INVESTIGATING THE EFFECT OF FRONT-END PLANNING IN FAST-TRACK DELIVERY SYSTEMS FOR INDUSTRIAL PROJECTS

A Thesis

by

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ABSTRACT

Numerous research studies to date have been conducted to examine the processes and effectiveness of Front-End Planning. However, very little is known about the impact of the “level” of Front-End Planning to the cost, schedule and change order performance, specifically for Fast-track Delivery Systems for Industrial projects. This study aims to address this issue by investigating correlation between the Front-End resource allocation and project performance, simultaneously comparing the Design-Build and Construction Manager at Risk delivery systems to the baseline traditional Design-Bid-Build system. The data used for statistical analysis were obtained from the Construction Industry Institute through a Project Level Survey conducted in 2009. The data compiled into a Benchmarking & Metrics database was used by this study for statistical analysis. 439 Industrial projects from both the Light and Heavy Industrial sectors were analyzed during this research.

Spearman’s correlation analysis was performed to test the relationship between the “level” of FEP and project performance and Kruskal Wallis test was used to compare the different delivery systems in terms of their performance. Results from the statistical analysis revealed that Design-Build projects with higher level of FEP performed more effectively considering cost and change metrics, whereas the level of FEP in CM-at-Risk projects exhibited a strong relationship with schedule performance. FEP was more effective in Design-Build cost performance because of the collaboration between the designer and the builder in the early phases of the project resulting in accurate estimations and minimized likelihood of major change orders. The Guaranteed Maximum Price ensured in the CM-at-Risk system, hinders the effect of FEP on its cost performance. This study is expected to encourage more effort into the Front-End of the project and could become a decision making tool for project participants on the choice of delivery systems in Industrial projects. This thesis study recommends Design-Build as the ideal delivery system for Industrial projects and for the implementation of Front-End Planning, based on statistical evidence.

ACKNOWLEDGEMENTS

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NOMENCLATURE

AIA	American Institute of Architects
CII	Construction Industry Institute
CM	Construction Manager
CMA	Construction Manager Agency
CMR	Construction Manager at Risk
CSP	Competitive Sealed Proposals
DB	Design Build
DBB	Design Bid Build
FDS	Fast-track Delivery System
FEL	Front-End Loading
FEP	Front-End Planning
GC	General Contractor
GMP	Guaranteed Maximum Price
IPD	Integrated Project Delivery
PDRI	Project Definition Rating Index
PDS	Project Delivery System
PPP	Pre-Project Planning

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1. INTRODUCTION & BACKGROUND

Front-End Planning (FEP) can be defined as a strategy to identify and assess risks and unknowns in a project so that sufficient resources can be utilized to mitigate them to ensure its successful completion (George, Bell, & Edward Back, 2008). This process is also often termed as Front-End Loading (FEL) and Pre-Project Planning (PPP). According to CII studies, FEP is done through three phases. The process usually ends at the third phase gate of detailed scope, after which the project can move on to the detailed design and construction phase. Each phase gate must be successfully passed before moving to the subsequent phase or the project is terminated (Construction Industry Institute, 2016b). Fast-track Delivery Systems (FDS) like Design-Build and Construction Manager at Risk are ideal for the study of the effect of FEP on project performance, as these systems involve relatively better collaboration among the various project participants during the early phases of the project.

Project Delivery Systems (PDS) specify the method of delivering a project from the programming phase to the operations and maintenance (O&M) phase, the roles and responsibilities of the different professionals and stakeholders that engage in a project and their legal obligations. PDS have evolved over the years, as each project is unique and demands the use of a PDS that is best suited for it. The most popular PDS that are in use today, are Design-Build (DB) and Construction Manager at Risk (CMR), as compared to the traditional Design-Bid-Build (DBB) (Rojas & Kell, 2008). Integrated Project Delivery

(IPD) is a relatively new PDS that has often been linked with extensive use of Building Information Modeling (BIM).

DB currently accounts for about 40% of the non-residential construction market, which is a 10% increase from 2005 and CMR market share has risen to about 10% (Reed Construction Data/RSMeans Consulting, 2014). In Design-Build, the owner enters into a single contract with the architect-builder, who executes both the design and construction phases for the project (Park, 2011). The major advantage of using DB project delivery over DBB, is to eliminate the risk of any inclinations for errors and omissions in the contract documents that can cause claims and disputes between the project participants (Tran & Molenaar, 2013). The designer and the builder can collaborate before construction to mitigate possible risks that may arise. The AGC, AIA and DBIA have compiled contract documents that can be used for a Design-Build PDS.

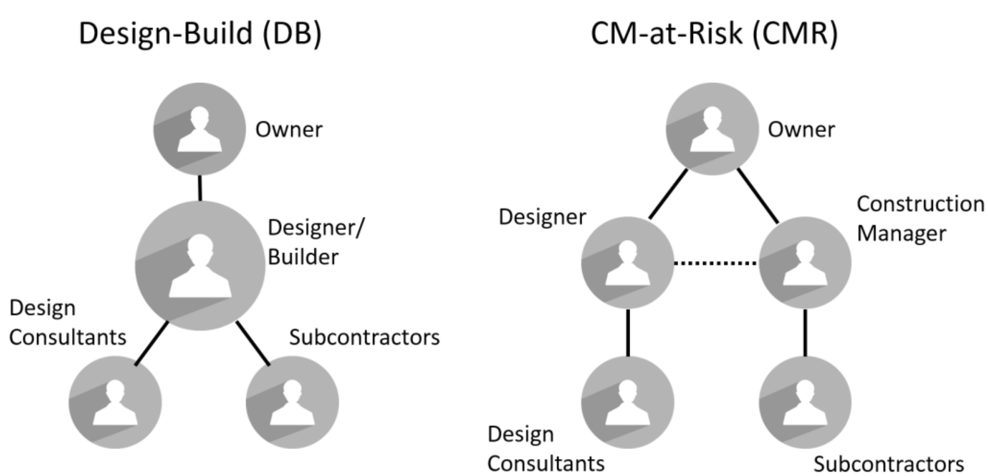


Figure 1: Innovative Project Delivery Systems

The contractual relationships in DB & CMR are represented in Figure 1. CM at Risk as the name suggests, holds the Construction Manager "at risk" for the project delivery process. The Guaranteed Maximum Price (GMP) offers the owner lesser risks in terms of construction cost of the project. The Construction Manager acts as an entity who provides both consultation during the preconstruction phases and manages the execution of the project within the guaranteed price (Strang, 2002). Like DB, the CM is involved in the preliminary phases of the project alongside the design team and can effectively contribute to the FEP process to mitigate risks. In contrast to the traditional DBB system, CMR also encourages collaboration between the designer and the CM to produce a cost-effective and "constructible" project with a well-defined scope. This study has investigated the cost, time and change performance of both DB and CMR which are collaborative FDS with respect to the baseline traditional DBB system, also considering the impact of the FEP process in each Project Delivery System.

2. REVIEW OF LITERATURE

2.1. Front End Planning

FEP is extensively used in large scale and capital intensive, industrial and processing projects to assess the various unknown factors that may affect the project performance and success adversely. The Construction Industry Institute (CII) has performed several studies in the area of the front end planning process, regarded now as one of the "best practices" promoted by the CII. CII has also developed a toolkit to assist the owners and contractors in maintaining consistency and effectiveness to carry out the planning process (Construction Industry Institute, 2016a). The FEP process includes the definition of missions and objectives of the project, development of the project scope, basic design requirements, cost benefit analysis, financial management of the project, project organization and execution plans and various risk factors that must be analyzed and mitigated. FEP when performed improperly can lead to insufficient definition of project scope, cost overruns, schedule delays and change orders. The pre project planning is followed by the detailed design and engineering of the project (National Research Council, 2001).

Recent studies have also explored the concept of FEP, like "Front End Planning in the Modern Construction Industry" which has discussed the CII body of knowledge and also reports the results of detailed surveys regarding the utilization of FEP tools and any factors that may inhibit the process (Bosfield, 2012). In a study of FEP in Building projects, statistical analysis was performed for FEP Phase Cost Analysis, PDRI Performance Analysis, Percent Design Complete Performance Analysis and Case Study (G. E. Gibson Jr., Irons, & Ray, 2006). Similar research was published for infrastructure projects which are capital intensive identifying the different critical issues and risk factors that may affect project success (Gibson, Jr., Bingham, & Stonger, 2010). FEP project input parameters were quantified in another study, which included additional factors such as team size and team work hours. The study also employs techniques such as one way ANOVA to determine differences in the mean between the input parameters based on factors such as project nature, size, complexity and industry sector (Yun, Suk, Dai, & Mulva, 2012). Thirty three activities were recognized by a research study as the essential processes in front end planning. Further analysis of the results obtained from a project success survey narrowed down seven factors that were critical to a project's success, which included scope and execution planning (George et al., 2008).

CII has been on the forefront of FEP studies since 1994, when they proposed that FEP can reduce the total project cost by about 20% and the total schedule duration up to 39% (Construction Industry Institute, 2016c). In 1995, CII also published a Pre-Project Planning Handbook which outlines the major principles and guidelines that can be followed for a successful FEP process. The Project Definition Rating Index (PDRI) was developed for Industrial projects in 1996. This tool was intended to assess whether the scope definite is complete based on a checklist which generated a score that corresponded directly to risk elements. On a scale with the maximum score of 1000, projects with lower scores were considered better defined in terms of scope (Gibson, Jr., 2004). A correlation analysis was conducted between the PDRI scores and project performance concluding that there was evidence of a relationship between the performance of a project and the level of scope definition (Wang, 2002).

A 2004 survey was conducted, including the existing members of the CII to gauge the utilization of the FEP tools such as PDRI in the industry. It was found that 61.7% of the members surveyed used PDRI for industrial projects. CII's Benchmarking & Metrics Database was used to perform analysis on the effect of PDRI scores on the cost, schedule and change performance of projects. Some of the important conclusions from the study are summarized as follows. For small scale projects, contractors spend more than the owners in terms of percentage mean FEP cost, but for larger projects in the infrastructure sector, owners were spending more. For industrial and building projects, the researchers concluded that there was statistical evidence to support the hypothesis that better PDRI scores lead to better project performance. For this analysis, data from 676 projects were used with index scores ranging from 0 to 10 (Bosfield, 2012). The Alignment Index of the projects was also studied, based on the measurement of the extent of synchronization between the project participants to meet a uniform set of goals and objectives through collaboration (Griffith & Gibson, Jr., 2001). In the same year of 2006, CII developed a Front End Planning Toolkit, which was a compilation of all the latest versions of the FEP tools and guidelines that were developed over the years to establish a common platform for implementing a standardized FEP process.

2.2. Design Build versus Construction Manager at Risk

2.2.1. Design Build (DB)

In the traditional DBB system, the design and construction entities are separated with their own contracts and realm of work. During the last 15 years, the adoption of DB as an alternative to the traditional system has become a popular trend in the US construction scenario. The DB method consists of a single designer-builder entity with a single contract and a collaborative platform for work. Contrary to the antagonistic interaction between the architect and the GC which exists in the traditional system, this alternate delivery system aims to bring the both parties together into an alliance. As a result of this improved teamwork and collaboration, DB projects have proven to be comparatively faster, more cost saving and with lesser number of change orders (Design-Build Institute of America, 2014).

Under the traditional DBB system, there are possibilities of design errors and omissions which later on lead to disputes between the architect and the contractor, with the owner caught in between. The Spearin doctrine warrants that the design documents submitted are sufficient to execute the construction of the project successfully. Often the information provided turns out insufficient and cause change orders and liability claims. DB eliminates such disputes, by transferring the responsibility of accuracy and sufficiency of the documents to the design-builder entity (Design-Build Institute of America, 2014). While DB allows for fast track delivery and overall quality improvement for a project, there are factors that discourage owners from adopting this system. The primary cause is that the owners are unfamiliar with DB and views it as risky. Since the design-build entity is completely responsible for a project, the owner feels that he has little control over the project delivery. The current legislations also make the adoption of DB difficult (Design-Build Institute of America, 2010). Various studies have been conducted regarding Design-Build which investigates issues ranging from commissioning projects and team selection to cost and time performance comparisons (El Asmar, Lotfallah, Whited, & Hanna, 2010; Minchin, Li, Issa, & Vargas, 2013; Shrestha, O'Connor, & Gibson, 2012; Turner, Jung, & Seung Hwan, 2012).

2.2.2. Construction Manager at Risk (CMR)

In the CMR delivery system, the owner enters into a contract with the designer and the construction manager separately, but the CM also acts as a consultant for the designers to review the preliminary costs, constructability and feasibility of the project. Often the CM assists in providing value engineering for the project as well. This front end collaboration between the architect and the CM proves beneficial to the project as costs, schedule, scope and quality are optimized to deliver a successful project. But the CM does assume “risk” in managing the construction of the project to keep it within the guaranteed maximum price assured to the owner (Strang, 2002).

The owners consider CMR as a better system than the traditional DBB as it was a combination of the services provided by both a Construction Manager Agency (CMA) and a General Contractor (GC) (Bilbo, Bigelow, Escamilla, & Lockwood, 2015). The CMR delivery system enables the CM to provide valuable input during the design, fast track the project schedule, enhance the cost certainty earlier in the design process, owner control over design details and the ability to bid early packages (Shane & Gransberg, 2010). A typical CMR project involves two different contracts for the preconstruction and the construction phase. This early collaboration allows for the fast tracking of CMR project schedule as the CM does not have to wait for the complete design to be ready to start inviting subcontractor bids or procurement. The design packages that have been completed early can be bid on earlier thereby accelerating the schedule significantly. The schedule savings of a CMR project has been reported to be up to 15% to 20% of the total schedule duration (Kenig, 2011). Any savings that may be possible by bringing costs below the GMP, may revert back to the owner or be awarded as an incentive to the CM. Due to the risk-reward nature of this delivery system, the CM has staked investment in the project, which provides the owners more confidence in the project success (Neidert, 2012).

2.2.3. Comparative Study of Project Delivery Systems

As innovative project delivery methods continues to gain popularity, many researchers have conducted studies in comparing the different PDS. One of the main criteria for comparison was found to be cost comparison. A summary of the different advantages and disadvantages of DBB, DB and CMR are listed in Table 1.

Table 1: Comparison of DBB, DB & CMR (The Construction Management Association of America, 2008, 2012)

	Advantages	Disadvantages
DBB	• *Familiar* • *Well defined roles* • *Competitive prices*	• *No fast-tracking* • *No value engineering* • *Conflict between designer & builder*
DB	• *Single contract* • *Time savings* • *Cost savings* • *Collaborative*	• *Owner control limited* • *No checks & balances*
CMR	• *Time savings* • *Guaranteed Maximum Price* • *CM assumes risk* • *Collaborative*	• *Uncertainty about best bid* • *Any cost overrun costs CM*

In a recent study, collaborative delivery systems were compared with traditional system like DBB, which acted as a baseline or benchmark for analysis. Since quantitative analysis of extremely collaborative systems like IPD is difficult due to the unavailability of data, CMR and CSP were used in this particular research study (Kulkarni, 2012). Other researchers have compared the cost of projects with the delivery systems used to find if there are correlations between the two, which can help in deciding the choice of PDS in a project. A cost study pertaining to public elementary schools in Texas comparing CMR and CSP found that cost performance of CMR projects were lower than that of the latter (Goyal Rakesh, 2013; Reinisch, 2011). Cost, schedule and change performance for ENR projects were compared for CMR and DB systems, but statistical significance tests could not be performed due to limited availability of project data (Rajan, 2010). A comparison of previous studies involving DB and the traditional DBB system was summarized in a project delivery performance study for municipal water/waste water projects in 2013. The findings were favorable to DB which outperformed DBB with respect to cost, unit cost, schedule and construction speed (Shane, Bogus, & Molenaar, 2013). Research has also been performed comparing time, schedule, impact of change orders etc. in different project delivery systems for the transportation sector, with special emphasis on comparing alternate PDS with the traditional systems (Gaur, 2013).

3. PROBLEM & RESEARCH SETTING

3.1. Problem Statement

Numerous research studies have been conducted by the CII and other researchers regarding the implementation and critical importance of front end planning in project success. But there are very few studies that provide results using quantitative statistical significance testing. CII has published data analysis for FEP data which analyses the relationship between project PDRI scores and scope definition, and project cost, schedule and change performance. Even though it is evident that projects that use FEP have seen considerable performance improvements, a direct correlation between the “level” of effort in FEP during the early phases of the project and the project performance have yet to be investigated. Moreover, there is a gap in the existing body of knowledge regarding the study of FEP concerning the different choices of delivery systems involved. The uniqueness of this study identified from the gaps in existing research can be summarized into three major components for analysis:

(i) The “level” of FEP that is implemented in a project

(ii) FEP “level” and project performance specifically for “Industrial” projects

(iii) FEP “level” and project performance by DB, CMR and traditional DBB delivery systems

As reviewed in the extensive literature study, very few project delivery comparison studies have attempted statistical significance testing due to unavailability of a large common pool of data. Most researchers have carried out studies either with a small sample of data, through case studies or qualitative methods. Also, most CMR studies used CSP for comparison, and a performance comparison between CMR, DB and DBB are few in number, especially in the industrial sector. Any statistical studies involving significant datasets have been outdated and results obtained from more recent databases are required to validate them. Since many of these studies have focused on the Building and Infrastructure sector, this study aims to produce meaningful statistical results that can be used in the industrial sector which comprises of complex construction systems and which can benefit most from significant front-end planning and fast-tracking. Since Industrial projects were the main target of early CII studies in PDRI and FEP, sufficient number of data samples were available in the database for this sector.

3.2. Research Objectives

The primary research objective is to investigate the interdependent relationship between the “level” of FEP effort and the project performance by comparing fast-track project delivery methods over the benchmarking traditional DBB system. This research aims to study the correlation between FEP effort and project cost, schedule and change performance. The objective of this study is to provide evidence that more effort and resources utilized in the front end of the project can lead to significant benefits during execution and improve the project’s success. A secondary objective of this study is to perform a comparative study between fast track delivery systems that are more collaborative on the front end like DB and CMR with the baseline traditional DBB system.

The comparison is again in in terms of quantifiable metrics such as cost, schedule and change performance of industrial projects. By achieving these two objectives, the delivery system that is best suited for FEP and improving project performance for Industrial projects can be identified.

3.3. Research Hypotheses

This study employs statistical methods such as Correlation Analysis and Ranked Sum Tests to achieve the research objectives. The research hypothesis that were tested are as follows:

(i) There is a positive linear correlation between the FEP effort and the cost and schedule performance of Industrial projects

(ii) There is a negative linear correlation between the FEP effort and change cost percentage of Industrial projects

(iii) Fast-track delivery systems DB & CMR outperform the traditional DBB system in terms of cost, schedule and change performance.

3.4. Research Assumptions

The following assumptions were made to support this research study:

(i) The projects from which the data would be collected were independently delivered from the programming phase to turnover phase. So these data can be assumed to be statistically independent for analysis.

(ii) The effort of Front-End Planning is a function of only the cost of Front-End Planning of the project as the duration of FEP may not be a true representation of the effort.

(iii) For the purpose of statistical analysis, the “Heavy Industrial” and “Light Industrial” sectors have been assumed to be from the parent sector “Industrial” for ample amount of data samples.

3.5. Research Questions and Limitations

The study addresses the following research questions:

(i) Is it beneficial to input more resources into front end planning for better performance results?

(ii) Using FEP along with which delivery system yields the best performance for industrial projects?

(iii) Which collaborative delivery system has the best project performance in the industrial sector?

(iv) Are fast-track delivery systems a better choice than traditional delivery system?

4. RESEARCH METHOD

The research method used for this study involves two parts: data collection and data analysis. The data used for the study was acquired from the Construction Industry Institute which has the most extensive database collected from its members using a project level survey. The database includes several crucial information for projects, including the factors that are critical for this study: cost, schedule and change order data. A preliminary trend analysis was performed to analyze the general behavior of the different industries and delivery systems involved with no significance level testing. A detailed analysis was then performed to validate the research hypotheses that were stated above. Spearman's non-parametric Correlation Analysis was used to observe linear relationships between FEP cost percentage and project performance. Kruskal-Wallis sum ranked test was performed to compare the means of project performance of the fast-track delivery systems to the baseline traditional system. All tests were conducted at the 95% significance level. The p-values obtained thus were used to support the conclusions of this study.

4.1. Data Collection

The required data samples were obtained from the Benchmarking & Metrics Project Level Survey database collected by the Construction Industry Institute (CII). A total of 526 projects were completed from 1990 to 2010 using the PDS that are the focus of this study, which are CM at Risk, Design-Build and Traditional DBB. The database also consisted of the "Parallel Primes" and "Other" delivery systems. A majority of project data were unclassified into any delivery system, and were not used to conduct this study. The total number of projects included in the database was 1945 taking into account all the unclassified data. The locations of the projects included projects from the North and South Americas, Europe, Africa, Asia and Australia. This study is limited to data from projects located in the United States only. The scale of the projects in terms of cost ranged from extreme outliers like simple renovation project costing $34,201 to large scale projects costing $8.726 billion.

The database was collected in the following broad categories:

(i) General Project Description

(ii) Engineering Deliverables

(iii) Cost Performance

(iv) Project Schedule

Both owners and contractors were surveyed to collect the Benchmarking & Metrics database. The industry groups covered were:

(i) Buildings

(ii) Infrastructure

(iii) Light Industrial

(iv) Heavy Industrial

The survey also included questions regarding the implementation of CII best practices and productivity metrics. Data was also classified according to the nature of the project as:

(i) Addition / Expansion

(ii) Grass Roots / New Project

(iii) Brownfield

(iv) Maintenance

(v) Modernization / Renovation

Furthermore, the projects were also classified according to the complexity, on a scale of 1 to 7 where 7 represented a highly complex project. A project had a low complexity score if it employed relatively well established and well known technology and construction methods for execution or if there were a relatively smaller number of processes involved in a small scale facility. A high complexity number indicates a project that used previously unused technology for a large scale facility that involved a larger number of process steps. An analysis of complexity and the actual cost of the project revealed a trend of increasing project cost with increasing scale of complexity.

The cost data was available in terms of the budgeted project cost, contingency amount, actual project cost and phase costs of FEP, detailed engineering, procurement, construction and startup. Similar data was available for schedule in terms of baseline start and finish dates, actual start and finish dates and phase divisions in the schedule. Change data was present in terms of both cost and schedule and included both preconstruction and construction changes and changes due to scope development and those incurred otherwise.

4.2. Data Analysis

The data analysis was conducted in three major parts. The initial trend analysis was aimed at identifying meaningful trends in the choice of fast-track or traditional delivery systems as inferred from their total market share, market share by industry sector, complexity of projects, project type and scale of the project in terms of project cost. Preliminary analysis of trends in cost and schedule performances were also conducted. 667 projects were used for the initial trend analysis which has been delineated in Chapter 5.

The data for the PDS that are the focus of the study, namely DB, CMR and DBB, were segregated and the statistical significance analyses was performed. The variable that were used for the correlation analysis and the comparison analysis as obtained from the database are listed below in Table 2.

Table 2: List of Variables Used for Statistical Analysis

Variable	Description
actcsppp	Actual FEP Cost
budcstot	Total Budgeted Project Cost
budcscon	Budgeted Construction Cost
actcscon	Actual Construction Cost
plnov_s	Baseline Schedule Start Date
plnov_f	Baseline Schedule Finish Date
actov_s	Actual Schedule Start Date
actov_f	Actual Schedule Finish Date
changecosttot	Total Change Cost
changeschtot	Total Schedule Change

A total of 439 industrial projects from both the Light and Heavy Industrial categories that were delivered using either DB, CMR or the traditional DBB system were analyzed for statistically significant results. The performance metrics that were used for the correlation analysis were FEP Cost %, Construction Cost Performance, Schedule Performance, Change Cost % and Schedule Change %. The comparison analysis used the metrics of Cost Performance, Schedule Performance, Change Cost % and Schedule Change %. The detailed calculations used to derive these metrics are provided in Chapter 6 and Chapter 7.

Each performance metric was tested for validating the assumptions for the initially planned statistical tests which were Pearson’s Correlation and a one way ANOVA. The Q-Q plots and Shapiro Wilk tests produced results showing deviation from normality. As data transformations aimed to reduce the normality deviations were not successful, the research was conducted using non-parametric statistical tests. Spearman’s Rho was used to test for correlation and Kruskal Wallis test was used as a ranked sum test to compare distributions. The correlation analysis was used as a means to study the relationship between the level of FEP and project performance. Whereas, the comparison study was performed to identify which delivery system inherently performed better without taking into account the FEP effort. The detailed methods involved in data assumption validation and performing the correlation and comparison analysis are described in Chapter 6 and Chapter 7 respectively.

5. TREND ANALYSIS

5.1. Trends in Choice of Delivery Systems

A total of 667 projects found in the database were analyzed for the preliminary trend analysis. This includes Parallel Primes and "Other" category of delivery systems apart those that are the topic of the study. The number of projects that were completed using each delivery system as a percentage of the total projects gives an idea of the market share of the project by their number. The most used delivery system was the traditional DBB with 39% of the share, closely followed by DB at 31%. CMR only represented 8% of the total share of projects as shown in Figure 2.

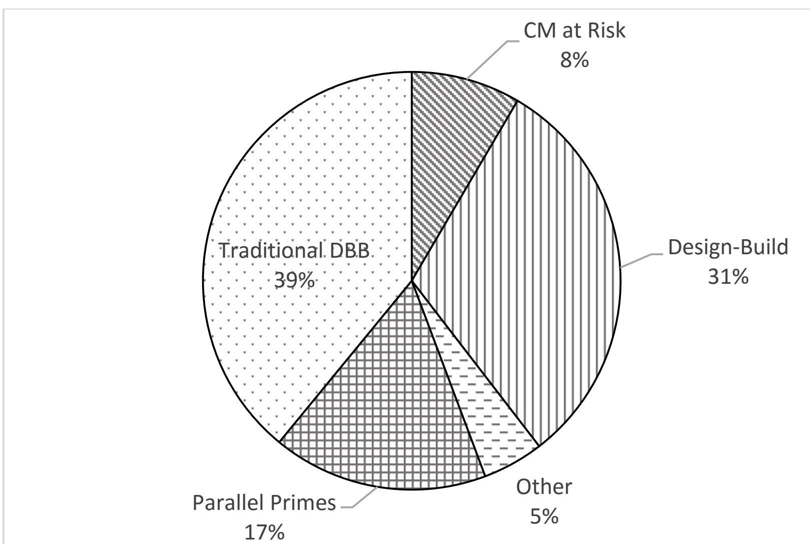


Figure 2: Choice of Delivery Systems

An analysis of the choice of delivery systems by the industry sector type (Figure 3) revealed that CMR was least used in Infrastructure projects (3.4%) and mostly used in

Light Industrial projects (21.3%). The majority of Heavy Industrial projects were delivered using DB (53.9%). This trend can be attributed to the fact that Industrial projects require considerably higher collaboration between the designer and the constructor to analyze the constructability, costs and risks of the project. The majority of infrastructure projects is still being delivered using the traditional system (65.5%).

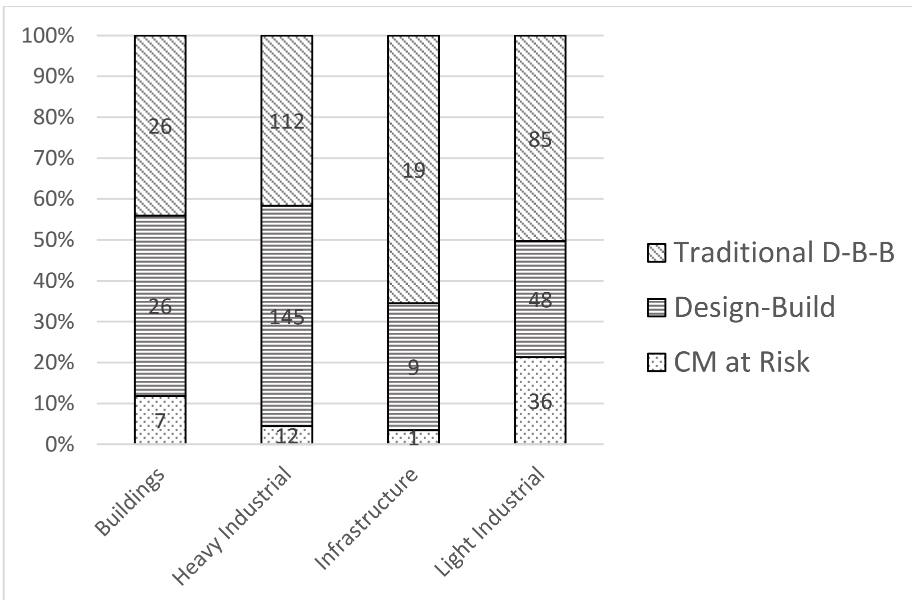


Figure 3: Choice of Delivery System by Industry Sector

In a comprehensive analysis of all project types ranked by complexity (Figure 4) on a scale of 1 to 7 (7 being the most complex), innovative PDS were the preferred choice when the complexity was higher. For low complexity projects traditional DBB was used about 60% of the times. Design-Build has seen consistent usage across all projects and the choice of CM at Risk saw an increase in highly complex projects. Owners for large scale, high risk projects prefer more collaborative delivery systems for better cost and schedule control.

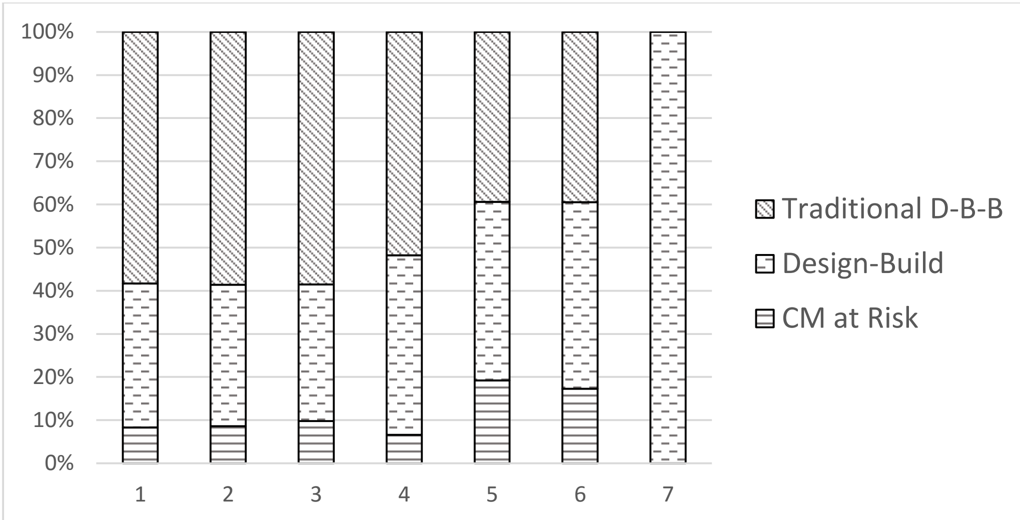


Figure 4: Choice of Delivery System by Complexity

The analysis of the implementation of different PDS according to the type of construction service performed (Figure 5), traditional DBB outranked the other innovative PDS only in Maintenance projects. Parallel Primes was a popular choice of delivery system after DB and DBB in projects that involved expansion, renovation or maintenance.

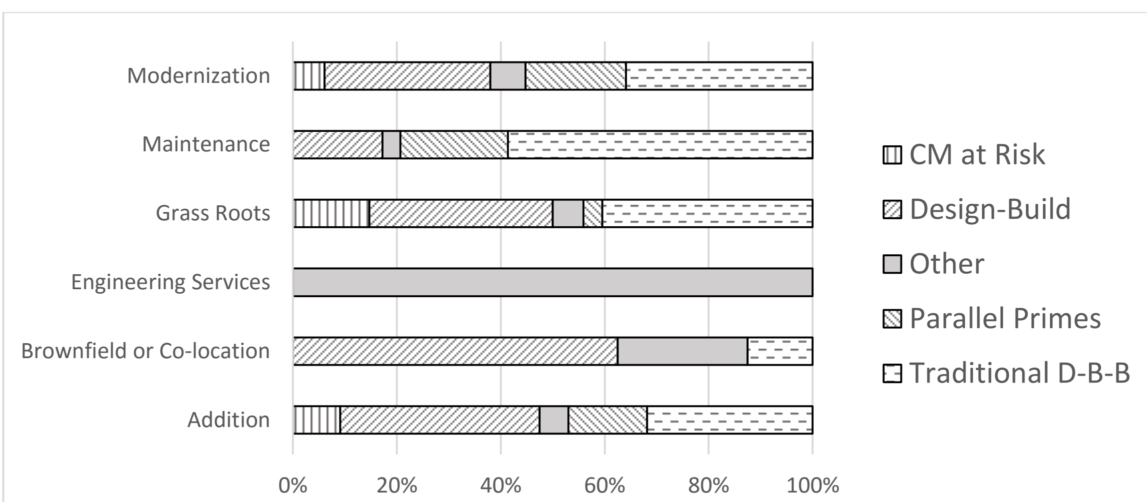


Figure 5: Choice of Delivery System by Project Nature

The database consists of projects ranging from low cost maintenance projects just under $100,000 to large scale multibillion dollar projects. An analysis of the choice of delivery systems based on project cost criteria shows that for smaller size projects costing less than $10 million, traditional DBB system was the popular PDS used. For projects costing greater than $10 million, DB and CMR outranked the traditional system as shown in Figure 6 below.

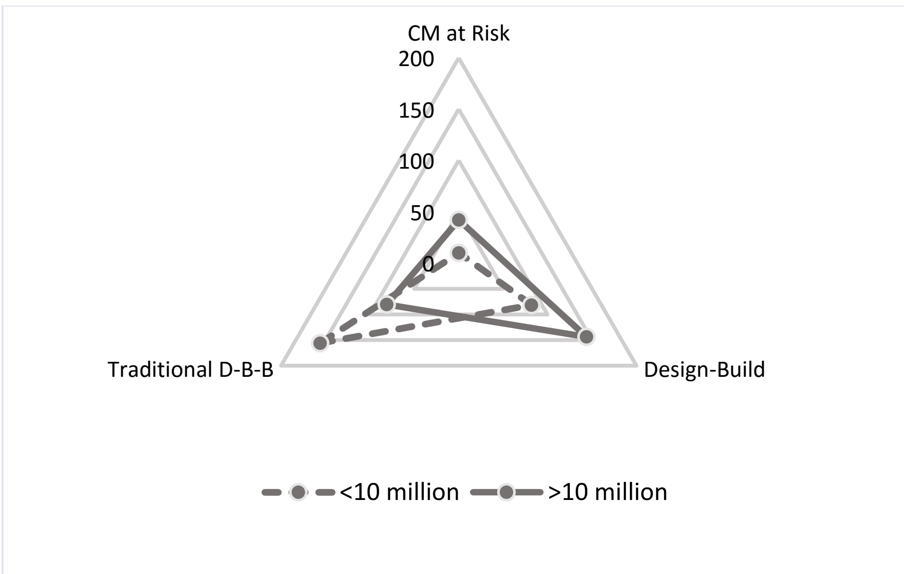


Figure 6: Choice of Delivery System by Project Cost

5.2. Trends in Project Performance

An initial data analysis was performed to study the performance of CM at Risk, Design-Build and Traditional DBB on the cost and schedule of projects. The analysis was performed by comparing similar project types. The number of projects and that had experienced cost savings or overruns and schedule savings and delays were studied along with the mean values of these performance metrics. It should be noted that CMR delivery system used for Infrastructure projects yielded only one data sample and which does not constitute any significant results.

Considering CM at Risk delivery system, there were a greater number of cost overrun projects than projects that were completed within budget, than DB or DBB. Only in Heavy Industrial projects CM at Risk there were lesser projects with cost overruns. Whereas, the opposite were the results for Design-Build. This is shown in Figure 7.

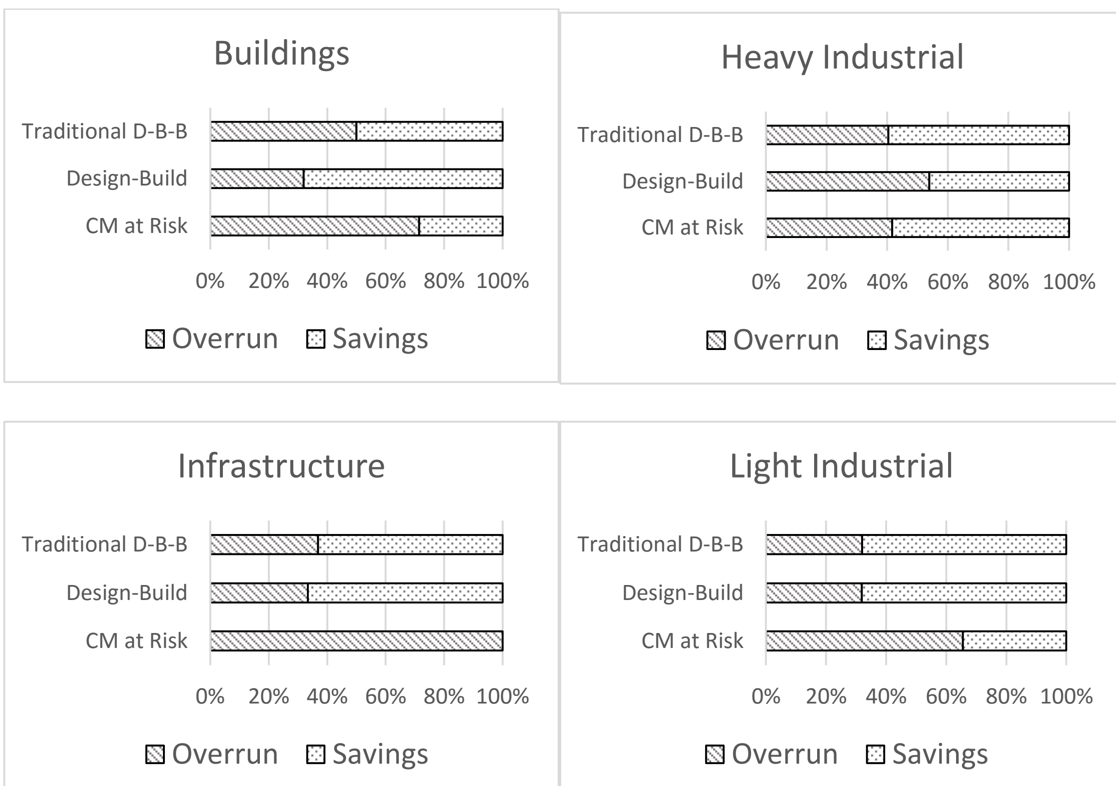


Figure 7: Percentage of Number of Projects with Cost Savings or Overrun

Infrastructure projects had a greater average percentage cost overrun of the overall project budget than other projects. In general, CM at Risk projects lesser variations in the final cost of the project than other PDS. Design-Build displayed a better cost performance in Infrastructure projects. Figure 8 below illustrates these results.

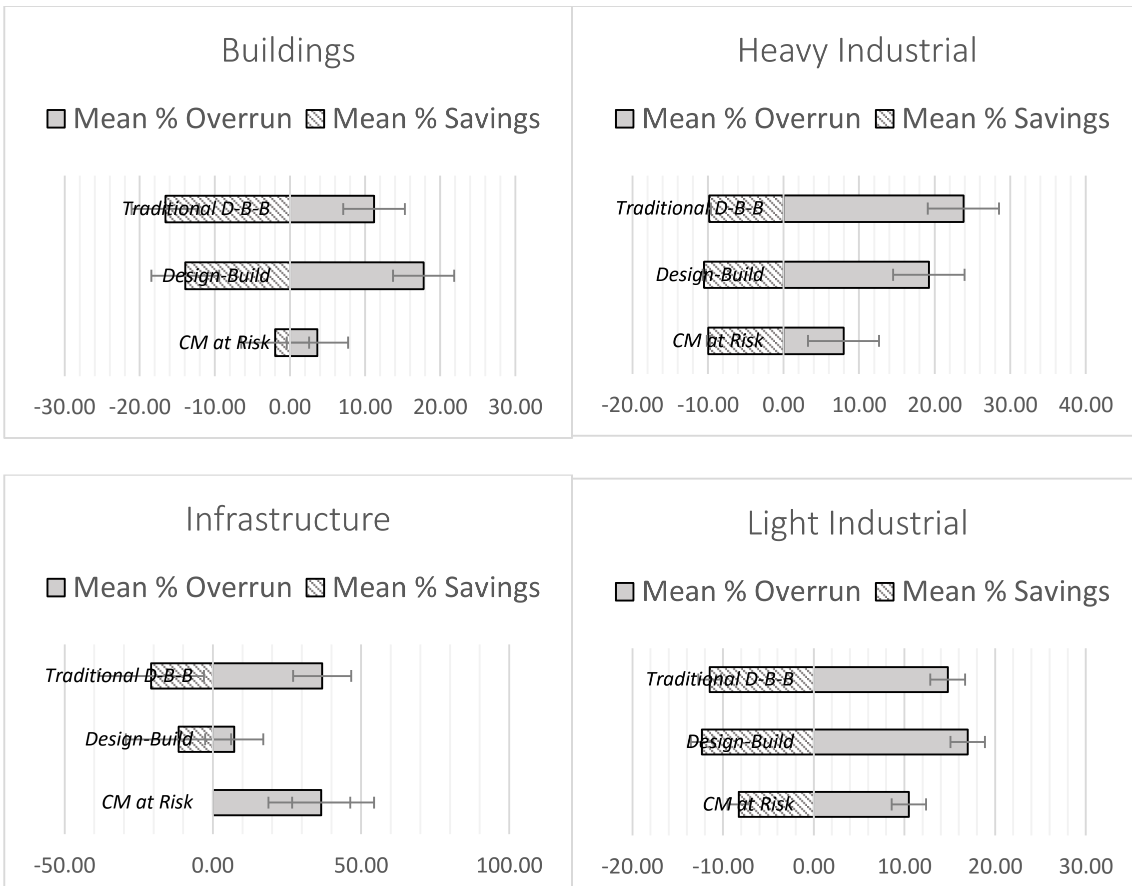


Figure 8: Mean Percentage Cost Savings or Overrun

A study of percentage number of projects that experienced schedule delays or expedites (Figure 9) show that most projects experienced schedule delays regardless of which PDS was implemented. There were more number of projects finishing before time for CM at Risk for only the Heavy Industrial sector.

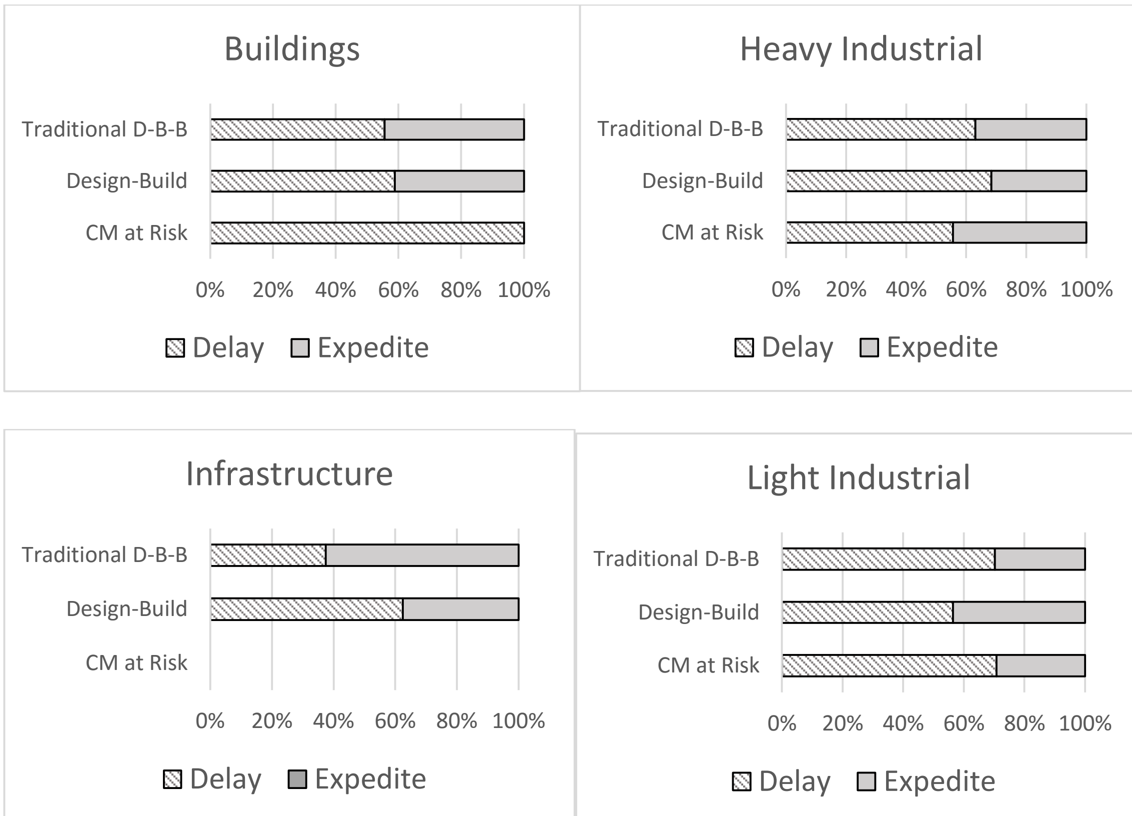


Figure 9: Percentage of Number of Projects with Schedule Delays or Expedites

CM at Risk projects in Heavy Industrial experienced on an average lower schedule variation than the other delivery systems. Design-Build in general, resulted in greater average expedited days as a percentage of the original schedule. Most heavy delays were caused in the Industrial sector caused by DBB and DB. These results are shown in Figure 10.

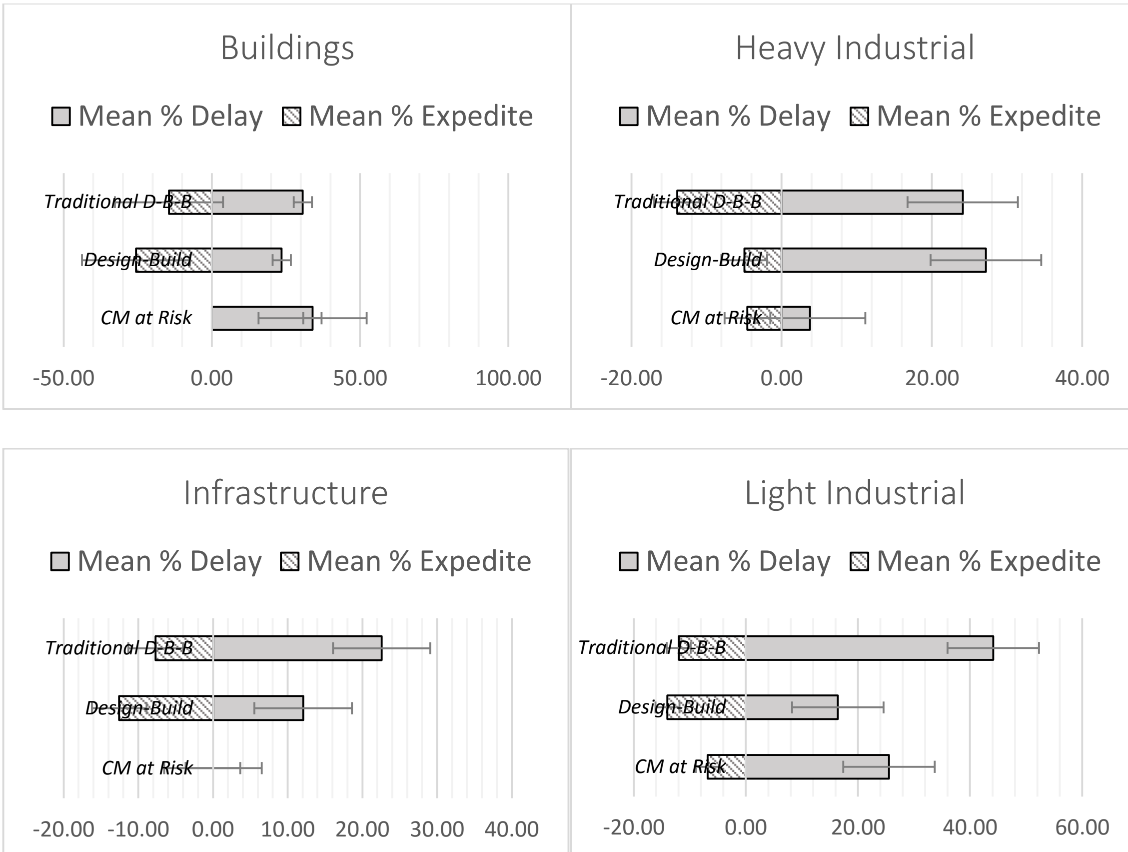


Figure 10: Mean Percentage Schedule Delays or Expedites

The preliminary performance analysis gave unique insight into the trends in project cost and schedule performance across the different industry sectors. The key findings were that in terms of cost performance, even though the percentage of the number of projects overrun was greater than either DB or DBB, the mean percentage overrun for CMR was lesser. This may be due to the fast-tracking nature of CMR and the early fixing of the GMP before designs were completed. This is consistent with the finding that CMR performed better when schedule performance was considered in Industrial projects.

6. EFFECT OF FEP EFFORT ON INDUSTRIAL PROJECT PERFORMANCE

6.1. Research Setting

For the purpose of obtaining a large enough data sample for statistical analysis, the "Light Industrial" and "Heavy Industrial" sectors were grouped into "Industrial" sector. This resulted in a total of 439 projects analyzed under the Industrial sector. This sector also seems an apt choice for the study of front-end planning, as industrial projects are characterized by their complex construction systems and process which require strategic planning at the early stages of the project to be successfully executed. Also complex large scale projects are ideal for identifying any significant differences in the cost and schedule performances between fast-track and traditional delivery systems.

The correlation analysis was performed by grouping the data by

(i) Type of delivery system
   a. Design-Build
   b. Construction Manager-at-Risk
   c. Traditional Design-Bid-Build

(ii) Complexity of the project
   a. Simple (complexity = 1,2,3,4)
   b. Complex (complexity = 5,6,7)

(iii) Nature of Project
   a. Expansion

b. New Project

c. Renovation

6.2. Performance Metrics

As described in the Chapter 4, selected variables from the CII database were used to calculate the following performance metrics. The primary variable of comparison is FEP Cost Percentage which is the actual cost of the FEP efforts in the project (actcsppp) as a percentage of the total project budget (budcstot).

*FEP Cost % = [Actual FEP Cost / Budgeted Total Cost] * 100*

The project performance metrics used for the correlation analysis are cost performance, schedule performance and cost and schedule change percentage. The cost performance is the amount of project cost savings or overruns as a percentage of the overall project baseline budget. Cost performance is positive if the project was completed within budget and negative if the project exceeded the original budgeted amount. The savings or overruns were calculated using the budgeted project cost (budcscon) and the actual project cost (actcscon).

*Cost Performance % = [(Budgeted Construction Cost – Actual Construction Cost) / Budgeted Total Cost] * 100*

The schedule performance metrics is set in a similar manner as the cost performance, as the schedule expedites or delays as a percentage of the baseline schedule duration of the project. The schedule expedites or delays were calculated using the variables, baseline schedule start date (plnov_s), baseline schedule end date (plnov_f), actual project start date (actov_s) and actual project end date (actov_f). The schedule performance yields a positive number if the project was expedited and a negative result if the project experienced schedule delays.

*Schedule Performance % = [(Baseline Schedule Duration – Actual Schedule Duration) / Baseline Schedule Duration] * 100*

The change performance was measured both in terms of the change costs of the project and also changes in schedule. For cost changes, the metric used was the amount of change costs as a percentage of the original project budget. Similarly, the metric for schedule changes was the number of days change introduced in schedule as a percentage of the baseline schedule duration. These calculations were made using the variables total project change costs (changecosttot) and total schedule impact of change (changeschtot).

*Total Change Cost % = [Total Change Costs / Budgeted Total Cost] * 100*

*Total Schedule Change % = [Total Schedule Change / Baseline Schedule Duration] * 100*

6.3. Assumptions Validation

The research aimed to perform Pearson's linear correlation analysis, which requires the following data assumptions to be validated:

(i) Normality (the variables should be normally distributed)

(ii) Linearity (there should be a linear relationship between the test variables)

(iii) Homoscedasticity (there is homogeneity among variances)

(iv) Independence (data samples should be independent of each other)

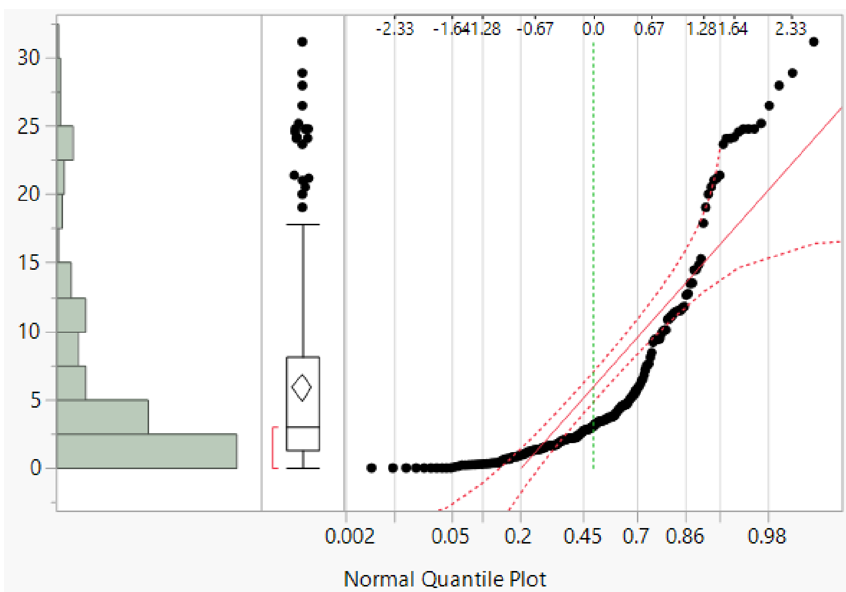


Figure 11: Q-Q Plot of FEP Cost %

It is justified to assume that the project data are independent of each other as each project is unique and was delivered independent to the other projects. The normality of data was preliminarily checked through Q-Q plots. Several deviations from normality were observed from the plots of the variables that were selected for the performance metric testing which are shown in Figure 11. The normality deviation was also evident in the Shapiro-Wilk test with W = 0.7547 and p-value < 0.0001.

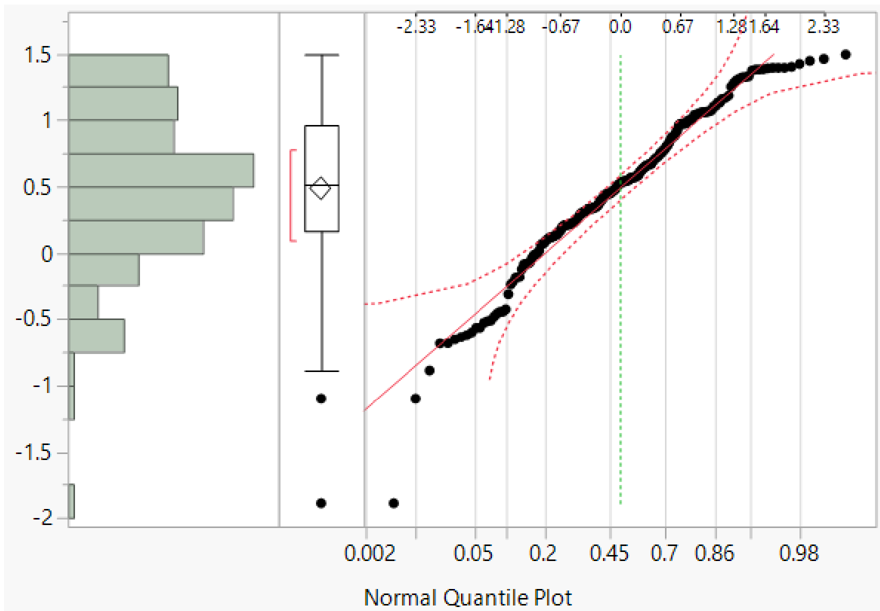


Figure 12: Q-Q Plot of log of FEP Cost %

To correct for normality, data transformations were applied to the data using logarithms. The Q-Q plot of the log transformed data is shown in Figure 12. The Shapiro-Wilk test yielded W = 0.9693 with a p-value < 0.0003. The log transformation still yielded non-normal data which lead to the usage of non-parametric methods of statistical analysis which does not require the normality assumption of data. For correlations analysis, Spearman's correlation was used for this study, which was performed using the multi-variate methods in the statistical analysis software JMP Pro 12.

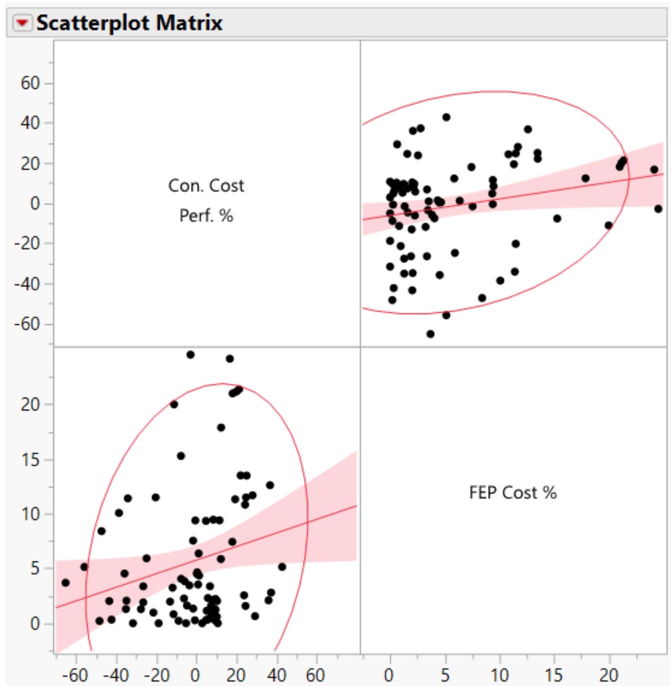
6.4. Hypotheses Testing

6.4.1. FEP versus Cost Performance

The first hypothesis that was tested was the correlation between FEP effort and the cost performance of the project. As stated earlier, since the data did not satisfy normality assumptions, Spearman's non-parametric correlation test was used to test the hypothesis:

> H_A = *There exists a correlation between the FEP Cost % and Cost Performance for Industrial projects*
>
> H_0 = *There is no correlation between the FEP Cost % and Cost Performance for Industrial projects*

Figure 13 shows the results of the correlation analysis for Design-Build projects. The coefficient of correlation, Spearman's $\rho = 0.2333$ which shows a positive correlation between the variables. The result is statistically significant at the 95% confidence level with a p-value = 0.0349. We can reject the null hypothesis and conclude that there is statistical evidence to suggest that more resource allocation in FEP at the front end leads to better construction cost performance of the project in Industrial projects delivered using Design-Build.



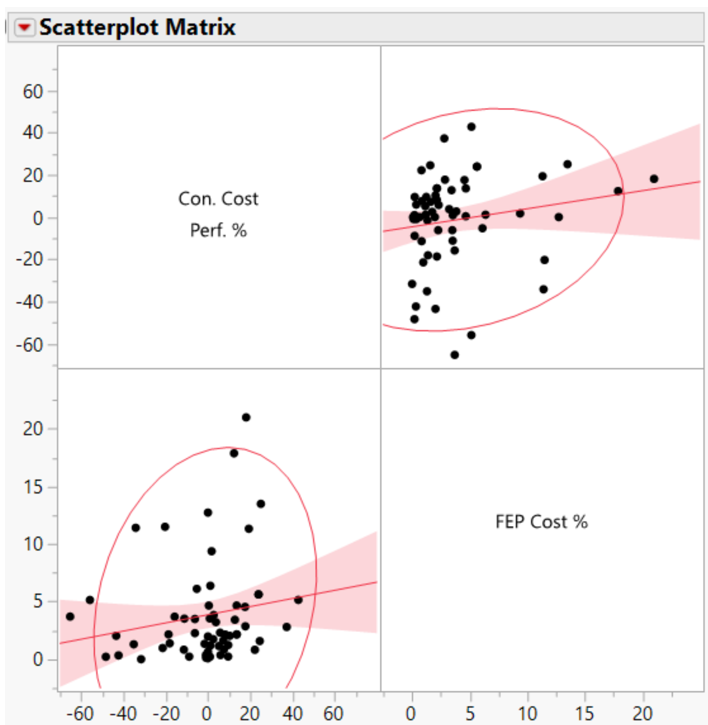
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Con. Cost Perf. %	0.2333	0.0349*	

Figure 13: FEP Cost % Versus Construction Cost Performance for DB System

Analysis of CMR showed a negative correlation of -0.2195 with a p-value = 0.3523, whereas the traditional DBB system displayed a positive correlation trend of ρ = 0.1078 and p-value = 0.3606. Both results are not statistically significant at the 95% level. Consequently, the null hypothesis cannot be rejected and there is no evidence of any correlation between the variables for CMR and DBB systems.

The projects were also analyzed based on the complexity factor, as FEP is essentially a process of problem solving and risk mitigation. The assumption made was that simpler project may not display any significant effects in concentrating more effort on FEP, whereas FEP resource allocation could indeed make significant contributions to project performance metrics in complex projects. The results of the correlation analysis as shown in Figure 14 presents a correlation factor of 0.2619 with a p-value of 0.0433 for complex industrial projects. Simpler projects experienced a slight correlation of 0.0642 but without a statistically significant p-value to reject the null (0.4958). At 95% significance level, there is evidence that increased FEP effort could benefit cost performance for more complex projects.

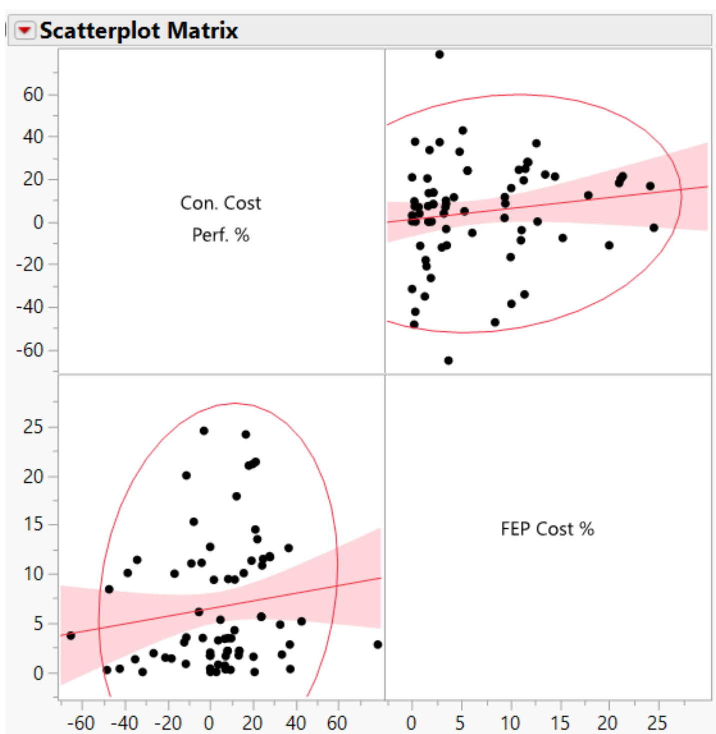


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Con. Cost Perf. %	0.2619	0.0433*	

Figure 14: FEP Cost % Versus Construction Cost Performance for Complex Projects

Analysis based on project type yielded significant results only for Renovation projects (Figure 15). The study produced a Spearman's $\rho = 0.2345$ with a p-value of 0.0474. Since the p-value is small enough to reject the null at the 95% level, the hypothesis that there exist a correlation between the tested variables is true for Renovation. The other two categories tested were Expansion ($\rho = -0.0489$, p-value = 0.7129) and New Project ($\rho = 0.0216$, p-value = 0.9021). Neither project types produced significantly small p-values to reject the null hypothesis.



Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Con. Cost Perf. %	0.2345	0.0474*	

Figure 15: FEP Cost % Versus Construction Cost Performance for Renovation Projects

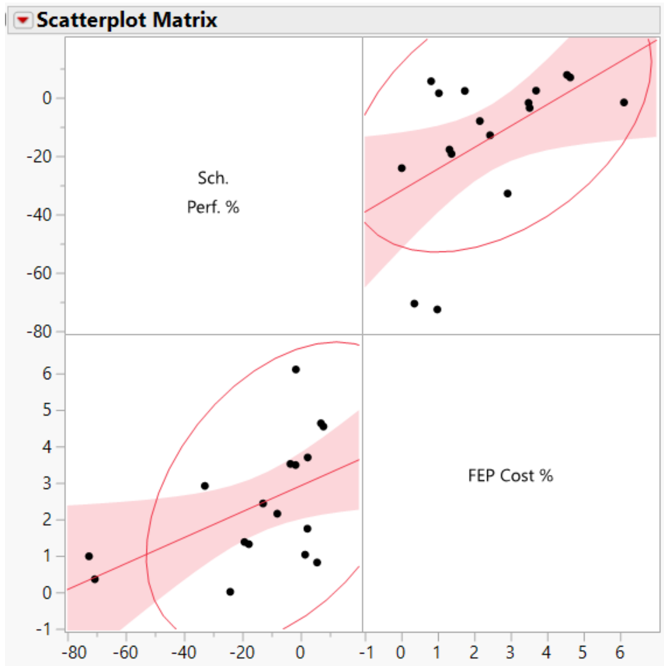
6.4.2. FEP versus Schedule Performance

The hypothesis that was tested regarding FEP effort and project schedule performance is stated as follows:

> H_A *= There exists a correlation between the FEP Cost % and Schedule Performance for Industrial projects*
>
> H_0 *= There is no correlation between the FEP Cost % and Schedule Performance for Industrial projects*

The analysis produced statistically significant results for the CMR delivery system only. The results are shown in Figure 16. There was a positive correlation of $\rho = 0.5417$ and a p-value of 0.0247, which is enough evidence to reject the null hypothesis at 95% confidence level, thereby validating the hypothesis that an increase in effort on FEP leads to an increase in schedule performance of Industrial projects.

The test was repeated for DB ($\rho = 0.0166$, p-value = 0.8837) and DBB ($\rho = -0.1244$, p-value = 0.2323) projects, simple ($\rho = -0.0267$, p-value = 0.7629) and complex ($\rho = -0.0021$, p-value = 0.9869) projects, and expansion ($\rho = 0.0178$, p-value = 0.8872), new ($\rho = -0.1737$, p-value = 0.3259) and renovation ($\rho = 0.0719$, p-value = 0.5185) projects. None of the tests produced statistical significant results for the 95% level.



Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Sch. Perf. %	0.5417	0.0247*	

Figure 16: FEP Cost % Versus Project Schedule Performance for CMR System

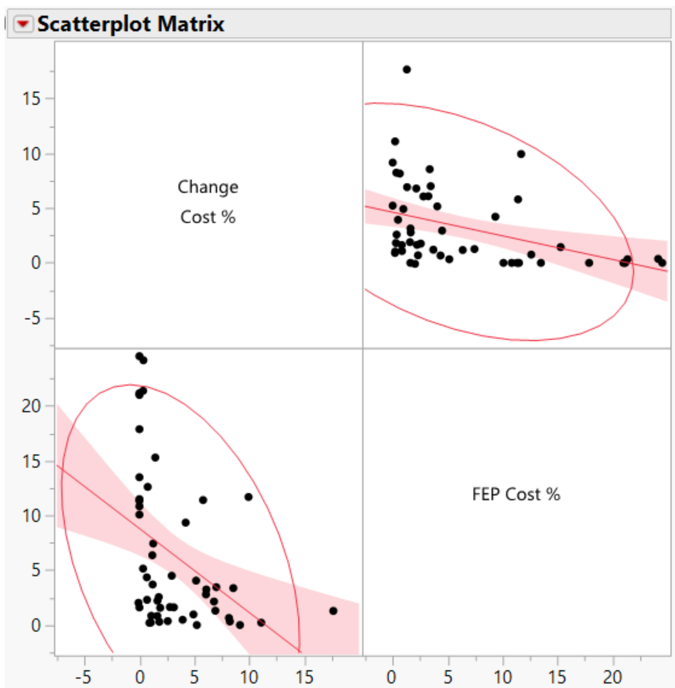
6.4.3. FEP versus Change Performance

The relationship between FEP effort and change performance was tested in two categories: cost change and schedule change. The cost change performance was tested according to the following hypothesis:

H_A = There exists a correlation between the FEP Cost % and Change Cost/Schedule % for Industrial projects

H_0 = There is no correlation between the FEP Cost % and Change Cost/Schedule % for Industrial projects

When tested by delivery systems, Design-Build showed significant negative correlation between FEP effort and change costs (Figure 17). The Spearman's ρ was -0.5120 with a p-value of 0.0001 which is a strong evidence in favor of the hypothesis that was tested. The other delivery systems did not yield meaningful results. For CMR, ρ = 0.2342 and p-value = 0.6132, and for traditional DBB, ρ = -0.0976 and p-value = 0.4783.



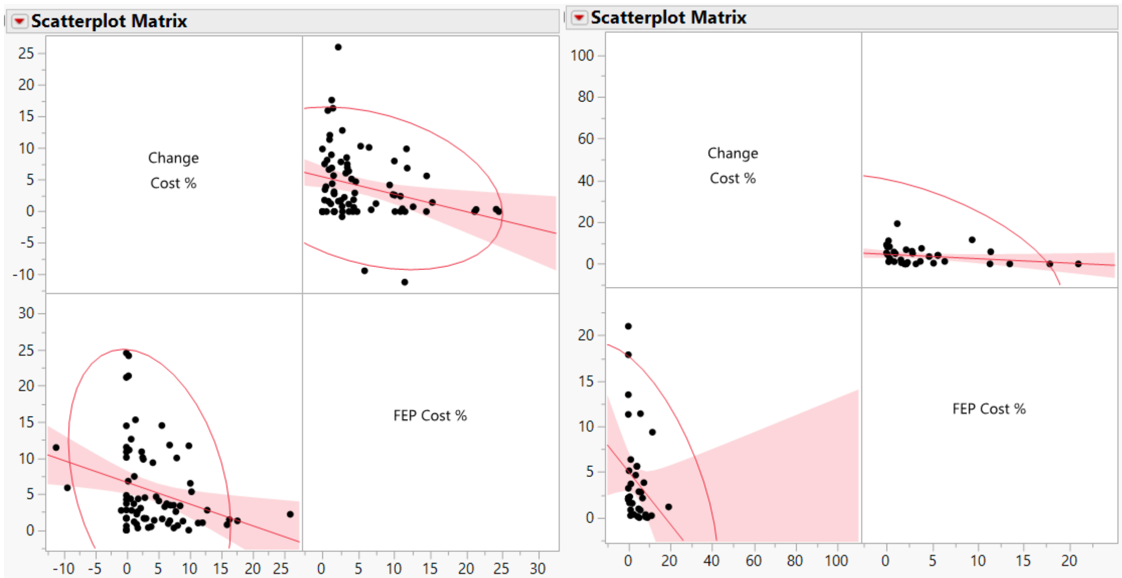
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Change Cost %	-0.5120	0.0001*	

Figure 17: FEP Cost % Versus Change Cost % for DB System

Regardless of the complexity of the project, the overall trend was a negative correlation between FEP effort and cost changes. Both simple and complex projects showcased the same result with significant p-values. The correlation factor was -0.2667 with a p-value of

0.0198 for the former, and -0.3481 with a p-value of 0.0322 for the latter.as shown in Figure 18 below.



Nonparametric: Spearman's ρ

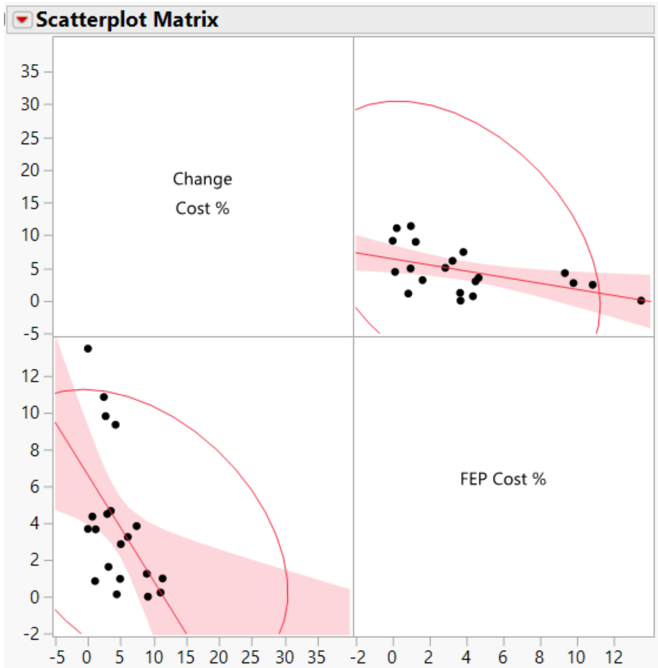
Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Change Cost %	-0.2667	0.0198*	

Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Change Cost %	-0.3481	0.0322*	

Figure 18: FEP Cost % Versus Change Cost % for Simple (Left Scatterplot, Top Table) & Complex (Right Scatterplot, Bottom Table) Projects

Among the project types, new projects seemed to exhibit a negative correlation between FEP effort and change costs (Figure 19) with Spearman's ρ = -0.5686 and p-value = 0.0089. The results of the other tests were expansion projects with ρ = -0.1548, p-value = 0.3535 and renovation projects with ρ = -0.2371, p-value = 0.1009.

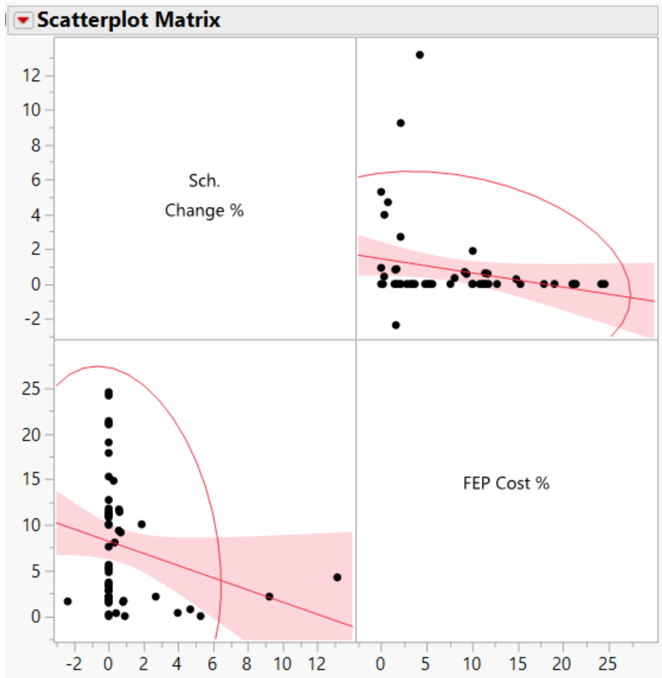


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Change Cost %	-0.5686	0.0089*	

Figure 19: FEP Cost % Versus Change Cost % for New Projects

The investigation of schedule changes affected by FEP lead to a significant result in the renovation projects (Figure 20). The p-value of 0.0361 with a correlation factor of -0.2860 presents evidence that enhanced efforts in FEP have a negative impact on schedule changes in renovation projects. The other categories tested and the statistical results are as follows: DB (ρ = -0.2230, p-value = 0.1196), CMR (ρ = -0.3429, p-value = 0.4057), DBB (ρ = -0.1140, p-value = 0.3775), Simple (ρ = -0.1377, p-value = 0.2088), Complex (ρ = -0.1712, p-value = 0.3180), Expansion (ρ = 0.1686, p-value = 0.2736) and New Project (ρ = -0.2010, p-value = 0.4725).



Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
FEP Cost %	Sch. Change %	-0.2860	0.0361*	

Figure 20: FEP Cost % Versus Schedule Change % for Renovation Projects

7. PERFORMANCE COMPARISON OF INDUSTRIAL PROJECT DELIVERY SYSTEMS

7.1. Research Setting

The performance comparison was done using the same 439 Industrial project data that was utilized for the correlation analysis. The three delivery systems compared are Design-Build, CM-at-Risk and the traditional Design-Bid-Build systems. The study aims to find significant differences between the performances of fast-track delivery systems (DB and CMR) and the traditional system. The project performance was compared in terms of schedule, cost, schedule change and cost change performance using the same metrics as done for the Spearman's correlation analysis.

7.2. Assumptions Validation

The performance metrics that were tested were first checked for the normality assumption. None of the variables satisfied normality according to the Q-Q plots. Shapiro Wilk test was conducted on each variable to ascertain the deviations from normal distribution. The cost performance generated a $W = 0.9186$ with a p-value < 0.0001 which supports the hypothesis that the data is not obtained from a normal distribution. The W for schedule performance was 0.4422 with a p-value < 0.0001. Similar was the case with cost change percentage ($W = 0.7484$, p-value < 0.0001) and schedule change percentage ($W = 0.5192$, p-value < 0.0001). The Q-Q plots are shown in Figure 21.

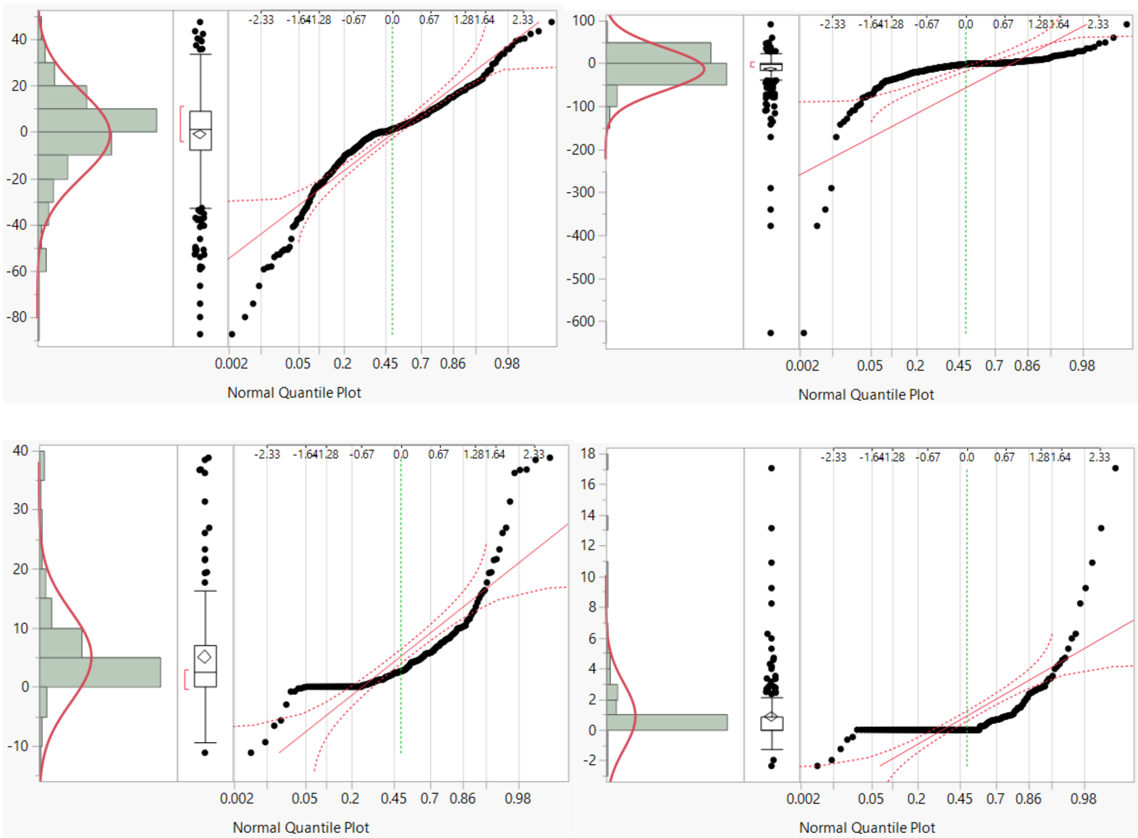


Figure 21: Q-Q Plots for Cost (Top Left), Schedule (Top Right), Change Cost (Bottom Left) and Schedule Change (Bottom Right) Performance

Log transformations were applied which still rendered the distributions non-normal. This led to the adoption of a non-parametric test for comparison instead of a one way ANOVA analysis. The Kruskal-Wallis sum rank test, which is an extension of the Wilcoxon's test for more than two populations, was chosen to be carried out to identify differences in the mean of the different delivery systems compared.

7.3. Hypotheses Testing

The performance metrics used for analysis were calculated using the variables and formulae as described in Chapter 6. Table 3 shows a list of the different metrics that were used for the hypothesis.

Table 3: Performance Metrics

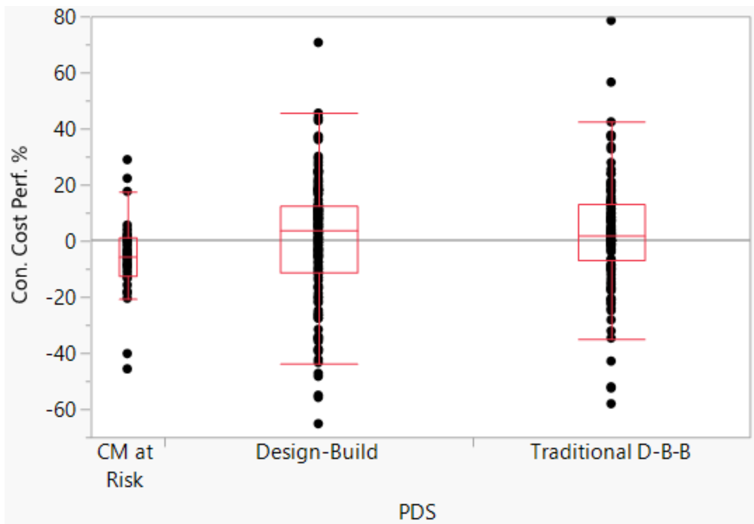
Metric	Formula
Cost Performance %	[(Budgeted Construction Cost – Actual Construction Cost)/Budgeted Construction Cost] * 100
Schedule Performance %	[(Baseline Schedule Duration – Actual Schedule Duration)/Baseline Schedule Duration] * 100
Change Cost %	[Total Change Cost/Budgeted Project Cost] * 100
Schedule Change %	[Total Schedule Change/Baseline Schedule Duration] * 100

7.3.1. Cost Performance Comparison

The first statistical test was targeted at validating the hypothesis that fast-track delivery systems have a better cost performance than traditional DBB system. The statistical hypothesis and the null hypothesis for the Kruskal Wallis test are given below:

> H_A = *There is a difference in Construction Cost Performance of Industrial projects between DB, CMR and traditional DBB systems*
>
> H_0 = *The Construction Cost Performance of Industrial projects between DB, CMR and traditional DBB systems is similar*

The box plot and results of the Kruskal Wallis test are shown in Figure 22. The p-value obtained was 0.0205. Therefore, there is statistical evidence to reject the null hypothesis at the 95% confidence level. There is a difference in cost performance among the various delivery systems tested. Further tests were conducted to assess how each delivery system differed in cost performance from the others.



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CM at Risk	32	3410.50	4640.00	106.578	-2.757
Design-Build	135	19946.5	19575.0	147.752	0.523
Traditional D-B-B	122	18548.0	17690.0	152.033	1.222

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.7745	2	0.0205*

Figure 22: Construction Cost Performance Comparison of PDS

The delivery systems were then compared individually with one another using the Wilcoxon method to understand the difference in their cost performances. The performance of CMR delivery system was the lowest showing statistical differences from the DB and traditional DBB system. There was no meaningful difference in the performances between DB and DBB with a p-value of 0.7330. Ranking the systems by their Score Mean Difference from best to worst, DBB achieved first, followed by DB and lastly CMR. The detailed results of the test can be referred to in Figure 23.

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
Traditional D-B-B	CM at Risk	25.79816	8.856872	2.912784	0.0036*	8.248191	3.01401	13.54528
Design-Build	CM at Risk	22.20868	9.506893	2.336061	0.0195*	7.994902	1.36642	14.09729
Traditional D-B-B	Design-Build	3.16764	9.285299	0.341146	0.7330	0.788559	-3.96720	5.33104

Figure 23: Individual Construction Cost Performance Comparison of PDS

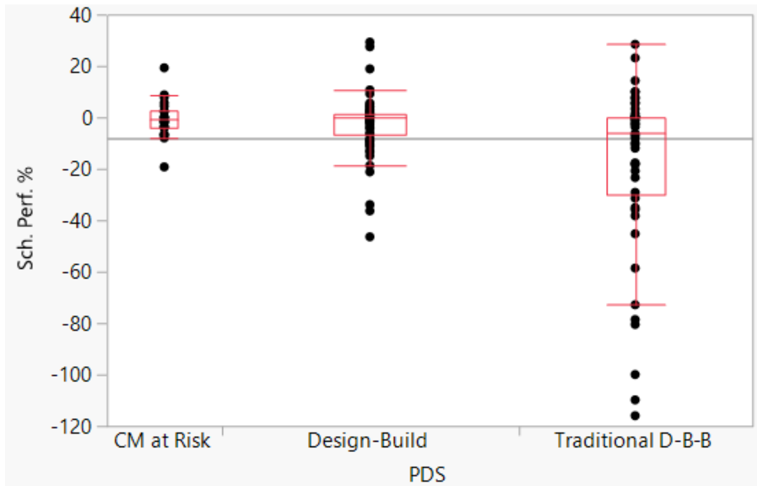
7.3.2. Schedule Performance Comparison

The hypothesis that was tested for schedule performance is provided as follows:

H_A = There is a difference in Schedule Performance of Industrial projects between DB, CMR and traditional DBB systems

H_0 = The Schedule Performance of Industrial projects between DB, CMR and traditional DBB systems is similar

The test generated a p-value of 0.5455, which was not low enough to reject the null hypothesis. There was no evidence of any schedule performance difference between the delivery systems. The same test was attempted using only the data samples from Complex projects (complexity = 5, 6, 7). The assumption was that more complex projects would display significant performance changes according to the choice of the delivery system, as fast-track systems are more suited to large scale facilities. As expected, the p-value generated was significantly lower (0.0337), sufficient enough to support the hypothesis that the schedule performance of delivery systems were different as shown in Figure 24.



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CM at Risk	24	1825.00	1632.00	76.0417	1.110
Design-Build	62	4589.00	4216.00	74.0161	1.648
Traditional D-B-B	49	2766.00	3332.00	56.4490	-2.593

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.7797	2	0.0337*

Figure 24: Schedule Performance Comparison of PDS

Further tests were performed to determine the difference in these delivery systems using the Wilcoxon method. Individual comparisons with each other showed that the traditional DBB system had the worst schedule performance. DB and CMR did not exhibit any significant differences in the schedule performance (p-value = 0.8205), which was the case with cost performance as well. Ranking the delivery systems from best to worst schedule performance in terms of score mean difference, DB led the other systems, followed by CMR and then DBB. The results are exhibited in Figure 25.

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
Design-Build	CM at Risk	-1.3582	5.987060	-0.22686	0.8205	0.00000	-4.2843	2.06495
Traditional D-B-B	CM at Risk	-10.4596	5.277151	-1.98206	0.0475*	-6.79344	-17.7154	0.00000
Traditional D-B-B	Design-Build	-14.4870	6.143216	-2.35821	0.0184*	-5.03356	-12.6857	-0.66587

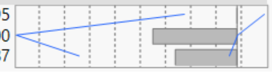


Figure 25: Individual Schedule Performance Comparison of PDS

7.3.3. Change Performance Comparison

The change performance was measured in terms of cost and schedule changes. The following research hypothesis was tested for statistical significance.

> *H_A = There is a difference in Change Cost/Schedule % of Industrial projects between DB, CMR and traditional DBB systems*
>
> *H_0 = The Change Cost/Schedule % of Industrial projects between DB, CMR and traditional DBB systems are similar*

The Kruskal Wallis test for comparison of change cost percentages gave a p-value of 0.5443. It is to be noted that change cost percentage data was available for only 15 CMR projects. This limitation did not allow for the testing by the complexity of the projects, as the sample size was very small. The comparison of schedule changes also produced similar result as above. The p-value obtained through the Kruskal Wallis test was 0.5880. The p-value is not significant enough to reject the null hypothesis at the 95% significance level. To conclude, there was no significance difference in either the cost or schedule changes in a project due the choice of delivery systems.

8. CONCLUSIONS & RECOMMENDATIONS

8.1. Summary of Results

This section summarizes the results of all the statistical tests that have been performed in this study. The correlation analysis was performed between the primary variable of FEP Cost % and the Cost Performance, Schedule Performance, Change Cost % and Schedule Change %. The results show that there is a positive correlation between the effort allocated to FEP and the cost performance of the project in DB system, Complex projects and Renovation projects. The schedule performance was affected positively by the FEP effort only in projects delivered using the CMR system. In general, there was an observable trend of negative correlation between the FEP effort and the change costs that occurred on a project. For this test, the statistical evidence was more significant in the case of DB system, both Simple and Complex projects and New projects. Increase in FEP effort reduced the schedule changes in projects only in the case of Renovation.

Table 4 summarizes the results of the correlation analysis with the corresponding p-values. A positive value for Spearman's ρ suggests a positive correlation and a negative value implies an inverse relationship between the variables. P-values that are less than 0.05 are considered significant at the 95% confidence level

Table 4: Spearman's Rho & P-Values Summary of Correlation Analysis

FEP Correlation Analysis	Cost Performance		Schedule Performance		Change Cost %		Schedule Change %	
	ρ	p	ρ	p	ρ	p	ρ	p
DB	+0.2333	0.0349	+0.0166	0.8837	-0.5120	0.0001	-0.2230	0.1196
CMR	-0.2195	0.3523	+0.5417	0.0247	+0.2342	0.6132	-0.3429	0.4057
DBB	+0.1078	0.3606	-0.1244	0.2323	-0.0976	0.4783	-0.1140	0.3775
Simple (1-4)	+0.0642	0.4958	-0.0267	0.7629	-0.2667	0.0198	-0.3481	0.2088
Complex (6-7)	+0.2619	0.0433	-0.0021	0.9869	-0.3481	0.0322	-0.1712	0.3180
Expansion	-0.0489	0.7129	+0.0178	0.8872	-0.1548	0.3535	+0.1686	0.2736
New Project	+0.0216	0.9021	-0.1737	0.3259	-0.5686	0.0089	-0.2010	0.4725
Renovation	+0.2345	0.0474	+0.0719	0.5185	-0.2371	0.1009	-0.2860	0.0361

The second objective of the study was to identify the best performing delivery system for Industrial projects in terms of cost, schedule and change orders. The Kruskal Wallis test that was performed on the dataset produced significant results for both cost and time performance of the projects. In both cases the fast-track delivery systems performed statistically differently than the traditional system. For cost performance the ranking of delivery systems based on score mean difference was: (i) Traditional DBB (ii) Design-Build (iii) CM-at-Risk. For the schedule performance results, the ranking of the PDS was: (i) Design-Build (ii) CM-at-Risk (iii) Traditional DBB.

8.2. Research Limitations

Since Industrial projects involve complex MEP systems and requirement of detailed engineering for each part of the execution process, FEP is critical for success in this particular sector. Previous CII research also indicate that PDRI scores were majorly used by Industrial project participants for scope clarity. Therefore, this study is limited to performance analysis of industrial projects only. When considering the FEP effort in a project, the metric is limited to the FEP cost only which is the most accurate representation of the resources utilized during the planning phase. The duration of the Front-End Planning process was not taken into account when calculating the FEP effort. The correlation analysis that was performed is limited to linear relationships between the variables and non-parametric methods were employed for statistical significance testing. Finally, a major limitation of the study is that the analysis is limited to describing the relationships between the variables and cannot be used to attribute any cause-effect results.

8.3. Conclusions

From the correlation analysis, it can be observed that fast-track systems showed evidences of improvement with increased resource allocation on FEP, whereas the traditional system did not exhibit any significant relationship. This can be explained by the collaborative nature of the DB and CMR systems. In both these FDS, the builder/construction manager is involved with the designer early on in the project. Inputs regarding constructability, cost control, risk management and feasibility can be provided by the builder/CM in the starting stages of the project. Thus, more FEP effort could indeed improve the project performance in these systems. FDS tend to support the Front-End Planning process considerably than the traditional system in which the bid is awarded to the GC only after the designs are already completed.

Design-Build projects involve a single designer/builder entity that takes on the contract for the project. The construction can begin even before the final design are complete, which means that there is a chance of change orders and cost overruns if the designs get changed later on in the project. The builder works closely with the designer precisely to ensure constructability and minimize the chances of change orders. Any major design changes are finalized at the front-end of the project with close collaboration of all project stakeholders. This is supported by the results of the analysis that DB projects experienced a better cost and change cost performance when FEP effort was increased.

CMR is an FDS that is based on a guaranteed maximum price to the owner. This guaranteed price helps the owners to transfer the risk to the CM. The CM is consulted early on in the project to provide preconstruction services. As each design package gets completed, it can be bid out to the subcontractors and the construction of that design package can begin. As earlier design packages can be built early, the schedule is fast-tracked and can expedite the project considerably. More FEP resource allocation can help more design packages to be completed efficiently and accurately to accelerate the fast-track process. The evidence for this can be obtained from the correlation analysis between the FEP effort and schedule performance for CMR systems.

The GMP for CMR projects are fixed before the entire design process gets completed. Since the price is guaranteed, any cost overruns can cause losses to the Construction Manager. More effort is concentrated on fast-tracking the project to gain schedule savings.

This could cause cost overruns and change orders in the project, which is supported by the cost-time tradeoff nature of construction projects. It is meaningful, therefore, to observe that CMR projects performed the worst in terms of cost. The traditional system which is a completely linear design-bid-build process has no inherent opportunities for fast-tracking the schedule, thereby performing poorly in terms of schedule. Among the other delivery systems, Design-Build seemed to perform better when both cost and schedule are considered.

8.4. Recommendations

One of the objectives of this research study was to identify which project delivery system is the best choice for industrial projects. DB and CMR (the fast-track delivery systems) and the traditional DBB system were analyzed both in terms of FEP correlation and performance comparisons. The correlation analysis clearly presents evidence in support of Front-End Planning. FEP must be implemented as a "best practice" as the CII suggests, to clearly define the scope and identify challenges within a project. Resource allocation on the FEP process has a positive effect on the cost, schedule and change performance of the project as deduced from the statistical data. The correlation was especially significant in DB projects which showed positive results for both cost performance and change cost performance. It should also be noted that DB projects were ranked second in the cost performance comparison study and first in the schedule performance comparison study. A project which is delivered using the Design-Build system, along with an appropriate allocation of resources in Front-End Planning can achieve considerable cost, schedule and change cost savings according to the results of the study. Therefore, this thesis recommends the adoption of Design-Build PDS with focused efforts in Front-End Planning for the successful completion of Industrial projects.

8.5. Significance of Study

This study serves as an extension to the existing CII literature on front-end planning. The uniqueness of this research lies in the analysis of the relationship between the "level" of FEP and the choice of project delivery system. The research has tried to provide a statistical support to promote FEP usage in complex industrial projects. By studying the correlation between the level of FEP effort on project performance, the study hopes to encourage project participants to focus their efforts in the initial stages of the project for better definition of scope and eliminating unknowns. The research community has been provided with a comparative analysis of fast-track delivery systems and the traditional system by utilizing an extensive database of project information. This will enable project stakeholders to make evidence based choices with regards to the different delivery system options that are available to execute a project. Furthermore, the study aims to promote collaborative delivery systems which can best utilize FEP concepts for implementation in large scale, risky and complex projects.

8.6. Future Research

As stated in the Research Limitations, the correlation analysis performed in this study does not imply causation. Future studies can tackle this limitation by the means of regression analysis to clearly delineate any cause-effect relationships between the FEP effort and the project performance metrics. A regression model can be used to generate a reliable decision making model for calculating the required FEP effort that can result in the anticipated project performance. Other variables included in the CII Benchmarking & Metrics database including engineering deliverables, cost and schedule data for detailed engineering, procurement, and startup, effort put into design etc. which were not analyzed as a part of this study, presents scope to future researchers to conduct similar statistical studies. This research study can also be extended to other industry sectors like Building and Infrastructure based on availability of data. Including relatively new PDS like Integrated Project Delivery which is highly collaborative, can provide meaningful results in promoting FEP in future research.

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