DOES DESIGN-BUILD (DB) OUTPERFORM CONSTRUCTION MANAGEMENT AT RISK (CMAR)? A COST AND SCHEDULE COMPARATIVE STUDY OF DB PROJECTS AND CMAR PROJECTS

A Thesis

by

MIN MA

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ABSTRACT

Design-Build (DB) and Construction Management at Risk (CMAR) are two widely used alternative project delivery systems in the construction industry. Previous studies have found inconclusive results on which of the two has better cost and schedule performances when applied in construction projects. This study chose unit cost, change order factor, cost growth, schedule growth, and construction intensity as the metrics to measure the cost and schedule performance of both DB projects and CMAR projects. Two statistical analysis tools, Analysis of Variance and Wilcoxon Signed Rank Test, were applied to see if there is any difference between the two project delivery systems' means of the five measurements. The test results were used to determine which project delivery system has better performance in the real world. The results showed that Design-Build is superior to Construction Management at Risk in construction intensity, while Construction Management at Risk has better performance on change order, cost growth, and schedule growth. And there is no difference on unit cost.

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NOMENCLATURE

ANOVA	Analysis of Variance
APDM	Alternative Project Delivery Systems/Methods/Methodologies
CMAR	Construction Management at Risk
CSP	Competitive Sealed Proposal
DB	Design Build
DBB	Design Bid Build
GC	General Contractors
GMP	Guaranteed Maximum Price
PDS	Project Delivery Systems/Methods/Methodologies
GSF	Gross Square Feet

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Construction was recognized as a technological profession in the late 1800s (Thomsen, 2006). The participants in the process of completing a construction project include owners, architects, contractors, materials and equipment suppliers, the government, and others. The efforts to complete a construction project are irreversible but temporary, usually costing large amounts of money and taking a long time to complete Each construction project is unique and different from the others. Because of these unique attributes, the methods used in a construction project to manage the various parties and set rules for collaboration and responsibility are different from other industries. These methods are called Project Delivery Systems/Methods/Methodologies (Moynihan & Harsh, 2015). In the past decades, new project delivery systems were developed and became more well-known (Ohrn & Rogers, 2008). While the advantages of these new methods are still being debated, more and more owners are choosing to implement the new project delivery systems.

1.2 Project Delivery Methods/Methodologies/Systems

According to the definition of Associated General Contractors (AGC) (2004), Project Delivery Systems/Methods/Methodologies (PDS) is “the comprehensive process of assigning the contractual responsibilities for designing and constructing a project. A delivery method identifies the primary parties taking contractual responsibility for the performance of the work." In other words, it is a process by which the construction will be designed and constructed (Francom, Asmar, & Ariaratnam, 2014). Thomsen (2006) believed that relationships among various parties are also part of a project delivery system how to define responsibility is crucial in PDS. In the construction industry, choosing a proper delivery system is critical to the success of a construction project. Researchers and practitioners in the Architecture Engineering Construction industry believe that different PDS have a direct effect on different project management performances.

1.2.1 Design-Bid-Build

Design-Bid-Build (DBB) is the traditional project delivery method and has been widely used in the past decades. In a project that uses DBB, the owner first chooses two independent entities, the architect, and the general contractor (GC), by bidding. The chosen architect is responsible for design work, and the general contractor is responsible for performing the construction work. After the architect finishes designing, the general contractor starts the construction process. The various parties in DBB are separated from each other; for example, the general contractors do not get involved with the architects during the design phases. This separation is said to be designed so that each party could focus on its own duties (Ghassemi & Becerik-Gerber, 2011). Harper, Molernaar, and Cannon (2016) claimed that such "separation" in the DBB system brings problems like design deficiencies, budget overages, and project delays. The evaluation of long-term performance of a project is also easily ignored when using DBB (Culp, n.d.). On the other hand, using DBB gives the owners a high level of control over the all phases. DBB causes project management problems like overrun change orders, budget overages, and schedules delays (Shakya, 2013; Francom et al., 2014). In such background, the Alternative Project Delivery Systems/Methods (APDM) have become more popular and gained more attention in the Architecture Engineering Construction industry (Francom et al., 2014).

1.2.2 Alternative Project Delivery Methods/Systems

Alternative Project Delivery Methods/Systems include Design-Build (DB), Construction Management at Risk (CMAR) or Construction Management/General Contractor (CM/GC), Integrated Project Delivery (IPD), Competitive Sealed Proposal (CSP), Engineer Procure Construct (EPC) and others (Francom et al., 2014; Kulkarni, Rybkowski, & Smith, 2012); DB and CMAR are the most recognized and utilized methods among all APDM. DB refers to the delivery system where owners choose one entity to be responsible for both design and construction work; the entity usually gets involved after "the performance requirements are defined" by owners (Ghavamifar & Touran, 2008). In CMAR, the project delivery procedures and responsible entities are almost the same as DBB, except general contractors will be chosen before the construction phase. They get involved in the early design phase and provide construction management services to the architects and help reduce design deficiencies.

Table 1 Comparison among DBB, DB, and CMAR; Data from American Institute of Architects- the Associated General Contractors of America (AIA-AGC) (2011)

	DBB	CMAR	DB
Prime Players	*Owner*	*Owner*	*Owner*
	Designer	*Architect*	*Design-Build Entity*
	Contractor	*CM at-Risk*	
Contracts	*Owner to Designer*	*Owner to Architect*	*Owner to Design-Build Entity*
	Owner to Contractor	*Owner to CM at-Risk*	
Phases	*Design*	*Overlapping Phases: Design and Build*	*Overlapping Phases: Design and Build*
	Bid		
	Build		
Typical Characteristics	*Well-established and broadly documented roles*	*Hiring of the CM at-Risk during the design phase*	*Final design-builder selection may be based on direct negotiation, qualifications based selection, and best value*
	Construction planning based on completed documents	*Establishment of a Guaranteed Maximum Price*	*Project-by-project basis for establishing and documenting roles*
	Complete specifications that produce clear quality standards	*Clear quality standards produced by the contract's prescriptive specifications*	*Project-by-project basis for establishing and documenting roles*

1.2.3 APDM vs. DBB

Previous researchers and studies claimed that Alternative Project Delivery Systems outperform the traditional Design Bid Build. APDM has advantages on integration, collaboration, improved cost and schedule performance, and facilities qualities in both vertical and horizontal construction projects (Rojas & Kell, 2008; Shakya, 2013; Konchar & Sanvido, 1998; Francom et al., 2014; Kulkarni et al., 2012). In a study conducted by Fernane (2011), a lower contract award cost growth and total cost growth were found in DB projects compared with DBB projects. Shrestha and Fernane (2016) used Analysis of Variance (ANOVA) to compare DB projects with DBB projects and found the same conclusion as Fernane (2011). Studies by Alternative (1999) and Adams (2003) claimed similar cost savings benefits of DB projects." Francom (2015) concluded that CMAR has a better baseline of performance on cost and scheduling compared with DBB.

On the other hand, Minchin Jr., Li, Issa, and Vargas (2013) used statistical methods including Student's t-test and nonparametric Mann-Whitney U test to compare the cost and schedule performance of DB projects and DBB projects. According to their research, DBB projects outperformed DB projects in cost management, and there was no significant difference in schedule performance was found. Carpenter and Bausman (2016) also found that the satisfaction level of the quality of buildings and services were almost the same between DBB projects and CMAR projects, although CMAR projects were said to be more effective at schedule management and cost control. Another study conducted by Ibbs, Kwak, Ng, and Odabasi (2003) showed that using DB as a project delivery method might bring timesaving benefits, but with regard to cost savings and higher productivity, there were not significant difference always between DB projects and DBB projects (Ibbs et al., 2003).

1.3 Problem Statement

Although many efforts have been put into the area of comparing traditional Design-Bid-Build with new Alternative Project Delivery Systems, little research has been done in comparing different Alternative Project Delivery Systems. The differences between various Alternative Project Delivery Systems have not been fully studied and understood. First, previous studies on CMAR and DB show conflicting conclusions. Some studies claimed that CMAR outperformed DB (Charoenphol et al., 2016). Some concluded that DB is better than CMAR on project cost and schedule performances (Konchar & Sanvido, 1998). Second, among the previous studies, most of them reached convincing conclusions on the comparison of cost performance of various project delivery systems; however, their study on schedule differences suffered from data and methodology limitations. Therefore, this study plans to perform a comparison study between DB projects and CMAR projects using statistical analysis methods. The research goal is to find out if there is any statistically significant difference in the cost and schedule performance of DB projects and CMAR projects, and then compare the results with previous studies.

1.4 Research Objectives

The fundamental goal of this work is to study and analyze the performance differences between projects using Design-Build as their project delivery methods and projects using Construction Management at Risk:

a. Find out if there is a statistically significant difference between DB projects and CMAR projects in terms of project cost performances;

b. Find out if there is a statistically significant difference in the schedule performances between DB projects and CMAR projects;

c. Compare the results with previous studies and analyze any differences.

1.5 Definitions of Key Terms

Project Delivery Systems(PDS)

It is the comprehensive process of assigning the contractual responsibilities for designing and constructing a project. A delivery method identifies the primary parties taking contractual responsibility for the performance of the work. (AGC, 2004)

Alternative Project Delivery Systems(APDS)

This term refers to all the project delivery systems except the traditional Design-Bid-Build, including Design-Build, Construction Management at Risk, Integrated Project Delivery, and others.

Design-Bid-Build(DBB)

This method involves three roles in the project delivery process—owner, architect, and contractor—in traditionally separate contracts. “Traditional” is frequently used to describe the Design-Bid-Build method, which typically involves competitively bid, lump sum construction contracts that are based on complete and prescriptive contract documents prepared by architects. These documents generally include drawings, specifications, and supporting information. The phases of work are usually conducted in linear sequence. The owners contract with an architect, use the design documents produced by the architect to secure competitive bids from contractors, and, based on an accepted bid, contracts with a contractor for construction of the building. (AIA-AGC, 2011)

Design-Build(DB)

Design-Build has gained popularity in recent years in both the private and public sectors. The primary reason for this interest in Design-Build as a viable project delivery option is the owner’s desire for a single source of responsibility for design and construction. In the Design-Build approach to project delivery, the owner contracts with a single entity, the design-build entity, for both design and construction. The design-build entity can be led by an architect or a contractor and can consist of any number of people. (AIA-AGC, 2011)

Construction Management at Risk (CMAR)

Construction Management at-Risk (CMAR approaches involve a construction manager who takes on the risk of building a project. The architect is hired under a separate contract. The construction manager oversees project management and building technology issues, in which they typically have particular background and expertise. Such management services may include preparation of cost models, advice on the time and cost consequences of design and construction decisions, scheduling, cost control, coordination of construction contract negotiations and awards, timely purchasing of critical materials and long-lead-time items, and coordination of construction activities. (AIA-AGC, 2011)

Construction Cost

The sum of all costs, direct and indirect, inherent in converting a design plan for material and equipment into a project ready for start-up, but not necessarily in production operation; the sum of field labor, supervision, administration, tools, field office expense, materials, equipment, and subcontracts. (Dictionary of Construction, n. d.)

Schedule

A chronological itemization, often in chart form, of the sequence of project tasks. (Dictionary of Construction, n. d.)

Duration

> The amount of time estimated to complete an activity in the time scale used in the schedule (hours, days, weeks, etc.) Planned production rates and available resources will define the duration used in a given schedule. (Dictionary of Construction, n. d.)

In this thesis duration also refers to the total time spent on completing construction projects.

2. REVIEW OF LITERATURE

Debella and Ries (2006) performed a comparative study on projects that used Multiple Prime with Agent (MPwA), Multiple Prime (MP), and Single Prime (SP). In this study, the researchers found that there were no significant differences in cost growth nor change orders between MP and SP; SP brought advantages in litigation. The schedule differences of the three project delivery systems could not be studied due to the data limitations.

Konchar and Sanvido (1998) collected data about 351 projects using project delivery systems including DB, DBB, and CMAR, by sending out surveys. The purpose of their study was to compare the costs, schedule, and quality performance in construction projects using different project delivery systems. They performed both univariate analysis including two-sample t-test and Mood's median tests and multivariate analysis like linear regression models. According to the result of their statistical analysis, DB was the best among the three project delivery systems. CMAR outperformed DBB in terms of unit cost, construction speed, delivery speed, cost growth, and schedule growth. DBB projects had the worst performance among the three.

The study Konchar and Sanvido (1998) conducted opened the door of comparison studies between DB and CMAR delivery systems. Their study is also the most comprehensive one in terms of the sample size. Almost every later research targeting similar topics cited their work and compared findings with the conclusion of Konchar and

Sanvido (1998). However, William (2003) identified the following weaknesses in Konchar and Savidon's (1998) work:

1) The study did not find any statistically significant difference between cost and schedule growth;
2) The study did not take the variance of the data sample into account;
3) The comparisons on construction speed and delivery speed are meaningless because of the different inherent characteristics of each project delivery system: "The comparison is akin to comparing marathon runners against milers and then both against sprinters on the basis of how long their races take to run and finding sprinters superior because they finish in a shorter amount of time than either milers or marathoners!" (William, 2003);
4) The measurements that Konchar and Sanvido (1998) used to quantify "quality" are subjective and not reliable.

With the help of R-language, Charoenphol, Stuban, and Dever (2016) were able to evaluate the cost performance of DB, DBB, and CMAR delivery systems at the confidence level of 95%. They collected data from construction projects that were completed from 01/01/2008 to 07/01/2015 in the horizontal construction industry of Utah. By using ANOVA and planned contrast statistical methodology, they concluded that DBB outperformed CMAR and DB (CMAR outperformed DB) in cost growth factor and change order cost factor, which is contrary to the conclusion of Konchar and Sanvido (1998).

Maharjan (2013) sent a survey collecting data about the satisfaction level of owners in water and waste projects (35% of 455 participants responded). In a later study of the same questionnaire, Shrestha, Maharjan, and Batista (2014) found out that although DB was believed to have advantages on schedule growth, cost growth, and cost saving, no statistical significance was found. On the other hand, the overall satisfaction level of owners was significantly higher in projects using DB than ones using CMAR.

Shakya (2013) designed a performance comparison study of DB and CMAR in highway projects using data from the Department of Transportation in California, Colorado, Connecticut, Florida, Idaho, Kentucky, Louisiana, Maine, Michigan, Minnesota, Montana, Nevada, Ohio, Oregon, South Carolina, and Utah. By performing One-Way ANOVA test, DB was found to be more efficient in contract award cost growth and total cost growth than CMAR; no statistical significance was found in change order cost factor and construction intensity.

Korkmaz, Riley, and Horman (2010) used univariate analysis (One-Way ANOVA and regress analysis) and concluded that CMAR and DB outperformed DBB in delivery speed; no comparison study was done between CMAR projects and DB projects.

Table 2 Summary of Literature Review

Authors	Methodology	Compared Factors	Conclusion*
Charoenphol, D., Stuban, S. M., & Dever, J. R. (2016).	ANOVA	Cost Growth & Change Order	CMAR>DB
Shrestha, P. P., Maharjan, R., Shakya, B., & Batista, J. (2014).	Survey	Satisfaction Level of Owners	DB>CMAR
Shakya, B. (2013).	ANOVA	Contract Award Cost Growth	DB>CMAR
		Total cost growth	No Difference
		Change Order &Construction Intensity	No Difference
Maharjan, R. (2013).	Survey	Schedule Growth & Cost Growth	No Difference
		Satisfaction level	No Difference
Konchar, M., & Sanvido, V. (1998).	ANOVA; Liner Regression Models	Unit Cost	DB>CMAR
		Construction Speed	DB>CMAR
		Delivery Speed	DB>CMAR
		Cost Growth	DB>CMAR
		Schedule Growth	DB>CMAR
Korkmaz, S., Riley, D., & Horman, M. (2010).	Multivariate Analysis	Delivery Speed	No Difference

* ">"means the previous one is better than the latter one

3. METHODOLOGY

3.1 Research Design

The purpose of this study is to find out which project delivery system, Design-Build (DB) or Construction Management at-Risk (CMAR), has better cost and schedule performance. This study was designed as a two-phase study. In the first phase, the author used robust statistical analysis methods to analyze the group means of five metrics. First, the values of the five chosen measurements of 73 projects were calculated independently. The second step was to preprocess the data, calculate the values of five metrics, and test if the calculation results of metrics roughly obeyed the normal distribution; if not, the author took their logarithms and tested for normality. If the logarithms obeyed normal distributions, the study used the logarithms in the next steps. Third, the study used ANOVA to test if there was a statistically significant difference between the means of five metrics of DB projects and CMAR projects. Wilcoxon Signed Rank Test was also performed to check if the results of ANOVA were reliable. In the second phase is was to compare the results with the conclusions of previous studies.

3.1.1 Measurements

The measurements used to evaluate project cost and schedule performance in this study are the following:

a. Unit Cost = Actual Total Project Cost / Gross Square Feet (Konchar & Sanvido, 1998)

b. Construction Change Order Amount = Actual Total Project Cost - Projected Total Project Cost (Construction Industry Institute[CII], n.d.; Charoenphol et al., 2016; Konchar & Sanvido, 1998);
c. Project Cost Growth = Construction Change Order Amount / Projected Total Project Cost (CII, n.d.; Charoenphol et al., 2016; Konchar & Sanvido, 1998);
d. Change Order Factor = Construction Change Order Amount / Actual Total Project Cost (CII, n.d.; Charoenphol et al., 2016; Konchar & Sanvido, 1998);
e. Project Schedule Growth = (Actual Total Project Duration – Initial Predicted Project Duration) / Initial Predicted Project Duration (CII, n. d.)
f. Construction intensity (SF/day/1000) = Total Square Feet of Building / Final Design and Construction Duration/1000 (Engineering News Record, 2015)

Unit Cost(a), Project Cost Growth(c), and Change Order Factor(d) will be used to measure the cost performance of project delivery systems. The sample projects have various sizes and were built to fulfill different functions, making it meaningless to directly compare total costs among various projects. To minimize the influence on the final conclusion, the Unit Cost (a) is used instead of total costs to measure the cost performance of PDS. Project Cost Growth(c) and Change Order factor(d) are performance metrics that evaluate the cost control management. Cost Growth factor (d) tells how fast and how much actual project costs are growing above planned projected costs. Change Order factor (c) shows how much change orders affect the total project costs (Charoenphol et al., 2016). Similarly, projects that used fast-tracking construction methods could achieve shorter durations in a similar situation. To minimize the effect of other factors when testing the efficiency of the DB and CMAR in schedule control management, this study will use project Schedule Growth (e) and Construction Intensity (f) instead of actual durations as the measurements of project schedule performance. For metric (a)&(b), there is no conclusion on when higher or lower numbers are better; for metric (c)-(e), the lower calculation results represent a better performance than higher ones; for metric (f), the higher values are preferred.

3.1.2 Statistic

This study uses Sample Mean as the statistic to measure and reflect group attributes. The author planned to use sample projects and their costs and schedule data to make a reasonable implication toward the whole population. The two populations in this study are construction projects that used DB as their delivery methods, and projects that used CMAR. The ideal statistic should be the one which is able to reflect the "typical value" of a population. Then the study could compare the typical values of DB projects and CAMR projects and analyze the typical differences between the two groups. Mean and Median are both commonly-used statistics for representing typical value. They are both good indicators of the location of a typical value in a population. Median is a robust estimator that could be more efficient when wild outliers exist in a sample (Müller, 2000). Using Mean as the statistic will compromise the conclusions from the effects of wild outliers. However, Median as a statistic does not hold or reflect the attributes of a group; it only indicates the typical location of a typical value. Lehmann (1997) also pointed out that "the mean value provides a moderately better estimate of the central value than the median for the case of a Gaussian." As the author would test the normality of data and make the data obey normal distribution by taking the logarithms to achieve more confidence in the conclusion, Mean is more proper for this study. For these two reasons, the author chose to use Mean instead of Median as the statistic in this study.

3.1.3 Analysis of Variance

The statistical analysis method used in this study is Analysis of Variance (ANOVA). ANOVA tests if there are any significant differences among different group means. There are three assumptions for ANOVA, which means that to use ANOVA, the data must meet the three requirements: normality, independence of observations, and Homogeneity (equality of variances) (Snedecor & Cochran, 1967; Cochran & Cox, 1992; Anderson, Sweeney, & Williams, 1996; Howell, 2012). The author used the statistical software JMP to test if the data met these three requirements and perform the ANOVA test.

3.1.4 Nonparametric Test

If the data did not obey the normal distribution, the ANOVA test cannot be implemented, and nonparametric tests would be another available choice. The nonparametric test used in this study is Wilcoxon Signed Rank Test. Wilcoxon Signed Rank Test can be used to analyze if there are any significant differences between two group means, even data that do not obey the normal distribution. This study used the software JMP to perform Wilcoxon Signed Rank Test.

3.2 Data

3.2.1 Data Collection

The study used data provided by Dr. José L. Fernández-Solís. The data set includes the actual and planned unit cost, actual total costs, total gross square feet (GSF), and actual and planned total duration of 73 construction projects. An example data cell is shown below. All 73 projects were commercial buildings built in Texas between 2000-2017. Among the 73 projects, 16 of them used Design-Build as their delivery system and 57 projects used Construction Management at Risk. The sample projects used both Guaranteed Maximum Price (GMP) contracts and Competitive Sealed Proposal (CSV) contracts. 39 projects used CSP contracts and 34 used GMP contracts.

Table 3 Sample Data Cell

<table>
<tr><td>Project No.</td><td colspan="3">Year</td><td colspan="3">CIP</td><td></td></tr>
<tr><td>Contract Type</td><td colspan="3">Project Delivery System</td><td colspan="3">Project Type</td><td>Duration</td></tr>
<tr><td rowspan="2">GSF</td><td colspan="3">Cost-$</td><td colspan="3">Time - months</td><td rowspan="2">Unit Cost</td></tr>
<tr><td>Plan</td><td>Actual</td><td>Delta</td><td>Plan</td><td>Actual</td><td>Delta</td></tr>
<tr><td>Totals</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

3.2.2 Data Validation

The documentation and calculation of the 73 sample projects were carefully checked. Project No. 42 was found out to have been documented incorrectly. Its actual unit cost was $375/GSF, and the GSF was 12,000,000; the total cost should have been $375 times 12,000,000 which equals 4500 million. However, it was recorded as 450 million. This project thus was excluded and was not used in the future statistical analysis. The final sample dataset of this study consisted of 72 projects, 15 of which used DB and 57 of which used CMAR.

3.2.3 Data Preprocessing

3.2.3.1 Sample Grouping

The goal of this study is to analyze the cost and schedule differences between construction projects using DB and CMAR. However, the 72 sample projects used both GMP contracts and CSV contracts. Different contract types affect the final cost and schedule management of construction projects. So instead of grouping the 72 projects only by the PDS type, the study divided them into three groups using both PDS types and Contract types. The three sample groups are projects using DB and CSV (Group DBCSV), projects using CMAR and CSV (Group CMARCSV), and projects using CMAR and GMP (Group CMARGMP).

3.2.3.2 Time and Location Adjustment

The 72 projects were completed and delivered in various years. To minimize the influence of time value and inflation on project costs, the study adjusted all costs and used their present value in 2016 for future statistical analysis. The time value adjustment tool was provided by a Master's student, Daniel Wheeler (B. S. Agribusiness Finance, Texas A&M University). This table can be found in Appendix A. Wheeler suggested that because of the economic crisis in 2008, using inflation rates might not reflect the true costs of projects completed in those years. The author thus chose the average Escalation Rate of the last ten years when adjusting the time value of project costs. As all 72 projects were built in Texas, no location adjustment was needed.

3.2.3.3 Calculation of Measurements

After dividing data projects into three groups and adjusting their costs time value, the five metrics in 3.1.1 were calculated to four decimal places. Examples are shown below:

Table 4 Sample of Measurements Calculations

NO	Year	Group	Unit Cost	Change Order	Cost Growth	Project Schedule Growth	Construction Intensity
1	2000	CMARCSP	241.6740	-0.0115	-0.0114	0.0000	7.7143
2	2000	CMARCSP	236.7914	-0.0273	-0.0265	0.0417	5.7200
3	2014	CMARCSP	304.5174	0.0129	0.0131	-0.0448	7.6094
4	2008	CMARCSP	266.5987	0.0074	0.0074	0.0000	11.0000
5	2010	CMARCSP	731.3483	0.0241	0.0247	0.0526	5.0000
6	2009	CMARGMP	228.4351	0.0236	0.0241	0.0769	11.5357
7	2011	CMARGMP	289.8994	-0.0024	-0.0024	-0.0130	10.0526
8	2008	CMARGMP	362.8635	0.0034	0.0034	0.0000	17.7333
9	2017	CMARGMP	247.7262	0.0051	0.0052	0.0204	6.0000
10	2012	CMARGMP	874.3607	0.0067	0.0067	0.0000	6.6667
11	2011	DBGMP	244.0333	-0.0250	-0.0244	0.0588	41.6667
12	2010	DBGMP	229.4921	0.0110	0.0111	0.0417	20.0000
13	2010	DBGMP	190.1506	0.0053	0.0053	0.0500	55.2381
14	2010	DBGMP	229.4921	0.0110	0.0111	0.0417	20.0000
15	2010	DBGMP	190.1506	0.0053	0.0053	0.0500	55.2381

4. ANALYSIS AND FINDINGS

4.1 Statistical Analysis

4.1.1 ANOVA and Results

4.1.1.1 Hypothesis

The null hypothesis for this study is that there is no statistically significant difference between DB projects and CMAR projects in their cost and duration performances. The test hypothesis is that differences do exist. The null hypothesis and test hypothesis for each research metric will be:

$H_{0\ of\ A}$: There is no statistically significant difference among the means of unit costs of group DBCSV, group CAMRCSV, and group CMARGMP.

H_A: There is a statistically significant difference among the means of unit costs of group DBCSV, group CAMRCSV, and group CMARGMP.

$H_{0\ of\ B}$: There is no statistically significant difference among the means of project total cost growth of group DBCSV, group CAMRCSV, and group CMARGMP.

H_B: There is a statistically significant difference among the means of project total cost growth of group DBCSV, group CAMRCSV, and group CMARGMP.

$H_{0\ of\ C}$: There is no statistically significant difference among the means of change order cost factor of group DBCSV, group CAMRCSV, and group CMARGMP.

H_C: There is a statistically significant difference among the means of change order cost factor of group DBCSV, group CAMRCSV, and group CMARGMP.

$H_{0\ of\ D}$: There is no statistically significant difference among the means of project schedule growth of group DBCSV, group CAMRCSV, and group CMARGMP.

H_D: There is a statistically significant difference among the means of project schedule growth of group DBCSV, group CAMRCSV, and group CMARGMP.

$H_{0\ of\ E}$: There is no statistically significant difference among the means of the construction intensity of group DBCSV, group CAMRCSV, and group CMARGMP.

H_E: There is a statistically significant difference among the means of construction intensity of group DBCSV, group CAMRCSV, and group CMARGMP.

4.1.1.2 Normal Distribution

To use ANOVA, the data must meet the three requirements: independence of observations, normality, and equal variance. First, it is obvious that the sample projects are independent of each other: knowing the variables of one project does not necessarily predict any information about other projects. So the independence assumption is satisfied. This study used the Normal Quantile Plot in JMP to test if the data obey the normal distribution. The results show that the distribution of three groups' change order factor, cost growth, and project schedule growth value could be assumed as normal; construction intensity and unit cost were skewed, necessitating the author used their logarithms to perform the test again. The second test showed normality for construction intensity and unit cost. The study thus used the logarithms of unit cost and construction intensity in further analysis. The original Normal Quantile Plots of unit cost and construction intensity are included in Appendix B. The final Normal Quantile Plots of five measurements by three groups are shown below:

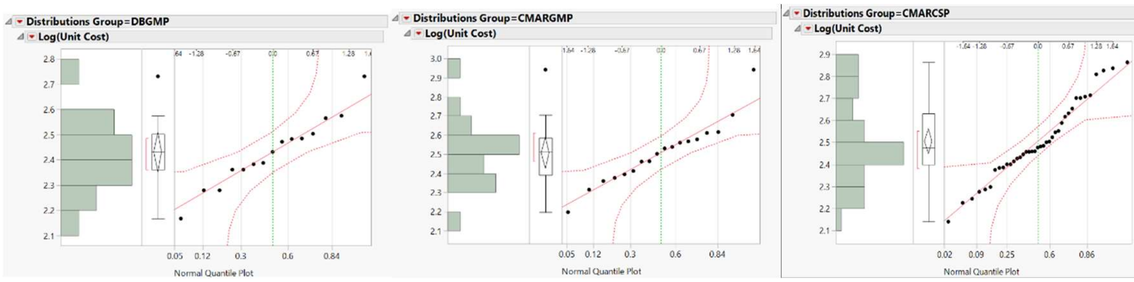

Figure 1 Normal Quantile Plots of Log (Unit Cost)

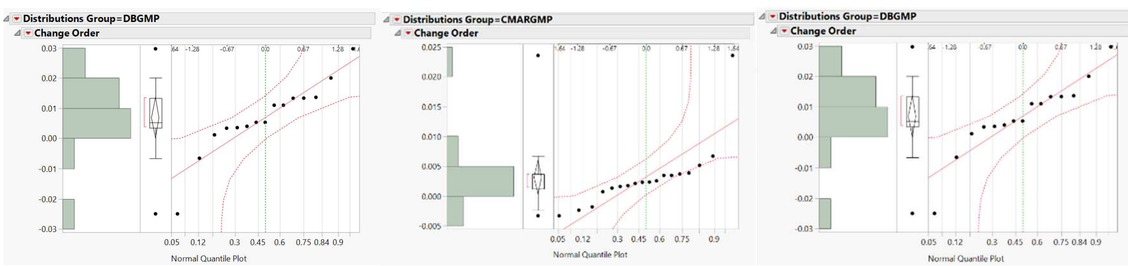

Figure 2 Normal Quantile Plots of Change Order

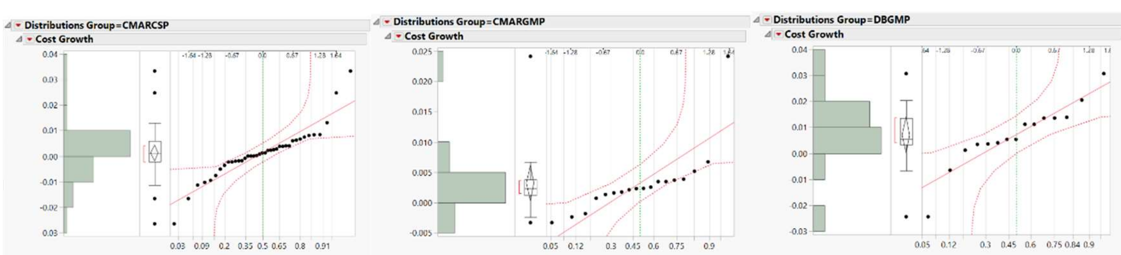

Figure 3 Normal Quantile Plots of Cost Growth

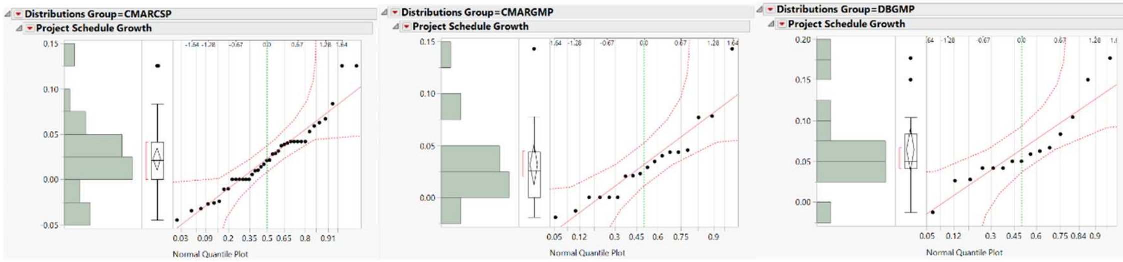

Figure 4 Normal Quantile Plots of Project Schedule Growth

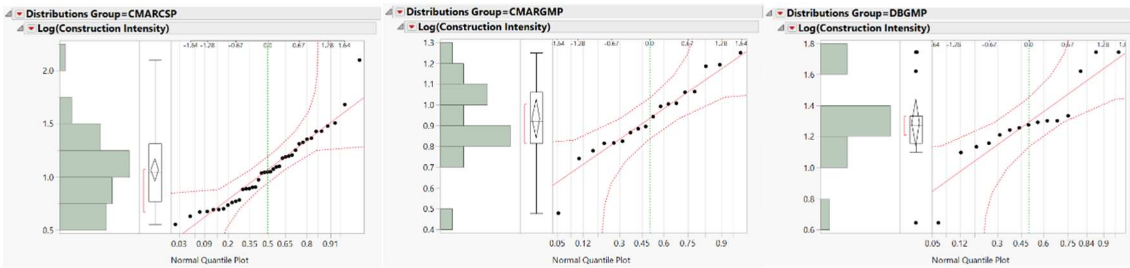

Figure 5 Normal Quantile Plots of Log (Construction Intensity)

4.1.1.3 ANOVA Test Results

As the data could be assumed that meet requirements of ANOVA, the study then used ANOVA test to analyze the sample data with the help of JMP.

4.1.1.3.1 Logarithm of Unit Cost

The ANOVA test results of the logarithms of unit costs of the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 5 ANOVA Results of Log(Unit Cost) in Three Groups (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.0659419	0.032971	1.1838	0.3123
Error	69	1.9218310	0.027853		
C. Total	71	1.9877729			

Table 6 ANOVA Results of Log(Unit Cost) in Three Groups (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
CMARGMP	DBGMP	0.0760043	0.0583456	-0.063752	0.2157608	0.3986
CMARCSP	DBGMP	0.0737824	0.0507051	-0.047673	0.1952376	0.3188
CMARGMP	CMARCSP	0.0022219	0.0475556	-0.111689	0.1161329	0.9988

The p-value is 0.3123 and larger than 0.1; therefore the null hypothesis that there is no significant difference among DBGMP, CMARGMP, and CMARCSP cannot be rejected. From the Table 6, it is obvious that the individual three-group' t-tests also show the same conclusion. Considering that contract type may have affected the results, the author did another ANOVA test by grouping sample projects only by project delivery system types (both passed the normality test). The results are shown below:

t Test

DB-CMAR

Assuming equal variances

Difference	-0.07448	t Ratio	-1.54905
Std Err Dif	0.04808	DF	70
Upper CL Dif	0.02142	Prob > |t|	0.1259
Lower CL Dif	-0.17038	Prob > t	0.9371
Confidence	0.95	Prob < t	0.0629

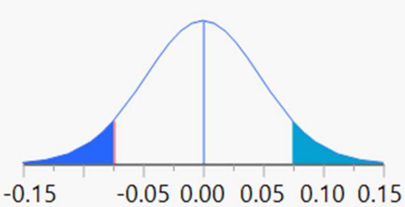

Figure 6 ANOVA Results of Log(Unit Cost) in Two Groups

The p-value is larger than 0.1; the only significant p-value is from a one-tail test where the author has 90% confidence that the mean of logarithms of the unit costs of DB is smaller than CMAR. However, as in this test the DB projects and CMAR projects used different contract types, it is not certain that this difference is caused only by different PDS.

From the box plot above (Figure 1), there are two outliers that affect the results. The author excluded the two outliers and applied ANOVA again to see if the results changed:

Table 7 ANOVA Results of Log(Unit Cost) in Three Groups without Outliers (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.0933675	0.046684	1.9247	0.1539
Error	67	1.6251235	0.024256		
C. Total	69	1.7184910			

Table 8 ANOVA Results of Log(Unit Cost) in Three Groups without Outliers (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
CMARCSP	DBGMP	0.0951801	0.0485230	-0.021124	0.2114844	0.1298
CMARGMP	DBGMP	0.0718010	0.0562080	-0.062923	0.2065254	0.4128
CMARCSP	CMARGMP	0.0233791	0.0452630	-0.085111	0.1318695	0.8636

The p-value is smaller, but still larger then 0.1, which indicates that the null hypothesis still cannot be rejected.

4.1.1.3.2 Change Order

The ANOVA test results of change order factors of the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 9 ANOVA Results of Change Order Factors in Three Groups (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.00035496	0.000177	1.9282	0.1532
Error	69	0.00635115	0.000092		
C. Total	71	0.00670611			

Table 10 ANOVA Results of Change Order Factors in Three Groups (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARCSP	0.0057066	0.0029149	-0.001275	0.0126887	0.1305
DBGMP	CMARGMP	0.0037201	0.0033541	-0.004314	0.0117543	0.5118
CMARGMP	CMARCSP	0.0019865	0.0027338	-0.004562	0.0085349	0.7486

The p-value is too large to reject the null hypothesis: there is no significant difference among the three group means of change order factors.

The author then performed a second ANOVA test: this time the sample projects were only grouped by their PDS types. The test results are shown below:

t Test

DB-CMAR

Assuming equal variances

Difference	0.00508	t Ratio	1.830569
Std Err Dif	0.00277	DF	70
Upper CL Dif	0.01061	Prob > |t|	0.0714
Lower CL Dif	-0.00045	Prob > t	0.0357*
Confidence	0.95	Prob < t	0.9643

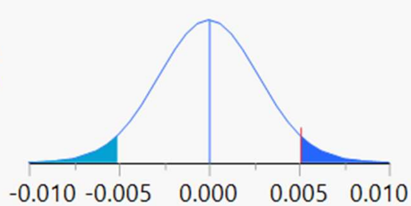

Figure 7 ANOVA Results of Change Order Factors in Two Groups

The p-value for the two-tailed test is 0.0714, which is smaller than 0.1; the p-value for the one-tailed test is 0.0357; so the conclusion can be made with 90% confidence that there is a significant difference between the means of change order factors of DB projects and

CMAR projects; at 95% confidence, the means of change order factors of DB projects are larger than CMAR projects. However, as the DB projects and CMAR projects used different contract types, it is hard to conclude whether or not this difference is caused by different PDS.

To exclude the effect of eight outliers and make the conclusion more convincing, the outliers in three groups are excluded and the new ANOVA test results are shown below:

Table 11 ANOVA Results of Change Order Factors in Three Groups without Outliers (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.00041777	0.000209	7.4628	0.0013*
Error	61	0.00170737	0.000028		
C. Total	63	0.00212514			

Table 12 ANOVA Results of Change Order Factors in Three Groups without Outliers (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARCSP	0.0066184	0.0017184	0.002490	0.0107463	0.0008*
DBGMP	CMARGMP	0.0052870	0.0019755	0.000541	0.0100324	0.0255*
CMARGMP	CMARCSP	0.0013314	0.0015966	-0.002504	0.0051668	0.6836

The p-values above indicated that with more than 99% confidence there is a statistically significant difference in the group means of change order factors of the three groups when the outliers were excluded. More specifically, at 99% confident level, the mean of change order factors of DBGMP group is larger than CMARCSP group by 0.0025 to 0.0107. At

97% confident level, the mean of change order factors of DBGMP group is larger than CMARGMP group by 0.0005 to 0.01.

To verify the conclusions, the author tested the residuals and the results are shown below:

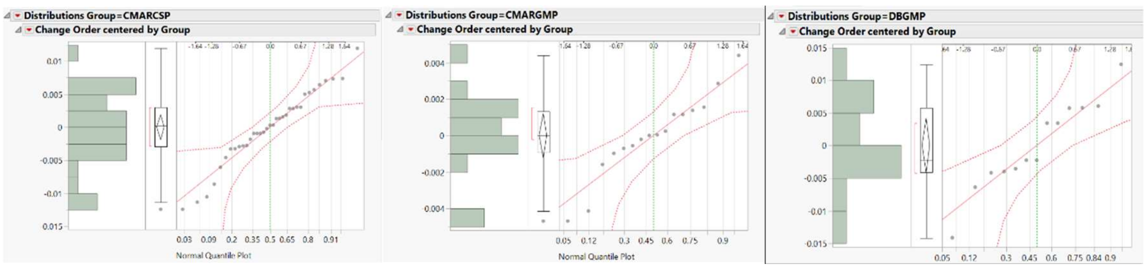

Figure 8 Normal Quantile Plots of Residuals of Change Order factors

From the figures above, it can be assumed that the three distributions are normal and the previous conclusions on change order factors are reliable.

4.1.1.3.3 Cost Growth

The ANOVA test results of cost growth factors of the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 13 ANOVA Results of Cost Growth Factors in Three Groups (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.00036589	0.000183	1.9599	0.1486
Error	69	0.00644088	0.000093		
C. Total	71	0.00680678			

Table 14 ANOVA Results of Cost Growth Factors in Three Groups (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARCSP	0.0058006	0.0029354	-0.001231	0.0128319	0.1258
DBGMP	CMARGMP	0.0038694	0.0033777	-0.004221	0.0119602	0.4896
CMARGMP	CMARCSP	0.0019312	0.0027531	-0.004663	0.0085257	0.7634

The p-value is not small enough to reject the null hypothesis that there is no significant difference among the means of cost growth factors of the three groups.

Another ANOVA test was performed where the sample projects were only separated into two groups: DB and CMAR. The test results are shown below:

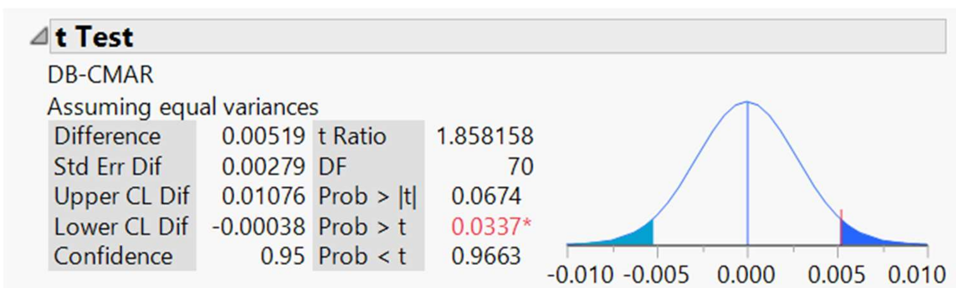

Figure 9 ANOVA Results of Cost Growth Factors in Two Groups

From the p-values above, there is more than 95% confidence to conclude that the mean of cost growth of DB projects is larger than CMAR projects. However, the difference cannot be credited to PDS because the sample projects used different types of contracts.

To minimize the influence of eight outliers, a new ANOVA with outliers excluded was performed and the results are shown in Table 15 and 16:

Table 15 ANOVA Results of Cost Growth Factors in Three Groups without Outliers (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.00042733	0.000214	7.5567	0.0012*
Error	61	0.00172476	0.000028		
C. Total	63	0.00215209			

Table 16 ANOVA Results of Cost Growth Factors in Three Groups without Outliers (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARCSP	0.0066905	0.0017271	0.002542	0.0108393	0.0008*
DBGMP	CMARGMP	0.0053800	0.0019855	0.000610	0.0101495	0.0234*
CMARGMP	CMARCSP	0.0013105	0.0016047	-0.002544	0.0051653	0.6942

The p-value is 0.0012, which means that when the outliers are excluded, at more than 99% confidence level, there is a significant difference among the three groups. More specifically, when the outliers in three groups are excluded, at more than 99% confidence level, the means of cost growth factors of DBGMP group is larger than the CMARCSP group by 0.0025 to 0.0108; at 97% confidence level, the means of cost growth factors of DBGMP is larger than the CMARGMP group by 0.0006 to 0.0101.

To determine if the conclusions were reliable, the author tested the residuals and the results are shown below:

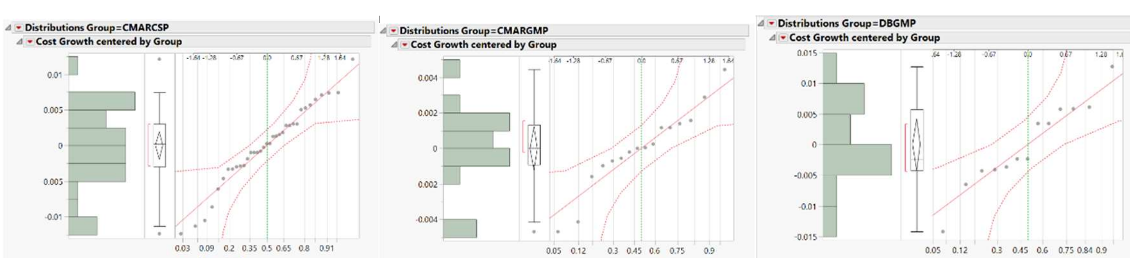

Figure 10 Normal Quantile Plots of Residuals of Cost Growth Factors

From the figures above, it can be assumed that the three distributions are normal and the previous conclusions on cost growth factors are reliable.

4.1.1.3.4 Project Schedule Growth

The ANOVA test results of schedule growth factors for the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 17 ANOVA Results of Project Schedule Growth in Three Groups (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	0.01937139	0.009686	5.7852	0.0048*
Error	69	0.11552082	0.001674		
C. Total	71	0.13489221			

Table 18 ANOVA Results of Project Schedule Growth in Three Groups (2)

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARCSP	0.0421795	0.0124315	0.012402	0.0719570	0.0033*
DBGMP	CMARGMP	0.0331536	0.0143048	-0.001111	0.0674181	0.0600
CMARGMP	CMARCSP	0.0090258	0.0116594	-0.018902	0.0369537	0.7201

The p-value (Prob > F = 0.0048) indicates that there are significant differences among the three groups: at 99% confidence level, the group mean of DBGMP group is higher than CMARCSP by 0.0124 to 0.072; at 94% confidence level, the group mean of DBGMP is higher than CMARGMP by -0.0011 to 0.0674.

To verify that the conclusions are reliable, the author tested the residuals and the results are shown below:

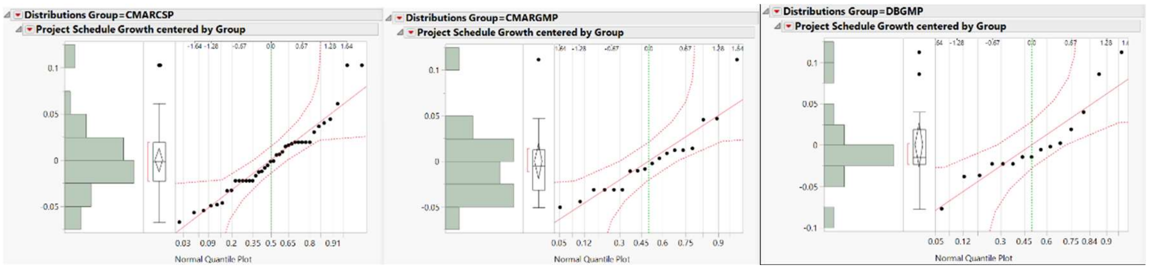

Figure 11 Normal Quantile Plots of Residuals of Project Schedule Growth

From the figures above, it can be assumed that the three distributions are normal and the previous conclusions on project schedule growth factors are reliable.

4.1.1.3.5 Logarithm of Construction Intensity

The ANOVA test results of the log value of construction intensity for the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 19 ANOVA Results of Construction Intensity in Three Groups (1)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	1.0615753	0.530788	6.3248	0.0030*
Error	69	5.7906012	0.083922		
C. Total	71	6.8521766			

Table 20 ANOVA Results of Construction Intensity in Three Groups (2)

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
DBGMP	CMARGMP	0.3572750	0.1012774	0.114683	0.5998669	0.0021*
DBGMP	CMARCSP	0.2259004	0.0880149	0.015076	0.4367244	0.0329*
CMARCSP	CMARGMP	0.1313746	0.0825479	-0.066354	0.3291034	0.2561

The p-value is 0.003, which indicates that at 99.997% confident level, there are significant differences among the three groups: at 99.9% confidence level, the mean of logarithm of construction intensity of the DBGMP group is higher than the CMARGMP group; at 96% confident level, the mean of logarithm of construction intensity of the DBGMP group is higher than the CMARCSP group.

To verify that the conclusions are reliable, the author tested the residuals and the results are shown below:

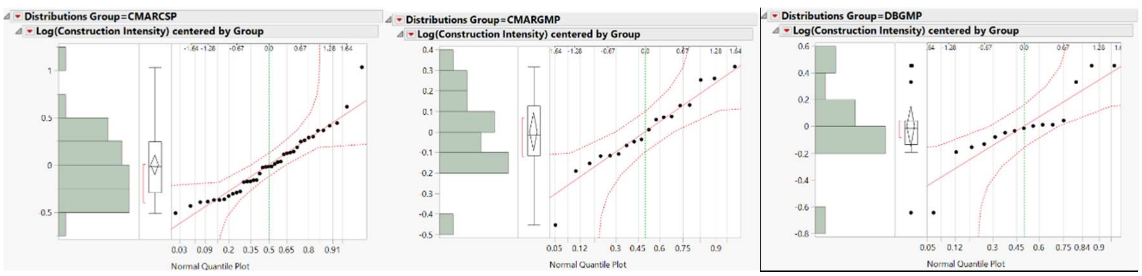

Figure 12 Normal Quantile Plots of Residuals of Construction Intensity

From the figures above, it can be assumed that the three distributions are normal and the previous conclusions on construction intensity are reliable.

4.1.2 Nonparametric Test and Results

To verify the previous conclusions made from ANOVA test results, a nonparametric test, the Wilcoxon Signed Rank Test was also performed.

4.1.2.1 Logarithm of Unit Cost

The Wilcoxon Signed Rank Test results for the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 21 Wilcoxon Test Results of Log(Unit Cost) in Three Groups

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.2140	2	0.3306

The p-value is too large to reject the null hypothesis that there is no significant difference among the three groups.

The table below shows the results of the test with data samples divided into two groups, DB and CMAR:

Table 22 Wilcoxon Test Results of Log(Unit Cost) in Two Groups

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.1808	1	0.1397

It is still not significant.

The table below shows the test results with the outliers excluded in the three groups

Table 23 Wilcoxon Test Results of Log(Unit Cost) in Three Groups without Outliers

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.2777	2	0.1942

The p-value is still not significant to make any conclusions.

4.1.2.2 Change Order

The Wilcoxon Signed Rank Test results for the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 24 Wilcoxon Test Results of Change Order Factors in Three Groups

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.2511	2	0.0266*

The p-value above indicates that without the effects from outliers, there are significant differences among the three groups. This supports the previous conclusion of the ANOVA tests without outliers.

When the outliers are excluded in the three groups, the p-value is even smaller and the confidence level rises to more than 99%:

Table 25 Wilcoxon Test Results of Change Order Factors in Three Groups without Outliers

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.4311	2	0.0054*

4.1.2.3 Cost Growth

The Wilcoxon Signed Rank Test results for the three groups (CMARGMP, CMARCSP, and DBCSP) are shown below:

Table 26 Wilcoxon Test Results of Cost Growth Factors in Three Groups

1-Way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
6.7831	2	0.0337*

The p-value above indicates that without the effects from outliers, there are significant differences among the three groups. This supports the previous conclusion of the ANOVA tests without outliers.

When the outliers are excluded in the three groups, the p-value is even smaller and the confidence level rises to more than 99.9%:

Table 27 Wilcoxon Test Results of Cost Growth Factors in Three Groups without Outliers

1-Way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
10.4311	2	0.0054*

4.1.2.4 Project Schedule Growth

The p-value from the Wilcoxon Signed Rank Test supports the previous conclusions made from the ANOVA tests result: there are significant differences among the means of schedule growth factors of CMARGMP, CMARCSP, and DBCSP groups.

Table 28 Wilcoxon Test Results of Project Schedule Growth in Three Groups

1-Way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
10.6620	2	0.0048*

4.1.2.5 Logarithm of Construction Intensity

The p-value from the Wilcoxon Signed Rank Test supports the previous conclusions made from the ANOVA tests result: there are significant differences among the means of logarithm values of construction intensity of CMARGMP, CMARCSP, and DBCSP groups.

Table 29 Wilcoxon Test Results of Construction Intensity in Three Groups

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
12.5789	2	0.0019*

4.2 Summary

A summary table of the above results is presented in Table 30. It is clear that no matter what kind of tests are applied, including outliers or not, how the samples are grouped, there is no significant difference between the unit cost of DB projects and CMAR projects.

At 94% and 96% confidence level, the schedule growth factor and construction intensity of DB projects are larger than CMAR projects when using the same type of contracts, which indicates the possibility that CMAR projects perform better in schedule growth control and DB projects perform better at construction intensity; at more than 99% confident level, the schedule growth factor and construction intensity of DB projects is larger than CMAR projects when using different types of contracts, but such differences are not necessarily caused by PDS. The test results of the Wilcoxon Signed Rank Test on schedule growth and construction intensity support the same conclusions.

There is no significant difference in the means of change order factor and cost growth factor between CMAR and DB projects when they used different types of contracts and when the outliers are included. However, when the outliers are excluded, the test results show that at more than 97% confidence level, both change order factors and cost growth factors of DB projects are larger than CMAR projects when using the same type of contracts, which indicates the possibility that CMAR performs better in change order control and cost growth control; at more than 99% confidence level, the change order factor and cost growth factor of DB projects are larger than CMAR when using different types of contracts, although such difference may not be purely caused by PDS types. The Wilcoxon test results indicate that at more than 97% confidence level, there are differences among the means of change order factors and cost growth of the three groups. Since the Wilcoxon Signed Rank Test minimizes the effect of outliers, the Wilcoxon test results in this study can be viewed as the evidence that the previous conclusions regarding DB and CMAR without outliers are reasonable.

Table 30 Summary of ANOVA & Wilcoxon Tests Results

Factor	Grouping	Include Outliers?	ANOVA	Wilcoxon***
Unit Cost*	CMARCSP CMARGMP DBGMP	Yes	No difference**	No difference**
		No	No difference**	No difference**
	CMAR DB	Yes	No difference**	No difference**
Change Order	CMARCSP CMARGMP DBGMP	Yes	No difference**	97.34%
		No	99.92% DBGMP>CMARCSP	99.46%
			97.45% DBGMP>CMARGMP	
	CMAR DB	Yes	96.43% DB>CMAR	N/A
Cost Growth	CMARCSP CMARGMP DBGMP	Yes	No difference**	96.63%
		No	99.92% DBGMP>CMARCSP	99.46%
			97.66% DBGMP>CMARGMP	
	CMAR DB	Yes	96.63% DB>CMAR	N/A
Schedule Growth	CMARCSP CMARGMP DBGMP	Yes	99.67% DBGMP>CMARCSP	99.52%
			94.00% DBGMP>CMARGMP	N/A
Construction Intensity*	CMARCSP CMARGMP DBGMP	Yes	99.79% DBGMP>CMARGMP	99.81%
			96.71% DBGMP>CMARCSP	N/A

*The study used the logarithm of the factors in ANOVA and Wilcoxon tests.

**"No difference" refers to at 90% confidence level, the null hypothesis can't be rejected.

***The content level in Wilcoxon test only indicates there are differences among the groups, but did not indicate which is larger.

4.3 Comparison

Table 31 shows the comparison of the conclusions of this study and previous studies. This study found that there is no significant difference between unit costs of DB projects and CMAR projects, while Konchar and Sanvido (1998) claimed that the unit costs of DB projects actually are smaller than CMAR projects.

When the outliers in the dataset were excluded, this study showed that the CMAR projects have better performance on change order and cost growth management, which is the same as the conclusions of Charoenphol et al. (2016); Shakya (2013) claimed that there is no difference in the two factors (change order and cost growth) between DB projects and CMAR projects; Konchar and Sanvido (1998) concluded that DB projects have a better performance on cost growth factors while Korkmaz et al. (2010) and Maharjan (2013) did not find a difference.

Both this study and the study of Konchar and Sanvido (1998) found that DB projects have a better performance on construction intensity, while no significant difference was found in the studies by Kormaz et al. (2010) and Shakya (2013).

This study's conclusion is contradicted with previous studies' conclusions on schedule growth factors: Konchar and Sanvido (1998) concluded that DB projects did better on schedule growth management while the test results of this study show that CMAR projects did better. However, no difference was found in the study of Maharjan (2013).

This study reached conclusions that conflict with those of previous studies. One important reason is that the sample projects used are from different sectors. This study used commercial building projects, and previous researches used projects from wastewater, transportation, and other sectors. In fact, this study has different conclusions with previous studies might indicate that one type of project delivery system could be more efficient in one sector than the others.

Another reason is that this study divided projects into groups by the contract type and the project delivery systems type. If the sample projects in previous studies used different contract types, the conclusions would be different.

Finally, all of the sample projects used in this study were built in Texas, while previous studies used sample projects located across the United States. Different locations and built years would affect the final conclusions.

Table 31 Comparison of Results with Previous Studies

Authors	Method	Compared Factors	Conclusion*
Charoenphol, D., Stuban, S. M., & Dever, J. R. (2016).	ANOVA	Cost Growth & Change Order	CMAR>DB
Shrestha, P. P., Maharjan, R., Shakya, B., & Batista, J. (2014).	Survey	Satisfaction Level of Owners	DB>CMAR
Shakya, B. (2013).	ANOVA	Contract Award Cost Growth	DB>CMAR
		Total cost growth	No Difference
		Change Order &Construction Intensity	No Difference
Maharjan, R. (2013).	Survey	Schedule Growth & Cost Growth	No Difference
		Satisfaction level	No Difference
Konchar, M., & Sanvido, V. (1998).	ANOVA; Liner Regression Models	Unit Cost	DB>CMAR
		Construction speed	DB>CMAR
		Delivery speed	DB>CMAR
		Cost growth	DB>CMAR
		Schedule Growth	DB>CMAR
Korkmaz, S., Riley, D., & Horman, M. (2010).	Multivariate Analysis	Delivery Speed	No Difference
This Study	ANOVA& Wilcoxon Test	Unit Cost	No Difference
		Construction Intensity	DB>CMAR
		Schedule Growth	CMAR>DB
		Change Order &Cost Growth	CMAR>DB without outliers

* ">"means the previous one is better than the latter one

4.4 Limitations & Assumptions

The conclusions of this study suffer from the following limitations:

a. The sample size is relatively small, the conclusions may not convincingly reflect the attributes of the true populations.

b. Technically, every project is unique and has its own characteristics, making it difficult, if not impossible, to ensure all the other variables remain the same. This leads to the second limitation of this study;

c. The way the sample projects were not randomly selected.

d. The chosen measurements have their own deficiencies and sometimes fail to accurately measure the cost and schedule performance of construction projects.

e. The deficiencies of the chosen economic methods used to adjust costs value from various years to the same year would affect the final conclusions;

f. There is more than one factor affecting owners' decisions when choosing the project delivery systems for construction projects. The owners may choose to use one particular project delivery system because they think this PDS is effective in controlling change order amounts or schedule baseline. In other words, PDS in a construction project are correlated with other variables, including cost, schedule, project size, and other. When multiple independent variables exist and correlated, the test results of univariate analysis would not be as convincing. The conclusions of this study would be more convincing if Multivariate Analysis Methods were applied to analyze the importance of the correlated variables in this study in predicting the dependent variables (Abdi, 2003). However, because of the lack of data, the study could not perform such tests.

5. CONCLUSION AND FUTURE WORK

This work designed a comparative study between the cost and schedule performances of DB projects and CMAR projects. Unit Cost, Change Order, Cost Growth, Schedule Growth, and Construction Intensity are five metrics used to evaluate the projects' cost and schedule performances. With the help of ANOVA and Wilcoxon Signed Rank Test, the author was able to find that CMAR projects may perform better on schedule and cost while DB projects have advantages on construction intensity in the real world.

The future work could be done in the following areas:

a. The conclusions are only made toward commercial construction projects in Texas. Future studies could use projects across the United States from all sectors to do a comparison between Design-Build and Construction Management at Risk;

b. Now that the comparison has been done between DB and CMAR projects, the future researches can start analyzing the reasons behind the results: why do CMAR projects have better performance on project cost management? why do DB projects have an advantage on construction intensity? The future studies can be made in the explanation of the comparison results of DB and CMAR, and find out the casual relationship;

c. Because of the data size is relatively small, this study did not group projects by their size. For future study, when there are enough data, the researchers could divide projects by their project size, and compare the projects that have the same size but different project delivery systems to see what would the conclusion be;

d. When conducting Design Build and Construction Management at Risk comparison studies, the dependent variables like cost and duration are correlated. For example, in some construction projects, the larger the budget is, the longer the duration is. In such circumstance, a Multivariate analysis methods called cluster analysis should be applied to identify groups variables that share similar attribute and reach out more convincing conclusions.

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APPENDIX A

The time value adjustment tool used in this study is provided by Daniel Wheeler, which is shown as following:

Legend:	
Input	**Output**

Discounted Project Value Calculator			
Use:	**Project Cost TVM Calculator**		
Rate Multiplier:	**Annual Escalation Rate**	**or**	**Annual US Inflation Rate**
Source:	**RS Means**		**US B.L.S.**

Select:	Rate Type	Average Type		Rate Type	Average Type
	Escalation Rate	**Last 10-Year**		**Escalation Rate**	**Last 10-Year**
	7.77%			2.25%	
	Historical Project: Present Value			**Current Project: Future Value**	
	Original Project Cost			*Present Value Project Cost*	
	$ 48,000,000.00			$ 48,000,000.00	
	Year Built		*Current Year*	*Project to year...*	
	1981		2017	2051	
	Project Present Value			*Future Project Value*	
	$709,771,927.08			**$102,278,552.25**	

APPENDIX B

The original Normal Quantile Plots of Unit Cost and Construction Intensity are shown as following: