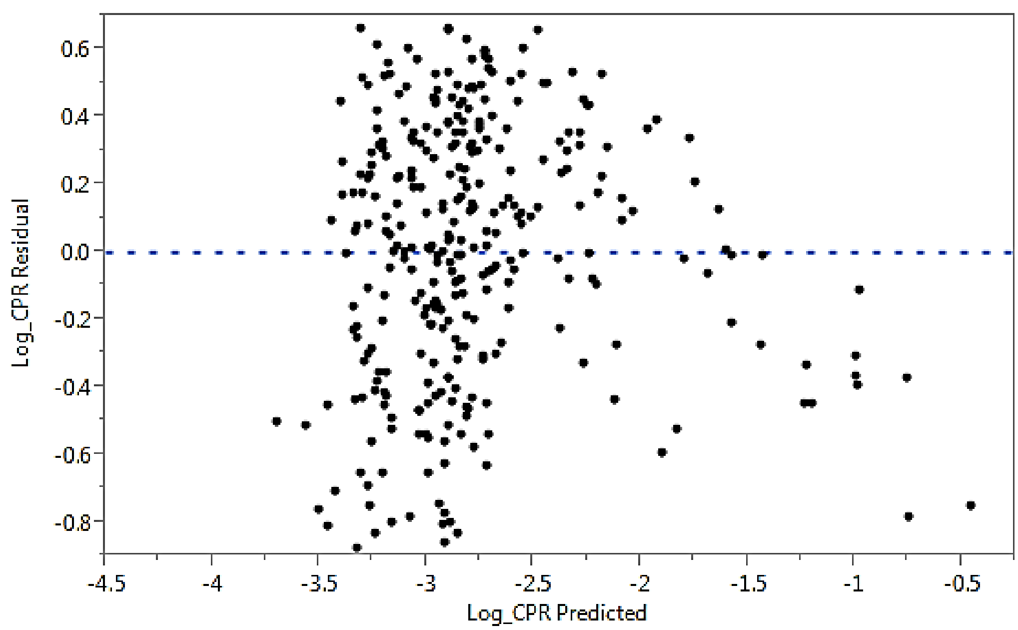

Figure 6.29 Scatterplot of Cost Performance Ratios for Contracting Methods

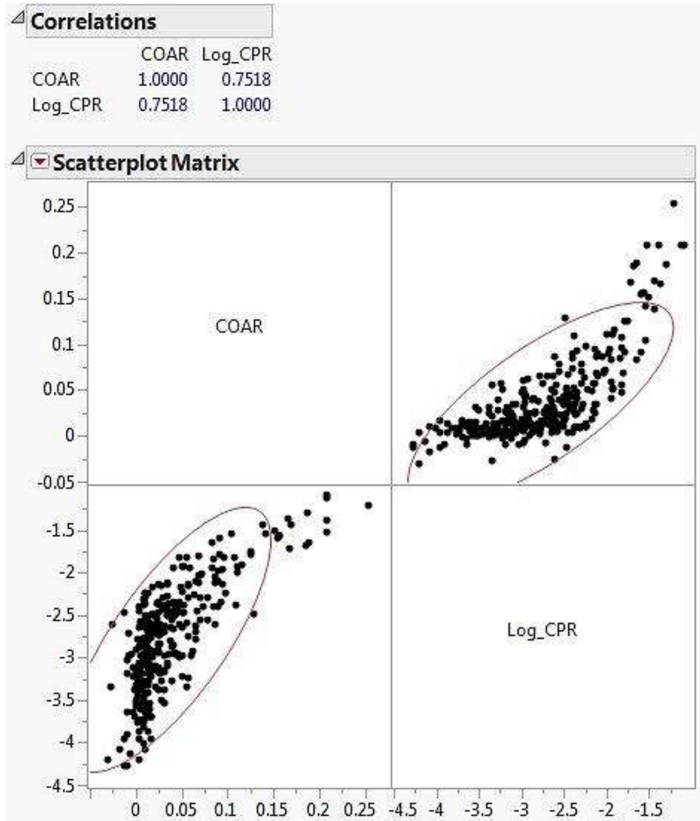

Figure 6.30 Correlation Test of Cost for Contracting Methods

Figure 6.31 represents the regression model for change order amount ratio (COAR) versus cost performance of each contracting method. As the slot of lines shows, COAR increased as the cost performance ratio increased. According to the outcome of the regression model, A+B showed worst cost performance and best for lump sum projects, followed by I/D projects. The reason of no excuse bonus's poor performance is assumed coming from the accelerated schedule. It means that there could have been extra expenses while shortening the project time. Therefore, no excuse bonus showed relatively low cost performance than others except A+B contracts (Table 6.18).

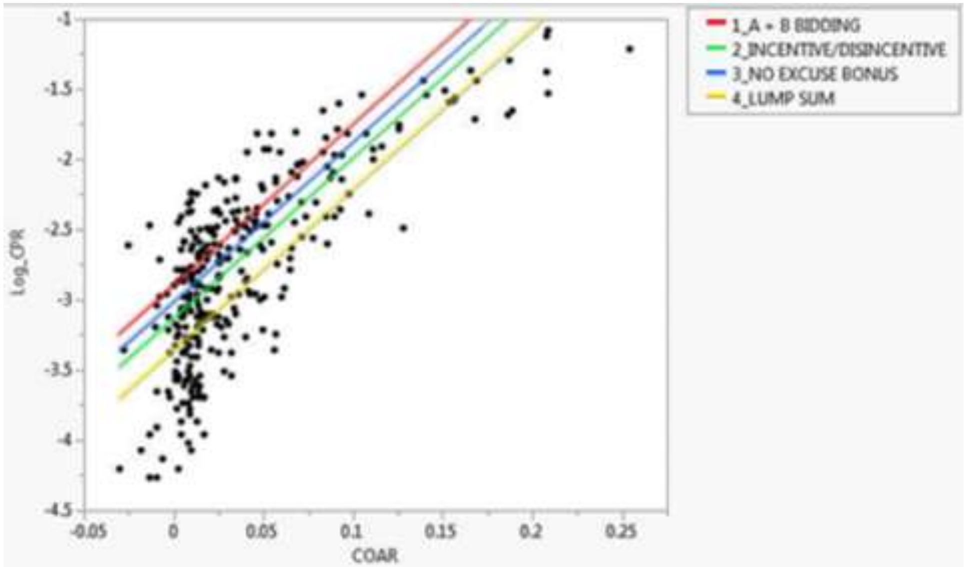

Figure 6.31 Cost Performance Ratios versus COAR for Contracting Methods

Table 6.18 Analysis of Variance of Cost Performances for Contracting Projects

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	4	83.09675	20.7742	140.2101
Error	315	46.67187	0.1482	**Prob > F**
C. Total	319	129.76862		<.0001*

Based on the information observed in Table 6.19 and 6.20, Lump sum performed the best in cost control among the all contracting methods followed by I/D, Lump Sum, and No excuse bonus in order. And the equation for the projects came out as the following:

- Log (SPR) = $\beta_0 + \beta_1\,_{COTR} + \beta_2 I_{1+} \beta_3 I_{2+} \beta_4 I_3$

Table 6.19 Parameter Estimates of Contracting Projects in Cost Performance

Parameter Estimates					
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob > ltl**	**VIF**
Intercept	-3.095	0.0291	-106.2	<.0001*	.
COTR	11.401	0.4877	23.37	<.0001*	1.045
Method: A+B	0.2059	0.0507	4.06	<.0001*	2.678
Method: I/D	-0.029	0.0444	-0.65	0.5188	2.431
Method: No Excuse Bonus	0.0824	0.0431	1.91	0.0566	2.389

- Log (SPR) = -3.06 + 11.4 COTR + $0.21I_1 – 0.03\ I_2 – 0.08\ I_3$.

Table 6.20 Validation Check for Cost Ratio of Contracting Methods

Press	
Press	**Press RMSE**
48.268230012	0.38837896

The ESC model ratio for the proposed model was 1.03 (PRESS/SSE = 48.27/46.67) based on the information obtained from the PRESS and Analysis of Variance tables (Table 6.18 and Table 6.20). Therefore, it suggests that the proposed model is robust enough.

6.4.3 Test Results

Throughout the quantitative analysis, the findings of the test are as the followings:

- D/B projects showed better performance (-0.11) in reducing schedule than conventional.
- D/B delivery method was more effective in saving project costs than conventional, as much as -0.36 in terms of cost performance ratio.
- A+B contract showed worse (0.36) in schedule performance than conventional, while I/D (-0.16) and No excuse bonus (-0.36) compared to conventional.
- A+B and No excuse bonus contracts were respectively 21% and 8% worse in terms of cost project performance than lump sum contract, while I/D (-0.2) performed better in cost saving.

6.5 Summary of Change Order Timing Impact

Major goal for this section was to examine the schedule change ratio of delivery and contract methods, and investigate the innovative contacting methods are really effective in schedule performance. Based on the quantitative analysis and study, the overall alternative contracts showed better performance in schedule control than conventional, except A+B. A+B contracts had the highest delay ratio as well as cost saving aspect. Other than A+B, however, most innovative delivery and contracting methods showed much better project performances in schedule compression and cost saving.

7. CONCLUSION

Increase of utilizing innovative contracting strategies in the U.S. nation is to accelerate project completion and economize on project costs consequently. The overall results of research analysis revealed the followings:

- Conventional delivery method had more issues for cost and schedule growths compared to D/B. In other words, D/B remarkably performed for projects delivery and coped with change orders.
- I/D contracting method showed an outstanding performance both in cost and schedule controls. By granting incentive bonuses to contractors who delivered projects ahead schedule, the project duration could have been significantly compressed.
- No excuse bonus contracting method, which has a very similar to the I/D contract except that no schedule extension is allowed, also performed an remarkable schedule and cost controls.
- A+B contracting method showed the dullest performances among the all delivery and contract methods for managing project schedule and cost.
- Lump sum saved a significant amount of project cost but strength was identified in schedule control.

Overall innovative contracting and delivery methods, except A+B, had better and stronger points than conventional in most of the cases. Among the innovative strategies, however, the major schedule overrun was identified in A+B. The reason of such late finish of projects can be supposed from contractors' bidding less amount and time solely to win the contract. It means that the A+B projects often cause contractors to bid the projects with underestimated cost (A) and schedule (B).

In the last section, delivery and contracting methods with less contingency amount showed less cost growth ratio. This is the critical evidence which reveals that the contingency amount is dissimilarly allocated depending on the delivery or contracting type.

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