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

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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 the change order, cost growth, and schedule growth. And there is no difference in unit cost.

KEY WORDS: Design Build, Project Management at Risk, Cost and Schedule, Case studies

INTRODUCTION

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 et al. 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.

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), to perform design and construction work in a separate way. 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).

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 et al. 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 and 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.

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 and Kell 2008; Shakya 2013; Konchar and 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. et al. (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 et al. (2003) showed that using DB as a project delivery method might bring timesaving benefits, but with regard to cost savings and higher productivity, there was no significant difference always between DB projects and DBB projects (Ibbs et al. 2003).

REVIEW OF LITERATURE

Col 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 the work of Konchar and Sanvido (1998):

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 et al. (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 et al. (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 et al. (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.

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 and 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.

METHODOLOGY

Data

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. The study used data provided by Dr. José L. Fernández-Solís. The dataset includes the actual and planned unit cost, actual total costs, total gross square feet (GSF), and actual and planned total duration of 73 commercial buildings built in Texas between 2000-2017. 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). As all 73 projects were built in Texas, no location adjustment was needed.

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. The documentation and calculation of the 73 sample projects were carefully checked. Project No. 42 was found out to have been documented incorrectly and was excluded. The final sample dataset of this study consisted of 72 projects, 15 of which used DB and 57 of which used CMAR. 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).

Measurements

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

Unit Cost = Actual Total Project Cost / Gross Square Feet (Konchar and Sanvido 1998) (1)

Construction Change Order Amount = Actual Total Project Cost - Projected Total Project Cost (Construction Industry Institute[CII] n.d.; Charoenphol et al. 2016; Konchar and Sanvido 1998) (2)

Project Cost Growth = Construction Change Order Amount / Projected Total Project Cost (CII n.d.; Charoenphol et al. 2016; Konchar and Sanvido 1998) (3)

Change Order Factor = Construction Change Order Amount / Actual Total Project Cost (CII n.d.; Charoenphol et al. 2016; Konchar & Sanvido 1998) (4)

Project Schedule Growth = (Actual Total Project Duration – Initial Predicted Project Duration) / Initial Predicted Project Duration (CII n. d.) (5)

Construction intensity (SF/day/1000) = Total Square Feet of Building / Final Design and Construction Duration/1000 (Engineering News Record 2015) (6)

Unit Cost (1), Project Cost Growth (3), and Change Order Factor (4) 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 (1) is used instead of total costs to measure the cost performance of PDS. Project Cost Growth (3) and Change Order factor (4) are

performance metrics that evaluate the cost control management. Cost Growth factor (4) tells how fast and how much actual project costs are growing above planned projected costs. Change Order factor (3) 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 (5) and Construction Intensity (6) instead of actual durations as the measurements of project schedule performance. For metric (1) & (2), there is no conclusion on when higher or lower numbers are better; for metric (3)-(5), the lower calculation results represent a better performance than higher ones; for metric (6), the higher values are preferred.

Statistics and Statistical Tests

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. 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.

The author used Analysis of Variance (ANOVA) to analyze the group means of five metrics. ANOVA is a statistical tool that tests if there are any significant differences among different group means. First, the values of the five chosen measurements of 72 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.

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:

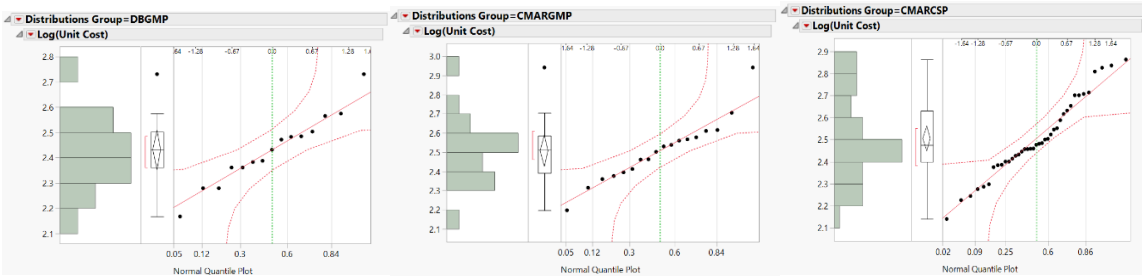


Figure 1 Normal Quantile Plots of Log (Unit Cost)

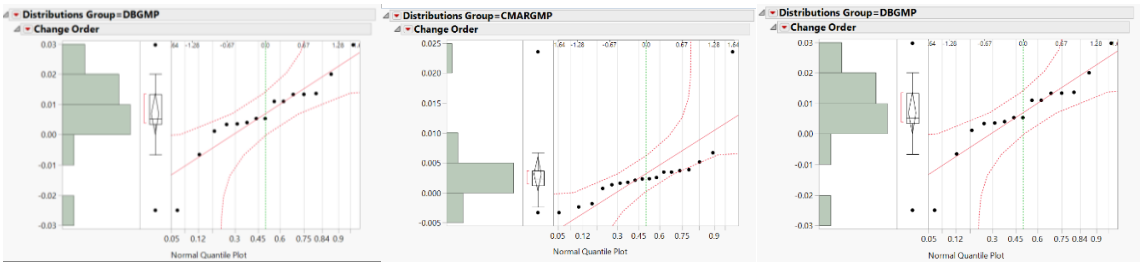


Figure 2 Normal Quantile Plots of Change Order

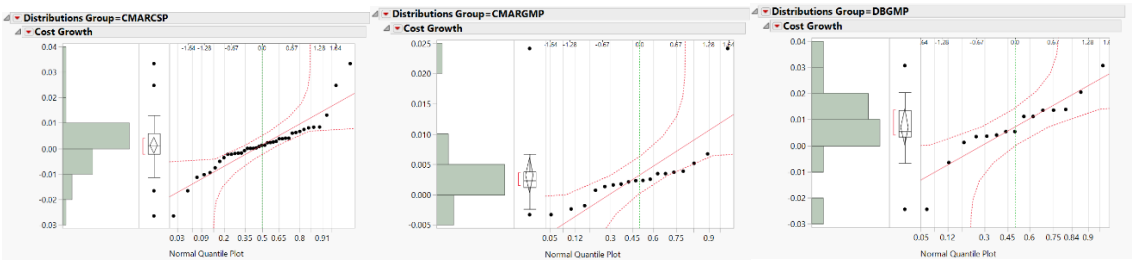


Figure 3 Normal Quantile Plots of Cost Growth

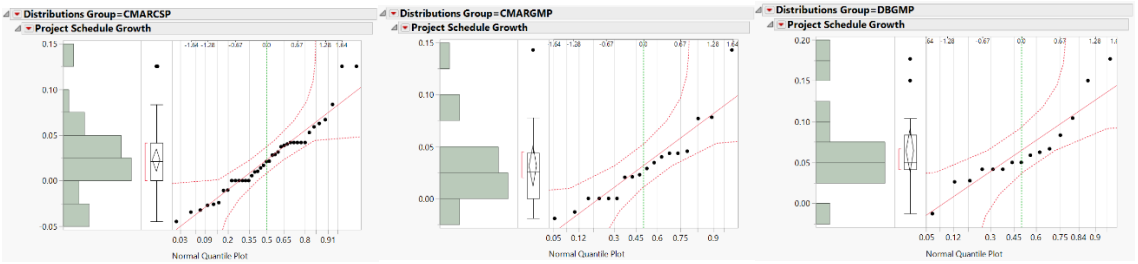


Figure 4 Normal Quantile Plots of Project Schedule Growth

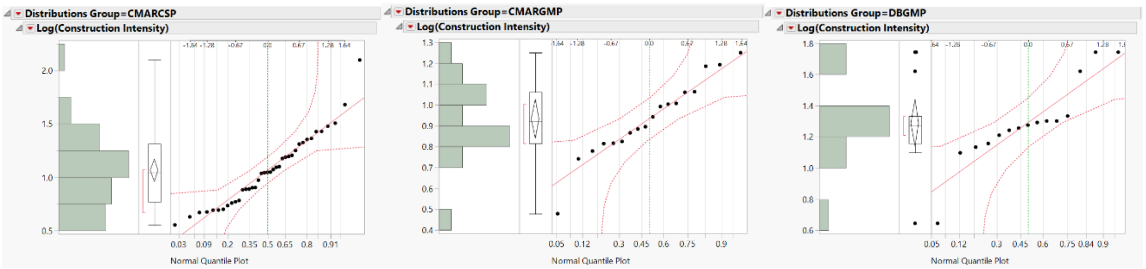


Figure 5 Normal Quantile Plots of Log (Construction Intensity)

SUMMARY

A summary table of the ANOVA and Wilcoxon Signed Rank Test results is presented in Table 1. 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 1 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.

COMPARISON

Table 2 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 are actually 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 researchers 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 2 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

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 is 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.

CONCLUSION

This work designed a comparative study in 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 researchers can start analyzing the reasons behind the results: why do CMAR projects have better performance in project cost management? why do DB projects have an advantage in 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.

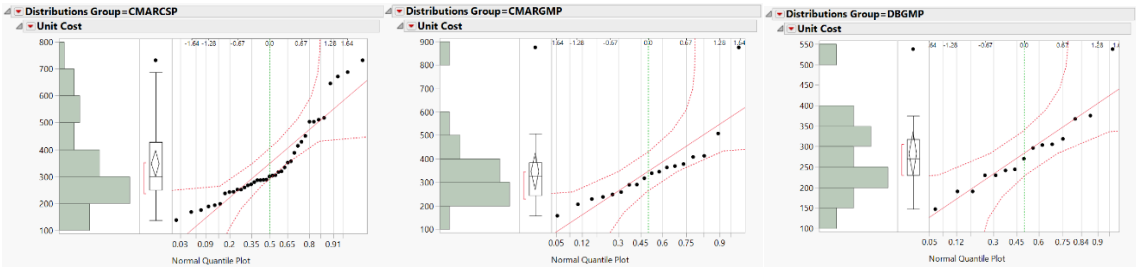
APPENDIX A

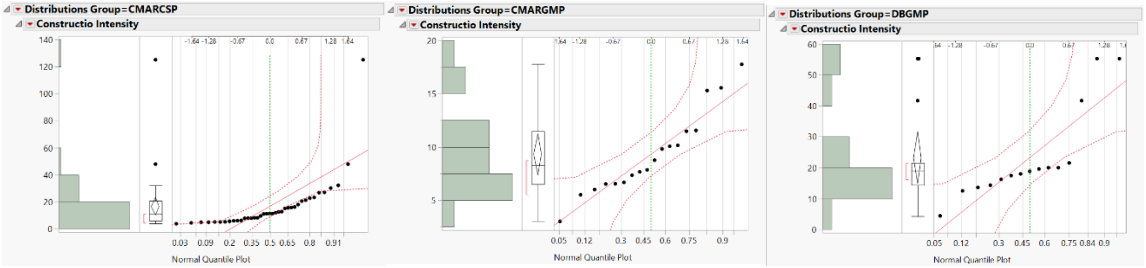
The time value adjustment tool used in this study is provided by Daniel Wheeler, which is shown as following:

							Legend:	
Discounted Project Value Calculator							Input	**Output**
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:





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