EFFECT OF THE COMBINATION OF MANAGEMENT THEORY AND THE PROJECT DELIVERY SYSTEM ON THE COST AND SCHEDULE OF A CONSTRUCTION PROJECT

A Thesis

by

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ABSTRACT

Management theories have been ignored by the construction industry for quite some time. Though there has been a significant impact of management on other fields, construction has never stepped up to embed them into the system. With advancement of technology, there is a necessity to bring all the streams together. This thesis investigates the effect of the two fundamental and competing conceptualizations of management: management by means (MBM) and management by results (MBR) in the field of construction. Therefore, this thesis analyzes the influence of these management concepts on project delivery systems like Design Build (DB) and Construction Management at Risk (CMAR) for commercial projects.

The research objectives were achieved through a combination of qualitative and quantitative methods. A thorough review of the existing literature on these topics and statistical analysis of data are steps taken to develop the matrix which determines the best combination of management theory and project delivery system for commercial projects. This research concludes that only time of a project will get affected with respect to the combination and cost will not. Because this research is limited to a data set of 73 projects, this research serves to create a model template or pilot study for a larger study.

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1. INTRODUCTION

"Construction is a complex field with a high degree of impulsiveness in every task, time and work when compared to other industries"(Allen & Iano, 2011). Hence, tracking and supervising the entire expanse of the project from commencement to finish, on a pre-planned schedule and budget without compromising the quality of the task at hand is essential. Any project has limitations on cost and schedule based on its scope. These might be major or minor and construction managers are tasked with organizing these limitations (Warburton, 2011). "Construction managers have the ability to find the best way to perform their duties of coordination and administration with the utmost cost-effective plan and schedule. This is characteristically completed in an authoritative and controlled top-down setting also called a push schedule" (Xiong & Nyberg, 2000). According to the Chaos theory by Sterman, adjustments late in the projects might cause the project to run over budget and any corrective adjustments or remedial actions at this stage will be inefficient and expensive.

"Not only the goals of schedule and budget but also factors like client satisfaction and total quality delivery of product and services have an impact on the success of a project. Hence there comes a continuous need to evaluate and restructure the management theories and practices for the successful execution of the project" (Lagoo, 2012). Typically, theories are observed through surveys and case studies Kim & Ballard, . According to Vrijhoef & Koskela, there cannot be improvements in practice before improving the theory and implementation of these theories become a source for improvement in design and controlling tools.

This research clearly focuses on establishing the integration of management theories, namely Management by Results (MBR) and Management by Means (MBM) with the project delivery systems Design Build (DB) and Construction Management at Risk (CMAR) for commercial projects.

Management by Results (MBR), as the name suggests, is a result driven management principle. It primarily focuses on the improving the financial outcomes per budget and schedule. In MBR, all the procedures, services and goals contribute to the increase in financial outcomes. In contrast to MBR, Management by Means (MBM) is relatively a new philosophy, which primarily focuses on the resources and their relationship with each other. MBM believes that providing the proper resources and interrelations leads to a long term success of the organization.

MBR and MBM include two principles of Earned Value Management (EVM) and Last Planner System (LPS) (Johnson & Broms, 2000) respectively. EVM is a project management technique that measures both performance and progress of the project as an objective approach. It has the ability to unite the triple constraints of scope, time and cost, as quoted by (Warburton, 2011), whereas Last Planner System uses flexible production planning procedures from the bottom up, in contrast to the standard top-down management principle. It tracks promise fulfillments made to deliver production as an element to keep the production environment stable (G. Ballard & Howell, 1994). "Although the literature shows significant evidence that some managers implement a micro-MBR management tool by assigning and tracking costs on each weekly assignment with Last Planner System, it is rare to find a project that uses both systems simultaneously" (Kim & Ballard, 2010). Though research has been done in the fields on EVM and LPS and their relationship with the management theories MBR and MBM, there has never been a study integrating these to Project Delivery Systems (PDS), Design Build (DB) and Construction Management at Risk (CMAR).

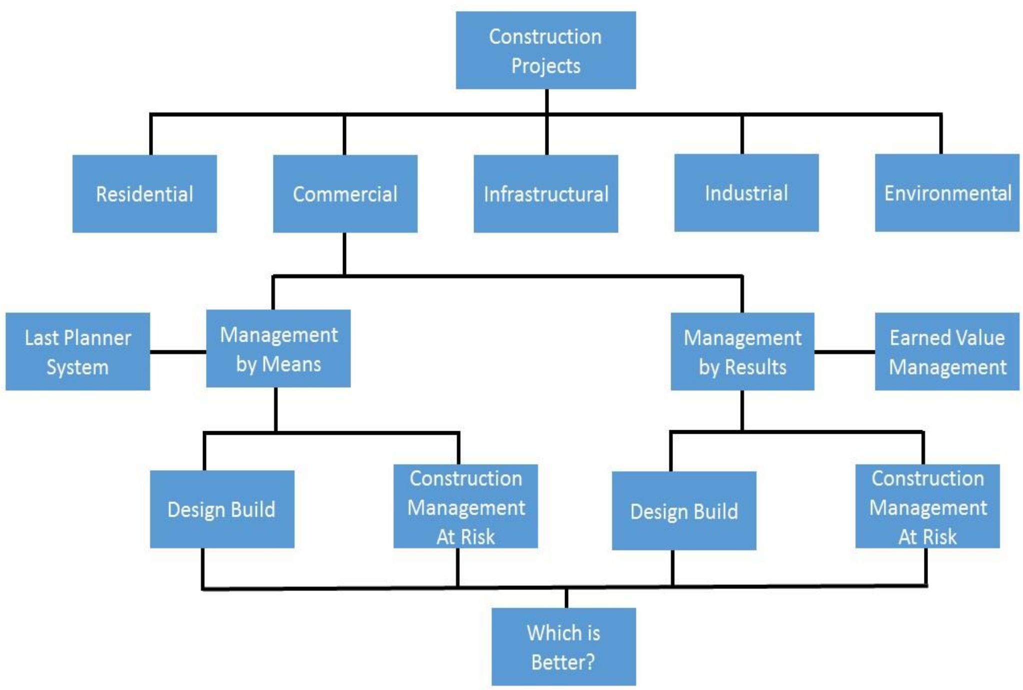


Figure 1: Thesis logic chart showing flow of the research and topic selection.

Hence, this research is based on the hypothesis that there exists a relationship between the management theory and project delivery system to efficiently complete a project and maximize the project margin. Hence, the key objective of this research may be specified as follows:

1. To analyze the different combinations of Management Theories and Project Delivery Systems in terms of cost variance and schedule variance.
2. To develop combinations of management theory v/s project delivery systems specifically for commercial projects.

This research will use the data provided by Dr. José L. Fernández-Solís, which includes the unit cost, actual total costs, planned total costs, actual duration, and planned total duration of 73 construction projects. Among the 73 projects, 6 used the combination of DB vs. MBM; 14 used the combination of CMAR vs. MBM; 10 used the combination of DB vs. MBR; and 43 used the combination of CMAR vs. MBR.

2. REVIEW OF LITERATURE

2.1 Background

A structured literature review has been done in the fields of construction management practices, stages of execution and planning, adaptation of sustainability in construction using different search. (Armitage & Keeble-Allen, 2008) defines structured literature review as a valid research methodology if it is done following strict guidelines. Structured literature review is a means by which critical literature central to and underpinning the research can be rigorously and systematically mapped out. The research key words were arrived from more than ten years of lean construction research and practice.

Initially, a wide range of topics were selected to gain some broader perspective of the current research in this sector, specifically fields with limited research and more current scope. A topic under the field of sustainable construction was taken up. In depth literature review was done in understanding the benefit-cost analysis of energy retrofit in institutional buildings, but limited or unavailability of data for analysis became a cul-de-sac for this project.

Other important field of research that caught interest is the collaboration of management and construction in terms of its implication, validation and utilization.

During the literature research frequent recurring words, most cited authors and practices were listed. These frequent recurrences were used as key words leading to a defined literature survey in the database of reputable publications like *Journal of Construction Engineering and Management, International Journal of Project Management, Conference Proceedings of the Annual Conferences of the International Group of Lean Construction (IGLC), Lean Construction Journal (LCI), Conference Proceedings of the Construction Congress of the American Society of Civil Engineering (ASCE), etc.* has provided a base for the literature survey and helped identify a gap in the knowledge giving an opportunity for research in that field.

According to (Vrijhoef & Koskela, 2000), enhancements in practice cannot be achieved without an enhancement in the theory. (Koskela & Howell, 2002) says, understanding the behavior through theory helps one to predict the future behaviors. But it is argued that construction doesn’t have a theory. According to (Kim & Ballard, 2010), the advancement business has dismissed organization theories, and starting any change late into a project uncommon and expensive (Sterman, 1992). As per (Nepal, Park, & Son, 2006), the later the corrective action, the less the ability to affect a project’s outcomes.

Hence, literature survey is being applied to understand the effect of management principles present in the construction industry, especially their effect in cost and schedule variance by understanding their relationship with the project delivery systems.

2.2 Management Theories

Arguments have been done between the management theories, Management by Results (MBR) and Management by Means (MBM) to decide the better among the two. Also, there have been proposals for applying both the theories in the same project from part to part to achieve the maximum the profitability (Kim & Ballard, 2010). These theories are further more researched to understand their implication in the construction industry.

2.2.1 Management by Results

Traditionally, financial targets played the major role in setting the organization's corporate goal. It was believed that each employee should have an individual financial target and this helps in achieving the corporate goals. Under this belief, the managers' important duty was motivating each and every employee which in turn increases their financial targets. (Johnson & Broms, 2000) coined the term "Management by Results" to emphasize this kind of management theory. According to (Johnson & Broms, 2000), MBR comes with quantitative approach which restricts one's perception to only one essential aspect, whereas nature and organization consist of numerous aspects. This kind of thinking assumes that the employee and items of work are separate from and independent of each other. "Quantitative generalizations apply to mechanistic systems whose interactions can be defined entirely in quantitative terms. MBR thinking is appropriate to mechanical systems because it neglects the attributes of organizations that differ from mechanical systems" (Kim & Ballard, 2010).

On a whole, the theory of MBR believes in optimizing parts to optimize the whole which is valid in mechanical systems but, when it comes to organizations, the reductionist approach of MBR appears entirely inappropriate as this theory highly concentrates on profit and loss. Also, this pragmatic approach is good for short term goals where stakes are low versus long term management responsibilities with high stakes. (Johnson & Broms, 2000)

This theory keeps a track on the progress of a project while foreseeing its future performance. It already incorporates the principles of Earned Value Management (EVM). Earned Value Management (EVM) is a construction technique used in controlling projects. It records quantitative measurement of work performed on a reporting date (Fleming & Koppelman, 2016). “Good planning, in addition to effective use of the EVM technique, can reduce a significant amount of issues caused due to schedule and cost overruns” (Kim & Ballard, 2010). Hence, to keep the project within predicted schedule and budget it has to be continuously monitored.

Though EVM is considered a highly established tool for integrating cost and schedule, still it is vulnerable to alterations. EVM focuses on marginal areas like structures-processes-outcomes, leading to management approaches that are less sustainable (Pavez, Gonzalez, & Alarcon, 2010). This is because least importance is given to the human behavior including their interests, traits and opinions(Beck & Cowan, 2014). A number of different theories have been established to support the implementation of both inner and outer worlds of management. And one such theory includes the theory of lean construction, a new management philosophy established in the construction industry (Barrett, 2006).

"Although there is extensive use of technical tools used for construction planning, scheduling, modeling, etc., there is no evident improvement in project performance. Thus, there is a need to establish management principles that can help improve construction performance by encapsulating both internal and external management theories" (Kim & Ballard, 2002).

2.2.2 Management by Means

In contrast to MBR which assumes that financial targets are achieved by optimizing the output of individual which in turn optimizes the output as a whole, Management by Means (MBM), focuses more on organized way of work which focuses on long term benefit to the organization. According to (Johnson & Broms, 2000), the difference between MBR and MBM theories reflects the changes between the philosophies that administer natural living systems and those that administer mechanical systems.

"While MBR-based project control focuses on accounting numbers and aims at minimizing negative variances, the goal of MBM-based control is to improve the flow of work across production units and continuously improving the performance of the whole system"(Kim & Ballard, 2010). (Kim & Ballard, 2010) proved that the production planning based on MBM philosophies show better performance. "The underlying belief of MBM is that what decides an organization's long-term profitability is the way it organizes its work. It is only by looking away from desired results that they can be achieved. Trying to optimize each part of an organization separately results in one part cannibalizing another and lowers the performance achieved by the entire system. Managers should be striving first to adhere to disciplined practices such as attention to how work is done, coordinating between parts of a system, and enabling those who do the work" (Kim & Ballard, 2010). A perfect example of this philosophy of management is provided by Liker's account of Toyota's management principles in his The Toyota Way (Liker, 2004).

MBM as a generalized term incorporates Last Planner System (LPS) as a part of lean construction principles. Last Planner System is a planning and control system in the field of construction, which is developed based on the principles of lean theory (H. G. Ballard, 2000). According to (Porwal, 2010), LPS plans, monitors and controls the construction process through principles like just-in-time (JIT) delivery, pull schedule and value stream mapping (VSM), which are considered to be the principle elements in lean theory. As per (González, Alarcón, & Mundaca, 2008), LPS improves the consistency in planning and diminishes the adverse impacts caused by variability. This is done by monitoring Percentage Plan Completed (PPC) in a short-term period by following a listed procedure. PPC is a ratio of number of tasks completed as planed versus the total number of tasks actually planned at a specific duration (H. G. Ballard, 2000).

Reliability and client satisfaction support the basis of lean theory. The measure of reliability in lean construction is based on PPC data. It is influenced by the work done as per schedule rather than the total completion of work. Hence, if a job is executed per schedule, it is counted as “1” and those not executed per schedule as “0”. To compare, all the 1’s are added and divided by total number of jobs per schedule for a specific time frame. A PPC nearing to 100% is considered highly reliable, whereas lower PPC depicts unreliable planning (Lagoo, 2012).

2.3 Project Delivery Systems

Though immense effort has been made to define the term “project delivery system”, there is no general consensus on the definition. (Miller, Garvin, Ibbs, & Mahoney, 2000) defines project delivery system as “a system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a good or service”. (Oyetunji & Anderson, 2006) state that a “project delivery system defines the sequence of project phases, parties involved in the project and implicitly assigned roles and responsibilities to project parties” and the Associated General Contractors of America (Contractors, 2004) defines it as the complete procedure of handing over the predetermined responsibilities and a method for identifying the key parties taking responsibilities. The Construction Management Association of America (Thomsen & FAIA, 2009) asserts that project delivery systems have three basic domains of “project organization”, “operating systems” and “commercial terms” which for a PDS to be coherent, the structures within these domains must be “aligned and in balance”. It further states that “a delivery method identifies the primary parties taking contractual responsibility for the performance of the work”. Some literature highlight the major elements of PDSs as “project phasing”, “project (or team) relationships” and “compensation approach” (Anderson & Oyetunji, 2003). (Pishdad & Beliveau, 2010) categorize elements of project delivery and contracting strategies into macro and micro elements. Macro elements, as they define, are organizational structure, phasing & sequencing strategy, contract type, and award strategy.

2.3.1 Design-Build

The Design-build is one of the trending project delivery system which is being employed on numerous projects lately. This delivery system requires the owner to understand the project, its goals, and its aesthetic, functional and constructional details (Kwak & Bushey, 2000).

In Design-build, owner gives the contract to a single entity, the architect builder, for both design and construction services. The Design-build entity can be led by either a designer or a builder and can consist of any number of people as listed below Figure 2. Also, Design-build requires a clear knowledge of the roles and responsibilities of the Design-build team. Single source contracting concept has become popular in recent years in both the private and public sectors. (AIA & AGC, 2006)

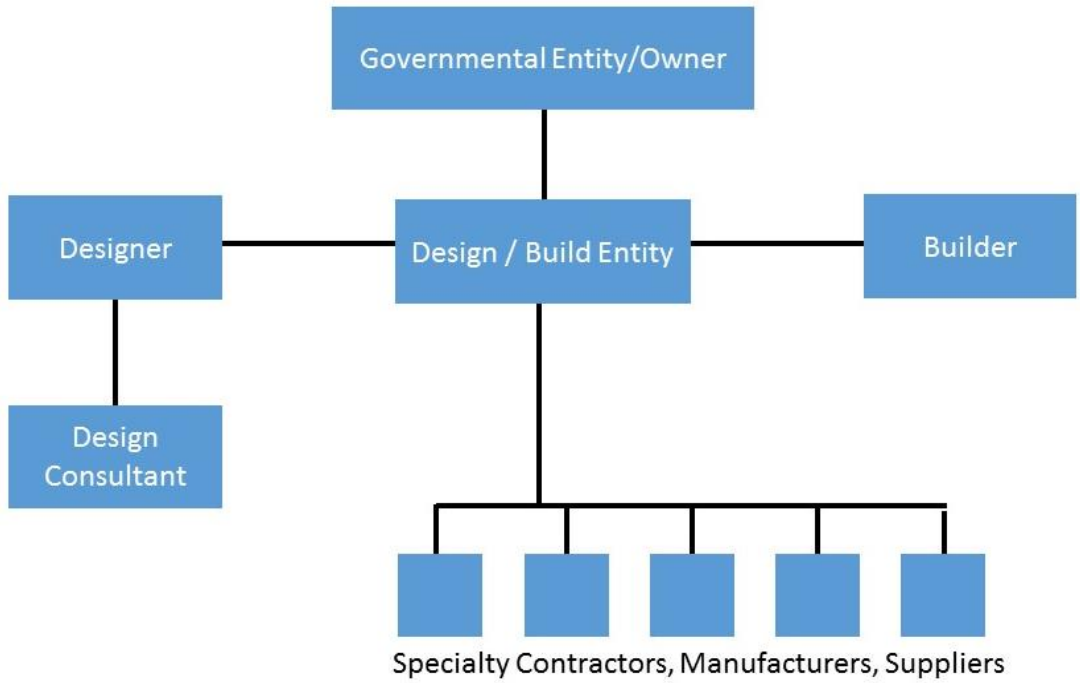


Figure 2: Design-Build- Relationships among Parties.

2.3.2 Construction Management at Risk

"The CM at Risk method is a two point contact method. It is based on team building between the owner, the design architect/engineer, and the contractor construction manager from the beginning of the project conceptual design through the final construction and operation or occupancy of the facility." (Kwak & Bushey, 2000)

In this method, the owner has a separate contract with the construction manager and architect/engineer as shown below Figure 3. The construction manager and his team, essentially provides preconstruction services, holds the trade contracts, takes responsibility for the performance of the work, and guarantees the construction costs and schedule. The CM at Risk also serves as the general contractor assuming the risk of the performance, either by its own crews or by specialty contractors and suppliers. (AGC, 2004)

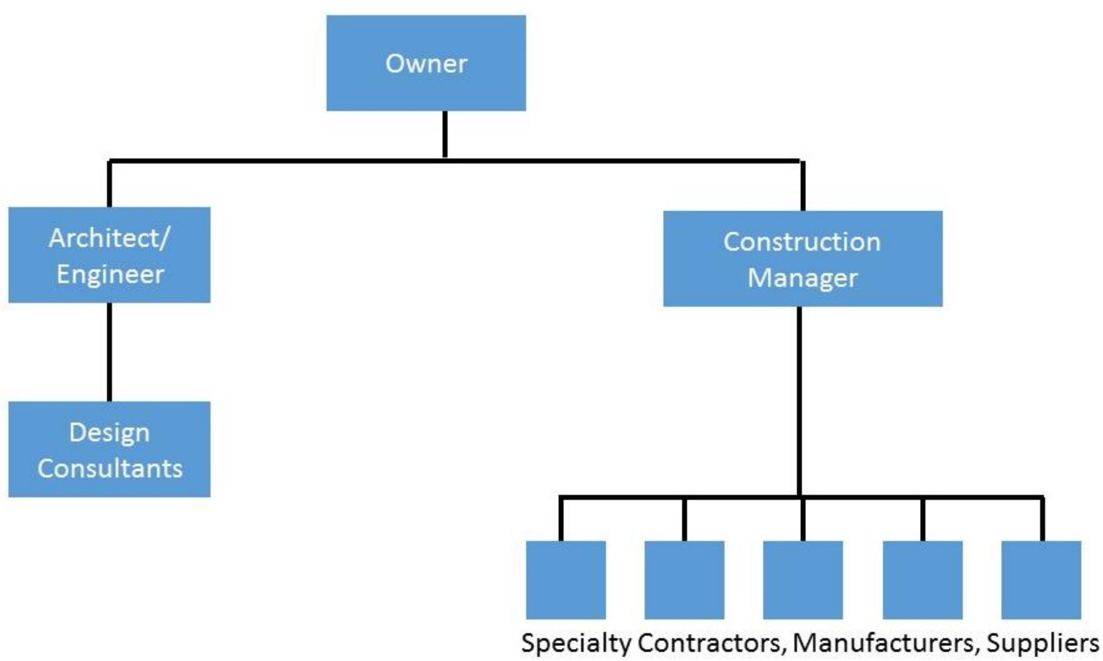


Figure 3: CM at Risk – Relationship among Parties.

3. PROBLEM STATEMENT

From table 1, it is obvious that much research has not been done to verify the adaptation of management theories in the field of construction, also, about their relation with project delivery systems. Some of the studies show similarity in the views of EVM and LPS with MBR and MBM respectively but their relationship with the project delivery systems has not been researched yet.

Hence, this research is based on the hypothesis that a particular combination of management theory and the project delivery system results in the maximum productivity for commercial projects in terms of cost and schedule. Firstly, the literature has been reviewed to understand the existing knowledge in this particular field and adapting it to the data. Secondly, the data will be analyzed using Analysis of variance (ANOVA) and pair-wise t –tests in terms of cost variance and schedule variance to find out the best combination.

Table 1: Topics of analysis by important researchers in the field

Authors & Year	Management Theory*	Project Delivery System	Other Construction Terms**
Anderson, S., & Oyetunji, A. (2003)	✗	✓	✗
Ballard, H. G. (2000)	✓	✗	✗
Barrett, R. (2006)	✗	✓	✓
Beck, D. E., & Cowan, C. (2014)	✓	✗	✓
Johnson, H. T., & Broms, A. (2000)	✓	✗	✗
Kim, Y.-W., & Ballard, G. (2010)	✓	✗	✗
Lagoo, N. (2012)	✓	✗	✓
Liker, J. K. (2004)	✓	✗	✗
Miller, J. B., Garvin, M. J., Ibbs, C. W., & Mahoney, S. E. (2000)	✗	✓	✗
Pavez, I., Gonzalez, V., & Alarcon, L. (2010)	✓	✗	✓
Vrijhoef, R., & Koskela, L. (2000)	✓	✗	✗
Xiong, G., & Nyberg, T. R. (2000)	✓	✓	✓

*includes studies of adaptation of management theories in automobile production.
**Other construction terms include EVM, LPS and so on.

4. HYPOTHESIS & RESEARCH QUESTION

4.1 Hypothesis

The whole set of data is divided into four groups based on the combination of the management theory and project delivery system used in each of the project. The four groups are then tested to see which combination out performs the rest in terms cost and schedule variance. Hence, here the H_0 and H_A tries to prove one combination out-performing the other. A series of 1 ANOVA and 6 paired t- tests each have to be done to analyze these combinations under cost variance and schedule variance.

ANOVA test:

$H_{0 \text{ of } A}$: All the combinations are equal and there is no difference, in terms of Cost Variance.

H_A: At least one of the combinations is different, in terms of Cost Variance.

Paired t-tests:

$H_{0 \text{ of } B}$: The combinations MBM-DB and MBM-CMAR are equal in terms of Cost Variance.

H_B: One of the combinations MBM-DB and MBM-CMAR out-perform each other in terms of Cost Variance.

$H_{0 \text{ of } C}$: The combinations MBM-DB and MBR-DB are equal in terms of Cost Variance.

H_C: One of the combinations MBM-DB and MBR-DB out-perform each other in terms of Cost Variance.

$H_{0 \text{ of } D}$: The combinations MBM-DB and MBR-CMAR are equal in terms of Cost Variance.

H_D: One of the combinations MBM-DB and MBR-CMAR out-perform each other in terms of Cost Variance.

$H_{0 \text{ of } E}$: The combinations MBM-CMAR and MBR-DB are equal in terms of Cost Variance.

H_E: One of the combinations MBM-CMAR and MBR-DB out-perform each other in terms of Cost Variance.

$H_{0 \text{ of } F}$: The combinations MBM-CMAR and MBR-CMAR are equal in terms of Cost Variance.

H_F: One of the combinations MBM-CMAR and MBR-CMAR out-perform each other in terms of Cost Variance.

$H_{0 \text{ of } G}$: The combinations MBM-DB and MBR-CMAR are equal in terms of Cost Variance.

H_G: One of the combinations MBM-DB and MBR-CMAR out-perform each other in terms of Cost Variance.

A similar series of ANOVA and paired t-test hypothesis testing is done using the schedule variance to understand the better combination that works in the commercial sector.

4.2 Research Questions

What researches have been doing in establishing a relationship between the management theory and project delivery system?

a. What kind of methodologies did they use?
b. What are their conclusions?
c. What are their limitations?

Considering Cost Variance, which combination of management theory and project delivery system outperforms the rest?

a. Is there a statistically significant difference in the hypothesis testing of cost variances of different combinations?
b. If so, which combination works better considering the existing data?

Considering Schedule Variance, which combination of management theory and project delivery system outperforms the rest?

c. Is there a statistically significant difference in the hypothesis testing of schedule variances of different combinations?
d. If so, which combination works better considering the existing data?

Are the results from both the statistical tests same?

a. If yes, why?
b. If not, what is the difference and how can one decide which combination is better?

4.3 Research Objectives

a. Summary the literature review done to understand the relationship between management theory and project delivery system;

b. Find out which combination outperforms in terms of cost variance;

c. Find out which combination outperforms in terms of schedule variance;

d. Compare the results from both the tests and analyze the difference.

5. METHODLOGY

5.1 Methodology

Research method revolves around the hypothesis that the combination of management theories with project delivery systems influences the project parameters such as cost and time. The research strategy is a combination of structured literature review (for understanding the previous research done in the field or relative fields and to develop a matrix establishing the relationship between management theory and project delivery system so as to maximize the profitability in a commercial project), data collection and interpretation (to establish the hypothesis) as sources to validate the hypothesis and provide results. This research paper is confined to data from 73 projects.

5.2 Methods

Research method involves three major steps that lead to a better understanding and consequences on cost and schedule of a project based on the utilization of different combinations of management theory with project delivery systems. The research goes through four phases before getting the results for interpretation and coming to conclusions. The phases include:

a. Literature search and review
b. Establishing topic and Data collection
c. Data interpretation and identifying variables for analysis
d. Identifying the analysis method and generating results.

5.2.1 Literature Search and Review

This was done to explore various avenues in which the thesis can be done, especially to understand the current research through reputed publications and their reviews. Based on this, various new fields were sorted favoring those with limited research done and with more scope for further research. Compiling the results from the search a pointed literature review has been done in specific fields including management theories, their application in manufacturing fields, studies relating them to construction management principles and tools. This gave an idea about unexplored topics that needed further attention.

5.2.2 Establishing Topic and Data Collection

Following the preliminary literature review, a topic was established. Prospective and relevant matrix has been developed to complete the research work. In accordance to the literature review and the topic, data of 73 commercial projects has been provided by Dr. José L. Fernández-Solís.

5.2.3 Data Interpretation and Identifying Variables for Analysis

The data includes the unit cost, actual total costs, planned total costs, actual duration, and planned total duration of 73 construction projects. Among the 73 projects, 6 used the combination of DB vs. MBM; 14 used the combination of CMAR vs. MBM; 10 used the combination of DB vs. MBR; and 43 used the combination of CMAR vs. MBR.

Table 2: Format used for gathering the data

<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 Type</td><td colspan="3">Project Type</td><td>Duration-months</td></tr>
<tr><td rowspan="2">GSF: 216.0K</td><td colspan="3">Cost-$</td><td colspan="3">Time - months</td><td>Unit Cost</td></tr>
<tr><td>Plan</td><td>Actual</td><td>Delta</td><td>Plan</td><td>Actual</td><td>Delta</td><td></td></tr>
<tr><td>Totals</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Once the data was collected, a table was constructed that summarizes and includes all relevant variables needed for analysis (see Table 3). These variables are derivatives of planned and actual costs and schedules. These variances were used as they give better relations compared to using either planned or actual costs and schedules. Tables were individually made for different combinations.

Table 3: Data calculation table showing different variables used

Project No.	PCW	ACW	CV	Year built	Effective cost variance as of 2017

Project No.	PSW	ASW	SV

Variables used in this study are following:

a. Basic variables:

   PCW: Planned cost of work

   ACW: Actual cost of work

   PSW: Planned schedule of work

   ASW: Actual schedule of work

b. Cost Variance (CV):

   CV= PCW-ACW

c. Schedule Variance (SV):

   SV = PSW-ASW

5.2.4 Identifying the Analysis Method and Generating Results

Once the calculations were done and tables were completed, interpretation became more comprehensible. Based on the data and inferences, ANOVA and paired t-test analysis were chosen to validate the hypothesis. Relevant outputs like p-values were obtained using JMP software to get significant outcomes.

5.3 Limitations

a. The sample size is small.

b. Technically, every single project is unique and has its own characters. It thus is hard, if not impossible, to assume all the other variables were the same when the data was collected and interpreted.

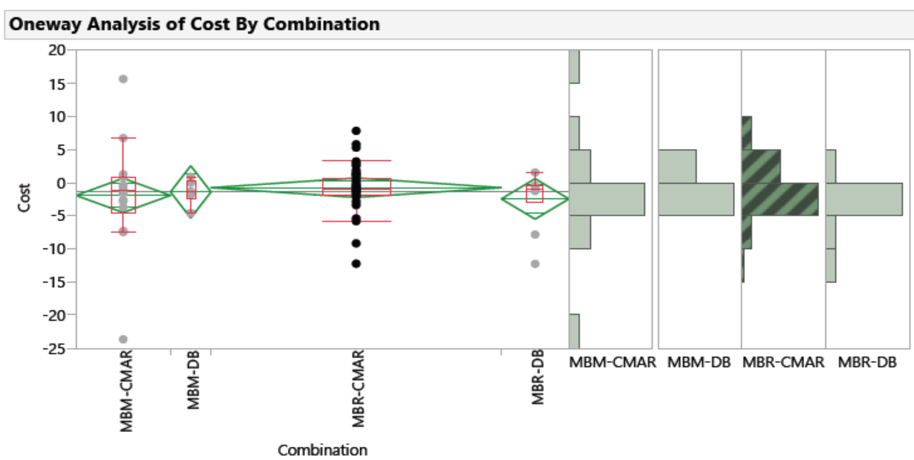
c. The way the sample projects are selected might not be random.

d. The years of projects vary and hence all the costs are brought to present day costs before analysis.

6. DATA ANALYSIS

In this research, analysis and observations of 4 different combinations was tested over cost and schedule, first using analysis of variance (ANOVA) to see if the combinations really have an impact on cost and schedule and further paired t-tests are conducted to see which combination uses lesser time and costs less than the rest. A total of seven tests each were decided to be conducted for both. Depending on the results given by ANOVA, paired t-tests were conducted.

6.1 Cost Variance



Oneway Anova

Summary of Fit

Rsquare	0.018967
Adj Rsquare	-0.02369
Root Mean Square Error	4.840199
Mean of Response	-1.25932
Observations (or Sum Wgts)	73

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	3	31.2528	10.4176	0.4447	0.7218
Error	69	1616.4991	23.4275		
C. Total	72	1647.7519			

Figure 4: ANOVA result of cost by combinations

ANOVA test was conducted taking combinations, MBM-CMAR, MBM-DB, MBR-CMAR, and MBR-DB on x-axis and cost on y-axis in JMP, it has error, □=5%. The hypothesis for the test were taken as

> H_0: All the combinations are equal and there is no difference, in terms of Cost Variance.
>
> H_A: At least one of the combinations out-performs the rest, in terms of Cost Variance.

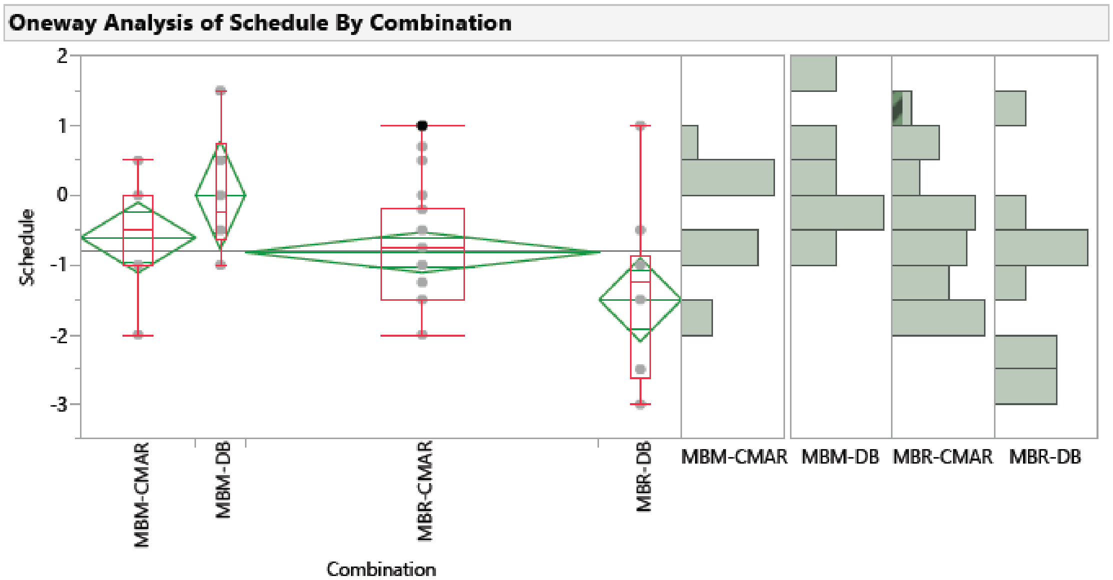
As shown in Figure 4, the test yielded a p-value of 0.7218 which is greater than □=0.05. With this outcome, we fail to reject H_0. Hence, we accept that cost is not affected by the combination of management theory and project delivery system.

6.2 Schedule Variance

ANOVA test was conducted taking combinations, MBM-CMAR, MBM-DB, MBR-CMAR, and MBR-DB on x-axis and cost on y-axis in JMP, where again error, □=5%. The hypothesis for the test were taken as

> H_0: All the combinations are equal and there is no difference, in terms of Schedule Variance.
>
> H_A: At least one of the combinations out-performs the rest, in terms of Schedule Variance.

As shown in Figure 5, the test yielded a probability of 0.0215 which is less than □=0.05. Hence, we reject H_0 as the result shows that schedule is affected by the combination of management theory and project delivery system.



Oneway Anova

Summary of Fit

Rsquare	0.130076
Adj Rsquare	0.092253
Root Mean Square Error	0.948187
Mean of Response	-0.80479
Observations (or Sum Wgts)	73

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	3	9.275839	3.09195	3.4391	0.0215*
Error	69	62.034983	0.89906		
C. Total	72	71.310822			

Figure 5: ANOVA result of schedule by combinations

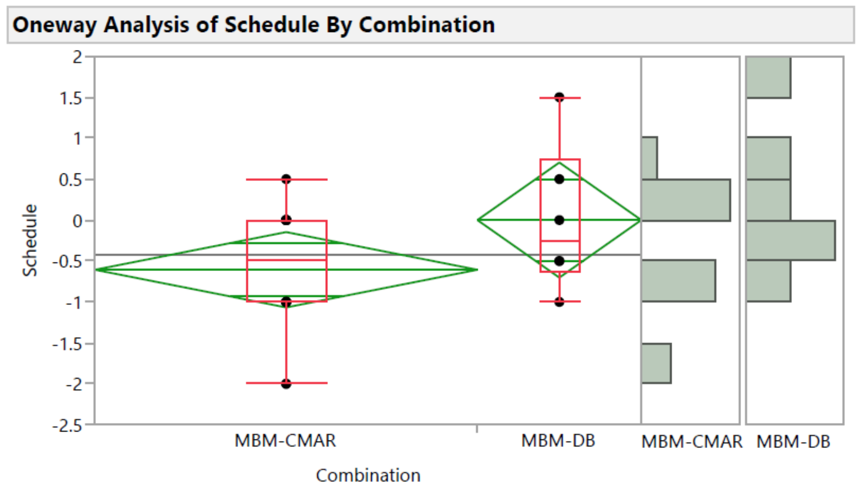
6.2.1 Paired t-tests

Further, a series of six paired t-tests are conducted matching all four combinations with each other to determine which combination outperforms the rest.

Hypothesis for test 1:

> H_0: The combinations MBM-DB and MBM-CMAR are equal in terms of Schedule Variance.

HA: One of the combinations MBM-DB and MBM-CMAR out-perform each other in terms of Schedule Variance.



t Test

MBM-DB-MBM-CMAR

Assuming equal variances

Difference	0.6071	t Ratio	1.518279
Std Err Dif	0.3999	DF	18
Upper CL Dif	1.4473	Prob > |t|	0.1463
Lower CL Dif	-0.2330	Prob > t	0.0732
Confidence	0.95	Prob < t	0.9268

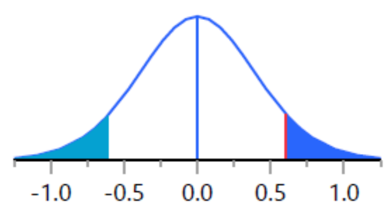


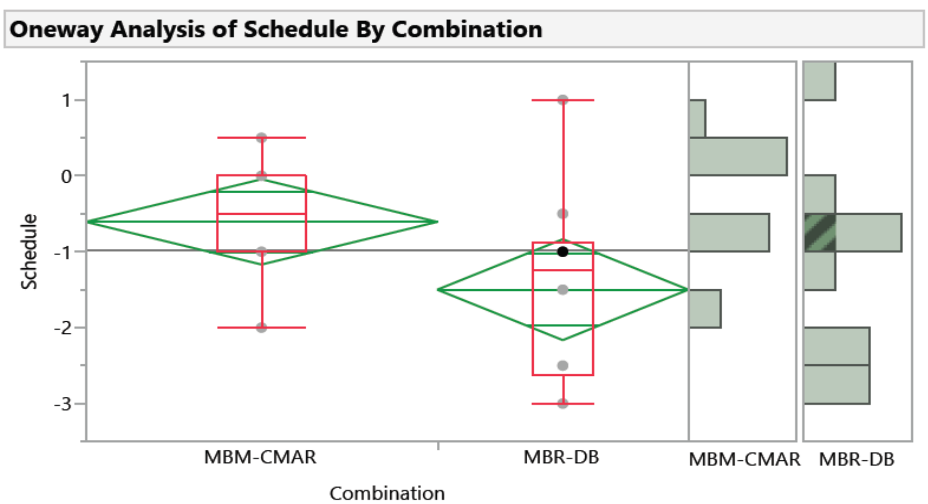
Figure 6: Paired t-test result of Schedule by MBM-CMAR, MBM-DB

As shown in Figure 6, the test yielded a probability of 0.1463 which is greater than □=0.05. With this outcome, we fail to reject H_0. Hence, the result shows that the effect of the combinations, MBM-DB and MBM-CMAR is similar on schedule.

Hypothesis for test 2:

H_0: The combinations MBM-CMAR and MBR-DB are equal in terms of Schedule Variance.

H_A: One of the combinations MBM-CMAR and MBR-DB out-perform each other in terms of Schedule Variance.



t Test

MBR-DB-MBM-CMAR

Assuming equal variances

Difference	-0.8929	t Ratio	-2.12814
Std Err Dif	0.4195	DF	22
Upper CL Dif	-0.0228	Prob > |t|	0.0448*
Lower CL Dif	-1.7629	Prob > t	0.9776
Confidence	0.95	Prob < t	0.0224*

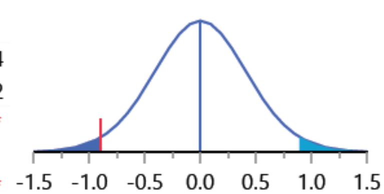
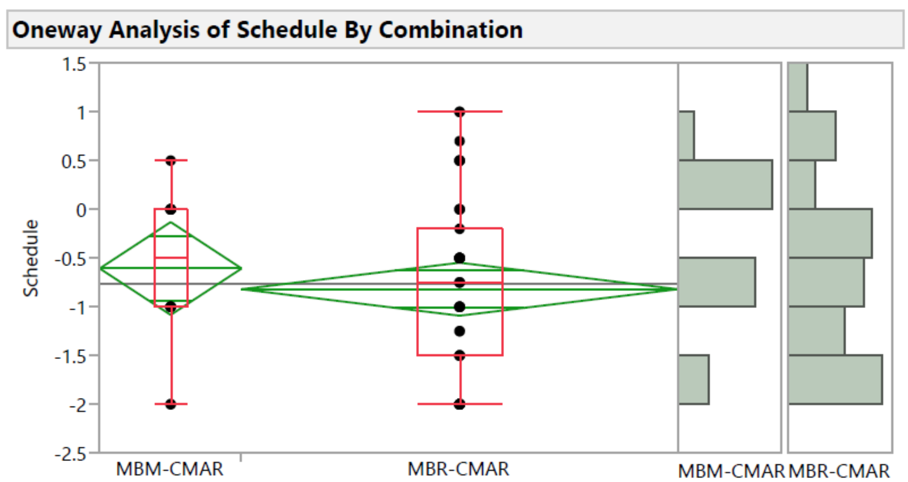


Figure 7: Paired t-test result of Schedule by MBM-CMAR, MBR-DB

As shown in Figure 7, the test yielded a probability of 0.0448 which is lesser than □=0.05. With this outcome, we reject H_0. Also, according to the t-test statistics, the combination MBM-CMAR out performs MBR-DB.

Hypothesis for test 3:

> H_0: The combinations MBR-CMAR and MBM-CMAR are equal in terms of Schedule Variance.
>
> H_A: One of the combinations MBR-CMAR and MBM-CMAR out-perform each other in terms of Schedule Variance.



t Test

MBR-CMAR-MBM-CMAR

Assuming equal variances

Difference	-0.21262	t Ratio	-0.77667
Std Err Dif	0.27376	DF	55
Upper CL Dif	0.33601	Prob > |t|	0.4407
Lower CL Dif	-0.76126	Prob > t	0.7797
Confidence	0.95	Prob < t	0.2203

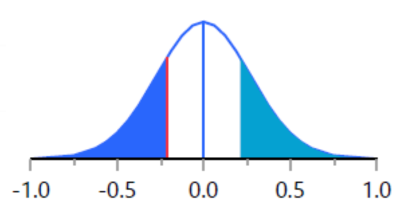
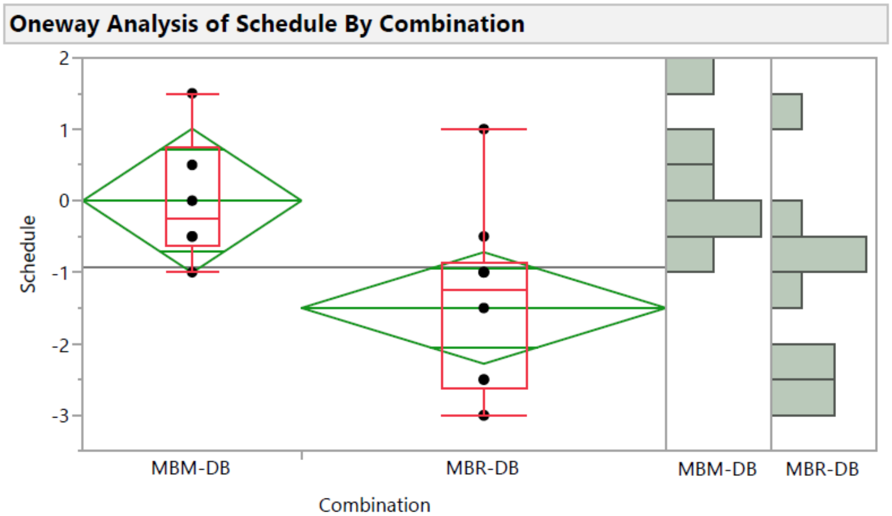


Figure 8: Paired t-test result of Schedule by MBR-CMAR, MBM-CMAR

As shown in Figure 8, the test yielded a probability of 0.4407 which is greater than α=0.05. With this outcome, we fail to reject H_0. Hence, the result shows that the effect of the combinations, MBR-CMAR and MBM-CMAR is similar on schedule.

Hypothesis for test 4:

> H_0: The combinations MBM-DB and MBR-DB are equal in terms of Schedule Variance.
>
> H_A: One of the combinations MBM-DB and MBR-DB out-perform each other in terms of Schedule Variance.



t Test

MBR-DB-MBM-DB

Assuming equal variances

Difference	-1.5000	t Ratio	-2.52688
Std Err Dif	0.5936	DF	14
Upper CL Dif	-0.2268	Prob > |t|	0.0242*
Lower CL Dif	-2.7732	Prob > t	0.9879
Confidence	0.95	Prob < t	0.0121*

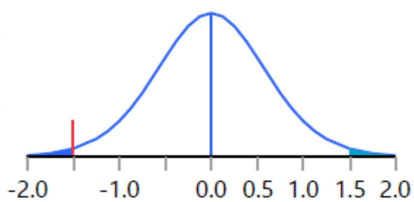
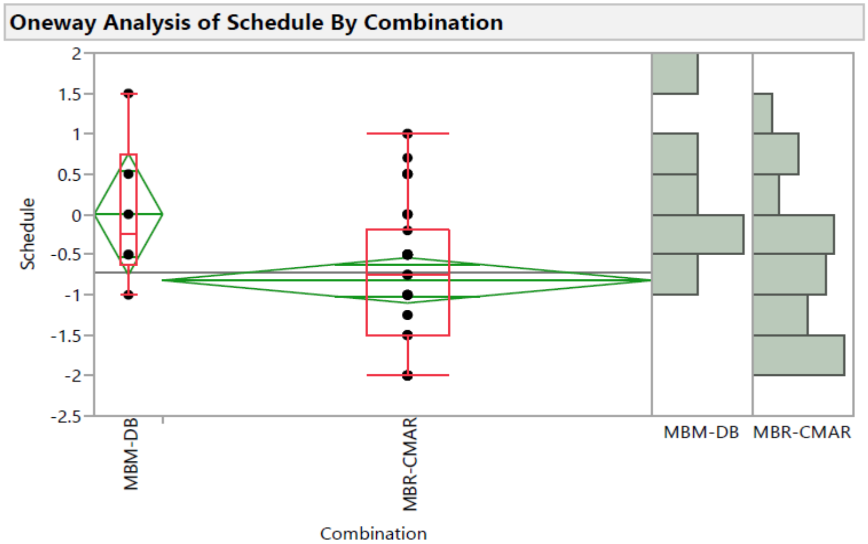


Figure 9: Paired t-test result of Schedule by MBM-DB, MBR-DB

As shown in Figure 9, the test yielded a probability of 0.0242 which is lesser than □=0.05. With this outcome, we reject H_0. Also, according to the t-test statistics, the combination MBM-DB out performs MBR-DB.

Hypothesis for test 5:

> H_0: The combinations MBM-DB and MBR-CMAR are equal in terms of Schedule Variance.
>
> H_A: One of the combinations MBM-DB and MBR-CMAR out-perform each other in terms of Schedule Variance.



t Test

MBR-CMAR-MBM-DB

Assuming equal variances

Difference	-0.8198	t Ratio	-2.0533
Std Err Dif	0.3992	DF	47
Upper CL Dif	-0.0166	Prob > |t|	0.0456*
Lower CL Dif	-1.6229	Prob > t	0.9772
Confidence	0.95	Prob < t	0.0228*

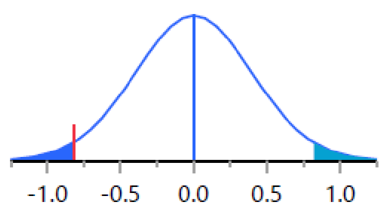


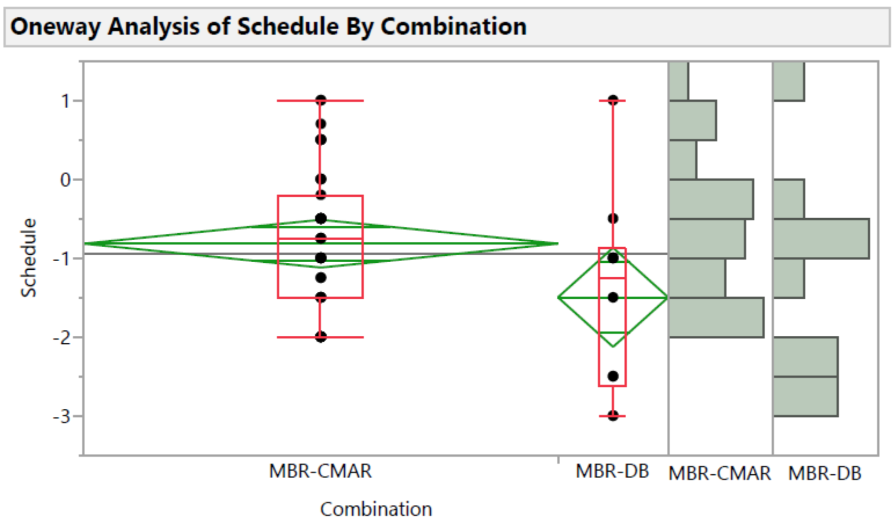
Figure 10: Paired t-test result of Schedule by MBM-DB, MBR-CMAR

As shown in Figure 10, the test yielded a probability of 0.0456 which is lesser than □=0.05. With this outcome, we reject H_0. Also, according to the t-test statistics, the combination MBM-DB out performs MBR-CMAR.

Hypothesis for test 6:

H_0: The combinations MBR-DB and MBR-CMAR are equal in terms of Schedule Variance.

H_A: One of the combinations MBR-DB and MBR-CMAR out-perform each other in terms of Schedule Variance.



t Test

MBR-DB-MBR-CMAR

Assuming equal variances

Difference	-0.6802	t Ratio	-1.9579
Std Err Dif	0.3474	DF	51
Upper CL Dif	0.0173	Prob > |t|	0.0557
Lower CL Dif	-1.3777	Prob > t	0.9721
Confidence	0.95	Prob < t	0.0279*

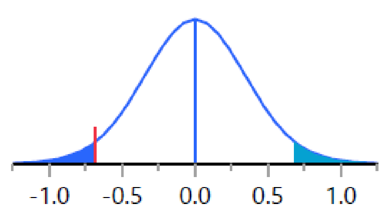


Figure 11: Paired t-test result of Schedule by MBR-DB, MBR-CMAR

As shown in Figure 11, the test yielded a probability of 0.0557 which is equal to □=0.05. With this outcome, we reject H_0. Also, according to the t-test statistics, the combination MBR-CMAR out performs MBR-DB.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The research inspected the effect of combination of management theory and project delivery system on cost and schedule of a commercial project. For the same, a data of 73 projects were collected which primarily used MBM and MBR management theories and DB and CMAR project delivery systems.

The data analysis shows that, when cost is plotted against the combination, there is no correlation between cost and combination or in other words, there is not much change in the cost of the project based on the combination used. But, plotting schedule against combination clearly states that there is a relationship between schedule and combination used.

Further, six pairwise t-tests were done to determine which combination out performs the rest. The outcomes suggest that MBR-DB < MBM-CMAR = MBR-CMAR < MBM-DB. Though result from test one gives a conclusion of MBM-CMAR = MBM-DB, the values are very low to accept the result. Hence, the final conclusions are drawn mainly based on the later five tests. Since the sample size is too small to conclude and draw concrete conclusions, these outcomes can be considered for future study that incorporates diverse and significant sample size of data.

7.2 Recommendations

This study laid a base for exploring various avenues related to management theories and their effects in construction industry. Primary goal of this research was to see if management principles paired with project delivery systems have an effect on cost and schedule of a project. Following are a few inferred contributions to the industry and research

a. Suggests opportunity for further exploration of the effect of management principles in the field of construction and examine if the theories in production industry can be adapted to raise the profitability in construction industry to the same level as production industry.
b. Correlations between various variables in a construction project.

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APPENDIX

Data Tables for cost and schedule

Cost Variance					
MBM-CMAR					
Project Number	Planned Cost	Actual Cost	Cost Variance	Current day CV	Year
1	166.22	164.33	1.89	6.74	2000
2	165.4	161.01	4.39	15.66	2000
3	169.96	174.06	-4.1	-7.46	2009
8	191	192.42	-1.42	-2.78	2008
9	566	580	-14	-23.64	2010
10	745	750	-5	-7.27	2012
11	240	240.67	-0.67	-0.9	2013
12	289	289.5	-0.5	-1.54	2002
13	258	258.18	-0.18	-0.41	2006
14	226	226.47	-0.47	-0.99	2007
28	294	293.32	0.68	0.79	2015
40	384	383.3	0.7	1.27	2009
60	410	413.44	-3.44	-3.71	2016
61	385	387.4	-2.4	-2.59	2016

Cost Variance					
MBM-DB					
Project Number	Planned Cost	Actual Cost	Cost Variance	Current day CV	Year

4	278.5	282.14	-3.64	-4.56	2014
5	238.16	237.59	0.57	0.89	2011
6	261	261.9	-0.9	-1.76	2008
7	252	253.3	-1.3	-1.3	2017
15	284	284.65	-0.65	-1.6	2005
62	230	230	0	0	2008

Cost Variance					
MBR-DB					
Project Number	Planned Cost	Actual Cost	Cost Variance	Current day CV	Year
16	148	148.57	-0.57	-1.12	2008
17	244	244.32	-0.32	-0.63	2008
18	171	171.27	-0.27	-0.53	2008
19	266	266.67	-0.67	-0.84	2014
44	295	296	-1	-1.08	2016
45	280	281	-1	-1.25	2014
46	283	283.33	-0.33	-0.45	2013
47	245	250	-5	-7.83	2011

53	280	278.57	1.43	1.54	2016
59	345	355.55	-10.55	-12.25	2015

Cost Variance					
MBR-CMAR					
Project Number	Planned Cost	Actual Cost	Cost Variance	Current day CV	Year
20	269	269.68	-0.68	-1.44	2007
21	267	267.6	-0.6	-1.09	2009
22	359	358.16	0.84	2.58	2002
23	360	359.32	0.68	1.44	2007
24	184.5	184.16	0.34	0.72	2007
25	130	134.33	-4.33	-9.15	2007
26	206	205.25	0.75	1.27	2010
27	344	344.8	-0.8	-0.86	2016
29	120	121	-1	-1.96	2008
30	490	491.8	-1.8	-2.09	2015
31	325	325	0	0	2008
32	142	142.85	-0.85	-1.67	2008
33	145	145.5	-0.5	-0.63	2014
34	150	150	0	0	2012
35	158	158.03	-0.03	-0.05	2011
36	258	257.14	0.86	1.16	2013
37	334	333.33	0.67	0.72	2016
38	226	225.8	0.2	0.42	2007
39	249	250	-1	-1.25	2014
41	410	410.3	-0.3	-0.51	2010
42	374	375	-1	-1.16	2015
43	396.5	397	-0.5	-0.63	2014
48	145	147	-2	-2.16	2016
49	315	317.1	-2.1	-2.83	2013
50	522.5	523.7	-1.2	-2.18	2009
51	370	374.98	-4.98	-12.22	2005
52	235	235.29	-0.29	-0.34	2015
54	225	223.53	1.47	1.84	2014
55	290	287.01	2.99	3.22	2016
56	620	625	-5	-5.81	2015

57	370	375	-5	-5.39	2016
58	120	118	2	2.91	2012
63	655	650	5	5.81	2015
64	210	208	2	5.29	2004
65	205	200	5	7.83	2011
66	264	265	-1	-1.25	2014
67	250	251	-1	-1.08	2016
68	180	182	-2	-3.38	2010
69	150	150.8	-0.8	-1.35	2010
70	264	265	-1	-1.25	2014
71	250	251	-1	-1.08	2016
72	180	182	-2	-3.38	2010
73	150	150.8	-0.8	-1.35	2010

Schedule Variance			
MBM-CMAR			
Project Number	Planned Schedule	Actual Schedule	Schedule Variance
1	28	28	0
2	24	25	-1
3	26	28	-2
8	30	30	0
9	38	40	-2
10	48	48	0
11	16	16	0
12	26	25.5	0.5
13	29	30	-1
14	26	26	0
28	47	48	-1
40	24	24	0
60	24	25	-1
61	27	28	-1

Schedule Variance			
MBM-DB			
Project Number	Planned Schedule	Actual Schedule	Schedule Variance
4	33.5	32	1.5

5	38.5	38	0.5
6	45	45	0
7	24.5	25	-0.5
15	32	33	-1
62	24	24.5	-0.5

Schedule Variance			
MBR-DB			
Project Number	Planned Schedule	Actual Schedule	Schedule Variance
16	17.5	20	-2.5
17	22	23	-1
18	34.5	36	-1.5
19	35	36	-1
44	17	20	-3
45	16	17	-1
46	18	18.5	-0.5
47	24	26.5	-2.5
53	31	30	1
59	20	23	-3

Schedule Variance			
MBR-CMAR			
Project Number	Planned Schedule	Actual Schedule	Schedule Variance
20	37.5	39	-1.5
21	36	36.5	-0.5
22	41.5	40.5	1
23	36	36	0
24	48	49	-1
25	34	36	-2

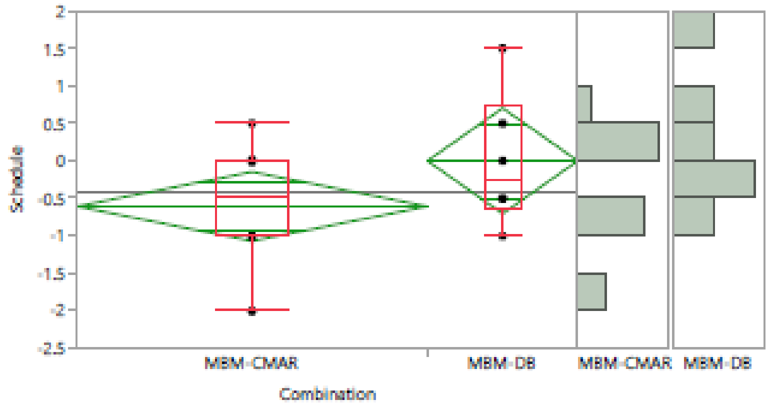
26	49	49.5	-0.5
27	54.75	56	-1.25
29	36	37	-1
30	52	53.5	-1.5
31	46	45.5	0.5
32	53	53.5	-0.5
33	23	24	-1
34	30	30.5	-0.5
35	18	19.5	-1.5
36	16	17.25	-1.25
37	37	37.2	-0.2
38	27	26.3	0.7
39	19	19.5	-0.5
41	36	36	0
42	9	9	0
43	25	26	-1
48	12	12.5	-0.5
49	12	12.75	-0.75
50	36	37.5	-1.5
51	24	26	-2
52	18.5	18	0.5
54	40	39.5	0.5
55	34	34.75	-0.75
56	48	50	-2
57	30	32	-2
58	29	28	1
63	48	47.5	0.5
64	18	18.75	-0.75
65	34	36	-2
66	16	18	-2
67	16	18	-2
68	12	12.5	-0.5
69	40	42	-2
70	26	27	-1
71	30	32	-2
72	12	12.5	-0.5
73	40	42	-2

Results of Paired-t-tests

data file 1-2 - Fit Y by X of Schedule by Combination

Page 1 of 1

Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

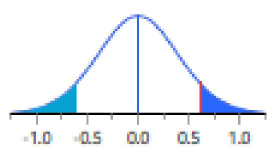
Rsquare	0.113526
Adj Rsquare	0.064278
Root Mean Square Error	0.819529
Mean of Response	-0.425
Observations (or Sum Wgts)	20

t Test

MBM-DB-MBM-CMAR

Assuming equal variances

Difference	0.6071	t Ratio	1.518279
Std Err Dif	0.3999	DF	18
Upper CL Dif	1.4473	Prob > |t|	0.1463
Lower CL Dif	-0.2330	Prob > t	0.0732
Confidence	0.95	Prob < t	0.9268



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	1.548214	1.54821	2.3052	0.1463
Error	18	12.089286	0.67163		
C. Total	19	13.637500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM-CMAR	14	-0.60714	0.21903	-1.067	-0.1470
MBM-DB	6	0.00000	0.33457	-0.703	0.7029

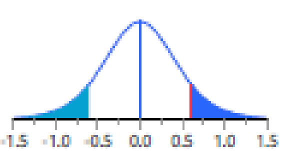
Std Error uses a pooled estimate of error variance

t Test

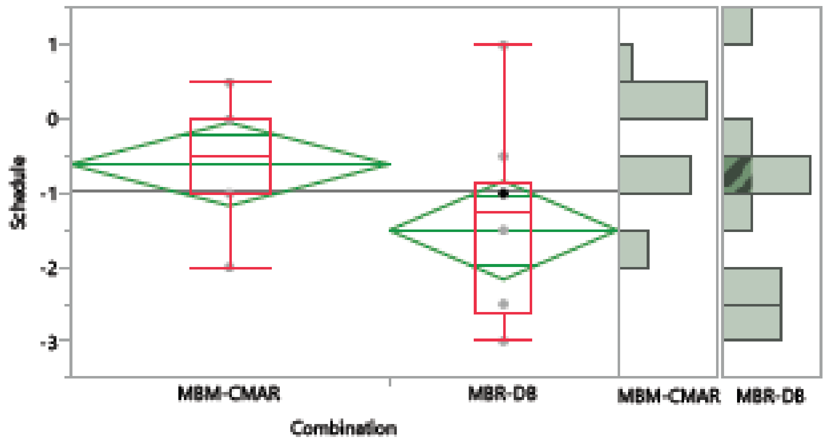
MBM-DB-MBM-CMAR

Assuming unequal variances

Difference	0.6071	t Ratio	1.439957
Std Err Dif	0.4216	DF	8.524765
Upper CL Dif	1.5691	Prob > |t|	0.1856
Lower CL Dif	-0.3548	Prob > t	0.0928
Confidence	0.95	Prob < t	0.9072



Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

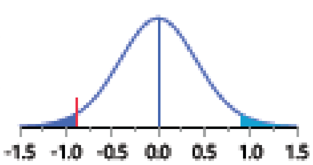
Rsquare	0.170718
Adj Rsquare	0.133024
Root Mean Square Error	1.013304
Mean of Response	-0.97917
Observations (or Sum Wgts)	24

t Test

MBR-DB-MBM-CMAR

Assuming equal variances

Difference	-0.8929	t Ratio	-2.12814
Std Err Dif	0.4195	DF	22
Upper CL Dif	-0.0228	Prob > |t|	0.0448*
Lower CL Dif	-1.7629	Prob > t	0.9776
Confidence	0.95	Prob < t	0.0224*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	4.650298	4.65030	4.5290	0.0448*
Error	22	22.589286	1.02679		
C. Total	23	27.239583			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM-CMAR	14	-0.6071	0.27082	-1.169	-0.0455
MBR-DB	10	-1.5000	0.32043	-2.165	-0.8355

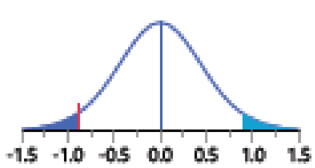
Std Error uses a pooled estimate of error variance

t Test

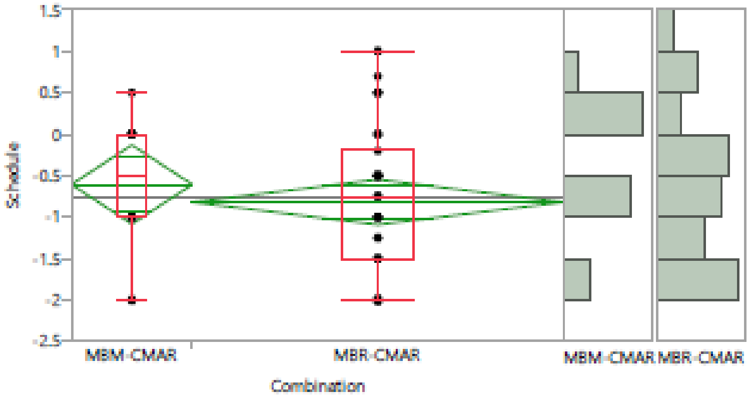
MBR-DB-MBM-CMAR

Assuming unequal variances

Difference	-0.8929	t Ratio	-1.96931
Std Err Dif	0.4534	DF	13.91742
Upper CL Dif	0.0801	Prob > |t|	0.0692
Lower CL Dif	-1.8658	Prob > t	0.9654
Confidence	0.95	Prob < t	0.0346*



Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

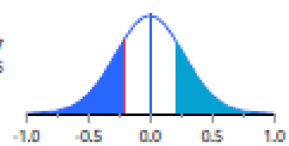
Rsquare	0.010849
Adj Rsquare	-0.00714
Root Mean Square Error	0.889688
Mean of Response	-0.76754
Observations (or Sum Wgts)	57

t Test

MBR-CMAR-MBM-CMAR

Assuming equal variances

Difference	-0.21262	t Ratio	-0.77667
Std Err Dif	0.27376	DF	55
Upper CL Dif	0.33601	Prob > |t|	0.4407
Lower CL Dif	-0.76126	Prob > t	0.7797
Confidence	0.95	Prob < t	0.2203



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	0.477473	0.477473	0.6032	0.4407
Error	55	43.534983	0.791545		
C. Total	56	44.012456			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM-CMAR	14	-0.60714	0.23778	-1.084	-0.1306
MBR-CMAR	43	-0.81977	0.13568	-1.092	-0.5479

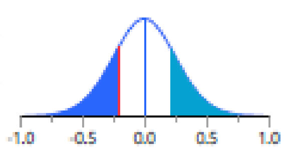
Std Error uses a pooled estimate of error variance

t Test

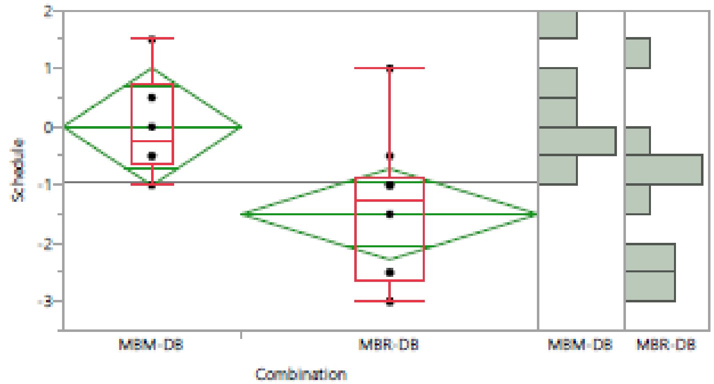
MBR-CMAR-MBM-CMAR

Assuming unequal variances

Difference	-0.21262	t Ratio	-0.83999
Std Err Dif	0.25313	DF	25.47818
Upper CL Dif	0.30820	Prob > |t|	0.4087
Lower CL Dif	-0.73345	Prob > t	0.7956
Confidence	0.95	Prob < t	0.2044



Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

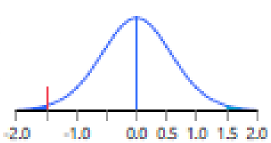
Rsquare	0.313225
Adj Rsquare	0.26417
Root Mean Square Error	1.149534
Mean of Response	-0.9375
Observations (or Sum Wgts)	16

t Test

MBR-DB-MBM-DB

Assuming equal variances

Difference	-1.5000	t Ratio	-2.52688
Std Err Dif	0.5936	DF	14
Upper CL Dif	-0.2268	Prob > |t|	0.0242*
Lower CL Dif	-2.7732	Prob > t	0.9879
Confidence	0.95	Prob < t	0.0121*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	8.437500	8.43750	6.3851	0.0242*
Error	14	18.500000	1.32143		
C. Total	15	26.937500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM-DB	6	0.0000	0.46930	-1.007	1.007
MBR-DB	10	-1.5000	0.36351	-2.280	-0.720

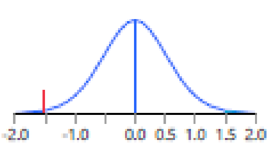
Std Error uses a pooled estimate of error variance

t Test

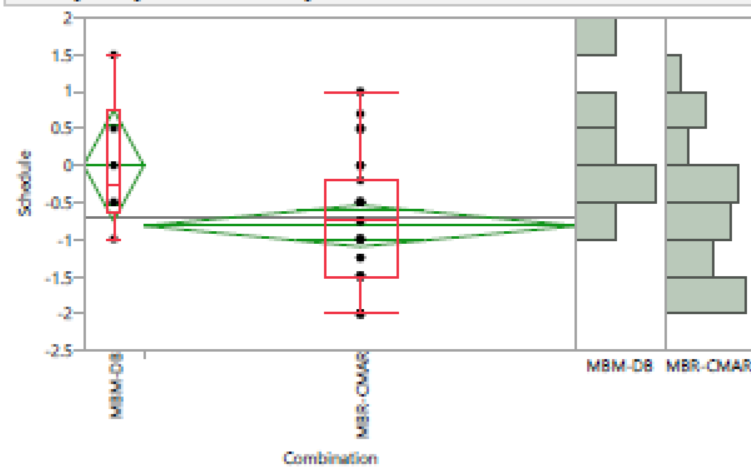
MBR-DB-MBM-DB

Assuming unequal variances

Difference	-1.5000	t Ratio	-2.76433
Std Err Dif	0.5426	DF	13.4631
Upper CL Dif	-0.3318	Prob > |t|	0.0157*
Lower CL Dif	-2.6682	Prob > t	0.9922
Confidence	0.95	Prob < t	0.0078*



Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

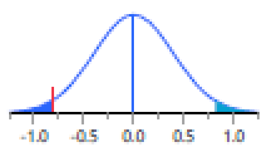
Rsquare	0.082318
Adj Rsquare	0.062793
Root Mean Square Error	0.916117
Mean of Response	-0.71939
Observations (or Sum Wgts)	49

t Test

MBR-CMAR-MBM-DB

Assuming equal variances

Difference	-0.8198	t Ratio	-2.0533
Std Err Dif	0.3992	DF	47
Upper CL Dif	-0.0166	Prob > |t|	0.0456*
Lower CL Dif	-1.6229	Prob > t	0.9772
Confidence	0.95	Prob < t	0.0228*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	3.538384	3.53838	4.2160	0.0456*
Error	47	39.445698	0.83927		
C. Total	48	42.984082			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM-DB	6	0.00000	0.37400	-0.752	0.7524
MBR-CMAR	43	-0.81977	0.13971	-1.101	-0.5387

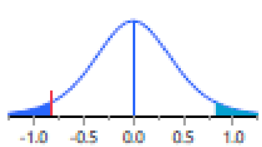
Std Error uses a pooled estimate of error variance

t Test

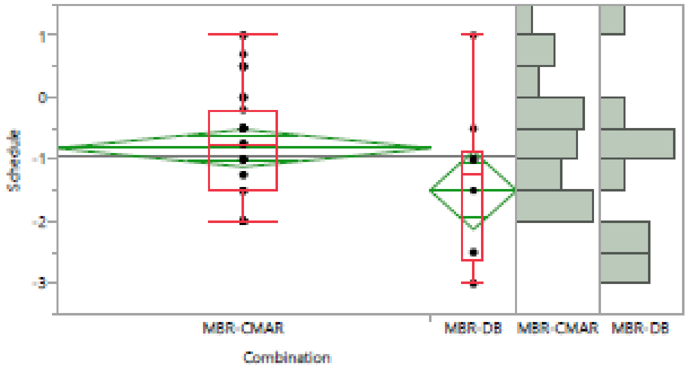
MBR-CMAR-MBM-DB

Assuming unequal variances

Difference	-0.8198	t Ratio	-2.09605
Std Err Dif	0.3911	DF	6.563406
Upper CL Dif	0.1177	Prob > |t|	0.0769
Lower CL Dif	-1.7572	Prob > t	0.9615
Confidence	0.95	Prob < t	0.0385*



Oneway Analysis of Schedule By Combination



Oneway Anova

Summary of Fit

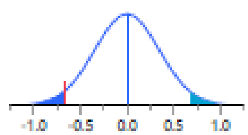
Rsquare	0.069909
Adj Rsquare	0.051672
Root Mean Square Error	0.98961
Mean of Response	-0.94811
Observations (or Sum Wgts)	53

t Test

MBR-DB-MBR-CMAR

Assuming equal variances

Difference	-0.6802	t Ratio	-1.9579
Std Err Dif	0.3474	DF	51
Upper CL Dif	0.0173	Prob > |t|	0.0557
Lower CL Dif	-1.3777	Prob > t	0.9721
Confidence	0.95	Prob < t	0.0279*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Combination	1	3.754114	3.75411	3.8334	0.0557
Error	51	49.945698	0.97933		
C. Total	52	53.699811			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBR-CMAR	43	-0.8198	0.15091	-1.123	-0.5168
MBR-DB	10	-1.5000	0.31294	-2.128	-0.8717

Std Error uses a pooled estimate of error variance

t Test

MBR-DB-MBR-CMAR

Assuming unequal variances

Difference	-0.6802	t Ratio	-1.60005
Std Err Dif	0.4251	DF	11.29043
Upper CL Dif	0.2525	Prob > |t|	0.1372
Lower CL Dif	-1.6130	Prob > t	0.9314
Confidence	0.95	Prob < t	0.0686