THE IMPACT OF THE LAST PLANNER SYSTEM ON CONSTRUCTION PROJECT PERFORMANCE IN TERMS OF SCHEDULE AND COST

A Thesis

by

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ABSTARCT

When speaking of project performance, historically, improvements in practice have been held in higher regards than improvements in management theory. Yet, it is argued that enhancement in practice cannot be achieved without improved theory. This research investigates and compares Management by Results (MBR) and Management by Means (MBM), as two primitive and competing conceptualizations of management underlying prevailing project management and control systems. The Earned Value Method (EVM) and the Last Planner System (LPS) are found to be based on MBR and MBM view respectively. According to existing literature, the LPS, as a MBM-based system, is claimed to be more efficient in comparison with EVM in cost and schedule performance. Yet, more quantitative research is required to be carried out in this area. This research starts with a comprehensive structured literature search of MBR and MBM-based control and management systems in terms of cost and schedule performance with the aim of figuring out which system is more appropriate to today's construction projects with a high level of complexity and uncertainty and where tasks are highly interdependent. Structured literature review and three different statistical data analyses are used as the methodology of this research. The data of over seventy construction projects is statistically analyzed in order to test the research hypothesis that the LPS, as a project planning and control method, positively influences the project performance in terms of cost and schedule. The results display that projects implementing the LPS are superior to projects with traditional management method in terms of schedule performance, yet, there is no significant difference between their cost performance.

DEDICATION

This thesis work is dedicated to my dear parents, Giti Zoghi and Bijan Vaziri, who have been a constant source of support and encouragement during my whole life and I would not be here today without their endless love and help.

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NOMENCLATURE

ANOVA	Analysis of Variance
ACWP	Actual Cost of Work Performed
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CIP	Construction in Progress
CMAR	Construction Management at Risk
CPI	Cost Performance Index
CSP	Competitive Sealed Proposal
CV	Cost Variance
DB	Design Build
DPS	Project Delivery System
EVM	Earned Value Method
GMP	Guaranteed Maximum Price
GSF	Gross Square Feet
LPS	Last Planner System
MANOVA	Multivariate Analysis of Variance
MBM	Management by Means
MBR	Management by Results
PPC	Percent Plan Complete
SF	Schedule Variance
SPI	Schedule Performance Index

WBS	Work Breakdown Structure

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1. INTRODUCTION

Construction is a highly complex field with high level of unpredictability in time, condition, and every task (Allen and Iano 2011). According to Fernandez-Solis, construction can be conceived as an adaptive complicated system that is dynamic and non-linear (Fernandez-Solis 2013). Moreover, the number of participants of projects is increasing and there are serious time limitations for projects (Howell and Ballard 1996). An enormous number of transaction of material and information leads to high levels of interdependency and uncertainty, which is typical at the operational level. Under these circumstances, reliability of work and information flow becomes more critical and important than ever (Howell and Ballard 1996).

With regards to the properties of current construction projects, it is crucial to opt for the proper management method contributing to the success of the project and it is critical to coordinate and supervise the entire process thoroughly while making sure that the project is completed on schedule and within budget (Kim and Ballard 2010; Lagoo 2012). This requires a continuous track and revise in terms of cost and time. The variances in schedule and cost need to be monitored regularly in order to prevent escalating disorder in estimated and planned time and cost. This need culminated in evaluation and revision of control theories and practices with the ultimate purpose of the success of construction projects (Kim and Ballard 2010; Lagoo 2012).

There are several different project control tools and measures used in the industry. By the advent of computerized control tools, which makes the process of information easy, managers have started trying to control projects at more detailed levels. Despite the application of improved tools using the advanced technology, there have been no significant improvement in projects performance (Kim and Ballard 2010).

It has been argued that an improved theory is vital for achieving improvement in practice (Koskela and Howell 2002; Vrijhoef and Koskela 2000). In fact, a theory elaborates observed behavior and contributes to grasping and predicting future behavior (Koskela and Howell 2002). In addition, the basis and source for the development of tools for analyzing, designing, and controlling are provided by implementation of theories (Kim and Ballard 2010).

According to the lack of an explicit theory in construction (Koskela 2000; Koskela and Howell 2002), in 1999, Koskela strived to develop a theory of construction (Koskela 1999). He proposed to consider construction as a type of production. In 2003, Bertelsen applied the theory of complex adaptive systems to construction (Bertelsen 2003). All these have addressed the nature of a project. Moreover, there have been some research and studies conducted on the question: What is project management? In 2002, Koskela and Howell explained the characteristics of traditional project management and lean project management by using thermostat and scientific model (Koskela and Howell 2002).

Management by results (MBR), is a target oriented management concept. In MBR, financial outcomes and their relation with the schedule are the main focus of the management or the 5 organization. Therefore, financial metrics and measures are used to evaluate and correct production process (Ballard and Howell 2003).

In contrast with MBR, Management by means (MBM) is a new concept of management focusing on resources, instead of finances, with the aim of achieving long term success by making improvement in methods, process, approaches, and their interrelations.

According to Johnson and Broms (2000), Earned Value Management method (EVM) reflects MBR thinking and the Last Planner System (LPS) is one of the examples of MBM concept; since the ‘lean thinking’ initiated from Toyota has roots and inferences that are well beyond manufacturing management alone (Ballard and Howell 2003).

EVM is a project management and control system that provides quantitative measure work performance and progress an objective approach (Fleming 1987). According to Warburton (2011), EVM can unite the triple main constraints of time, cost, and scope.

The LPS is a production planning and control tool introduced by Ballard (2000). The LPS applies flexible production planning procedures from the bottom that is in contrast with standard top down management principle, such as EVM. In LPS, promise fulfilments made to deliver production are being tracked with the purpose of keeping the production environment stable (Ballard and Howell 1994).

Although LPS, as an example of management methods reflecting MBM thinking, is elaborated and discussed adequately in the literature; however, there is no adequate quantitative evidence on the impacts of LPS on the performance of construction projects. Despite the fact that LPS is highly distributed and used across industry, most research studies conducted so far are mostly based on qualitative evidences of a few number of case studies (Formoso and Moura 2009). According to Ballard (2000), it is essential to evaluate and find out the advantages of greater plan reliability for time, cost, quality, and safety. As a result, there is a need to carry out quantitative studies and evaluate the impacts of each management concept (MBM and MBR) on the performance of construction projects.

This study first focuses on studying and comparing two management theories: Management-by Results (MBR) and Management-by-Means (MBM) in order to define a clear categorization of these two different management thinking's. Then, Earned Value Management system (EVM) and Last Planner system (LPS), as two project management and control systems reflecting MBR and MBM respectively, are compared in terms of their impact on schedule and cost performance in construction projects. This research is statistically considerable as it investigates a significant number of construction projects. twenty MBM-based and fifty-two MBR-based projects are statistically analyzed and studied in terms of schedule and cost performance.

This research endeavors to answer the following question:

Is the MBM more appropriate for construction project system where each task is highly independent?

The scope of the research is limited to investigating commercial projects, built in the state of Texas, with completion date in the interval of year 2000-2018.

2. REVIEW OF LITERATURE

2.1 Background

This literature review identifies concepts behind construction management practices, planning strategies, execution and planning tools, which are applied mostly within preconstruction, and construction planning and execution phases. Several search engines have been used for literature search and the content of this section is based on the search engines results for keywords, relevant data sources, and management practices applied in construction projects. Over thirty articles and books were found during the first step of literature search. Afterwards, specific criteria were applied to narrow down the database.

First, a wide ranging topic was chosen with the purpose of obtaining a broader perspective of construction management theories, concepts, and tools. Specific recurring words and most cited authors and practices were identified. Then, frequent recurrences were identified as keywords resulting to an outlined literature survey. A general database was developed for the literature search.

This database provided access to creditable and acclaimed publications and journals as following:

Journal of civil engineering and management, KSCE journal of civil engineering, journal of management in engineering (ASCE), Journal of construction engineering and management (ASCE), Alexandria Engineering Journal, Conference Proceedings of Annual Conferences of the International Group of Lean Construction (LGLC), Lean Construction Journal (LCI), etc.

The literature argues that it is not feasible to achieve improvement in practice without enhanced theory (Koskela and Howell 2002; Vrijhoef and Koskela 2000). A theory contributes to understanding observed behavior and anticipating future behavior (Koskela and Howell 2002). In addition, the development of tools for analyzing, designing, and controlling are based on a theory (Kim and Ballard 2010).

Whereas, there is an argument that there is no explicit theory in the area of construction (Koskela and Howell 2002). In fact, there is a clear need in establishing strong based theories that can be easily applies to construction practices. According to Kim and Ballard (2010), management theories are disregarded in construction industry. Moreover, making any late adjustment into a project is usually ineffective and expensive (Sterman 1992); in other words, the later the corrective action, the less effective it will be (Nepal et al. 2006).

Afterwards, literature based on existing theories that validates them through surveys and case studies was chosen. At the end, a holistic relation between construction theories and their corresponding practices was created. In addition, literature survey has been used to notice prevalent management principles applied in construction industry. Then, it develops a relation between these management concepts.

2.2 Prevalent Management Theories in Construction Industry

There are various concepts of management that are competing each other in different aspects. Johnson and Broms (2000) expressed the competing concepts of management in two distinct categories of Management-by-Results (MBR) and Management-by-Means (MBM).

MBR and MBM are continuously compared in construction industry. The controversy is that which of these two theories is better and more effective with the aim of improving management strategies that would lead to success of a construction project (Kim and Ballard 2010). These two theories will be discussed in detail in the research in order to establish the basis of choosing the topic of the research.

2.2.1 Management by Results (MBR)

Johnson and Broms (2000) proposed a distinction in management concept between MBR and MBM. MBR, displays the traditional management concept, expressing that organizations are driven by financial goals assuming that corporate purposes can be achieved by each part of the organization. In MBR, motivating and encouraging employees to reach or exceed financial goals is among the manager's key roles. That is the reason behind naming this management theory as "Managing-by-Results" by Johnson and Broms. In this category of management, managers set up financial targets and monitor performance against those targets. In other words, management is consisted of determining goal in advance to the act of production, monitoring during the course of production, and making correction after the act of production. In addition, financial metrics and measures are used to evaluate and correct production process (Ballard and Howell 2003).

MBR is driven from quantitative thinking. Consequently, this method of thinking delimits one's perception to only one dictated dimension; however, nature and organization are consisted of various dimensions (Johnson and Broms 2000). Under this quantitative thinking, the observers and objects are independent and separate from each other. The fact is that this quantitative thinking is appropriate to mechanical systems that all interactions can be defined in quantitative terms entirely. On the other hand, MBR neglects the attributes of organizations that are different from mechanical systems. In fact, it omits the assumption that the optimization of the whole can be achieved by optimizing all parts of the whole. In comparison with mechanical systems, organizational systems have more complicated relationships among their parts and subsystems. Therefore, MBR is considered as an inappropriate and insufficient management thinking for these systems. With regards to observations, MBR is worth to apply for short term goals where the stakes are low (Johnson and Broms 2000).

This system tracks the status and progress of a project as well as anticipating the likely performance in future. MBR, as a generalized term, incorporates the principles of Earned Value Management System (EVM).

2.2.1.1 Earned Value Method System (EVM)

Earned Value Method (EVM) is a project control system providing a quantitative measure of work performance (Fleming 1987). For every work performed, it includes crediting dollar or labor hour according to unit rates. The EVM is known for being superior to independent schedule and cost control for assessing work progress with the purpose of identifying possible schedule slippage and areas of budget overruns. Good planning along with efficient use of the EVM method, can reduce a considerable amount of problems arose from overruns in time and cost. Hence, in order to keep the project on time and within budget, it is essential to carefully direct the tracking of predicted schedule and cost (Kim and Ballard 2010).

Major components of this project control system are work package and variance analysis. A work breakdown structure (WBS), divides a project into the elements of work to be performed and completed. WBS defines cost accounts, which functions as management control points. This could be achieved by integrating elements of work need be accomplished with organization breakdown structure providing the “responsibility” field. Management control points are considered as the most detailed breakdown for project control, where resources are allocated, costs are collected, and performance is formally evaluated (McConnell 1985).

Every cost account acts as a control point and it is the minimum level at which individual variance analysis can be made. At any point in a WBS hierarchy, variance can be analyzed. According to cost/schedule control system criteria established by U.S Department of Defense, a cost account is defined as a management control point to accumulate actual cost and compare it to budged cost for work carried out (Kim and Ballard 2010).

2.2.1.1.1 Metrics

Cost Variance (CV) and Schedule Variance (SV) are the two relevant variances used in EVM. In this method, three types of data are collected for analysis (Kim and Ballard 2010):

1. Actual cost of work performed (ACWP): is the actual incurred cost typically in terms of dollar or labor hours of work carried out within a certain period of time.
2. Budgeted cost of work performed (BCWP) or Earned Value: is the budgeted value typically in terms of dollar or labor hours of work carried out within a certain period of time.
3. Budgeted cost of work scheduled (BCWS): is the budgeted value usually in terms of dollar or labor hours of work to be carried out within a certain period of time (Figure 1).

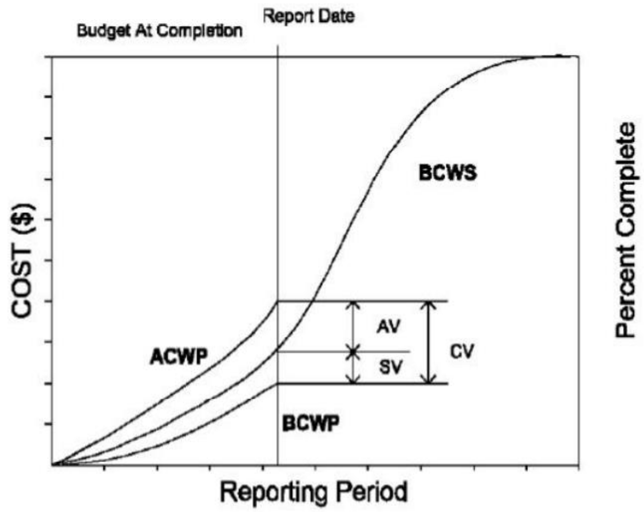


Figure 1. Variance Analysis for EVM curve (Reprinted from Kim and Ballard 2000)

In EVM, the monitoring of Cost Variance and Schedule Variance is required to achieve the objective of this method, which is having an integrated cost/schedule progress monitoring and control system.

CV is the difference between the budgeted and actual costs of the work carried out.

CV = BCWP – ACWP or CV% = BCWP – ACWP / BCWP

SV is the difference between the budgeted costs of work actually performed and the budgeted cost of the work schedules to be accomplished.

SV = BCWP – BCWS or SV% = BCWP – BCWS / BCWS

Table 1 displays the performance interpretations that may be drawn from CV and SV values.

Table 1. Schedule and Cost Performance from CV and SV (Reprinted from Kim and Ballard 2010)

Variance	-	0	+
CV	Cost overrun	On budget	Cost underrun
SV	Behind schedule	On schedule	Ahead of schedule

2.2.1.1.2 Assumptions

It is required to examine the assumptions of a project control method in order to probe management thinking behind it. In EVM, it is assumed that a project can be divided into independent subprojects packages, with contractual responsibilities and quantitative goals assigned (McConnell 1985). Also, it is assumed that packages are independent of each other. For instance, each package represents a contractual obligation between one party (i.e., owner, general contractor, etc.) and multiple other parties (i.e. subcontractors), without any connection between one contract and another. Moreover, EVM assumes that the success of each package results in the success of the entire project. In other words, if each package driven from WBS is managed and accomplished within its schedule/cost target, the success of the whole project will be achieved. The ultimate goal of managers applying this method in their projects is to improve financial performance, such as increasing earned value of each account (Kim and Ballard 2010).

2.2.1.1.3 Management Thinking

From the perspective of management thinking, the EVM can be categorized under MBR thinking. This categorizing is based on the following:

- In EVM, WBS and CV analysis assume that every task or package is independent.
- Cost and progress are the objects of measure. Cost and progress are the outcomes of the processes. Processes may encompass planning, operations, and system reliability.
- Management decisions are dependent on performance results, such as CV and SV

In project control, it is critical to monitor cost and progress in order to check if they are on the right track. EVM should be applied in at the system level with elements that are relatively independent of each other. Unlike in system level, this method is not suitable to be used at operational level where tasks are highly independent.

According to an investigation done by Kim and Ballard (2000), if cost and budget on each cost account are the main decision criteria for releasing assignments into workflow, workflow becomes unreliable. Consequently, this will result in longer duration and higher cost than necessary. Schedule and cost overruns relative to target will be additional consequences of workflow unreliability (Kim and Ballard 2010).

In fact, in EVM, cost and schedule are the objects to measure and evaluate. Cost and schedule are targets of the processes that encompass planning, operation, system reliability, and etc. Management decisions, such as resource allocation, are based on SV and CV in this system.

After these calculations, Cost Performance Index (CPI) and Schedule Performance Index (SPI) are calculated. The values of them indicate if the project in on schedule and within the budget or vice versa. CPI and SPI are calculated as following:

CPI = BCWP / ACWP

If CPI is equal or greater than one (CPI >= 1), the project is within or under budget.

SPI = BCWP / BCWS

If SPI is equal or greater than one (SPI >= 1), the project is on or ahead of the schedule.

Although EVM can be considered as a highly developed method for integrating schedule and cost (Kim and Ballard 2000), there are some limitations and disadvantages associated with this system:

- The graphical representation of outcomes simply displays variance between the amount to be spent without regards to progress and the actual expense (Kim and Ballard 2000).

- It is assumed that one earned hour equivalent to another, and the productivity of one activity has no influence on the performance of the other one, even if they are mutually dependent.
- A provision to evaluate and measure quality and customer satisfaction is lacking in EVM system. Therefore, if EVM indicates that a project is within budget or ahead of schedule and fully executed scope, it does not demonstrate that the client is satisfied with the project.
- Although the schedule variance (SV) is in fact a difference in schedule, it does not show its statistical implications. In addition, the unit of the SV is in dollars instead of weeks or months, and this makes it difficult to define units for the schedule (Cioffi 2006).

The majority of management approaches focus on external factors and domains such as structures-processes-outcomes. This explains why management approaches and tools are less sustainable (Pavez et al. 2010). The main reason behind this fact is the lack of importance associated with internal factors like people and their personalities, interests and viewpoint (Beck and Cowan 2014). Quite a few theories have been developed in order to compensate this shortage and with the aim of implementing both internal (people) and external worlds of management (Barrett 2006; Kofman 2008). Among these newly established theories, one includes Lean Construction, a novel management thinking influencing the construction industry substantially.

Several technical tools are being used extensively for construction planning, scheduling, modeling, etc.; nonetheless, no apparent improvement has been observed in project performance. This demonstrates a strong need to develop management concepts that can contribute in improving construction performance through integrating both inner and outer management theories (Kim and Ballard 2002).

2.2.2 Management by Means (MBM)

Johnson and Broms (2000) define and use Management-by-Means (MBM) as the opposite concept of MBR. They believe that the difference between MBR and MBM follows the difference between the governing principles of mechanical systems and natural living (organizational) systems. In contrast with mechanical systems, organizational systems are not divided into independent ad separated parts. In this type of system, what important is to nurture and improve relationships between parts, not maximizing the efficiency and output of each part. In fact, managing projects or other types of organization requires more than quantitative summing up of the separate contributions of each part (Johnson and Broms 2000; Johnson 1992; Kim and Ballard 2010).

The principle belief of MBM is that the way a system organizes its work is actually, what determines its long-term profitability. Aiming to optimize each part separately ends up in one part cannibalizing another and consequently reduces the overall performance of the system. In MBM, managers should aim at conforming to disciplined practices, coordinating among parts of the system, and enabling who performs the work.

In contrast with MBR that applies financial measures, MBM relies on process measures for feedback on system performance. MBM has production system design before, system operation within, and improvement after the phase of production. MBM achieves these through operating itself divided into goal setting, controlling, and correcting (Ballard and Howell 2003).

According to Johnson and Broms (2000), Toyota is one of the exemplars of MBM; since the ‘lean thinking’ initiated from Toyota has roots and inferences that are well beyond manufacturing management alone (Ballard and Howell 2003). Liker’s account of Toyota’s management principle has provided a perfect example of this type of theory in his 'The Toyota Way' (Kim and Ballard 2010; Liker 2004).

All in all, the MBM and MBR clearly elaborate the differences in perspective of control in traditional management and Lean management. In traditional management, control is conceived as after-the-fact variance detection. Whereas, Lean Construction has different conception for control; it considers control as active steering of a production system or project towards its targets (Ballard and Howell 2003).

2.2.2.1 Last Planner System (LPS)

MBM as a general term incorporates Last Planner system (LPS) as a part of lean construction principles.

The Last Planner System is a production planning and control tool introduced by Ballard (2000) with the purpose of enhancing work flow reliability. Since then, it has made substantial changes in construction project planning and control and there has been significant advancement in its tools, techniques, and associated metrics (Fernandez-Solis et al. 2012).

The concept of LPS has its roots in the demand for control, with a method of giving rise to work flow predictability through controlling the quality of assigned tasks in weekly work plans (Fernandez-Solis et al. 2012).

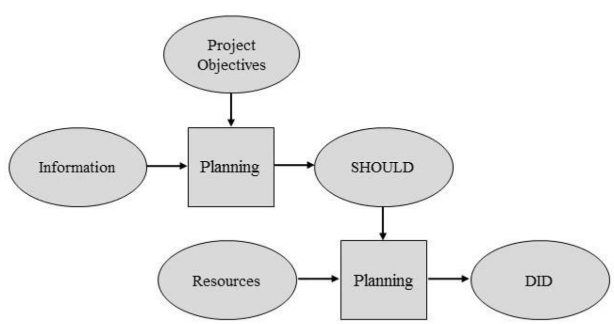
According to Fernandez-Solis et al. (2012), the last individual, typically the foreman, is referred as the last planner. The foreman is able to ensure predictable work flow downstream.

Despite some challenges, this method has been adopted by many companies and the result of their case studies, along with several reports and academic papers have provided evidence that

LPS contributes in, reliable and smooth workflow, improved productivity, and reduced project duration and cost subsequently. (Ballard et al. 2007; Fernandez-Solis 2013; Fiallo and Revelo 2002; Johansen and Porter 2003; Kim and Jang 2005).

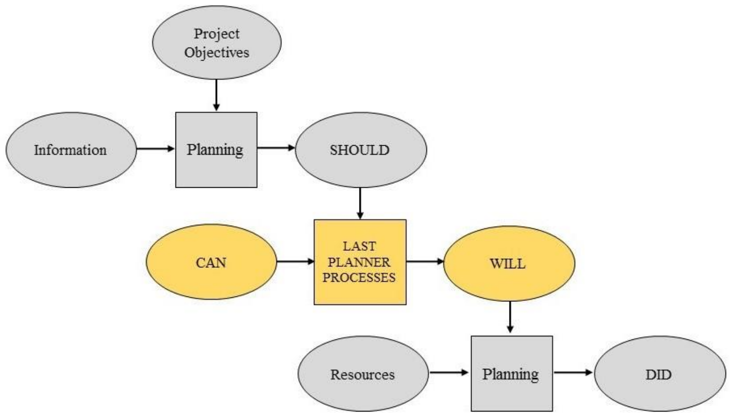
The LPS provides essential planning and control tools for projects even when they are complex and uncertain. Planning defines project goals and sequence of activities to achieve these goals. Control monitors activities following the desired sequence, and causes re-planning when the existing plan is no longer practical or desirable. In addition, control initiates learning from past failures when activities could not conform to the plan (Nieto-Morote and Ruz-Vila 2011).

LPS is in contrast with the traditional method. In traditional practice, assignments are pushed onto construction crews and design teams with the aim of meeting scheduled dates (Figure 2). Whereas, LPS releases only workable jobs to the field (Figure 3) (Kim and Ballard 2010).



(1) Traditional Planner Process

Figure 2. Traditional Planner Process (Reprinted from Ballard 2000)



(2) Last Planner Process

Figure 3. Last Planner Process (Reprinted from Ballard 2000)

In LPS, in addition to looking ahead and pre-screening upcoming tasks for any constraint, it is expected that all assignments meet certain quality requirements for definition, sequence, and size. LPS promotes learning from past failures with the purpose to avoid repeating mistakes.

Making quality assignments protects production units from workflow uncertainty. Also, it enables production units to enhance their own productivity and productivity of the downstream production units that receive and build on their work. This is important because downstream production units are dependent on reliable release of prerequisite work or shared resources to do their own planning (Ballard and Howell 1998; Kim and Ballard 2010).

In LPS, scheduling is completed in several phases: milestone planning, phase scheduling, look-ahead planning (six or ten weeks), and weekly work plan. The LPS metric for measuring the performance is Percent Plan Complete (PPC). There are other tools and techniques applied in LPS: Five Whys, Stickie's on the Wall, First Run Studies, Daily Huddle Meetings, Reason Charting, and Constraint Analysis (Fernandez-Solis et al. 2012).

2.2.2.1.1 PPC

Percent Plan Completion (PPC), is a metric proposed by Ballard (2000) for evaluating the reliability of the planning system. Ballard defines PPC as “the number of planned activities completed divided by the total number of planned activities, expressed as a percentage”:

PPC% = (number of completed activities / number of planned activities) X 100

Higher PPC implies for doing more of the right work with given resources; it demonstrates higher productivity and progress (Ballard 2000). The required numbers to calculate PPC can be easily obtained from foremen or project engineers. There is no need to acquire additional information like resource consumption for this calculation (Kim and Ballard 2010).

In contrast to other project performance criteria or variance analysis (such as Earned Value method, schedule index, cost index, etc.), the PPC does not measure whether the project is on schedule or on budget. The PPC gauges whether the planning system enables the reliable anticipation of what will actually be done. In PPC calculation, is it critical to determine correctly whether an assignment was completed or not according to the plan, yet, it is more important to elaborate and investigate the causes of failure to accomplish the work as planned (Choo 2003).

2.2.2.2 Assumption

The LPS assumes that there are uncertainties and constrains associated with schedule tasks that prevent them from being started or accomplished at the right time. Timely availability of resources, shop drawings, or prerequisite work are among possible uncertainties and constraints and they are revealed and addressed in process of look-ahead planning which usually takes about six weeks. In look-ahead planning, only sound tasks are selected for inclusion in daily or weekly work plans. A properly-done look ahead planning results in improved work-flow reliability. The reason behind it is for tasks which are screened for constraints and probed to be constraint-free, the possibility of being finished when planned is higher (Kim and Ballard 2010). According to an argument made by Howell and Ballard (1996) a reliable planning is the prerequisite for having reliable cost and progress measurements.

2.2.2.3 Management Thinking

While traditional project control, such as EVM, with MBR thinking is focused on managing each activity separately, the focus of the LPS is on work flow reliability. The LPS follows MBM thinking as:

- In LPS, monitoring is focused on planning reliability, not financial metrics.
- It is assumed that planned tasks include constraints and uncertainties.
- Management decisions are made according to planning reliability and this is a prerequisite to cost and progress measures.

This type of view for production control reflects MBM thinking and quite a few results driven from case studies suggest that such as view is efficient and practical in managing production (Kim and Ballard 2010).

2.3 Accounting Numbers versus Relationship

The main difference between MBR and MBM is as following:

The difference between MBR and MBM practices is driven from the differences between the principles that govern natural living systems and those that govern mechanistic systems (Johnson and Broms 2000). MBM requires developed system principles, while MBR needs continuous hard work to achieve and maintain success. MBR-based project control tools are considered to be less effective at the operational level with task interdependencies. On the other hand, the case studies and literature support the claim that MBM view is more applicable and suitable for managing work under these circumstances (Kim and Ballard 2010).

MBM and MBR are two different ways of improving performance. Although their methods, concepts and objectives are differing from each other, they both lead to a better performance (Johnson 2006). Professor H. Thomas Johnson (2006) presented figures displaying the progress curve for MBM and MBR. The MBR progress curve is saw toothed with periodical low and high growth; while, MBM progress curve is a stepped curve with gradual ascent to a desired goal (Figure 4).

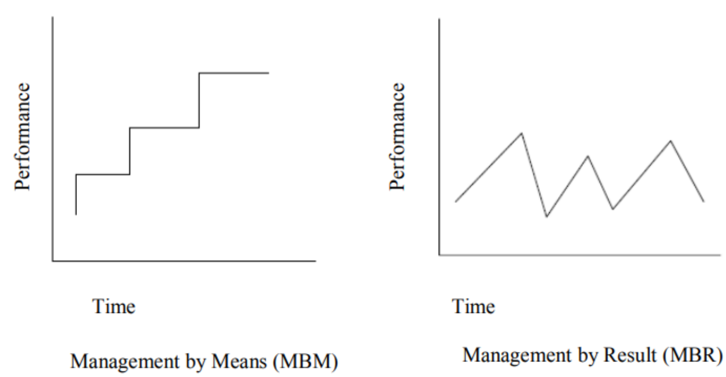


Figure 4. MBM and MBR progress curve (Reprinted from Johnson 2006)

As seen in EVM, accounting numbers such as budget and planned schedule are the main focus of MBR-based project control and the ultimate aim is to minimize negative variances from planned cost and schedule. Whereas, the purpose of MBM-based control is improving the workflow among production units. This is achieved in two steps: first making workflow reliable, then advancing the performance of the whole production system in a continuous way. Making enhancement in reliability results in developing and nurturing relationships with all participants involved in project. Building relationships in driven from trusting each other. Trust comes from reliability, not from contract or commitment. Hence, MBM-based project control tools lead to forming relationships among project participants and reducing cost and duration are byproducts (Kim and Ballard 2010).

Nowadays, due to the complex and uncertain nature of construction projects, reliability of workflow and information flow becomes more essential than ever (Howell and Ballard 1996). Under these conditions, it is approved through research in the lean construction community that workflow reliability must be achieved in advance to managing cost and schedule (Ballard and Howell 1998; Howell 1999).

2.4 Empirical Evidence from Literature

Kim and Ballard (2010) conducted a survey of several construction projects implementing EVM and LPS in their projects. A case study was performed to investigate and understand how workflow reliability and productivity are affected by different factors (Liu and Ballard 2008). This method has been applied by many companies and they have reported the results of case studies. All these reports along with academic papers have demonstrated the claim that LPS improves workflow reliability, thereby saving project time and cost (Ballard et al. 2007; Fiallo and Revelo

2002; Johansen and Porter 2003; Kim and Jang 2005). In some of these case studies, EVM is specified as being applied in advance to implementing the LPS. Yet, as MBR is the management concept which is underlying currently accepted practice, it could be assumed that most, if not all, projects on which the LPS has been applied were previously managed by implementing MBR tools such as EVM (Kim and Ballard 2010). Table 2 indicates a summary of findings from preliminary literature review:

Table 2. Preliminary Literature Review Findings

Researchers	Scope and case of research	Results
Ballard et al. 2007	LPS implemented at operational level on a pharmaceutical research and development center process and equipment building system.	• 54% < PPC < 94% • The LPS forced to think about tasks to be completed each day • Better understanding of causes of incompletion and their roots.
Ballard et al. 2007	LPS applied to ten heavy civil projects *EVM was implemented prior to LPS	• The average PPC increased from 50% to 80% • SPI improved by more than 10%
Ballard et al. 2007	LPS implemented on Refinery facility project in Indiana	• LPS improves PPC and productivity
Kim and Jang 2005	LPS applied to production planning at the operational level *EVM were employed previously at the operational level	• planning reliability, schedule and cost performance were improved at the system level
Kim and Ballard 2010	22 Projects were investigated to study how MBM and MBR are effective in production planning and control at the operational level. Relevant production control documents such as weekly schedule were analyzed.	• MBM tends to improve Cost Performance • MBM-based production planning showed better performance at the operational level

3. PROBLEM STATEMENT

Although LPS, as an example of management methods reflecting MBM thinking, is elaborated and discussed adequately in the literature; however, there is no adequate quantitative evidence on the impacts of LPS on the performance of construction projects. Despite the fact that LPS is highly distributed and used across industry, most research studies conducted so far are mostly based on qualitative evidences of a few number of case studies (Formoso and Moura 2009). According to Ballard, it is essential to evaluate and find out the advantages of greater plan reliability for time, cost, quality, and safety (Ballard 2000). As a result, there is a need to carry out quantitative studies and evaluate the impacts of each management concept (MBM and MBR) on the performance of construction projects in terms of cost and time.

Therefore, this research carries out a structured literature review to explore the theoretical implications, especially management thinking, of two project management and control tools: The Earned Value Method and the Last Planner System reflecting MBR and MBM view respectively. The second phase of this study uses statistical analysis methods to find out if there is any difference in the performance of projects implementing MBM-based and MBR-based management tools in terms of cost and time.

4. METHODOLOGY

4.1 Research Design

The ultimate objective of this research is to figure out if MBM-based planning and control method outperforms MBR-based system in terms of cost and time performance in construction projects. This study is designed as a three-phase research:

The first phase is a qualitative research method carried out by performing a structured literature review in order to have a complete and comprehensive knowledge about the previous studies conducted about comparison of cost and schedule performance of MBR and MBM-based projects (this phase of the research has been covered and explained previously in "Review of Literature").

The second phase is conducting in-depth statistical analysis on data from seventy-three actual construction projects. First, clear measurement priorities are set, which represent schedule and cost performance in construction project; and their values are calculated independently.
The second sub-step is choosing the appropriate statistical analysis method and performing it on data. The final phase is interpreting the results of the statistical analysis and comparing them with the existing relevant literature.

This research is statistically significant, as it studies a considerable number of construction projects. Twenty-one MBM-based and fifty-two MBR-based projects are analyzed and investigated thoroughly in terms of schedule and cost performance. Furthermore, since the provided data set also includes information on delivery system and contract type of each construction project, the author uses them as two complementary factors to investigate if Project Delivery System (DPS) and Contract Type are also influential in project schedule and cost performance. Moreover, the influence level of these two additional factors and management method on cost and schedule performance are compared in order to determine the most and least effective ones.

4.2 Measurements

The following measurements, representing cost and schedule performance of projects, are used in this study:

a. Unit Cost = Actual Total Project Cost / Gross Square Feet (Konchar and Sanvido 1998)
b. Construction Change Order Amount = Actual Total Project Cost – Planned Total Project Cost
c. Project Cost Growth = Construction Change Order Amount / Planned Total Project Cost (Charoenphol et al. 2016; Konchar and Sanvido 1998)
d. Project Schedule Growth = (Actual Total Project Duration - Planned Project Duration) / Planned Project Duration
e. Construction Intensity (SF / day /1000) = Total Square Feet of Building / Actual Total Design and Construction Duration / 1000 (Engineering News Record website, 2015)

Unit Cost (a), Change Order Amount (b), and Cost Growth (c) are used to evaluate the cost performance of projects. Due to different sample project sizes and types, it is not logical to compare their total costs directly; therefore, Unit Cost is measured as an indicator of cost performance. Project Cost Growth (c) is an indicator of how fast and how much project actual costs are increasing versus planned costs. Instead of Actual Total Duration, Project Schedule Growth (d) and Construction Intensity (e) are used as metrics addressing project schedule performance.

For Unit Cost (a) and Change Order Amount (b) there is no conclusion on when lower or higher numbers represent better performance. For both project Cost and Schedule Growth (c & d), the lower calculation results are better than higher ones, and for Construction Intensity (f) the higher values are preferred.

4.3 Statistical Analysis Methods

In order to have an in-depth statistical analysis on the data, three different statistical analysis methods are used in this research. After consulting with statistics professionals and researchers, considering type of the data and the objectives of the research, the most appropriate statistical analysis methods have been chosen as following:

4.3.1 Multivariate Regression Analysis

Dr. Eric Jing, Du, in his “Manual for Data Analysis” for Zachry Company, describes the use of Multivariate Regression Analysis as this: “if an observed variable (metric) is affected by multiple variables (factors), then Multivariate Regression Analysis cam be utilized to reveal the relationship between response and predictors, and used for prediction purpose.”

In this research, Multivariate Regression is performed, using JMP, to evaluate and measure the impact of all independent variable (factor) on each single dependent variable (measurement).

4.3.2 Discriminant Analysis

Discriminant Analysis is a statistical analysis, developed by Ronald Fisher in 1936, used to predict a categorical dependent variable by one or more independent variables. This statistical analysis is different from Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA), as they are used to predict one or multiple continuous dependent variables by one or more independent categorical variables. Discriminant Analysis is used for determining if a set of variables is effective in predicting category membership (Green and Salkind 2003).

In this research, Discriminant Analysis is conducted twice, each time with different number of metrics, in JMP, to evaluate and measure the impact of every independent variable (factor) on dependent variables (measurements). The application of Discriminant Analysis helps with identifying effective and ineffective factors and measuring their level of influence over construction project performance.

4.3.3 Two Sample t-Test

T-test is a generic statistical hypothesis test, which can be used in many problems. It is sometimes treated a statistical test to evaluate the importance of a variable. Coefficients of independent variables (the slop of regression line) are standardized, called t-ratios. T-ratio then can be used to evaluate the importance of a factor.

Since, the focus of this study is on MBM and MBR management methods and the difference between their impacts on project performance, in this research, Two Sample t-test is only performed to evaluate and compare the impact of the two management principles (MBM and MBR) on the measurements.

4.3.4 Factors and Metrics

In advance to conducting any statistical analysis on the data set, variables are defined as following (Table 3):

Table 3. Factors and Metrics

Factor (independent variable)	Measurement (dependent variable)
• Management method (MBM, MBR) • Project Delivery System (DB, CMAR) • Contract Type (GMP, CSP)	• Unit Cost • Change Order Amount • Cost Growth • Schedule Growth • Construction Intensity

4.4 Data

4.4.1 Data Collection

Dr. José L. Fernández-Solís has provided the required data that are used and studied in this research. The provided data from seventy-three projects includes the following information and numbers, which are analyzed in this research: actual and planned unit cost, actual total cost, actual and planned duration, total gross square feet (GSF), and PPC (for MBM-based projects). Table 4 displays a sample of data cell for each project.

Table 4. Sample Data Cell for Each Project

Project No.	Year			CIP			MBM / MBR
Contract type	Project Delivery System Type			Project Type			
Gross square feet (GSF)	Cost per GSF			Time - months			PPC % (If applicable)
	Plan	Actual	Delta	Plan	Actual	Delta	
Totals							

All seventy-three projects are commercial buildings which are constructed in the state of Texas from year 2000 to 2017.

Among the seventy-three projects, fifty-two (52) of them used Management-By-Results (traditional) planning and control method and twenty-one (21) projects used Management-by-Means planning and control system. Thirty-four (34) projects used Guaranteed Maximum Price (GMP) and thirty-nine (39) ones used Competitive Sealed Proposal (CSP) as their type of contract. Construction Management at Risk and Design-Build are two delivery systems applied in these seventy-three projects (Figure 7); Fifty-seven (57) projects used Design-build (DB) and sixteen (16) projects used Construction Management at Risk (CMAR) (Figure 5).

Figure 5. Number of Projects in Different Categories

4.4.2 Data Validation

After carefully checking the documentation and calculation of all the seventy-three sample projects, project No. 42 is found out to have been documented incorrectly. The correct total actual cost of this project has not been calculated correctly according to its GSF and Actual Unit Cost. Thus, Project No. 42 is excluded from the sample group and the remaining seventy-two projects are used in the statistical analysis.

4.4.3 Data Preprocessing

4.4.3.1 Time and Location Adjustment

The seventy-two sample projects are finished and delivered in different years from 2000 to 2017. With the purpose of minimizing the impact of time value and inflation on project cost values, all cost data are adjusted to their present value in year 2017 for future statistical analysis. An Excel table is used as the time value adjustment tool, which is provided by a Master's student, Daniel Wheeler (B. S. Agribusiness Finance, Texas A&M University). According to Wheeler's suggestion, with regards to the US economic crisis in 2008, using inflation rates can not represent the real costs of projects built in those years. As a result, the average Escalation Rate of the last ten years are selected when adjusting the time value of project costs. Since all sample projects are constructed in the state of Texas, no location adjustment is applied.

4.4.3.2 Calculation of Measurements

After adjusting projects costs time value, the defined measurements of Change Order Amount, Cost Growth, Schedule Growth, and Construction Intensity were calculated to four decimal places (Table 5).

Table 5. Sample of Measurements Calculations

No.	Year	Management Method	Delivery System	Contract Type	CIP (Actual Total Cost)	GSF	Cost-2017/GSF		Time Duration (month)		Change Order Amount	Cost Growth	Schedule Growth	Constructio Intensity
							Planned (Unit Cost)	Actual (Unit Cost)	Planned	Actual				
1	2000	MBM	CMAR	CSP	35500000	216000	244.4536	241.6740	28	28	-600383	-0.0114	0.0000	7.7143
2	2000	MBM	CMAR	CSP	23020000	143000	243.2476	236.7914	24	25	-923238	-0.0265	0.0417	5.7200
4	2014	MBM	CMAR	CSP	68700000	243500	300.5887	304.5174	33.5	32	956638	0.0131	-0.0448	7.6094
8	2008	MBM	CMAR	CSP	63500000	330000	264.6313	266.5987	30	30	649247	0.0074	0.0000	11.0000
9	2010	MBM	CMAR	CSP	116000000	200000	713.6951	731.3483	38	40	3530647	0.0247	0.0526	5.0000
11	2013	MBM	CMAR	CSP	36100000	150000	269.5782	270.3307	16	16	112886	0.0028	0.0000	9.3750
19	2014	MBR	CMAR	CSP	40800000	153000	287.0973	287.8205	35	36	110640	0.0025	0.0286	4.2500
21	2009	MBR	CMAR	CSP	47900000	179000	350.4089	351.1964	36	36.5	140951	0.0022	0.0139	4.9041
22	2002	MBR	CMAR	CSP	115900000	323600	511.4305	510.2338	41.5	40.5	-387240	-0.0023	-0.0241	7.9901
23	2007	MBR	CMAR	CSP	63600000	177000	504.0286	503.0766	36	36	-168514	-0.0019	0.0000	4.9167
25	2007	MBR	CMAR	CSP	85970000	640000	182.0103	188.0727	34	36	3879901	0.0333	0.0588	17.7778
26	2010	MBR	CMAR	CSP	80870000	394000	259.7547	258.8090	49	49.5	-372609	-0.0036	0.0102	7.9596
28	2015	MBM	CMAR	CSP	177500000	602200	303.4374	302.7356	47	48	-422641	-0.0023	0.0213	12.5458
29	2008	MBR	CMAR	CSP	121000000	553000	166.2605	167.6460	36	37	766184	0.0083	0.0278	14.9459
31	2008	MBR	CMAR	CSP	80000000	246500	450.2888	450.2888	46	45.5	0	0.0000	-0.0109	5.4176
32	2008	MBR	CMAR	CSP	475000000	315000	196.7416	197.9192	53	53.5	370969	0.0060	0.0094	5.8879
34	2012	MBR	CMAR	CSP	51000000	340000	174.8721	174.8721	30	30.5	0	0.0000	0.0167	11.1475
35	2011	MBR	CMAR	CSP	48200000	305000	192.7863	192.8229	18	19.5	11165	0.0002	0.0833	15.6410
37	2016	MBR	CMAR	CSP	75000000	225000	334.0000	333.3300	37	37.2	-150750	-0.0020	0.0054	6.0484

4.4.3.3 Sample Grouping

The ultimate goal of this study is to investigate the cost and duration differences between MBM and MBR-based construction projects. The seventy-two sample projects used different Delivery System and Contract type. With regards to the fact that different delivery system and contract types might affect cost and schedule management of construction projects, it is decided to perform the last statistical analysis (Two Sample t-Test) on the projects divided into four groups with the same Project Delivery System and Contract type. In other words, PDS and contract are the controlled variables in this analysis.

Group 1: (GMP, DB)

Group 2: (CSP, DB)

Group 3: (GMP, CMAR)

Group 4: (CSP, CMAR)

5. ANALYSIS AND FINDINGS

5.1 Statistical Analysis

5.1.1 Hypothesis

The general null hypothesis for this research is that there is no difference between the cost and time performance of projects applying MBR and MBM-based planning and control tools. The general alternative hypothesis is that there do exists differences. The null hypothesis and alternative hypothesis for each research question will be as following (Table 6):

Table 6. Table of Research Hypothesis

Measurement	Hypothesis Description
Unit Costs	$H_{0:}$: There is no statistically significance difference between the means (μ) of unit costs of projects applying MBR and MBM-based planning and control tools. $H_{A:}$: There is a statistically significance difference between the means (μ) of unit costs of projects applying MBR and MBM-based planning and control tools.
Change Order Amount	$H_{0:}$: There is no statistically significance difference between the means (μ) of change order cost factor of projects applying MBR and MBM-based planning and control tools. $H_{A:}$: There is a statistically significance difference between the means (μ) of change order cost factor of projects applying MBR and MBM-based planning and control tools.
Schedule Growth	$H_{0:}$: There is no statistically significance difference between the means (μ) of schedule growth of projects applying MBR and MBM-based planning and control tools. $H_{A:}$: There is a statistically significance difference between the means (μ) of schedule growth of projects applying MBR and MBM-based planning and control tools.
Cost Growth	$H_{0:}$: There is no statistically significance difference between the means (μ) of cost growth of projects applying MBR and MBM-based planning and control tools. $H_{A:}$: There is a statistically significance difference between the means (μ) of cost growth of projects applying MBR and MBM-based planning and control tools.

Table 6. Continued

Measurement	Hypothesis Description
Construction Intensity	$H_{0:}$: There is no statistically significance difference between the means (μ) of construction intensity of projects applying MBR and MBM-based planning and control tools. $H_{A:}$: There is a statistically significance difference between the means (μ) of construction intensity of projects applying MBR and MBM-based planning and control tools.

5.1.2 Discriminant Analysis

Discriminant Analysis is conducted to determine if each factor (independent variable) influences the value of the metrics. To have a more accurate result, the confidence level in all tests is set as 0.05. In other words, if the null hypothesis in each test is rejected at this significance level, it can be concluded that there is a probability of 95% that this factor affects the metrics value.

a) Management Method:

Test Hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of all metrics value.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.1315242	100.0000	100.0000	0.34093447	0.88376369	1.7361	5	66	0.1386

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.8837637	1.7361	5	66	0.1386
Pillai's Trace	0.1162363	1.7361	5	66	0.1386
Hotelling-Lawley	0.1315242	1.7361	5	66	0.1386
Roy's Max Root	0.1315242	1.7361	5	66	0.1386

Figure 6. Discriminant Analysis Results, Management Method vs All Metrics

Test result: P-Value is 0.1328, which is greater than the confidence level (0.05): 0.1328 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles are different in terms of cost and schedule performance. The Canonical Correlation indicates that 34% of all metric values can be explained by management method. Canonical Correlation refers to the linear relation between a set of independent variables and a set of more than one dependent variables (Figure 6).

b) Project Delivery System (PDS):

Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of all metrics value.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.274427	100.0000	100.0000	0.46404056	0.78466636	3.6224	5	66	0.0059*

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.7846664	3.6224	5	66	0.0059*
Pillai's Trace	0.2153336	3.6224	5	66	0.0059*
Hotelling-Lawley	0.274427	3.6224	5	66	0.0059*
Roy's Max Root	0.274427	3.6224	5	66	0.0059*

Figure 7. Discriminant Analysis Results, Project Delivery System vs All Metrics

Test result: P-Value is 0.0059, which is smaller than the confidence level (0.05): 0.0059 < 0.05. Thus, the null hypothesis can be rejected and it is concluded that different Project Delivery Systems have different cost and schedule performance. The Canonical Correlation indicates that 46% of all metric values can be explained by PDS (Figure 7).

c) Contract Type:

Test Hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of all metrics value.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) $\neq$ Mean of CSP (μ_{CSP})

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.1315242	100.0000	100.0000	0.34093447	0.88376369	1.7361	5	66	0.1386

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.8837637	1.7361	5	66	0.1386
Pillai's Trace	0.1162363	1.7361	5	66	0.1386
Hotelling-Lawley	0.1315242	1.7361	5	66	0.1386
Roy's Max Root	0.1315242	1.7361	5	66	0.1386

Figure 8. Discriminant Analysis Results, Project Contract Type vs All Metrics

Test result: P-Value is 0.1386, which is greater than the confidence level (0.05): 0.1386 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different cost and schedule performance. The Canonical Correlation indicates that 34% of all metric values can be explained by contract type (Figure 8).

Table 7 displays a summary of discriminant analysis results in this research.

Table 7. Discriminant Analysis Results

Independent Variable (Factor)	P-value	Canonical Correlation
Management Method	0.1328	0.34323504
PDS	0.0059(**)	0.46404056
Contract type	0.1386	0.34093447

5.1.2.1 Discriminant Analysis with Grouped Metrics

Although the metrics possibly have influence on each other values, the author decides to group the five metrics into two categories of Cost Related and Schedule Related metrics and redo the Discriminant Analysis with less number of metrics each time. Cost Growth, Actual Unit Cost, and Change Order Amount are grouped as Cost related metrics, while Schedule Growth and Construction Intensity are grouped as Schedule related ones.

a) Management Method

i. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Cost Performance.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.5148, which is greater than the confidence level (0.05): 0.5148 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles are different in terms of cost performance. The Canonical Correlation indicates that 18% of cost related metric values can be explained by management method.

ii. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Schedule Performance.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.0495, which is smaller than the confidence level (0.05): 0.0495 < 0.05 Thus, the null hypothesis can be rejected and it can be concluded that projects with different Management Principles are different in terms of cost performance. The Canonical Correlation indicates that 28% of schedule related metric values can be explained by management method.

b) Project Delivery System (PDS)

i. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Cost Performance.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Test result: The P-Value is 0.0347, which is smaller than the confidence level (0.05): 0.0347 < 0.05. Thus, the null hypothesis can be rejected and it is concluded that projects with different Delivery Systems have different cost performance. The Canonical Correlation indicates that 34% of cost related metric values can be explained by PDS.

ii. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Schedule Performance.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Test result: The P-Value is 0.0022, which is smaller than the confidence level (0.05): 0.0022 < 0.05. Thus, the null hypothesis can be rejected and it is concluded that projects with different

Delivery Systems have different duration. The Canonical Correlation indicates that 40% of schedule related metric values can be explained by PDS.

c) Contract Type:

i. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of Cost Performance.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) ≠ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.1859, which is greater than the confidence level (0.05): 0.1859 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different cost performance. The Canonical Correlation indicates that 26% of cost related metric values can be explained by contract type.

ii. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of Schedule Performance.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) ≠ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.0533, which is greater than the confidence level (0.05): 0.0533 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different duration. The Canonical Correlation indicates that 28% of schedule related metric values can be explained by contract type.

Table 8 displays a summary of discriminant analysis with group metrics results in this research.

Table 8. Discriminant Analysis with Grouped Metrics Results

Factor	Cost Performance	Schedule Performance
Management Method (MBM , MBR)	P-Value: 0.5148 Canonical Correlation: **0.1812**	P-Value: 0.0495(**) Canonical Correlation: **0.2888**
Project Delivery System (DB , CMAR)	P-Value: 0.0347(**) Canonical Correlation: **0.3439**	P-Value: 0.0022(**) Canonical Correlation: **0.4028**
Contract Type (GMP , CSP)	P-Value: 0.1859 Canonical Correlation: **0.2605**	P-Value: 0.0533 Canonical Correlation: **0.2854**

5.1.3 Multivariate Regression Analysis

In this study, Multivariate Regression is used to evaluate and measure the impact of every independent variable (Management principle, PDS, and Contract type) on each dependent variable (measurement). This analysis helps with identifying effective and ineffective factors and measuring their level of influence (F-Ratio) over construction project performance.

1) Management Method

a. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of total Change Order Amount.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.76162, which is greater than the confidence level (0.05): 0.76162 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Change Order Amount.

Project Delivery System (PDS)

b. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of total Change Order Amount.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Test result: P-Value is 0.684, which is greater than the confidence level (0.05): 0.684 > 0.05. Thus, the null hypothesis cannot be rejected and it is concluded that different Project Delivery Systems have different Change Order Amount.

Contract Type

c. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of total Change Order Amount.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) ≠ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.63889, which is greater than the confidence level (0.05): 0.63889 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different Change Order Amount.

2) Management Method

d. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Cost Growth rate.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.43955, which is greater than the confidence level (0.05): 0.43955 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Cost Growth rate.

Project Delivery System (PDS)

e. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Cost Growth rate.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Test result: P-Value is 0.067, which is greater than the confidence level (0.05): 0.067 > 0.05. Thus, the null hypothesis cannot be rejected and it is concluded that different Project Delivery Systems have different Cost Growth rate.

Contract Type

f. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of total Cost Growth rate.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) ≠ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.48548, which is greater than the confidence level (0.05): 0.48548 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different Cost Growth rate.

3) Management Method

g. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Schedule Growth rate.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.1105, which is greater than the confidence level (0.05): 0.1105 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Schedule Growth rate.

Project Delivery System (PDS)

h. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Schedule Growth rate.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) ≠ Mean of CMAR (μ_{CMAR})

Test result: P-Value is 0.0094, which is smaller than the confidence level (0.05): 0.0094 < 0.05. Thus, the null hypothesis can be rejected and it is concluded that different Project Delivery Systems have different Schedule Growth rate.

Contract Type

i. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of total Schedule Growth rate.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) ≠ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.25126, which is greater than the confidence level (0.05): 0.25126 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different Schedule Growth rate.

4) Management Method

j. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Unit Cost.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.28256, which is greater than the confidence level (0.05): 0.28256 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Unit Cost.

Project Delivery System (PDS)

k. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Actual Unit Cost.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) $\neq$ Mean of CMAR (μ_{CMAR})

Test result: P-Value is 0.12611, which is greater than the confidence level (0.05): 0.12611 > 0.05. Thus, the null hypothesis can be rejected and it is concluded that different Project Delivery Systems have different Unit Cost.

Contract Type

l. Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of Unit Cost.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) $\neq$ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.97659, which is greater than the confidence level (0.05): 0.97659 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different Unit Cost.

5) Management Method

m. Test hypothesis: Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Construction Intensity.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.35049, which is greater than the confidence level (0.05): 0.35049 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Construction Intensity.

Project Delivery System (PDS)

n. Test hypothesis: Projects using Design Build (DB) and Construction Management at Risk (CMAR) are different from each other in terms of Construction Intensity.

H_0 : Mean of DB (μ_{DB}) = Mean of CMAR (μ_{CMAR})

H_A : Mean of DB (μ_{DB}) $\neq$ Mean of CMAR (μ_{CMAR})

Test result: P-Value is 0.019, which is smaller than the confidence level (0.05): 0.019 < 0.05. Thus, the null hypothesis can be rejected and it is concluded that different Project Delivery Systems have different Construction Intensity.

Contract Type

o. Test hypothesis: Projects using Guaranteed Maximum Price (GMP) and Competitive Sealed Proposal (CSP) are different from each other in terms of Construction Intensity.

H_0 : Mean of GMP (μ_{GMP}) = Mean of CSP (μ_{CSP})

H_A : Mean of GMP (μ_{GMP}) $\neq$ Mean of CSP (μ_{CSP})

Test result: P-Value is 0.1382, which is greater than the confidence level (0.05): 0.1382 > 0.05. Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Contract Types have different Construction Intensity.

Table 9 displays a summary of multivariate regression analysis results in this research.

Table 9. Multivariate Regression Analysis Results

	Actual Unit Cost	Change Order Amount	Cost Growth	Schedule Growth	Construction Intensity
Management Method (MBM , MBR)	P-Value: 0.28256 F-Ratio: 1.173	P-Value: 0.76162 F-Ratio: 0.093	P-Value: 0.43955 F-Ratio: 0.604	P-Value: 0.1105 F-Ratio: 2.613	P-Value: 0.35049 F-Ratio: 0.884
Project Delivery System (DB , CMAR)	P-Value: 0.12611 F-Ratio: 2.397	P-Value: 0.684 F-Ratio: 0.167	P-Value: 0.067 F-Ratio: 3.457	P-Value: 0.0094(**) F-Ratio: 7.136	P-Value: 0.019(**) F-Ratio: 5.770
Contract Type (GMP , CSP)	P-Value: 0.97659 F-Ratio: 0.001	P-Value: 0.63889 F-Ratio: 0.222	P-Value: 0.48548 F-Ratio: 0.492	P-Value: 0.25126 F-Ratio: 1.339	P-Value: 0.1382 F-Ratio: 2.250

5.1.4 Two Sample t-Test

The last analysis is on the projects divided into four groups with the same Project Delivery System and Contract type. PDS and contract are the controlled variables in this analysis.

Group 1: (GMP, DB)

Group 2: (CSP, DB)

Group 3: (GMP, CMAR)

Group 4: (CSP, CMAR)

H_0 : MBM and MBR-based Projects with the same DPS and contract type are not different from each other in terms of Cost and Schedule Performance.

$H_{A:}$ MBM and MBR-based Projects with the same DPS and contract type are different from each other in terms of Cost and Schedule Performance.

5.1.4.1 Group 1: (GMP , DB)

a) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of total <u>Change Order Amount</u>.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.271, which is greater than the confidence level (0.05): 0.271 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Change Order Amount.

$\mu_{MBM} = 280065$	
$\mu_{MBR} = 1057097$	$\mu_{MBM} < \mu_{MBR}$

b) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of <u>Actual Unit Cost</u>.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.1813, which is greater than the confidence level (0.05): 0.1813 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Actual Unit Cost.

$\mu_{MBM} = 0.002125$	
$\mu_{MBR} = 0.008250$	$\mu_{MBM} < \mu_{MBR}$

c) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Cost Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.4842, which is greater than the confidence level (0.05): $0.4842 > 0.05$

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Cost Growth.

$\mu_{MBM} = 327.0470$	
$\mu_{MBR} = 296.3983$	$\mu_{MBM} > \mu_{MBR}$

d) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Schedule Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.002187, which is smaller than the confidence level (0.05): $0.002187 < 0.05$

Thus, the null hypothesis can be rejected and it can be concluded that projects with different Management Principles have different Schedule Growth.

$\mu_{MBM} = 0.001850$	
$\mu_{MBR} = 0.0941125$	$\mu_{MBM} < \mu_{MBR}$

e) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Construction Intensity.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.1882, which is greater than the confidence level (0.05): 0.1882 > 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Construction Intensity.

$\mu_{MBM} = 10.07527$

$\mu_{MBR} = 14.82806$ | $\mu_{MBM} < \mu_{MBR}$

5.1.4.2 Group 2: (CSP, DB)

a) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of total Change Order Amount.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.4626, which is greater than the confidence level (0.05): 0.4626 > 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Change Order Amount.

$\mu_{MBM} = 478319$

$\mu_{MBR} = - 44780$ | $\mu_{MBM} > \mu_{MBR}$

b) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Actual Unit Cost.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.09576, which is greater than the confidence level (0.05): 0.09576 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Actual Unit Cost.

$\mu_{MBM} = 311.5917$	
$\mu_{MBR} = 283.1952$	$\mu_{MBM} > \mu_{MBR}$

c) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Cost Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.4308, which is greater than the confidence level (0.05): 0.4308 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Cost Growth.

$\mu_{MBM} = 0.00655$	
$\mu_{MBR} = -0.00130$	$\mu_{MBM} > \mu_{MBR}$

d) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Schedule Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.8418, which is greater than the confidence level (0.05): 0.8417> 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Schedule Growth.

$\mu MBM = -0.01200$

$\mu MBR = -0.00185$ | $\mu MBM < \mu MBR$

e) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Construction Intensity.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.3756, which is greater than the confidence level (0.05): 0.3756> 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Construction Intensity.

$\mu MBM = 14.00880$

$\mu MBR = 4.45835$ | $\mu MBM > \mu MBR$

5.1.4.3 Group 3: (GMP, CMAR)

a) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of total Change Order Amount.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.3232, which is greater than the confidence level (0.05): 0.3232 > 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Change Order Amount.

μ_{MBM} = 782839.200

μ_{MBR} = 5188.812

$\mu_{MBM} > \mu_{MBR}$

b) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Actual Unit Cost.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.2498, which is greater than the confidence level (0.05): 0.2498 > 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Actual Unit Cost.

μ_{MBM} = 440.2163

μ_{MBR} = 286.6970

$\mu_{MBM} > \mu_{MBR}$

c) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of <u>Cost Growth</u>.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.4827, which is greater than the confidence level (0.05): 0.4827 > 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Cost Growth rate.

μ_{MBM} = 0.00706000

μ_{MBR} = 0.00334375 | $\mu_{MBM} > \mu_{MBR}$

d) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of <u>Schedule Growth</u>.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.2366, which is greater than the confidence level (0.05): 0.2366> 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Schedule Growth rate.

μ_{MBM} = 0.0184400

μ_{MBR} = 0.04260625 | $\mu_{MBM} < \mu_{MBR}$

e) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Construction Intensity.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.01273, which is smaller than the confidence level (0.05): $0.01273 < 0.05$

Thus, the null hypothesis can be rejected and it can be concluded that projects with different Management Principles have different Construction Intensity.

μ_{MBM} = 7.98346

μ_{MBR} = 19.81609 | $\mu_{MBM} < \mu_{MBR}$

5.1.4.4 Group 4: (CSP, CMAR)

a) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of total Change Order Amount.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) $\neq$ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.9635, which is greater than the confidence level (0.05): $0.9635 > 0.05$

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Change Order Amount.

μ_{MBM} = 227392.6

μ_{MBR} = 196112.2 | $\mu_{MBM} > \mu_{MBR}$

b) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Actual Unit Cost.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.674, which is greater than the confidence level (0.05): 0.674 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Actual Unit Cost.

$\mu_{MBM} = 372.5954$	
$\mu_{MBR} = 345.7868$	$\mu_{MBM} > \mu_{MBR}$

c) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Cost Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.944, which is greater than the confidence level (0.05): 0.944 > 0.05

Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Cost Growth.

$\mu_{MBM} = 0.0008333333$	
$\mu_{MBR} = 0.0011961538$	$\mu_{MBM} < \mu_{MBR}$

d) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Schedule Growth.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.6178, which is greater than the confidence level (0.05): 0.6178> 0.05 Thus, the null hypothesis cannot be rejected and it cannot be concluded that projects with different Management Principles have different Schedule Growth.

$\mu_{MBM} = 0.02158889$

$\mu_{MBR} = 0.02718462$ | $\mu_{MBM} < \mu_{MBR}$

e) Projects using Management by Means (MBM) and Management by Results (MBR) are different from each other in terms of Construction Intensity.

H_0 : Mean of MBM (μ_{MBM}) = Mean of MBR (μ_{MBR})

H_A : Mean of MBM (μ_{MBM}) ≠ Mean of MBR (μ_{MBR})

Test result: P-Value is 0.5389, which is smaller than the confidence level (0.05): 0.5389 < 0.05 Thus, the null hypothesis can be rejected and it can be concluded that projects with different Management Principles have different Construction Intensity.

$\mu_{MBM} = 23.41533$

$\mu_{MBR} = 15.06161$ | $\mu_{MBM} > \mu_{MBR}$

Table 10 displays a summary of two sample T-test results in this research.

Table 10. Two Sample t-Test Results

		Change Order Amount	Actual Unit Cost	Cost Growth	Schedule Growth	Construction Intensity
Group 1 (GMP , DB)	P-Value	0.271	0.1813	0.4842	0.002187(**)	0.1882
		$\mu_{MBM} < \mu_{MBR}$	$\mu_{MBM} < \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	**$\mu_{MBM} < \mu_{MBR}$**	$\mu_{MBM} < \mu_{MBR}$
Group 2 (CSP , DB)	P-Value	0.4626	0.09576	0.4308	0.8418	0.3756
		$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} < \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$
Group 3 (GMP , CMAR)	P-Value	0.3232	0.2498	0.4827	0.2366	0.01273(**)
		$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} < \mu_{MBR}$	**$\mu_{MBM} < \mu_{MBR}$**
Group 4 (CSP , CMAR)	P-Value	0.9635	0.674	0.944	0,6178	0.5389
		$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$	$\mu_{MBM} < \mu_{MBR}$	$\mu_{MBM} < \mu_{MBR}$	$\mu_{MBM} > \mu_{MBR}$

5.2 Summary

5.2.1 Summary Result of Discriminant Analysis

At 95% confidence level, the measurements value of MBM- and MBR-based projects are similar; in other words, there is no discrimination between projects with different types of management method in terms of cost and schedule performance. According to the results, neither the contract type factor has significant influence on metrics value. Whereas, the results show that Project Delivery System is an influential factor and DB projects are different from CMAR projects at cost and schedule performance.

When grouping the metrics into cost and schedule related and at 95% confidence level, the results indicates that although management method has no significant impact on project cost performance, it has considerable influence on project duration and 28% of schedule related metric values can be explained by management type. Yet, in comparison to management method, project delivery system has more influence on schedule related measurements (Canonical Correlation: 40% > 28%). Also, PDS affects the project cost performance, while management method and contract type do not.

5.2.2 Summary Result of Multivariate Regression

At 95% confidence level, PDS factor has a significant influence on Schedule Growth and Construction Intensity metrics, which both represent schedule performance in a construction project. As the absolute value of the F-ratio addresses the level of influence, it can be concluded that DPS factor has more effect on Schedule Growth comparing to Construction Intensity (F-ratio: 7.136 > 5.770). Since the F-ratio in all other tests is a small number, it can be interpreted that Management Method and Contract Type have no considerable influence on project cost and schedule performance.

5.2.3 Summary Result of Two Sample t-Test

When keeping the Delivery system and Contract type as controlled variables and grouping all 72 projects into 4 groups with the same type of contract and delivery system:

There is a probability of 95% that projects using different management principles (MBM, MBR), have different Schedule Growth and Construction Intensity values. In other words, MBM and MBR-based projects are dissimilar in terms of schedule performance.

According to the results of the two-sample t-test on the sample projects, in Group 1, the sample mean of the MBM-based projects has smaller value in comparison with the sample mean of MBR-based projects in terms of Schedule Growth. On the other hand, for this particular measurement, smaller value indicates a shorter duration of the project and is preferred. Therefore, this result shows that among projects with GMP and DB as their delivery and contract type respectively, MBM-based projects have better Schedule Growth values.

In contrast, In Group 3, the sample mean of the MBM-based projects is smaller in comparison with the sample mean of MBR-based projects in terms of Construction Intensity. For this measurement, greater value indicates a better schedule performance and is preferred. Thus, this result addresses that among projects with GMP and CMAR as their delivery and contract type respectively, MBR-based projects have better Construction Intensity values.

5.3 Comparison

This study finds that there is no significant difference between cost performance of MBM- and MBR-based projects, while Kim and Jang (2005) and Kim and Ballard (2010) claim that MBM-based projects have a better cost performance in comparison with projects with traditional management method.

In Discriminant Analysis, when the metrics are grouped as cost and schedule performance related, this study shows that MBM-based projects have better performance on schedule performance related measurements, which is the same as the conclusion of Ballard et al. (2007) and Kim and Jang (2005).

This study reaches conclusions that conflict with those of previous studies. A very critical reason is that the sample projects used in this study and previous ones are from different sectors. This study used commercial building projects, while previous researchers used projects from heavy civil, industrial, and other sectors. In other words, the difference among the conclusions of this study and previous studies may indicates that one type of management method could be more efficient and effective in one sector than the other ones. Another reason is that all the sample projects used in this study are built in the state of Texas, whereas previous studies used sample projects located across the nation. Different locations and built years would influence the final conclusions.

5.4 Limitations and Assumptions

The conclusion of this research suffers from the following limitations:

1. The sample projects used in this study were not selected randomly.
2. The sample size is relatively small; thus, the conclusions might not convincingly reflect the attributes of the real populations.
3. Practically, every construction project is unique and has its own characteristics; therefore, it is very difficult to make sure that all the variables remain the same.
4. The samples are limited to commercial projects in terms of project type.

5. The samples are limited to Guaranteed Maximum Price and Competitive Sealed Proposal in terms of contract type.
6. The samples are limited to Construction Management at Risk and Design-Build in terms of delivery system.
7. The deficiencies associated with the chosen economic methods used for adjusting cost values from different years to one certain year would affect the final conclusions.
8. The measurements used in this study have their own deficiencies and sometimes fail to accurately measure and reflect the cost and schedule performance of construction projects.
9. The sample projects might have not been categorized accurately in terms of management method. Sometime, people who work on projects, such as superintendents, are not aware that they are actually implementing lean tools in their projects. For instance, they have weekly work plan or daily huddle sessions on the jobsite, yet, they would deny when asked if they use any lean principles in their project. Hence, a sample project cell labeled as MBR, does not necessarily reflect a non-lean project. On the other hand, a question arises that is PPC the most important and reflective principle of MBM-based projects? Typically, PPC is mostly a leverage tool and it does not reflect the overall management method of a project. Therefore, it might not be convincing to label a construction project as MBM-based when PPC data is attached to it.

6. CONCLUSION AND FUTURE WORK

This research designed a comprehensive comparative study between the cost and schedule performance of MBM- and MBR-based projects.

While Change Order Amount, Actual Unit Cost, and Cost Growth were used as the metrics representing the cost performance, Schedule Growth and Construction Intensity were used as the measurements to evaluate the schedule performance of the projects.

After conducting several statistical analyses, including Discriminant Analysis, Multivariate Regression, and Two Sample t-Test, the author was able to conclude that the factor of management method has influence on schedule performance, but not on cost performance of construction projects. While MBM-based projects tend to have better schedule growth rate, MBR-based ones have more preferred construction intensity values. Moreover, in comparison with Project Delivery System (PDS), management principle and contract type are less influential.

The future work that could be done is as following:

1. The conclusions of this study are only made toward commercial construction projects built in the state of Texas. Future studies could use sample projects across the country from all sectors to investigate and compare the effects of MBM- and MBR management principles on project performance.
2. The sample data size of this research is relatively small; therefore, in this study the sample projects were not divided based on their size. For future studies, with a sufficient number of data samples, projects can be grouped by their size. In this case, it can be possible to compare

the projects having the same size but applying different management methods to make a more accurate conclusion.

3. The reason behind the conclusion of this research can be studied and analyzed in future studies: the reason of why MBM-based projects tend to have better value in terms of schedule growth? What principle of this management method impact the schedule and duration of construction projects and how it works?
4. The criteria on which construction projects are labeled as MBM- and MBR-based can be investigated and studied. Also a study on determining an element accurately reflecting Lean projects, rather than PPC, can be carried out.

REFRENCES

Allen, E., and Iano, J. (2011). *Fundamentals of building construction: materials and methods*, John Wiley & Sons.

Ballard, G., and Howell, G. (1994). "Implementing lean construction: stabilizing work flow." *Lean construction*, 101-110.

Ballard, G., and Howell, G. (1998). "Shielding production: essential step in production control." *Journal of Construction Engineering and management*, 124(1), 11-17.

Ballard, G., and Howell, G. A. "Competing construction management paradigms." *Proc., Construction Research Congress: Wind of Change: Integration and Innovation*, 1-8.

Ballard, G., and Howell, G. A. "An update on last planner1." *Proc., Proc., 11th Annual Conf., International Group for Lean Construction, Blacksburg, VA.*

Ballard, G., Kim, Y., Jang, J., and Liu, M. (2007). "Roadmap for lean implementation at the project level." *The Construction Industry Institute*.

Ballard, H. G. (2000). "The last planner system of production control." The University of Birmingham.

Barrett, R. (2006). *Building a values-driven organization: A whole system approach to cultural transformation*, Routledge.

Beck, D. E., and Cowan, C. (2014). *Spiral dynamics: Mastering values, leadership and change*, John Wiley & Sons.

Bertelsen, S. "Construction as a complex system." *Proc., Proceedings for the 11th annual conference of the International Group for Lean Construction*, 11-23.

Charoenphol, D., Stuban, S. M., and Dever, J. R. (2016). "Using Robust Statistical Methodology to Evaluate the Cost Performance of Project Delivery Systems: A Case Study of Horizontal Construction." *Journal of Cost Analysis and Parametrics*, 9(3), 181-200.

Choo, H. J. (2003). "Distributed planning and coordination to support lean construction." University of California, Berkeley.

Cioffi, D. F. (2006). "Completing projects according to plans: an earned-value improvement index." *Journal of the Operational Research Society*, 57(3), 290-295.

Fernandez-Solis, J. L. (2013). "Building construction: A deterministic non-periodic flow–A case study of chaos theories in tracking production flow." *Architectural Engineering and Design Management*, 9(1), 21-48.

Fernandez-Solis, J. L., Porwal, V., Lavy, S., Shafaat, A., Rybkowski, Z. K., Son, K., and Lagoo, N. (2012). "Survey of motivations, benefits, and implementation challenges of last planner system users." *Journal of construction engineering and management*, 139(4), 354-360.

Fiallo, M., and Revelo, V. "Applying the last planner control system to a construction project: a case study in Quito, Ecuador." *Proc., Proceedings of the 10th Annual conference of the International Group for Lean Construction*.

Fleming, Q. W. (1987). *Put earned value (C/SCSC) into your management control system*, Humphreys & Associates.

Formoso, C. T., and Moura, C. B. "Evaluation of the impact of the last planner system on the performance of construction projects." *Proc., Proceedings of 17th Annual Conference of the International Group of Lean Construction*, 153-164.

Howell, G., and Ballard, G. "Can project controls do its job?" *Proc., Proceedings of the 4th annual conference of the International Group for Lean Construction*.

Howell, G. A. "What is lean construction-1999." *Proc., Proceedings IGLC*, 1.

Johansen, E., and Porter, G. (2003). "An experience of introducing last planner into a UK construction project."

Johnson, H. T., and Broms, A. (2000). *Profit beyond measure: Extraordinary results through attention to work and people*, Simon and Schuster.

Johnson, T. (1992). "Relevance regained: From top-down control to control to bottom-up." Free Press, New York.

Kim, Y.-W., and Ballard, G. "Is the earned-value method an enemy of work flow." *Proc., Proceedings Eighth Annual Conference of the International Group for Lean Construction, IGLC*.

Kim, Y.-W., and Ballard, G. (2002). "Earned value method and customer earned value." *Journal of Construction Research*, 3(01), 55-66.

Kim, Y.-W., and Ballard, G. (2010). "Management thinking in the earned value method system and the last planner system." *Journal of Management in Engineering*, 26(4), 223-228.

Kim, Y.-W., and Jang, J.-W. "Case study: An application of last planner to heavy civil construction in korea." *Proc., 13th International Group for Lean Construction Conference: Proceedings*, International Group on Lean Construction, 405.

Kofman, F. (2008). *Conscious business: How to build value through values*, ReadHowYouWant. com.

Konchar, M., and Sanvido, V. (1998). "Comparison of US project delivery systems." *Journal of construction engineering and management*, 124(6), 435-444.

Koskela, L. (1999). "Management of production in construction: a theoretical view."

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*, VTT Technical Research Centre of Finland.

Koskela, L., and Howell, G. "The theory of project management: Explanation to novel methods." *Proc., Proceedings IGLC*, 1-11.

Lagoo, N. (2012). "A Seminal Case Study on Application of Last Planner System with Cash Flow Data for Improvements in Construction Management Practices." Texas A & M University.

Liker, J. K. (2004). *The toyota way*, Esensi.

Liu, M., and Ballard, G. "Improving labor productivity through production control." *Proc., Proceedings of the 11th Annual Conference of International Group for Lean Construction*.

McConnell, D. R. (1985). "Earned value technique for performance measurement." *Journal of Management in Engineering*, 1(2), 79-94.

Nepal, M. P., Park, M., and Son, B. (2006). "Effects of schedule pressure on construction performance." *Journal of Construction Engineering and Management*, 132(2), 182-188.

Nieto-Morote, A., and Ruz-Vila, F. (2011). "Last planner control system applied to a chemical plant construction." *Journal of Construction Engineering and Management*, 138(2), 287-293.

Pavez, I., Gonzalez, V., and Alarcon, L. (2010). "Improving the effectiveness of new construction management philosophies using the integral theory." *Revista de la Construcción*, 9(1).

Sterman, J. D. (1992). "System dynamics modeling for project management." *Unpublished manuscript, Cambridge, MA*, 246.

Vrijhoef, R., and Koskela, L. "The prevalent theory of construction is a hindrance for innovation." *Proc., IGLC Conference, Brighton, UK, 17-19 July, 11*.

Warburton, R. D. (2011). "A time-dependent earned value model for software projects." *International Journal of Project Management*, 29(8), 1082-1090.

Discriminant Analysis

Discriminant Analysis Results

Independent Variable (Factor)	P-value	Canonical Correlation
Management Method	0.1328	0.34323504
PDS	0.0059(**)	0.46404056
Contract type	0.1386	0.34093447

Discriminant Analysis

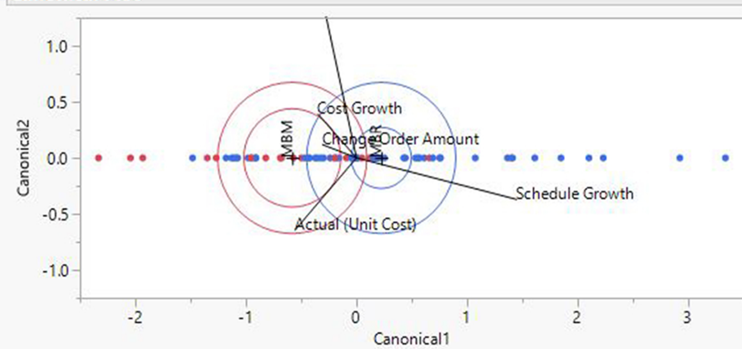
Group Means

Count	Management Method	Change Order Amount	Cost Growth	Schedule Growth	Construction Intensity	Actual (Unit Cost)
20	MBM	401881.35	0.003220	0.01350	15.95	374.29
52	MBR	257367.54	0.002846	0.04111	16.08	317.60
72	All	297510.26	0.002950	0.03344	16.04	333.35

Discriminant Method: Linear

Classification: Management Method

Canonical Plot



Canonical Details

Canonical Details calculated from the overall pooled within-group covariance matrix.

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.13354304	100.0000	100.0000	0.34323504	0.8821897	1.7628	5	66	0.1328

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.8821897	1.7628	5	66	0.1328
Pillai's Trace	0.1178103	1.7628	5	66	0.1328
Hotelling-Lawley	0.133543	1.7628	5	66	0.1328
Roy's Max Root	0.133543	1.7628	5	66	0.1328

- Within Matrix
- Between Matrix
- Scoring Coefficients
- Standardized Scoring Coefficients

Score Summaries

Source	Count	Number Misclassified	Percent Misclassified	Entropy RSquare	-2LogLikelihood
Training	72	25	34.7222	-0.0386	88.3636

Training

Actual Management Method	Predicted Count MBM	MBR
MBM	13	7
MBR	18	34

Groups

Management Method	Count
MBM	20
MBR	52

Management Method (MBM, MBR) vs All Metrics

Discriminant Analysis

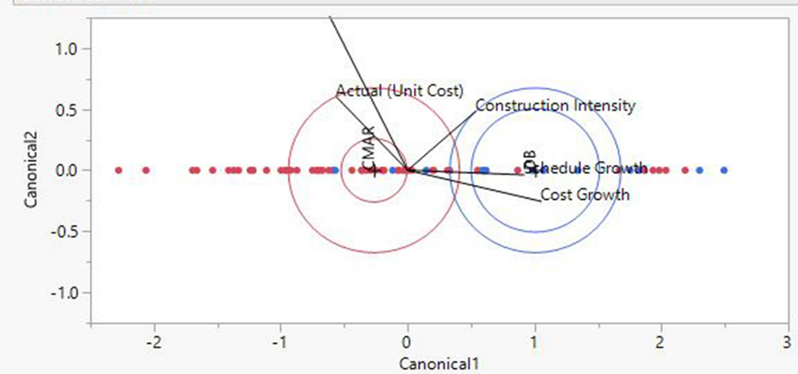
Group Means

Count	Delivery System	Change Order Amount	Cost Growth	Schedule Growth	Construction Intensity	Actual (Unit Cost)
57	CMAR	252970.91	0.001868	0.02524	14.15	346.63
15	DB	466759.80	0.007060	0.06458	23.24	282.87
72	All	297510.26	0.002950	0.03344	16.04	333.35

Discriminant Method: Linear

Classification: Delivery System

Canonical Plot



Canonical Details

Canonical Details calculated from the overall pooled within-group covariance matrix.

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.274427	100.0000	100.0000	0.46404056	0.78466636	3.6224	5	66	0.0059*

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.7846664	3.6224	5	66	0.0059*
Pillai's Trace	0.2153336	3.6224	5	66	0.0059*
Hotelling-Lawley	0.274427	3.6224	5	66	0.0059*
Roy's Max Root	0.274427	3.6224	5	66	0.0059*

- Within Matrix
- Between Matrix
- Scoring Coefficients
- Standardized Scoring Coefficients

Score Summaries

Source	Count	Number Misclassified	Percent Misclassified	Entropy RSquare	-2LogLikelihood
Training	72	14	19.4444	-0.0295	75.8636

Training

Actual Delivery System	Predicted Count CMAR	DB
CMAR	46	11
DB	3	12

Groups

Delivery System	Count
CMAR	57
DB	15

Delivery System (DB, CMAR) vs All Metrics

Discriminant Analysis

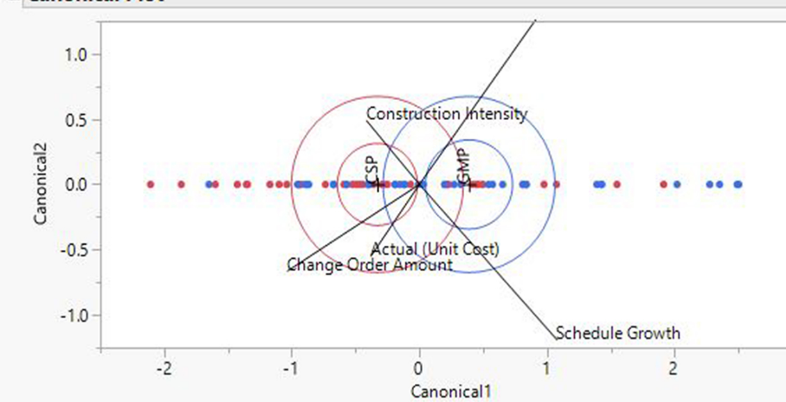
Group Means

Count	Contract Type	Change Order Amount	Cost Growth	Schedule Growth	Construction Intensity	Actual (Unit Cost)
39	CSP	205449.46	0.001259	0.02239	16.39	347.01
33	GMP	406309.39	0.004948	0.04649	15.63	317.20
72	All	297510.26	0.002950	0.03344	16.04	333.35

Discriminant Method: Linear

Classification: Contract Type

Canonical Plot



Canonical Details

Canonical Details calculated from the overall pooled within-group covariance matrix.

Eigenvalue	Percent	Cum Percent	Canonical Corr	Likelihood Ratio	Approx. F	NumDF	DenDF	Prob>F
0.1315242	100.0000	100.0000	0.34093447	0.88376369	1.7361	5	66	0.1386

Test	Value	Exact F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.8837637	1.7361	5	66	0.1386
Pillai's Trace	0.1162363	1.7361	5	66	0.1386
Hotelling-Lawley	0.1315242	1.7361	5	66	0.1386
Roy's Max Root	0.1315242	1.7361	5	66	0.1386

- Within Matrix
- Between Matrix
- Scoring Coefficients
- Standardized Scoring Coefficients

Discriminant Scores

Score Summaries

Source	Count	Number Misclassified	Percent Misclassified	Entropy RSquare	-2LogLikelihood
Training	72	26	36.1111	0.08496	90.8749

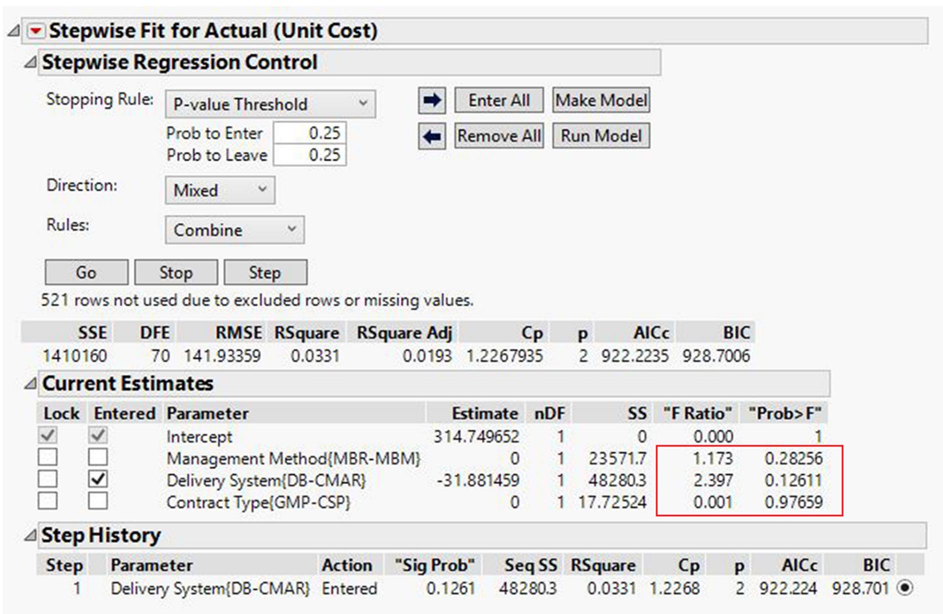
Groups

Contract Type	Count
CSP	39
GMP	33

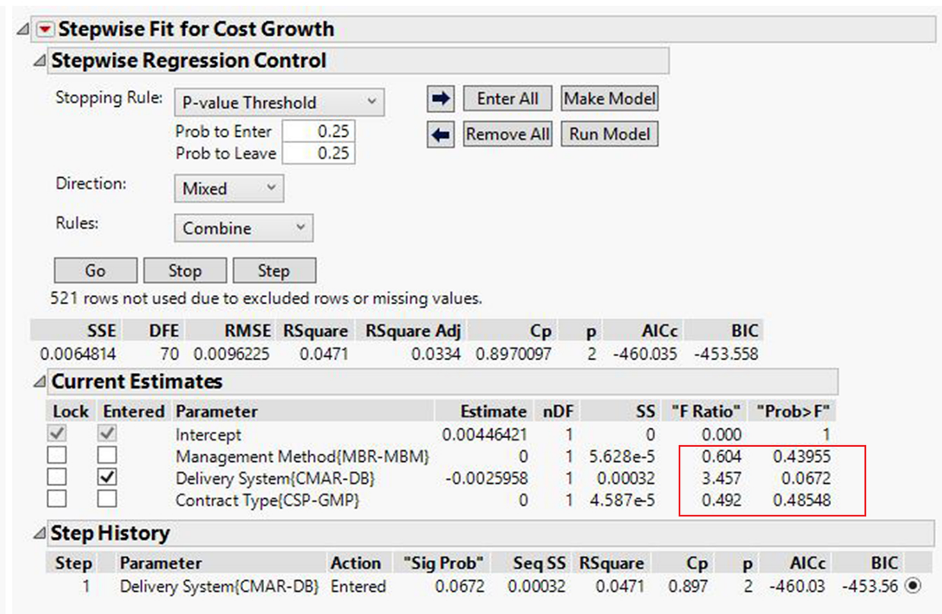
Contract Type (GMP, CSP) vs All Metrics

APPENDIX B

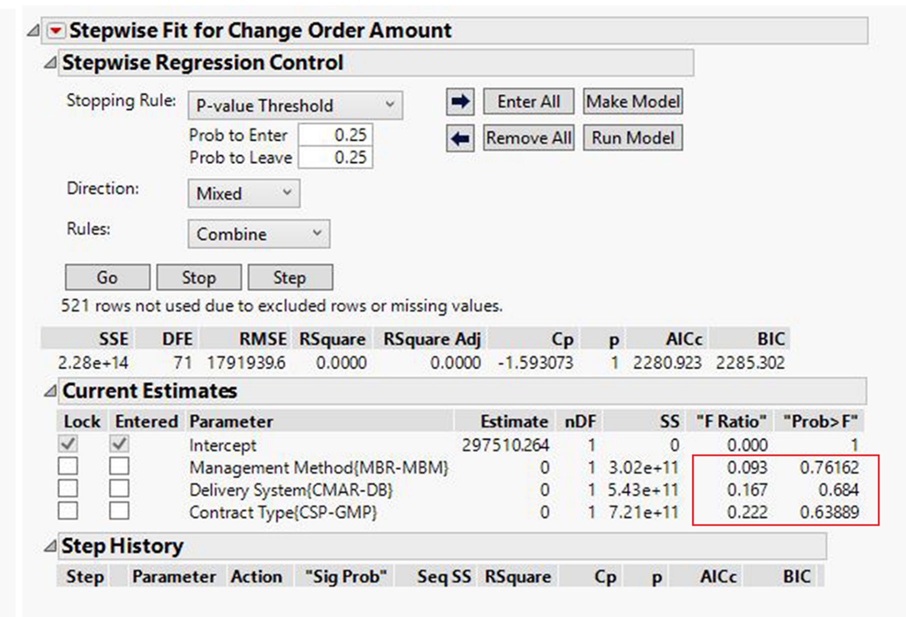
Multivariate Regression Analysis



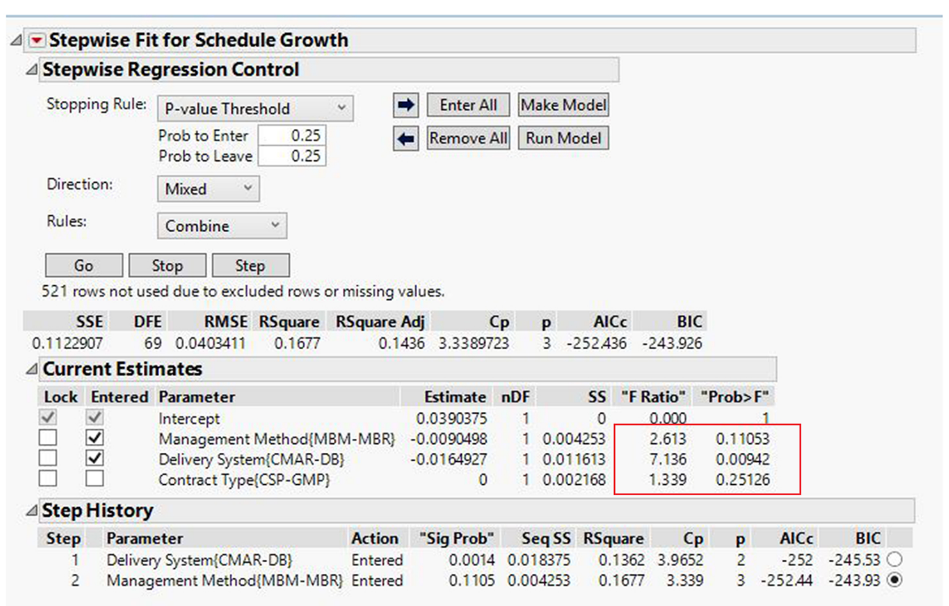
All Factors vs Actual Unit Cost



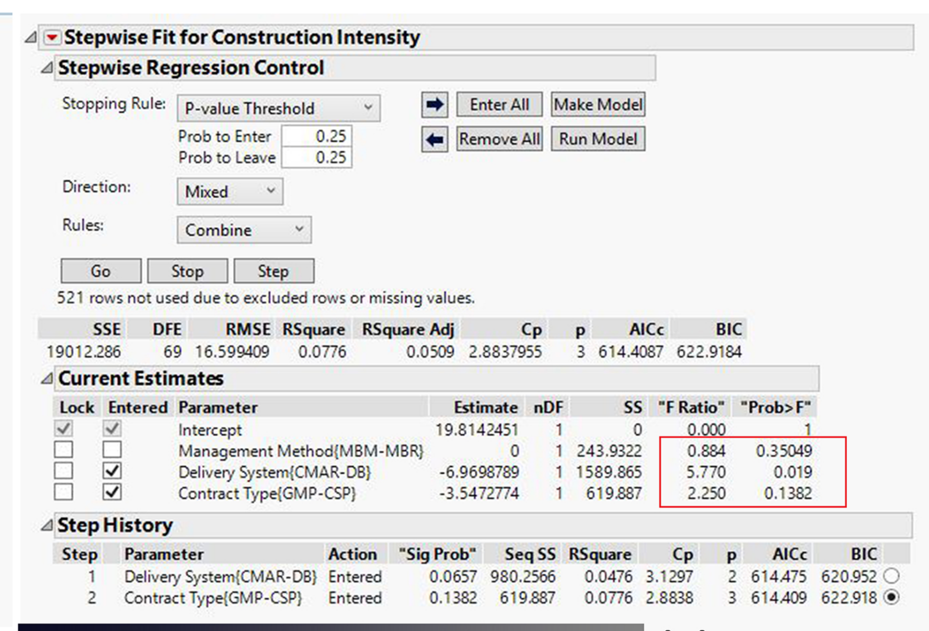
All Factors vs Cost Growth



All Factors vs Change Order Amount



All Factors vs Schedule Growth



All Factors vs Construction Intensity

Multivariate Regression Analysis Results

	Actual Unit Cost	Change Order Amount	Cost Growth	Schedule Growth	Construction Intensity
Management Method (MBM , MBR)	P-Value: 0.28256 F-Ratio: 1.173	P-Value: 0.76162 F-Ratio: 0.093	P-Value: 0.43955 F-Ratio: 0.604	P-Value: 0.1105 F-Ratio: 2.613	P-Value: 0.35049 F-Ratio: 0.884
Project Delivery System (DB , CMAR)	P-Value: 0.12611 F-Ratio: 2.397	P-Value: 0.684 F-Ratio: 0.167	P-Value: 0.067 F-Ratio: 3.457	P-Value: 0.0094(**) F-Ratio: 7.136	P-Value: 0.019(**) F-Ratio: 5.770
Contract Type (GMP , CSP)	P-Value: 0.97659 F-Ratio: 0.001	P-Value: 0.63889 F-Ratio: 0.222	P-Value: 0.48548 F-Ratio: 0.492	P-Value: 0.25126 F-Ratio: 1.339	P-Value: 0.1382 F-Ratio: 2.250

APPENDIX C

Time Value Adjustment

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 Ty
	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**	