Project Delivery Method Performance Evaluation for Water and Wastewater Capital Projects

by

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ABSTRACT

The water and wastewater industry in the United States is in dire need of renovation due to dwindling infrastructure and requires substantial reinvestment. Design-bid-build (DBB) is the traditional method of project delivery most widely applied in this industry. However, alternative project delivery methods (APDM) are on the rise and touting the benefits of reduced project schedule and cost. The main purpose of this study is to conduct a qualitative and quantitative performance evaluation to assess the current impact of APDM in the water and wastewater industry. A national survey was conducted targeting completed water and wastewater treatment plant projects. Responses were obtained from 75 utilities and constructors that either completed their projects using DBB, construction manager at risk (CMAR), or design-build (DB). Data analysis revealed that CMAR and DB statistically outperformed DBB in terms of project speed and intensity. Performance metrics such as cost growth, schedule growth, unit cost, factors influencing project delivery method selection, scope changes, warranty and latent defects, and several others are also evaluated. The main contribution of this study was that it was able to show that for the same project cost, water and wastewater treatment plants could be delivered under a faster schedule and with higher quality through the utilization of APDM.

I dedicate this thesis to my late father who has instilled within me the values and principles of hard work and resilience. To my loving mother Marleine, my brothers Julien and Joey, and my partner May, thank you for always believing in me and supporting me throughout this journey. I am eternally grateful.

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CHAPTER 1

INTRODUCTION

The first chapter of this thesis introduces the study and consists of two sections. The first section provides a brief background of the current state of the water and wastewater industry. Followed by the second section that provides a short summary on the three project delivery methods of interest for this study.

1.1 Water and Wastewater Industry Background

Today, there is a dire need to upgrade existing drinking water and wastewater treatment facilities and build new ones. Water and wastewater infrastructure in the United States is relatively below standard and many of its elements are slowly approaching the end of their service life (ASCE 2013). Treatment plants typically have a 50-year design life and major renovation works are often done after 25 years (mainly due to corrosion of concrete vessels). Sometimes laws and regulations change resulting in water and wastewater utilities having to upgrade technologies and retrofit old tanks to newer, state-of-the-art ones for improved efficiency and environmental compliance.

According to the American Water Works Association, an estimated $1 trillion is needed to sustain current services and to expand to meet future demands throughout the next 25 years (AWWA 2016). Moreover, the financial challenge to address deteriorating water and wastewater infrastructure has fallen to individual states and municipalities as a result of declining federal funding for water utilities from $16 billion in 1976 to $4.4 billion in 2014 (CBO 2015). Due to these constraints, decision-makers in this field are now opting for innovative technological solutions to aid them in delivering their water infrastructure projects.

Water and wastewater treatment plants have traditionally been constructed, retrofitted, and rehabilitated using design-bid-build (DBB) project delivery. The traditional DBB delivery system has been used successfully for decades. This delivery system is especially successful for projects where the work is well defined and there is relatively low uncertainty (i.e., projects that are repetitive, with low complexity). However, non-traditional alternative project delivery methods such as design-build (DB) and construction manager at risk (CMAR) are slowly gaining popularity across various industries, including the water and wastewater industry. APDM are touting benefits such as lower cost, faster schedule, and higher quality. There are several forms of project delivery methods applied across various industries. However, this study only focuses on the application of DBB, CMAR, and DB applied for water and wastewater infrastructure projects.

To gauge the benefits of these three most prevalent project delivery methods, a performance based empirical investigation needs to be performed. Quantitative and qualitative performance evaluations have been conducted on these delivery methods in the transportation and building sectors. However, there is a need to conduct similar investigations in the water and wastewater sector specifically focusing on treatment plants.

Results of this research will provide utility owners with statistically significant comparative results for delivery options for common project metrics (cost, schedule, and quality). The analytical evaluation of these results will increase utilities' abilities to select the project delivery method that best suits their project-specific construction needs.

1.2 Project Delivery Methods

This section provides a brief background on the three delivery methods of interest for this study, which are DBB, CMAR, and DB.

1.2.1 Design-Bid-Build

Being the most widely understood and accepted project delivery method across all industries, DBB is frequently referred to as the traditional project delivery method (ACRP 2009). In DBB, the owner has two separate and independent contracts, one with a designer and one with a contractor. DBB is typically a linear process, and construction only begins after detailed design has been completed and after the contractor has been awarded the bid. Since there is no contractual relationship between the designer and contractor, any design changes or adjustments that may arise during or after construction will have to be handled as change orders (Shrestha & Mani 2014). DBB also does not generally allow the contractor an opportunity to provide input during the design phase, and this lack of communication may sometimes lead to project delays and cost overruns. Additionally, DBB is typically awarded based on a low-bid process and the contractor is selected based on cost rather than their qualifications (Bearup et al. 2007).

1.2.2 Construction Manager at Risk

A key difference between DBB and CMAR is that CMAR firms are involved during the design-phase and are capable of providing valuable contractor input to the design. An advantage of CMAR is the pre-construction services that the CMAR firm can offer, and this includes services such as cost engineering (ACRP 2009). While using CMAR—similarly to DBB— the owner has two separate and independent contracts, one with a designer and one with the CMAR firm. However, the difference is that with CMAR, the CMAR firm is usually contractually required to coordinate with the designer. The CMAR firm is typically handed major design responsibilities; however, the owner typically still retains the actual ownership and liability of the design (ADEED 2017). Moreover, the bid award process of CMAR is unlike DBB, and could be awarded based on a combination of cost and qualifications.

1.2.3 Design-Build

DB caters for owners who prefer to have one contract with one single-point of communication for their project. In DB, the design-builder is typically engaged early in the design phase and is responsible for both designing and constructing the project. Having the design-builder engaged early on in the design phase allows opportunities for schedule compression and project phasing (Bearup et al. 2007). DB is similar to CMAR as it can also be awarded based on qualifications. On a DB project, the design-builder is responsible for the design, and design liability is transferred from the owner to the design-builder (Culp 2011). This method is ideal for owners who are less familiar with construction project management and delivery, and are willing to give up some owner control and influence over a project.

CHAPTER 2

APDM PERFORMANCE LITERATURE REVIEW FOCUSING ON WATER AND WASTEWATER PROJECTS

Projects contain several key performance metrics, and typically the three common metrics utilized for project evaluations are cost, schedule, and quality (Ibbs et al. 2003, Warne 2005). Cost growth and schedule growth are particularly the most critical metrics as they measure the deviation of the budgeted cost and allotted schedule time. Owners are typically concerned most about these two metrics in specific, and attempt to avoid these overruns for their projects. It is important for owners to have both cost and schedule certainty in order to properly allocate the resources needed for their current and future projects.

Numerous performance evaluations studies have been conducted for DBB, CMAR, and DB across various industries and project types that include: transportation, building, industrial, military, and mixed-projects. This chapter is divided amongst three sections as seen in Figure 1, comprising of: 1. APDM performance evaluation across all industries, 2. APDM in the water and wastewater industry, and 3. APDM performance evaluation in the water and wastewater industry.

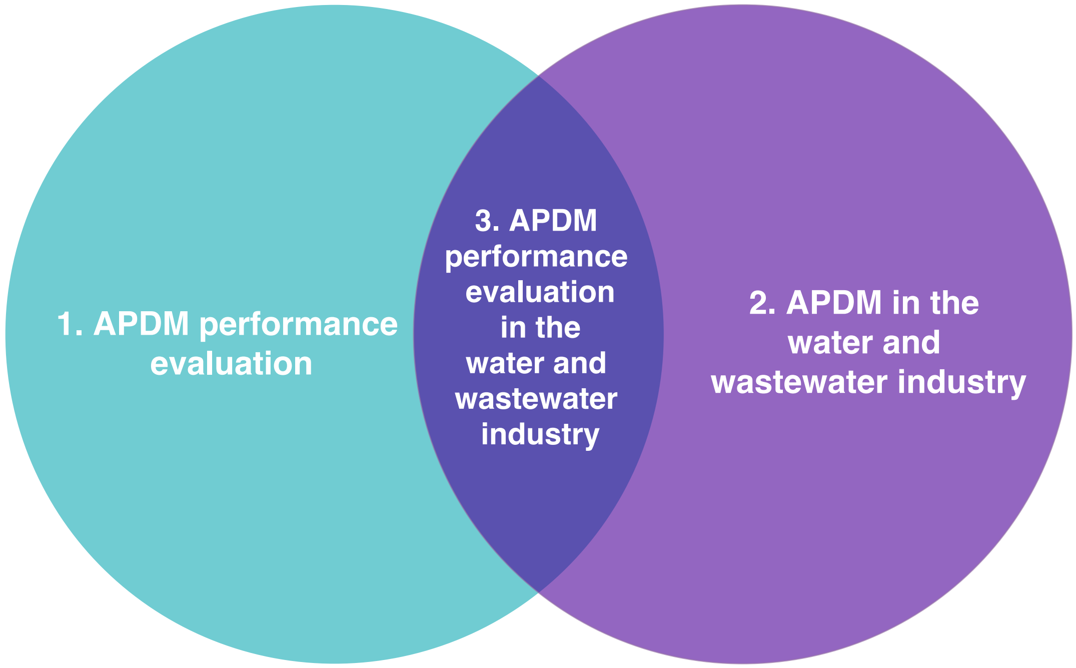

Figure 1: Literature Review Sections

2.1 APDM Performance Evaluation Across all Industries

From the transportation industry, around 20 publications that evaluate project performance were examined, a selection of studies that contain a sample size of 55 completed projects or greater include publications by Migliaccio et al. (2010), Shakya (2013), Bingham (2014), Aleeman et al. (2016) and Park and Kwak (2017). Moreover, around 15 publications were reviewed for measuring project performance on building, industrial, military, mixed-projects and other industries. Some of these publications that include a sample size of 100 completed projects or greater are studies by Konchar and Sanvido (1998), Molenaar et al. (1999), Rojas and Kell (2008), and Carpenter and Bausman (2016).

Migliaccio et al. (2010) evaluated 146 DB transportation projects across the United States that have project costs ranging from $150,000 to $1.84 billion. This study evaluated several performance metrics, which included: cost change, schedule change, and procurement duration. Findings in this study revealed that cost growth for DB projects was at 0.4%, while schedule growth was at 13%. Overall, this study represented a large benchmarking effort for DB transportation projects and documented a direct linear correlation between procurement time and schedule change.

Shakya (2013) studied the performance of 55 DB and 34 CMAR projects. Performance metrics used by the author to conduct this study included cost change, change order cost-factors and construction intensity. The results revealed that the average cost change of DB projects was negative 3.65%. Statistical analysis was completed using a one-way analysis of the variance (ANOVA), and the differences in cost change were found to be significant, as contract award cost growth was significantly lower in DB projects than in CMAR projects.

Bingham (2014) performed a quantitative study that measured cost and schedule performance for 40 DBB, 21 DB, and 18 CMAR projects. DB had the least average cost change at negative 5.37%, meaning that the average DB project was completed under the original budgeted cost. While for average schedule change, DBB (4.65%) outperformed both CMAR (13.27%) and DB (20.24%). However, statistical analysis was completed using ANOVA, and no statistically significant differences were observed between the three delivery methods.

Alleman et al. (2016) studied the application and performance of APDM on small highway construction projects. The sample size consisted of 291 US highway projects that utilized DBB, CMAR, and DB. This study quantitatively verified the advantages of APDM for small transportation projects. The outcome of this study showed that APDM could provide timesavings on small projects without any negative impacts on project cost.

Park and Kwak (2017) analyzed 1257 DBB and 255 DB projects, aiming to assess the performance of both delivery methods. Several factors were measured in this study and include: 1. The willingness of the owners to implement a certain delivery method over the other when it comes to a certain project, and 2. The different consequences of delivery methods when it comes to cost and schedule. After the completion of this study, it was determined that transportation project owners are shifting to DB due to the impatience of the lengthy DBB construction process.

Konchar and Sanvido (1998) conducted a study of 351 building and industrial projects to quantify the performance of DBB, CMAR, and DB delivery systems. The study empirically compared cost and schedule performance metrics between the delivery methods. The results from a univariate analysis showed that DB had better cost and schedule performance than CMAR, and in turn CMAR had better cost and schedule performance than DBB.

Molenaar et al. (1999) studied single-step, two-step, and qualification based design-build (DB) projects from an owner's perspective. Data from 104 DB projects, mostly U.S. Federal building projects, were collected from a national survey. Cost growth, schedule growth, expectations, administrative burden, and owner satisfaction data was obtained. Results showed that two-step DB outperformed single-step and qualifications based DB by a margin of 2.6% for cost growth and 1.5% for schedule growth.

Rojas and Kell (2008) compared the cost performance of 273 DBB and 24 CMAR public school projects completed in the Pacific Northwest. The results showed no statistical difference between CMAR and DBB in change order costs during the construction phase. DBB projects had a median change order ratio of 4.98% and CMAR had a median change order ratio of 4.5%. However, CMAR projects exceeded the guaranteed maximum price (GMP) in 75% of the cases, and DBB projects averaged less cost growth when compared to a small sample of CMAR projects.

Carpenter and Bausman (2016) analyzed the differences between DBB and CMAR for public school construction projects. The authors of this study collected data from a sample size of 137 Southeastern U.S. public schools. The aim of their study was to analyze different delivery methods against several project performance metrics such as quality, claims, time, and cost. Based on the results of the analysis, DBB outperformed CMAR in terms of cost. However, CMAR outperformed DBB in terms of quality.

2.2 APDM in the Water and Wastewater Industry

Around 18 publications that relate to APDM application in the water and wastewater industry were obtained, a selection of studies that contain projects with minimum values of $10M or greater include publications by Molenaar et al. (2004), Rao (2009), Gilbert (2010), Meszaros (2011) and Benson et al. (2013).

Molenaar et al. (2004) conducted an industry-wide survey and three case studies to record the use of DB in the water and wastewater industry. The study identified the industry's best practices with regards to selecting a delivery system, contracting, allocating risk, evaluating proposals, determining the level of design in the request for proposals, employing consultants, establishing trust, identifying key players, and permitting for DB. The study also found widespread growth for the use of DB for water and wastewater treatment facilities.

Rao (2009) conducted a case study analysis of four water treatment plants in the state of California and noted several benefits of using DB delivery over traditional DBB in the water and wastewater industry. These benefits included: 1. Single source responsibility for design and construction, 2. A focus on lowering life cycle costs, and 3. Schedule compression. Advantages of DB over DBB included: the notion that DB project teams are formed between engineers and contractors to seek out the best cooperation, DB project teams can potentially offer cutting edge technology or innovation solutions to the project, and DB project teams are more likely to meet the owner's objectives because the engineers and contractors are better aligned. A noted disadvantage was that the DB selection process is often much more time intensive and difficult, and that owners are not typically familiar with DB project execution.

Gilbert (2010) presented an overview of applying CMAR on the Highland Avenue Water Treatment Plant project in Augusta, Georgia. The objective of the project was to treat water pumped from the Savannah River and distribute it to local customers. The project scope included seven new deep-bed filters, all chemical facilities, operation and maintenance areas, and ancillary pumping systems. CMAR was selected because of its benefits for risk funding allocation, risk allocation/mitigation, project implementation, and commissioning priorities.

Meszaros (2011) advocated the benefits of CMAR to project teams due to the improvement of team alignment using this delivery method. Meszaros determined that

CMAR is an advantageous project delivery method by exploring the benefits of collaboration of CMAR on the City of Austin's Water Treatment Plant No. 4 project.

Benson et al. (2013) outlined the innovative procurement process of using DB for a long-term control plan (LTCP) in the District of Columbia aimed at reducing combined sewer overflow (CSO) into the District's waterway. This publication describes the innovative procurement process utilized for a tunnel dewatering pump station (TDPS) and the enhanced clarification facility (ESF) components of the LTCP. Lessons learned concluded that for the collaboration process to be successful, a disciplined and structured approach must be advocated by all parties, including an experienced owner consultant, to help guide the owner through the DB delivery process.

2.3 APDM Performance Evaluation in the Water and Wastewater Industry

Six publications that evaluate APDM performance in the water and wastewater industry were reviewed and include publications by Bogus et al. (2010), Bogus et al. (2013), Shane et. al (2013), Shrestha et al. (2014), Francom (2015) and Shrestha et al. (2016).

Bogus et al. (2010) conducted a survey of public water and wastewater facility owners to study cost and schedule performance. Data was gathered from 100 projects, each with a minimum total cost of $3 million. The study showed that projects were delivered faster using DB, compared to DBB. The average schedule growth for DB projects (one month) was half of the schedule growth for DBB projects (two months). Despite the differences in cost growth not being statistically significant, DB projects were actually completed on or below budget 38% of the time, as compared to 20% of the time for DBB. This study determined that DB projects have greater cost intensity (cost per unit of time) than DBB, with no difference in overall quality. Finally, the study concluded by stating that projects using a GMP do not experience as much schedule and cost growth as projects using a lump sum contract.

Bogus et al. (2013) also examined the relationship between procurement duration and performance of water and wastewater projects. The researchers surveyed water and wastewater project owners and gathered information on 47 completed DB projects. Average cost change was 2% and average schedule change was 3.8%. Statistical analysis based on project size showed no statistical correlation between cost growth and procurement duration, and no correlation between procurement period and project performance. The study further found that providing a longer procurement period was unlikely to result in better project performance, while allowing a short procurement period may result in poor schedule performance.

Shane et al. (2013) collected data through a national survey directed to utility owners and investigated their project's cost and schedule growth. Overall, data was collected from 31 DB and 69 DBB projects. The results obtained showed statistical significance between DB and DBB in terms of schedule growth, but not in cost growth.

Shrestha et al. (2014) compared the satisfaction levels of owners who executed water and wastewater projects through APDM, consisting of CMAR and DB. A survey was distributed to 455 owners out of which 145 responded. The survey results showed that owner satisfaction level was high for projects executed using APDM. Moreover, the project team was satisfied with the owner's involvement level in the design phase, the communication level between the different parties, and the quality of the executed project. Schedule advantages were the main reason for implementing APDM for water and wastewater projects. The results showed that most of the DB respondents were more satisfied with the benefits of APDM when compared to CMAR respondents.

Francom (2015) conducted a survey of pipeline industry stakeholders to investigate the utilization rate, industry comfort level, and perceptions of performance of APDM. The outcome of the pipeline industry survey results indicated that the most utilized project delivery system was the traditional DBB system. The results also denoted that respondents perceived APDM to most impact schedule, return business and profit, and communication between stakeholders. Overall, the author was capable of collecting performance data from more than 100 CMAR and DBB projects and the outcome of this study verified the superior cost performance (by 6.5%) and schedule performance (by 12.5%) of CMAR projects when compared to similar DBB projects.

Shrestha et al. (2016) compared the satisfaction levels of utility managers and project managers implementing APDM for water and wastewater projects. The authors surveyed management level and project level staff of water and wastewater utilities, inquiring on the performance of their projects. The survey collected 153 responses, of which 116 were either utility managers (UM) or project managers (PM). The data was subjected to statistical analysis, and revealed a slight disconnect between UMs and PMs. The results showed that UMs estimated that their projects were completed 1.38% behind schedule, while PMs estimated their projects were completed 1.15% ahead of schedule. Both UMs and PMs agreed that schedule, quality, cost and fewer disputes are from the main reasons for conducting a project using APDM.

CHAPTER 3

OBJECTIVE AND METHODOLOGY

The objective of this research is to qualitatively and quantitatively assess the performance impact of APDM on water and wastewater treatment plant projects. To address this objective, the research method first consisted of conducting a through review of the literature and identifying the knowledge gap, which has been shown in Chapter 2 of this paper. Next, a survey was developed to gather performance data for completed water and wastewater plant projects across the United States. After completion of the initial survey, an industry expert workshop was conducted consisting of 20 professionals with extensive experience in project delivery in the water and wastewater industry. Workshop participants assisted the research study by reviewing the data collection survey questions and validating their composition. Industry experts then pilot tested the survey, before the initiation of the data collection phase. The survey was administered nationally and sent to about 200 project delivery decision-makers across the water and wastewater industry. Subsequently, the collected data was compiled, cleaned, and validated. Finally, data analysis was performed to assess the impact of APDM in the water and wastewater industry. The following subsections delve into the sequential steps that were undertaken for this study, as shown in Figure 2.

Figure 2: Research Methodology Flowchart

3.1 Initial Survey Development

The completion of the literature review and identification of key performance metrics served as the initial basis for the survey's development. The initial survey questions were designed to encompass identified quantitative and qualitative metrics from the literature.

The data collection questions first consisted of gathering information on a project's general characteristics, location, site condition, type of project (e.g.; new construction, renovation), plant capacity before and after construction, and the project delivery method used. Additionally, questions specific to other project characteristics examined include: reasons for delivery method selection, selection process utilized (e.g.; low-bid, best value), compensation types for the construction team (e.g.; lump sum, unit price, GMP), and approximate level of design completed before engaging the constructor. The survey also inquired if there had been any major scope changes in the project, warranty issues and latent defects after completion of the project, and if the chosen delivery method would be implemented again for future projects within their organization. Furthermore, the survey sought to gauge the respondents opinion on owners, constructors, and designers experience with the chosen delivery method, owner's involvement in design and construction, and overall stakeholder communication. A 5-

point Likert scale was used to express their agreement or disagreement with each statement. This study also explored an owner's driving metrics for "success." Therefore, a section in the survey was aimed in measuring a project's key driving metrics (e.g.; owner involvement, early cost certainty) that mostly defined "success."

Questions based on quantitative performance metrics examined project cost, schedule, and other hybrid metrics. To measure cost performance, the survey-collected data on project contingency costs, in-house design costs, and initial and final: design costs, pre-construction costs, construction and total project costs. Schedule performance information was similarly gathered by collecting data on a project's planned and actual: start date, design and construction start date, substantial completion date, and final acceptance date. Cost performance metrics measured design cost growth, construction cost growth, total cost growth, and unit cost. While schedule performance metrics measured design schedule growth, construction schedule growth, total schedule growth, and speed. Information on a hybrid performance metric was also collected, and includes a metric that measures a project's intensity. Other performance metrics are also studied and will be discussed in detail in the following chapters of this paper.

3.2 Expert Workshop & Survey Pilot Testing

An industry expert workshop was assembled through the assistance of 20 industry experts with experience in various project delivery methods applied to water and wastewater treatment plants. The workshop participants included professionals from both utility and contracting organizations. The main objective of the workshop was to review and improve the initial data collection survey. During the workshop, the industry experts provided detailed feedback, while also suggesting additions and modifications to the initial survey questions. The industry experts also added impactful questions that had not been initially included in the survey, and rephrased sentences and modified wording in questions of the survey. Moreover, the industry experts were asked to fill out a sheet with the contact information of individuals in their professional network that may help provide relevant project data during the data collection phase.

After completion of the workshop, the survey was modified to reflect the feedback obtained. Thereafter, the survey was pilot tested by a limited number of utilities that were involved in the workshop. These utilities provided additional feedback during the survey pilot testing phase and verified that the survey is simple to use and could be performed in less than 30 minutes as intended. The finalized questions of the survey that were used for the national data collection process can be seen in the appendix section of this paper.

3.3 National Data Collection & Validation

During the national data collection phase, respondents were asked to only provide information on their water and wastewater plant projects if they have been recently completed (after 2005). The survey aimed to target projects from diverse sizes, including those more or less successful. The respondents were also strictly advised to only submit data if they had been intimately involved with their project. For example, respondents may include: project managers, senior staff members, or chief estimators. Qualtrics, an online survey and data collection tool was used to design the survey. The final survey consisted of 67 questions and was administered nationally. The survey was sent to about 200 project delivery decision-makers and professionals in the water and wastewater industry, of which there was a response rate of about 38%. The data collected was then cleaned and validated by verifying the responses through online publications, news articles, and other resources that contain publically accessible information on completed water and wastewater treatment plant projects.

3.4 Methods for Data Analysis

The data was analyzed using different statistical methods and approaches. This included using boxplots, descriptive statistics, removing outliers using Tukey's outlier detection method, quantile-to-quantile (Q-Q) plots to test for normality, and using either ANOVA or Kruskal-Wallis tests to test for statistical significance.

A boxplot is a nonparametric graphical summary of a data's minimum, lower quartile (Q1), median, upper quartile (Q3), and maximum (El Asmar et al. 2013). Boxplots provide an effective way to graphically depict the distribution of a data set. In a boxplot, the median is represented through a horizontal line in the rectangle that divides the data set. The rectangle represents 50% of the data that lies around the median, and the other 50% of the data is represented above and below the rectangle (El Asmar et al. 2013). Data outliers are plotted separately as points outside the whiskers of the boxplot, and for this study Tukey's outlier detection model was used to remove the outliers before performing statistical analysis.

Tukey (1977) developed an outlier detection model that targets outliers, which are values that fall far from the median. Tukey (1977) states that outliers can be removed from the data set if their values lay outside of "Tukey's inner fences" which are values below $Q1-1.5(IQR)$ or above $Q3+1.5(IQR)$, where the inter-quartile range (IQR) is defined as the interval between Q1 and Q3. By using Tukey's outlier detection model, values that are observed outside these cut off points are removed and overall bias and error is reduced. As a result, the distribution of the data is more refined.

It is necessary to determine if a data set is normally distributed or not in order to utilize the appropriate statistical test before performing any statistical analysis. Q-Q plots display whether the data points fall along the reference line, and through a visual representation it allows one to judge if a data set is normally distributed.

Both the one-way ANOVA and the Kruskal-Wallis test are used to measure for significant differences on a continuous dependent variable by a categorical independent variable for two or more groups. For the application of one-way ANOVA, the dependent variable should be normally distributed; hence, normality is checked prior to deciding the most appropriate method for statistical analysis. In the case a data set is not normally distributed, the Kruskal-Wallis test, a nonparametric test, is used when the normality assumption of the one-way ANOVA test are not met. In this study, all variables are tested at a 95% confidence interval (α=0.05).

CHAPTER 4

DATA CHARACTERISTICS

Through the support of industry collaborators and experts, the national data collection process attained responses for a total of 75 projects. These 75 projects were distributed between 25 DBB (33%), 27 CMAR (36%), and 23 DB (31%) projects. The survey was administered over an 11-month period from August 2017 to June 2018. The average survey response time was approximately 30 minutes. Utilities represented 70% of the survey responses, with constructors representing the remaining 30%. Project managers and company executives represented 75% of the respondents, with the other 25% being split amongst construction managers, lead and section engineers, and other senior design and construction project team members. From the utilities respondents, 72% stated that their organization performs in-house engineering and design, and 24% stated that their organization performs in-house construction. While all constructors performed in-house construction and did not perform in-house engineering. Moreover, 67% of DBB projects respondents had an agency in-house design cost for their project, followed by 59% for CMAR, and 57% for DB. The study also evaluated the respondents experience with their chosen delivery method, the total percentage of projects completed using the same delivery method is displayed in Table 1.

Table 1: Total Percentage of Projects Completed using Delivery Methods

	Projects Completed			
Delivery Method	**0 to 5**	**5 to 10**	**10 to 20**	**20+**
DBB (N=24)	8%	-	-	92%
CMAR (N=26)	35%	23%	-	42%
DB (N=21)	48%	38%	5%	9%

The projects obtained through this survey originated from all major regions of the United States and represented a total of 15 US states as seen in Figure 3. About 62% of these projects were water treatment plants facilities, and the remaining 38% were wastewater treatment plant facilities. The capacity of these water and wastewater treatment plant projects ranged from one million to 600 million gallons per day. The range of total project schedule from start to finish varied from one month to 12 years. The total dollar amount of all projects combined was about $4.1 billion. Total project costs ranged from $0.430 million to $438 million. While the average total project contingency of the total contracted total project cost was 6.42% for DBB, 5.94% for CMAR, and 4.55% for DB. This contingency was either shared by the owner and the contractor (e.g.; owner contingency 75% and contractor contingency 25%), or solely allocated as owner contingency. The associated costs for the design completed prior to engaging the constructor as a percentage of the contracted total design cost was highest for DBB at 89%, followed by CMAR at 43.6%, and DB at 9.2%. While the owner's administrative and oversight cost for their project in comparison to the contracted total project cost was highest for DB at 12.5%, followed by DBB at 6.3%, and CMAR at 3.1%.

Moreover, 85% of the projects were constructed on project sites that are on a greenfield or previously undisturbed land, with the remaining 15% accounting for projects that have been constructed on either an existing facility or disturbed land. Nearly 50% of the projects are new construction, 25% are retrofit/expansion, and the remaining 25% are renovation/rehabilitation projects. Additionally, 44% of CMAR projects used separate construction contracts through multiple work packages, followed by 28% for DBB, and only 5% for DB. Furthermore, 40% of the DB projects continued existing facility service during construction, followed by 25% for DBB, and 9% for CMAR.

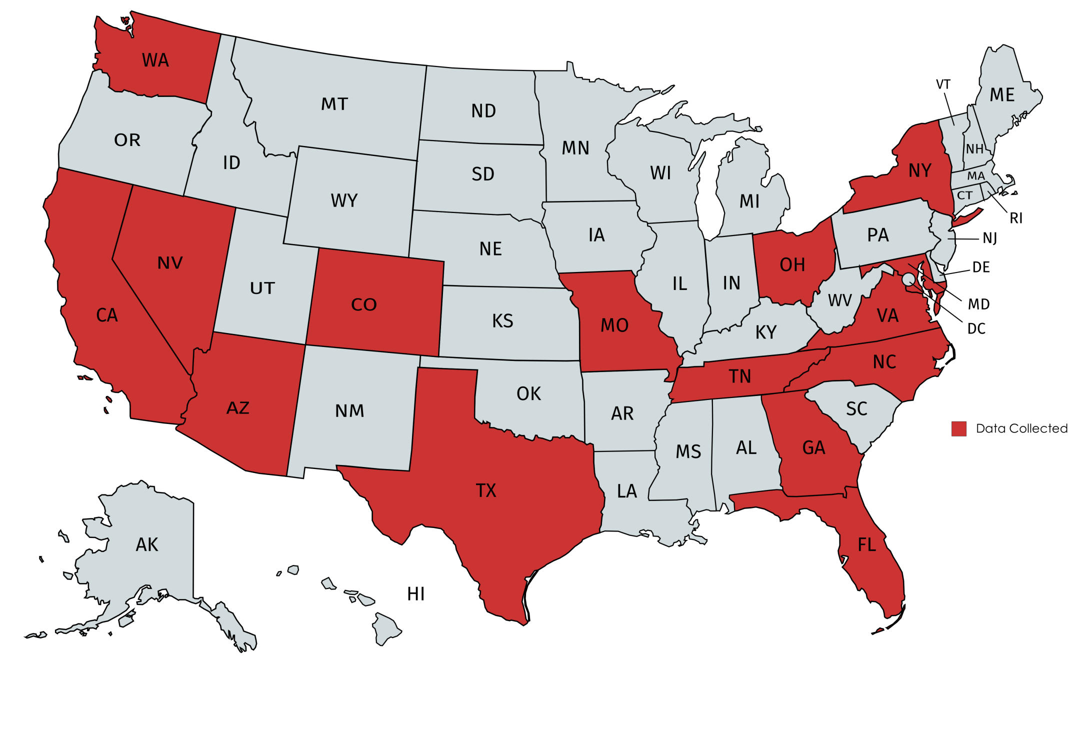

Figure 3: Data Collected Across the United States

CHAPTER 5

FINDINGS ON PROJECT CHARACTERISTICS: AN INDUSTRY STATE OF PRACTICE

The fifth chapter performs a water industry state of practice and displays the various results acquired through the data collection process. These findings are based on different project characteristics that assess: design completion before constructor engagement, procurement process and compensation types, factors for project delivery method selection, project complexity, owner's driving metrics for a successful project, owner/stakeholder experience, owner involvement with delivery method, overall communication, and duration between the request for proposal (RFP) and contract award date. The following subsections provide further detail on the results obtained for these metrics.

5.1 Percent Design Complete Before Engaging the Constructor

Respondents were asked to provide the percentage of design completion before engaging the constructor. This data was plotted using a boxplot as shown in Figure 4. In accordance to the literature, it can be observed from the boxplot that for DBB projects the constructor is typically engaged around 100% design completion, for CMAR the constructor is engaged early on in the design phase, and for DB at an even earlier stage. Table 2 presents brief descriptive statistics on design completion prior to constructor engagement for each of the three delivery methods.

Table 2: Design Completion Prior to Constructor Engagement

Delivery Method	Average (%)	Median (%)	Std. Deviation
DBB (N=24)	97.92	100	10.21
CMAR (N=24)	38.96	30	26.42
DB (N=20)	22	12.5	20.29

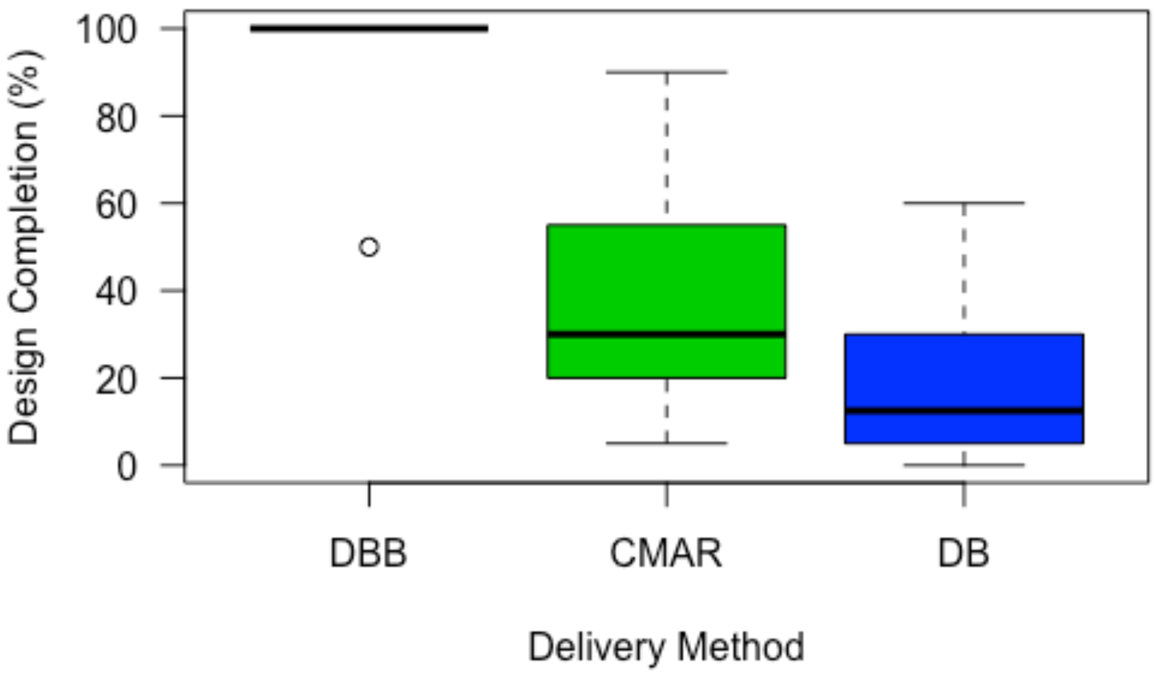

Figure 4: Design Completion Before Constructor Engagement vs. Delivery Method

5.2 Procurement Process

It is important to identify the most appropriate procurement process for the different delivery methods. Hence, the respondents were asked to provide information on their selected procurement process for their projects. Procurement processes included: low bid, best value, qualifications-based, and hybrids/other. Chosen procurement processes for each delivery method, as a percentage out of 100%, is displayed in Figure 5.

As shown in Figure 5, low-bid is the most popular procurement process for DBB in this study, as nearly 70% of DBB projects opted for this process. Moreover, it is important to note that all CMAR and DB projects did not utilize low bid procurement. Additionally, for both CMAR and DB, qualifications-based procurement was clearly favored.

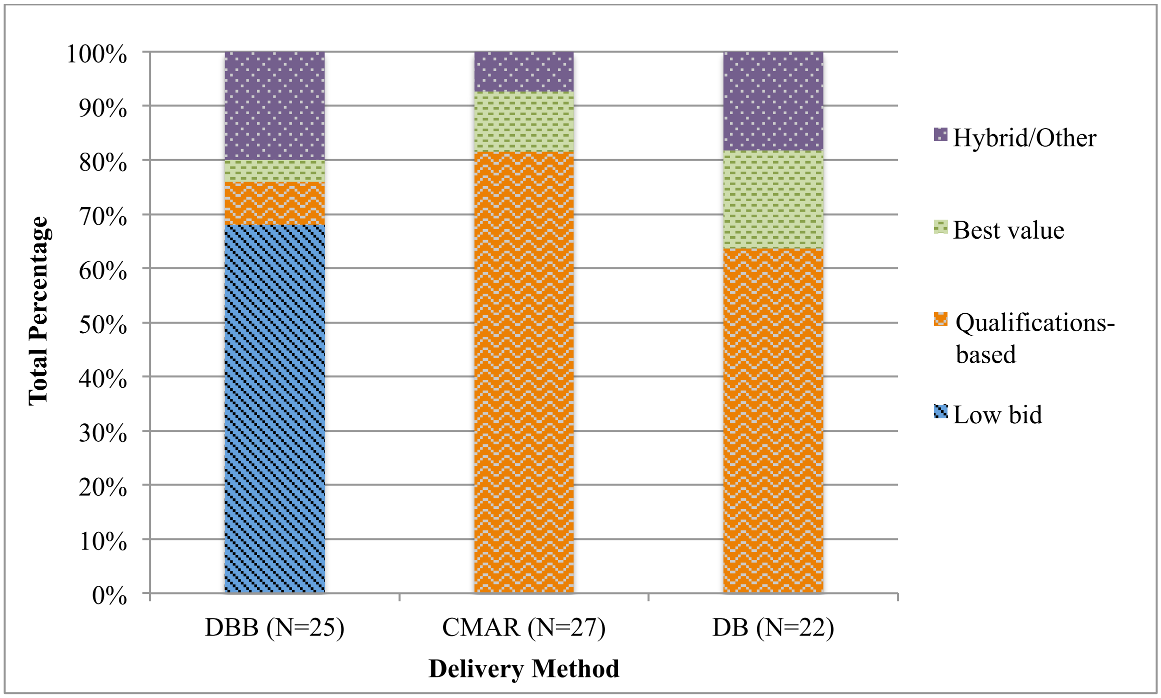

Figure 5: Procurement Process

5.3 Compensation Types

Choosing the appropriate compensation type(s) for a project is an important matter for decision-makers. Selection options in this survey question included: unit price, lump sum, negotiated, GMP, cost plus percentage, cost plus fixed fee, and other. A frequency chart of compensation types used by the different delivery methods is displayed in Figure 6. The respondents used combinations of compensation types, with some utilities choosing a mixture of two or three different types. DBB project owners clearly favored lump sum as their project's compensation type, with 84% DBB projects opting for this form. Cost plus compensation types were present for both CMAR and DB, but were not chosen for any of the obtained DBB projects. Additionally, GMP was the most popular compensation type for the APDM projects in this study, with 85% of CMAR projects and about 60% of DB projects choosing this compensation type. The popularity of GMP as a compensation type is in parallel to the literature, as a study by Bogus et al. (2010) determined that projects that used a GMP performed better in terms of schedule and cost growth, than projects that used a lump sum contract.

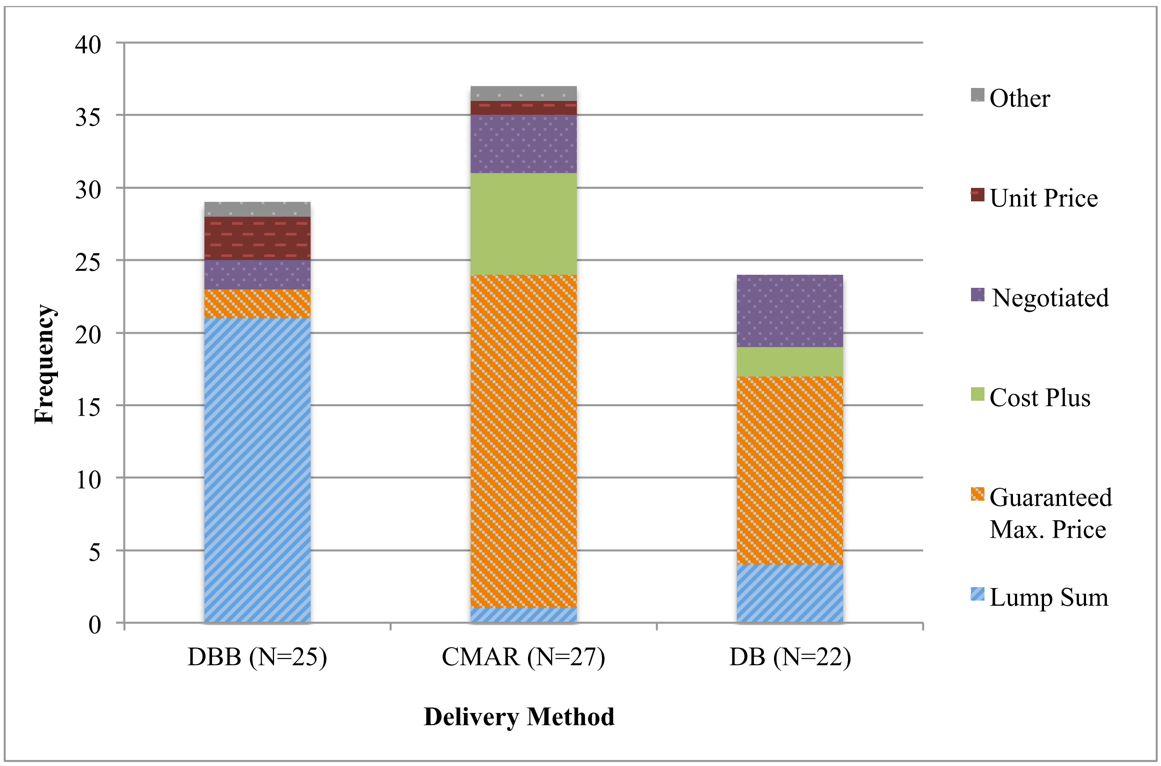

Figure 6: Compensation Type

5.4 Factors for Project Delivery Method Selection

There are several factors that influence project delivery selection and potentially make one method more favorable over another. The selection factors choices were developed by first identifying key selection factors in the literature, and then further developing them during the industry expert workshop. For example, some of the factors included as choices within the survey are: expedited schedule, owner's experience with the delivery method, cost certainty, and project size/cost. The survey respondents were asked to identify if any of these factors were motives for their particular project delivery method selection. The responses were compiled and are illustrated in Figure 7.

Expedited schedule was the selection factor with the highest frequency amongst all three delivery methods, and 97% of the delivery methods that selected this factor were APDM. The second most selected factor was experience with delivery method, and for this case DBB consisted of the majority of these responses. The values obtained in this study are consistent with the literature, which states that DBB is the most common delivery method in the construction industry. This mainly is a result of DBB being the only method that many owners are familiar with. Furthermore, CMAR and DB project decision-makers in this study also selected their respective delivery methods due to factors such as: transferring risk, using innovative technologies, strict regulatory compliances, a need for early cost determination, and requiring phased project delivery.

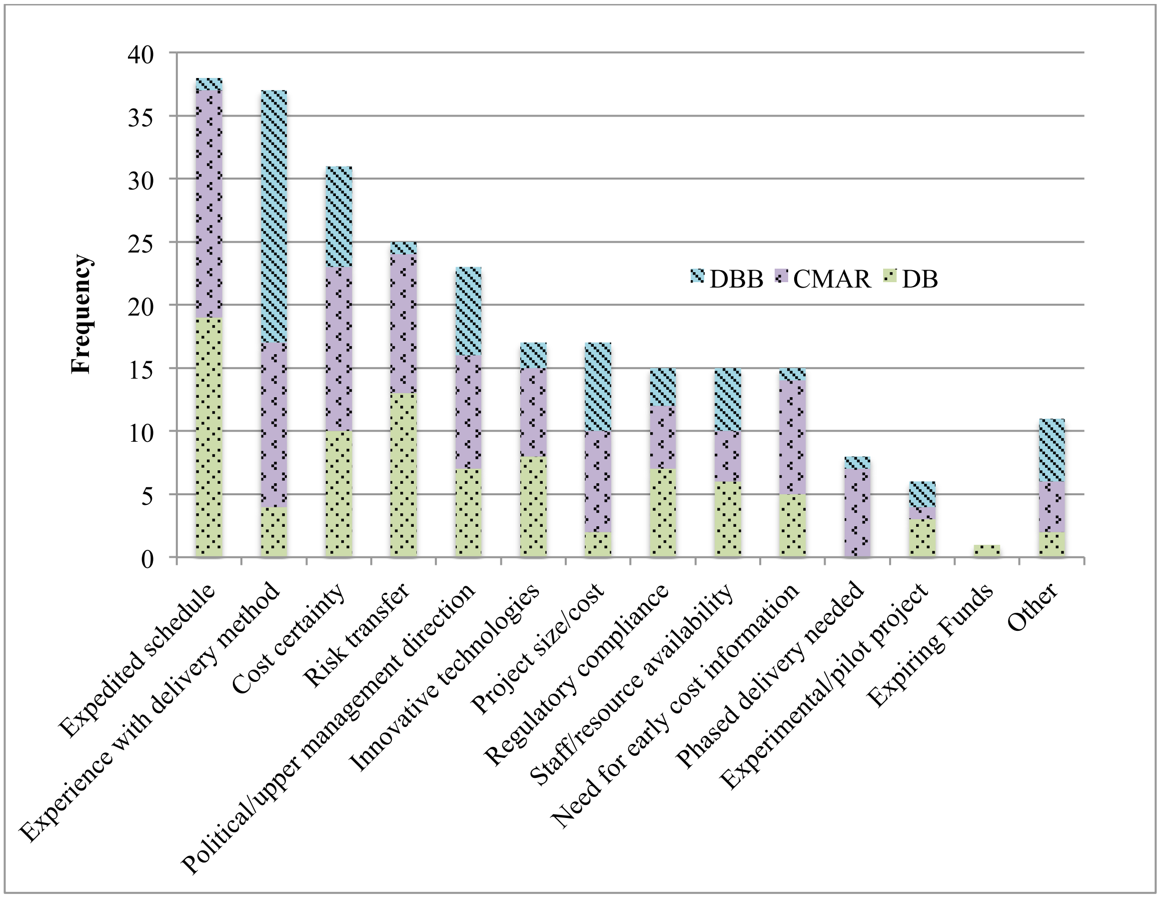

Figure 7: Factors for Project Delivery Method Selection

5.5 Assessing Project Complexity

Respondents were asked to select project complexity factors that were encountered by their respective projects. The study sought to observe if specific complexity factors were more common when undertaking certain delivery methods. The survey selection choices consisted of a diverse range of 16 internal and external factors, which were developed and validated during the industry expert workshop. The compiled results obtained from the survey can be seen in Table 3. Moreover, the complexity factor score (total quantity of complexity factors per project) of each delivery method was collected and illustrated through the use of a box plot, as shown in Figure 8.

Table 3. Observed Complexity Factors

Complexity Factors	DBB (N=25)	CMAR (N=27)	DB (N=22)	Total
Integration to Existing Systems	22	18	11	**51**
Operational Constraints	20	17	13	**50**
Schedule Constraints	12	22	15	**49**
Project Size/Cost	19	18	10	**47**
Constructability Challenges	15	14	11	**40**
Project Footprint	15	15	5	**35**
Permitting	14	6	12	**32**
Plant Capacity	16	7	8	**31**
Aggressive Scheduling	4	12	12	**28**
New Technology	8	9	9	**26**
Environmental Constraints	5	9	9	**23**
Weather Constraints	5	7	7	**19**
Challenging Project Participants	5	3	8	**16**
Project Location	5	6	5	**16**
Market Constraints	1	1	2	**4**
Litigation	1	1	1	**3**

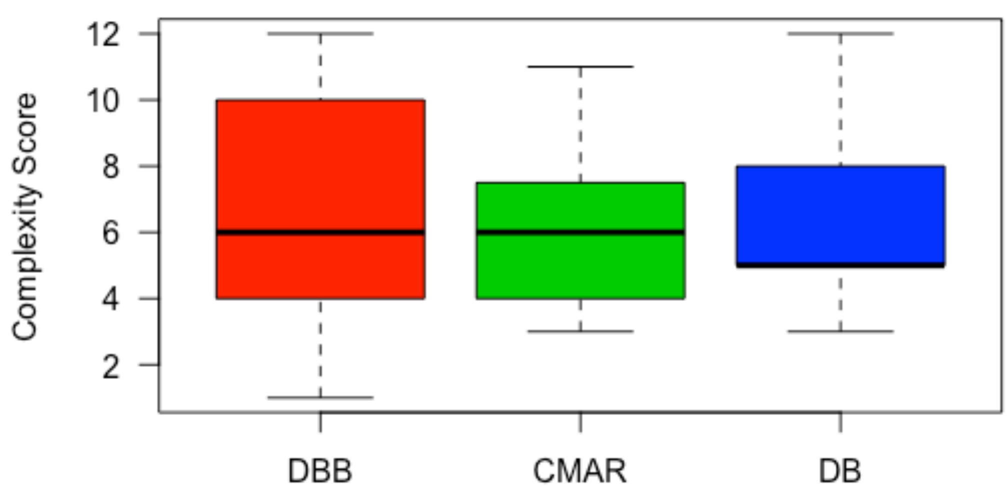

Figure 8. Complexity Score vs. Delivery Method

By observing Table 3, it can be seen that the most common complexity factor for all delivery methods was integration with existing systems. However, this factor was not as predominantly selected by DB projects. In parallel to the literature, this value could show that DB projects assist in fostering an environment that supports a project's integration with existing systems. Schedule constraints and aggressive scheduling were also more common in APDM when compared to DBB. The obtained values are similarly consistent with the literature that claims that APDM are ideal for projects that require aggressive scheduling. Another distinguishable observation is the values obtained for constructability challenges. Under DB, this factor was not as common, when compared to DBB and CMAR. This outcome may be linked to the constructability related-benefits DB offers, due to having the contractor engaged early on in the project delivery process.

The box plot in Figure 8 illustrates that both DBB and CMAR had median complexity scores of 6, while DB had a median of 5. These results show that all three project delivery methods face similar amounts of complexity issues for their respective projects. However, in terms of assessing the medians, DB tends to have a slightly lower complexity score.

5.6 Owner's Driving Metrics for a Successful Project

The survey sought to gauge the respondents by identifying owner's driving metrics for a successful project. The industry expert workshop contributed significantly with this portion of the study, and the experts assisted in developing the survey questions' selection choices that included: owner involvement, project functioning to specifications, early cost certainty, reduced cost, safety, time to completion, and several more. The results of the 75 responses were compiled and are displayed in Figure 9.

Driving metrics for success that were uniformly selected by respondents across projects of all three delivery methods include: owner involvement, project functioning to specifications, maintainability, meeting lifecycle expectations, scope matching owners expectations, and regulatory compliances. Metrics that were predominantly selected from CMAR projects consist of: early cost certainty, time to completion, and reduced costs. There were no driving metrics that were particularly dominant for DB projects.

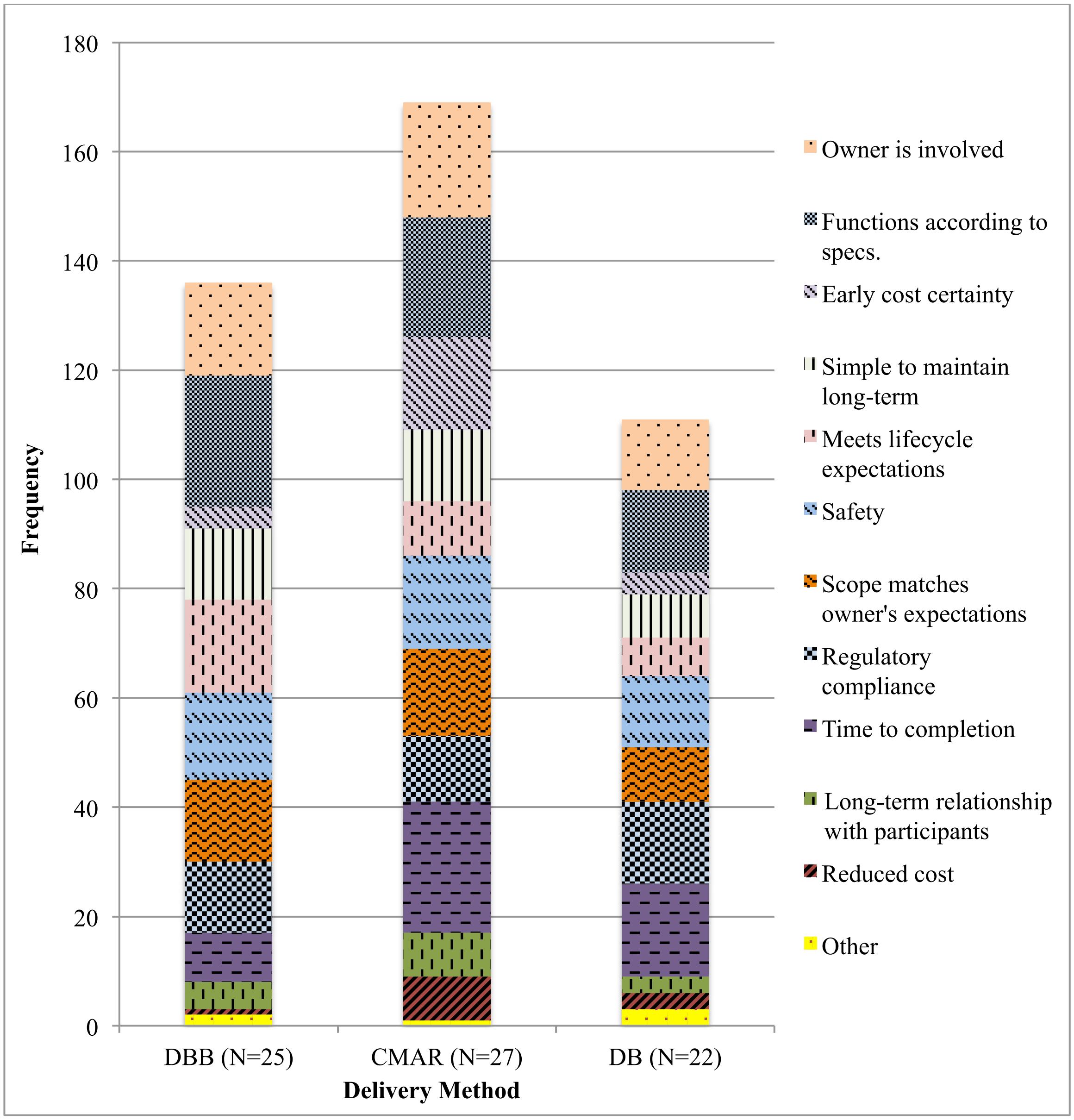

Figure 9: Owner's Driving Metrics for a Successful Project

5.7 Owner Experience, Involvement, and Overall Communication

A 5-point Likert scale was used to measure respondents' opinions on certain characteristics related to the project delivery method chosen. Respondents were asked to share their view of the owner's, constructor's, and designer's experience with their chosen delivery method. With 1 point representing "no or few previous projects" and 5 representing "having many previous projects." Owner's involvement in design and construction was also evaluated, with 1 representing "no or little involvement" and 5 representing "significant involvement." Finally, the respondent's perception of overall stakeholder communication in their project was measured, with 1 representing "no or little communication" and 5 represents "significant communication."

The average score for each performance metric was computed and tested for statistical significance. First, the data was tested for normality using a Q-Q plot, which resulted in confirming that the data is not normally distributed. The next step consisted of testing for statistical significance by using the Kruskal-Wallis test. The test resulted in *p*-values less than 0.05 for owners, constructors, and designers experience, as shown in Table 4. It can be inferred from Table 4 that owners who opt for APDM are far less experienced with the selected delivery method, as CMAR and DB have average owner's experience scores of 2.89 and 2.7 respectively; compared to DBB projects where the average owner's experience score is 4.92 out of 5. That is also the case for constructor's experience with the delivery method, which follows the same trend. However, for designer's experience the average score was greater than 4 for all three methods, implying that designers may be more experienced with APDM delivering projects in comparison to constructors and owners.

Table 4: Average Value and *p*-value for Stakeholder Experience

Delivery Method	Owner Experience	Constructor Experience	Designer Experience
DBB	4.92	4.96	4.84
CMAR	2.89	3.85	4.19
DB	2.70	4.17	4.09
***p*-value**	0.000*	0.000*	0.002*

*Statistical significance obtained when *p*-value <0.05

The same statistical analysis rigor was used for assessing owner involvement in design, construction, and overall stakeholder communication as seen in Table 5. The average score for owner involvement in design and construction is also consistent with the literature, as DB owners are expected to be less involved in the design and construction when compared to DBB and CMAR. Moreover, overall stakeholder communication had an average score of about 4 across the delivery methods; potentially implying that stakeholder communication is not a major concern for any specific delivery method. Likewise, the average owner overall satisfaction was greater than 4 points across all 3 methods, implying that all methods could potentially lead to a successful project. This is not in line to the results obtained by Shrestha et al. (2014), in which their study stated that APDM is superior to DBB in terms of overall project satisfaction and communication for water and wastewater projects.

Table 5: Average Value and *p*-value for Owner Involvement in Design, Construction, and Overall Stakeholder Communication

Delivery Method	Owner Involvement in Design	Owner Involvement in Construction	Overall Communication
DBB	4.56	4.04	4.00
CMAR	4.44	4.11	3.96
DB	3.86	3.77	4.05
p-value	0.055	0.607	0.972

*Statistical significance obtained when *p*-value <0.05

5.8 Duration between RFP and Contract Award Date

The duration between the RFP solicitation and the contract award date was examined across the delivery methods. The study aimed to see if there are any observable differences between the delivery methods. The results were complied and are presented in Figure 10. By observing Figure 10, it can be inferred that there were no noteworthy variations between the delivery methods in terms of duration between RFP and contract award date.

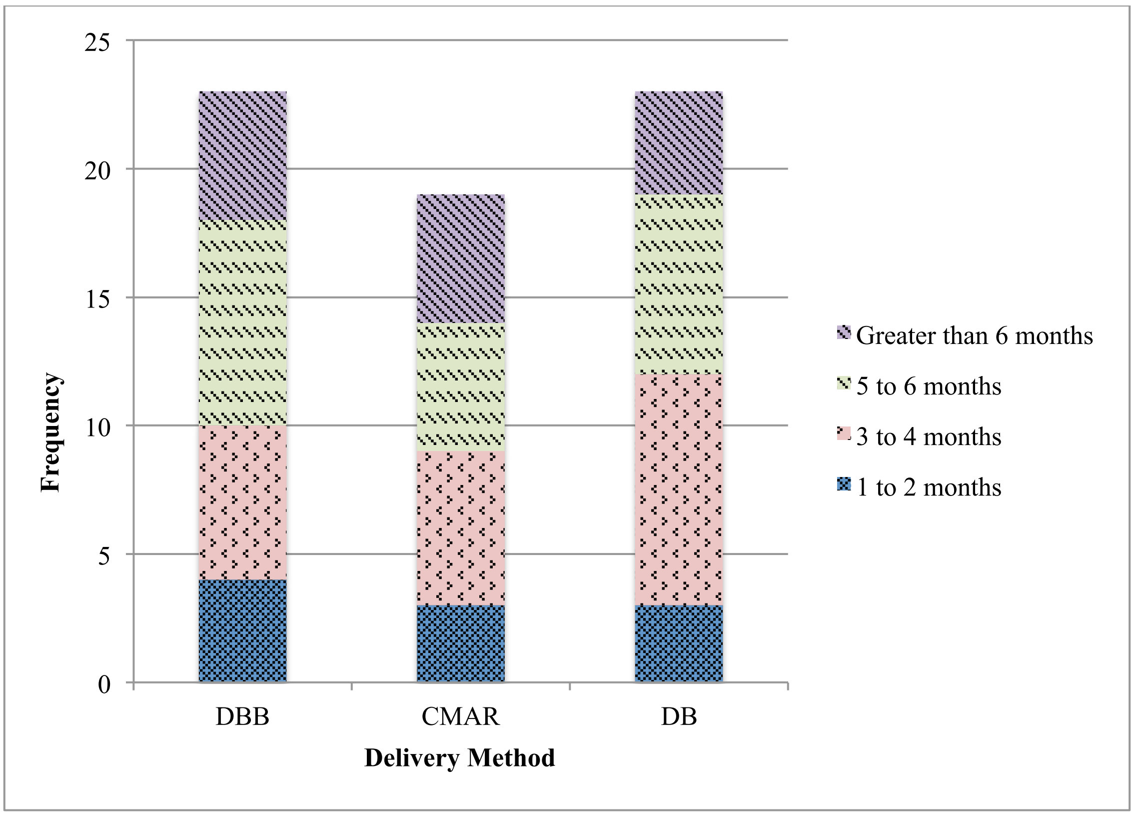

Figure 10: Duration between RFP Solicitation and Contract Award Date

CHAPTER 6

PROJECT PERFORMANCE RESULTS

This chapter analyzes the different project performance metrics of this study and performs various statistical analyses. This includes cost performance metrics such as: design cost growth (DCG), construction cost growth (CCG), total cost growth (TCG), and unit cost. Moreover, schedule performance metrics include: design schedule growth, construction schedule growth, total schedule growth, and speed. Other performance metrics are also assessed, such as: intensity, scope changes, warranty issues, and latent defects. Finally, other metrics that are examined also include: investigating unresolved claims, the ability for project's to meet specifications, maintenance requirements, meeting owners life cycle costs expectations, room for innovation, appropriateness of delivery method, and finally the reuse of the delivery method on future projects.

6.1 Cost Performance Metrics

The cost performance metrics that are assessed include DCG, CCG, TCG, and unit cost. The following subsections present the equations utilized to calculate the metrics, the data distribution, and results of the statistical analysis.

6.1.1. Design Cost Growth

DCG compares the design cost certainty of a project. In order to calculate DCG, the actual design cost and the contracted design cost are required as seen in Equation 1.

$$DCG(\%) = \frac{(Actual\ Design\ Cost - Contracted\ Design\ Cost)}{Contracted\ Design\ Cost} \times 100 \qquad (1)$$

Data Distribution

Boxplots are used to visualize the data distribution of the 50 DCG data points obtained and assist in identifying data outliers, which may need to be removed before completing statistical analysis. Referring to the DCG boxplot shown in Figure 11, it is observed that DBB contains a much wider distribution compared to the two other delivery methods. It can also be seen that CMAR and DB have data points below zero, meaning that for those particular projects, the actual design cost was below the original contracted value. Despite clear visual differences across the data distribution in the boxplots amongst the delivery methods, the median DCG for all three delivery methods was 0%. DBB had the largest average DCG at 13.76%, followed by CMAR at 10.46%, and DB at 3.91%. When compared to the literature, these results are consistent to the findings of Konchar and Sanvido (1998), which revealed that APDM performed better than DBB in terms of cost growth.

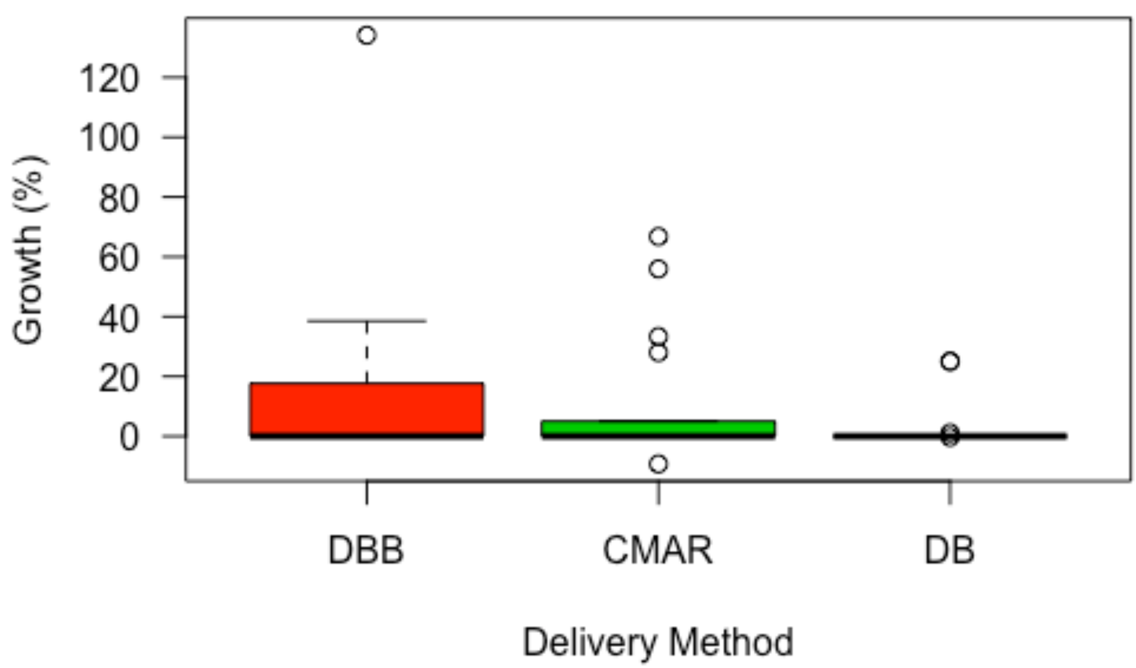

Figure 11: Design Cost Growth vs. Delivery Method

Testing for Statistical Significance

In total, 6 outliers were observed in the DCG data set and removed from the analysis using Tukey's outlier detection method. This brought down the total sample size from 50 to 44. After developing the Q-Q plot and judging that the DCG data was not normally distributed, the Kruskal-Wallis test was used to analyze if there are any significant differences. The Kruskal-Wallis test resulted in a p-value of 0.15, which is greater than the α-value of 0.05, meaning that the differences between the delivery methods are not statistically significant.

6.1.2 Construction Cost Growth

CCG similarly to design cost growth also compares cost certainty. To obtain the CCG of a project, the actual construction cost and the contracted construction cost are needed, as seen in Equation 2.

$$CGW(\%) = \frac{(Actual\ Construction\ Cost - Contracted\ Construction\ Cost)}{Contracted\ Construction\ Cost} \times 100 \qquad (2)$$

Data Distribution

Data was obtained from 54 projects and plotted using a boxplot, as illustrated in Figure 12. It can be observed from Figure 12 that there are significant outliers for CMAR. The median CCG was 5.74% for DBB, 1.26% for DB, and 1.07% for CMAR. DBB had the largest average CCG at 5.19%, followed by CMAR at 4.99%, and DB at 2.31%. These findings also follow that same trend revealed in the study by Konchar and Sanvido (1998) and other literature reviewed which state that DB outperforms CMAR in terms of cost growth, and CMAR in turn outperforms DBB.

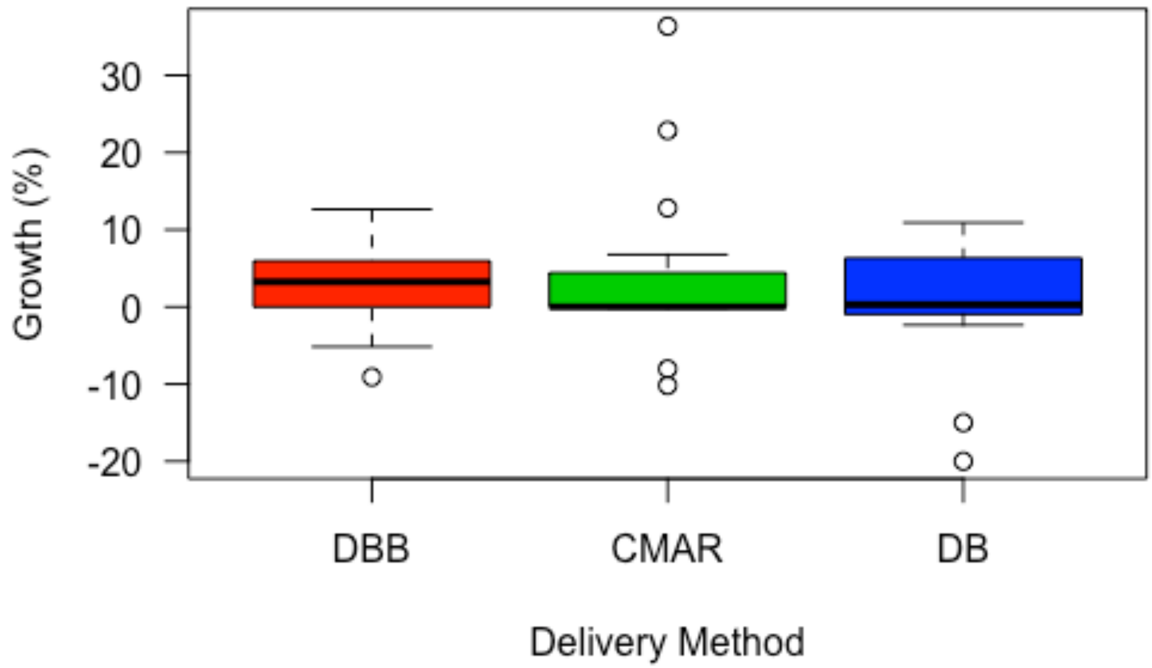

Figure 12: Construction Cost Growth vs. Delivery Method

Testing for Statistical Significance

After using Tukey's outlier detection method, 8 outliers were observed in the CCG data set and removed from the analysis. This brought down the sample size from 54 to 46. A Q-Q plot illustrated that CCG data was not normally distributed; hence, the Kruskal-Wallis test was used. The result of this test also showed no significant differences between the delivery methods, and led to a *p*-value of 0.44.

6.1.3 Total Cost Growth

To obtain the TCG of a project, the actual total cost and the contracted total costs are required, as seen in Equation 3.

$$TCG(\%) = \frac{(Actual\ Total\ Cost - Contracted\ Total\ Cost)}{Contracted\ Total\ Cost} \times 100 \qquad (3)$$

Data Distribution

Total project cost growth for 53 projects were obtained; a visual presentation of the data is shown in Figure 13. All three delivery method contained projects that finished both under and above budget. The median TCG for DBB was 3.76%, followed by 0.72% for DB, and 0% for CMAR. Moreover, DBB had the largest TCG average at 3.76%, followed by CMAR at 3.36%, and DB at a 2.37%. These results were also coherent to the literature, as a study by Francom (2015) concluded that CMAR outperformed DBB in terms of TCG and another study by Shane et al. (2013) also indicated that DB outperformed DBB.

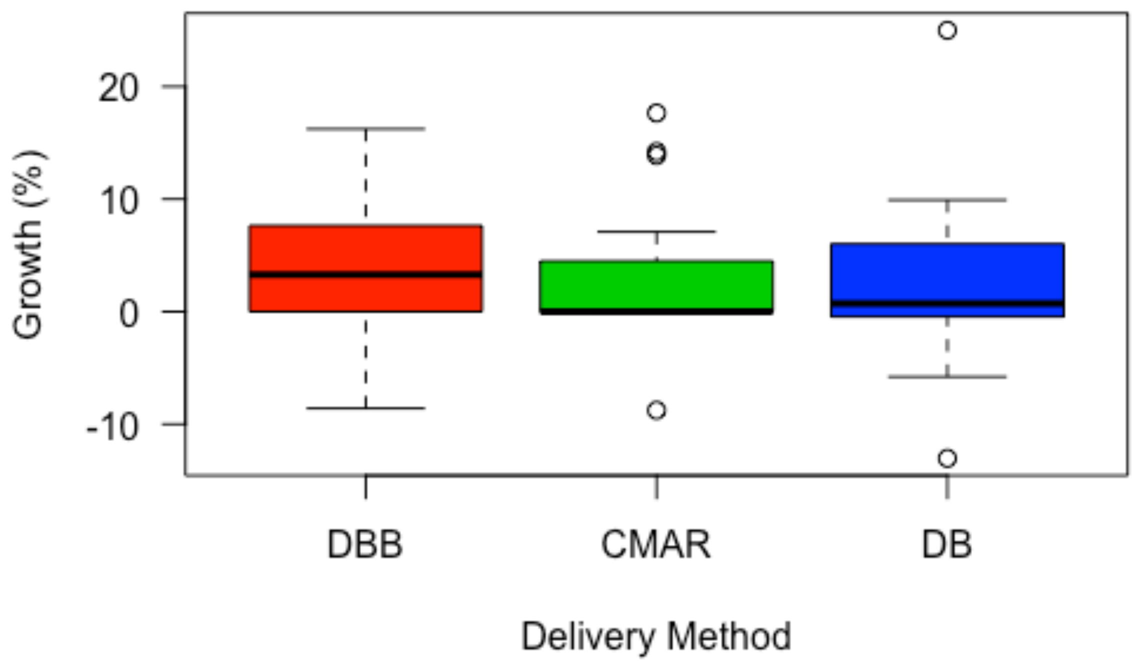

Figure 13: Total Cost Growth vs. Delivery Method

Testing for Statistical Significance

By using Tukey's outlier detection method 4 outliers were removed from the analysis. This brought down the sample size from 53 to 49. A Q-Q plot revealed that the TCG data set was not normally distributed; hence, the Kruskal-Wallis test was used. The result of this test also concluded that there were no significant differences between the delivery methods, leading to a p-value of 0.465.

6.1.4 Unit Cost

Unit cost measures a project's actual total cost over its increased plant capacity as seen in Equation 4. Unit cost is capable of measuring the overall cost of a single million gallon for a treatment plant project. Increased capacity is calculated as the difference between the new plant capacity and the original plant capacity in million gallons. In the case the project is a new construction type of project, then the original plant capacity is considered to be 0 million gallons.

$$Unit\ Cost = \frac{Total\ Project\ Cost\ \ (million\ USD)}{Increased\ Plant\ Capacity\ (million\ gallons)} \tag{4}$$

Data Distribution

In total, 21 unit cost data points were obtained and plotted using a boxplot, as shown in Figure 14. Referring to Figure 14, CMAR had the widest data distribution between the methods, and DBB and DB are similar in terms of data distribution. The median unit cost was highest for CMAR at 6.40, followed by DBB at 3.09, and finally DB at 1.81. The average unit cost was also highest for CMAR at 9.93, followed by DB at 7.16, and DBB at 6.62.

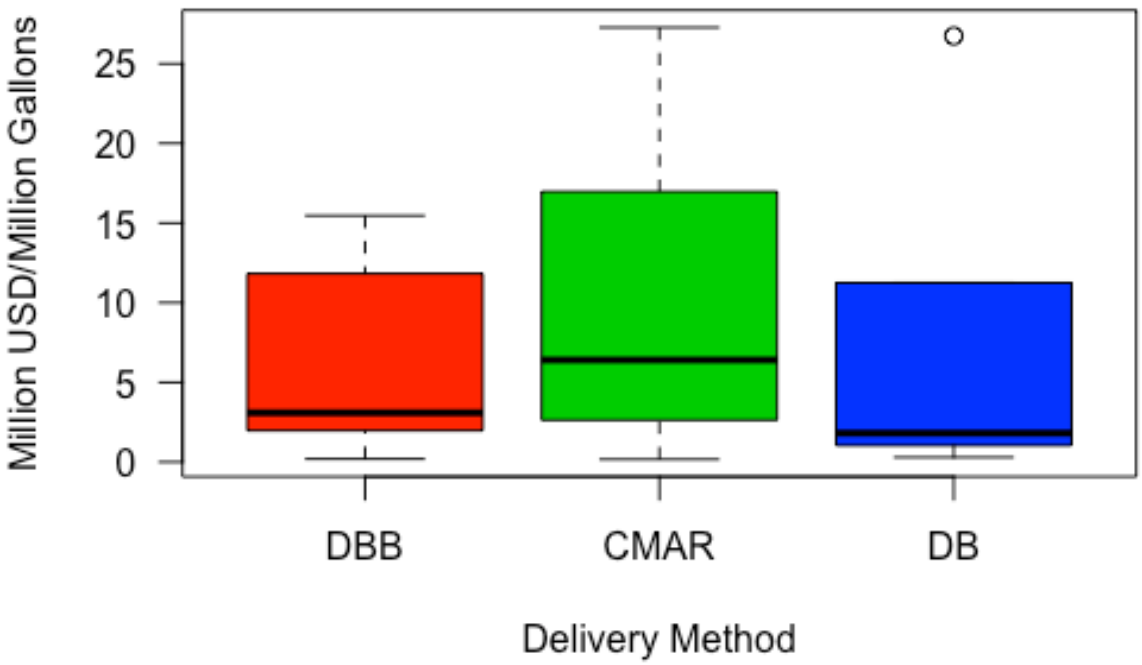

Figure 14: Unit Cost vs. Delivery Method

Testing for Statistical Significance

After applying Tukey's method for outlier removal, it was observed that there were no outliers in this data set. Thus, the 21 data points were tested for normality using a Q-Q plot. The results showed that the sample is not normally distributed; therefore, a Kruskal-Wallis test was used to test for statistical significance. This test resulted in a *p*-value of 0.632, meaning that the differences between the delivery methods are not statistically significant.

6.2 Schedule Performance Metrics

Schedule performance metrics are also examined and include design schedule growth, construction, schedule growth, total schedule growth, and speed. The following subsections display the equations utilized to calculate these metrics, their data distribution, and statistical analysis results.

6.2.1 Design Schedule Growth

Design schedule growth compares the variance of the project schedule, by comparing the actual deign phase to the planned design phase as a percentage.

Data Distribution

A boxplot representing the design schedule growth data points obtained from 33 projects can be seen in Figure 15. By studying this figure, it can be inferred that DBB has the widest spread data and that the majority of projects for CMAR and DB had little or no design schedule growth. The median design schedule growth for all three delivery methods was the same at 0%. However, DBB had an average design schedule growth of 7.52%, while both CMAR and DB had negative design schedule growth at -1.61% and -1.43% respectively. The results obtained for schedule growth is similar to that obtained in the literature by Bogus et al. (2010) and Shane et al. (2013), who also found that DB was superior to DBB in terms of schedule growth. Additionally, the results are similar to the study by Francom (2015), which stated that CMAR is superior to DBB in terms of schedule growth.

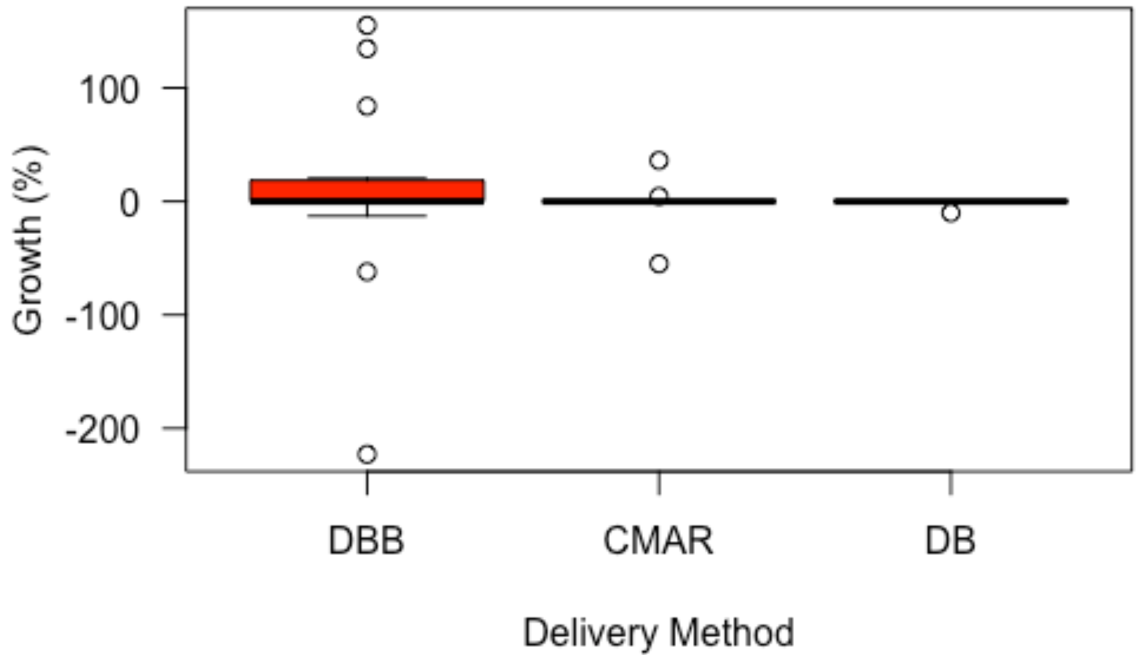

Figure 15: Design Schedule Growth vs. Delivery Method

Testing for Statistical Significance

The original sample size of 33 was reduced to 25 after the application of Tukey's outlier detection method. Using a Q-Q plot, the data set was shown to be not normally distributed; hence, the Kruskal-Wallis test was used to test for statistical significance. The test resulted in a *p*-value of 0.311, implying that the differences are not statistically significant.

6.2.2 Construction Schedule Growth

Similarly to design schedule growth, construction schedule growth compares the variance of project schedule of the actual construction phase to the planned construction phase as a percentage.

Data Distribution

A total of 44 construction schedule growth data points were obtained and a boxplot depicting the data is shown in Figure 16. All three delivery methods had both positive and negative growth, and contained significant outliers in their data sets. The median design schedule growth was greatest for DBB at 10.09%, followed by CMAR at 5.44%, and DB at 0.73%. Moreover, the average construction schedule growth was greatest for DB at 27.75%, then DBB at 14.71%, and CMAR at 9.43%. However, one specific data point had inflated the average growth for DB significantly; which is the only outlier for DB, as seen in the boxplot in Figure 16. If that particular outlier were to be removed, the average construction schedule growth for DB would be reduced to 13.9%.

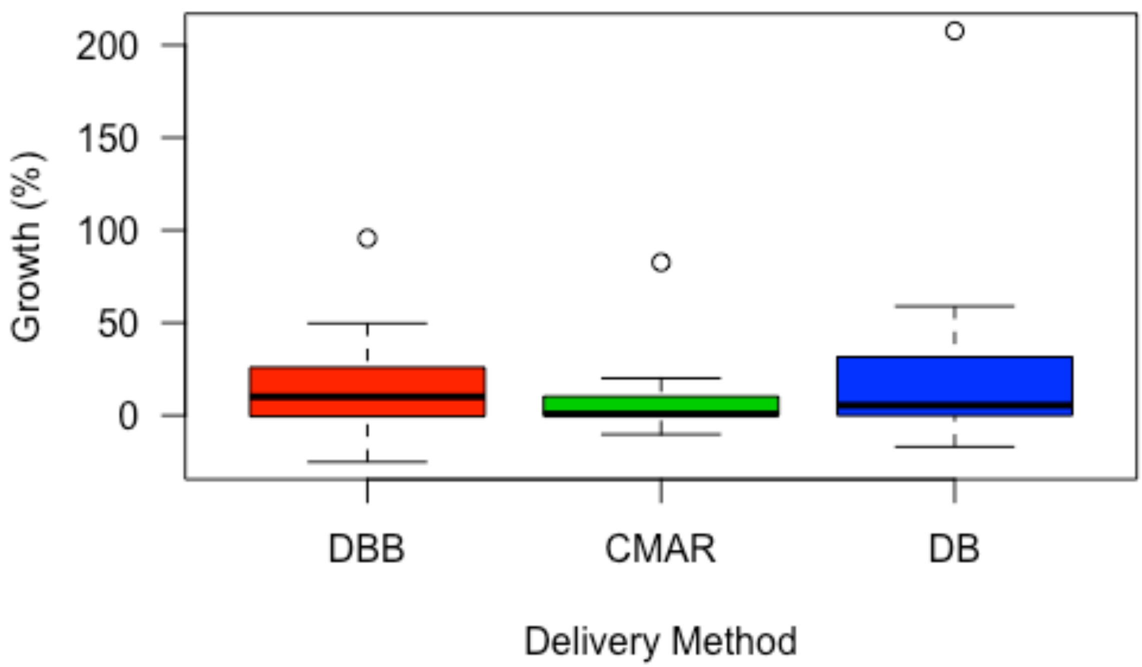

Figure 16. Construction Schedule Growth vs. Delivery Method

Testing for Statistical Significance

Tukey's outlier detection method reduced the sample size from 44 to 41. The Q-Q plot illustrated that the data is not normally distributed; thus, the Kruskal-Wallis test was used to test for statistical significance and resulted in a *p*-value of 0.651. These results indicated that the differences are not statistically significant

6.2.3 Total Schedule Growth

Total schedule growth is calculated by obtaining the variance of schedule of the actual design initiation to the actual substantial completion date over the variance of the planned design initiation to the planned substantial completion date, also as a percentage.

Data Distribution

Overall, respondents were able to provide data for 43 projects in terms of total schedule growth. A boxplot representing the obtained data is shown in Figure 17. The boxplot indicates that all three project delivery methods have both positive and negative total schedule growth. Moreover, the median total schedule growth for all three delivery method was at 0%. While the average total schedule growth was greatest for DB at 8.05%, followed by CMAR at 4.96%, and DBB had the lowest total schedule growth at 2.72%. These results do not follow the general trend of the findings in the literature on schedule growth performance of APDM vs. DBB. However, the obtained results are similar to a study by Bingham (2014), where DBB also outperformed CMAR and DB in terms of total schedule growth.

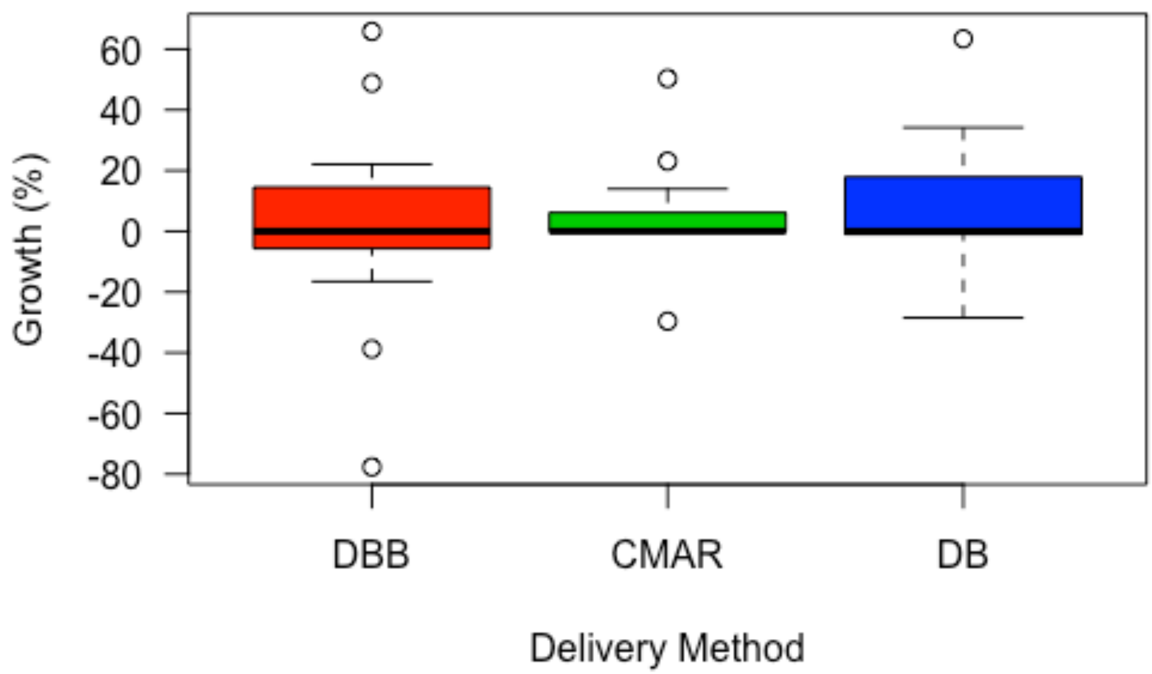

Figure 17: Total Schedule Growth vs. Delivery Method

Testing for Statistical Significance

The sample size was reduced from 43 to 37 by the removal of the outliers using Tukey's outlier detection method. The Q-Q plot illustrated that data set was also not normally disturbed, therefore the Kruskal-Wallis test was used and a *p*-value of 0.94 was obtained.

6.2.4 Speed

Speed is a performance metric that was used in this study and measures a project's increased plant capacity over its total project duration, as seen in Equation 5. Increased plant capacity, as discussed in an earlier chapter of this study, is measured as the difference between final plant capacity and original capacity. Total project duration is measured as the difference between the actual substantial completion date and the actual design contract start date.

$$Speed = \frac{Increased\ Plant\ Capacity\ (million\ gallons)}{Total\ Project\ Duration\ (days)} \quad (5)$$

Data Distribution

Speed metric data points were obtained for 24 projects and their respective boxplot is shown in Figure 18. The boxplot clearly shows that DB contained the widest dispersed data, when compared to DBB and CMAR. The largest median value was for DB at 0.0627, followed by DBB at 0.0097, and CMAR at 0.0095. The average speed for the delivery methods were recorded at 0.1022 for DB, 0.0132 for CMAR, and 0.0103 for DBB. The results obtained in this study followed the same trend observed in the literature, such as the study completed by Konchar and Sanvido (1998), which also revealed that DB is superior to CMAR and DBB in terms of project speed.

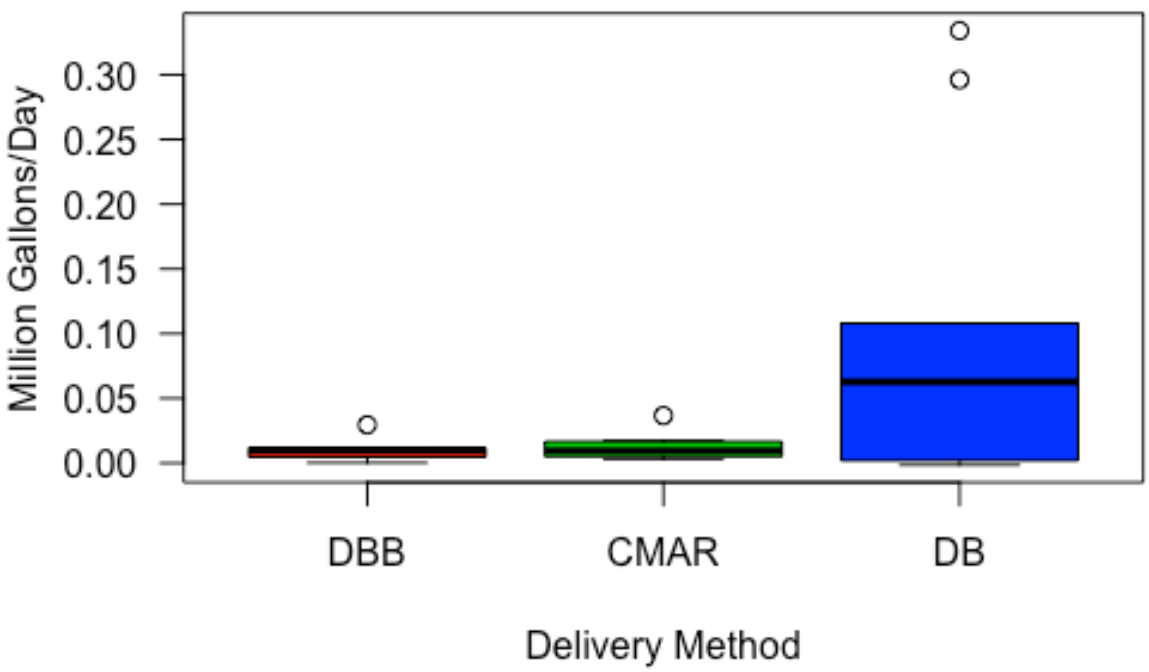

Figure 18: Speed vs. Delivery Method

Testing for Statistical Significance

Tukey's outlier model reduced the sample size from 25 data points to 22. The 22 points were then tested for normality using a Q-Q plot, and the plot revealed that the sample is normally distributed, as the majority of the data points lied on the reference line. As a result, a one-way ANOVA test was used to test for statistical significance. The test resulted in a *p*-value of 0.02, meaning that the differences were statistically significant.

6.3 Other Performance Metrics

The next section evaluates other performance metrics and include intensity, scope changes, warranty issues, latent defects, unresolved claims, project meeting specifications, maintenance requirements, meeting owners life cycle costs expectations, room for innovation, appropriateness of delivery method, and finally reusing the delivery method on future projects. This section also displays the formulas used, data distribution, statistical analysis, and other forms of quantitative measures used.

6.3.1 Intensity

Intensity is a hybrid schedule and cost performance metric that is measured by assessing a project's total cost in million USD over its total duration in months as seen in Equation 6.

$$Intensity = \frac{Total\ Project\ Cost\ (million\ USD)}{Total\ Project\ Duration\ (months)} \tag{6}$$

Data Distribution

Data relating to intensity was obtained from 47 projects and plotted using a boxplot, as illustrated in Figure 19. From the boxplot, it can be inferred that DB had the widest dispersed data and the largest median value. The largest median value was for DB at

1.448, followed by CMAR at 0.676, and DBB at 0.502. The average intensity followed the same trend, with DB at 2.065, CMAR at 1.289, and DBB at 1.164. The observed findings are in parallel to the results obtained by Bogus et al. (2010), where DB was also superior to DBB in terms of intensity.

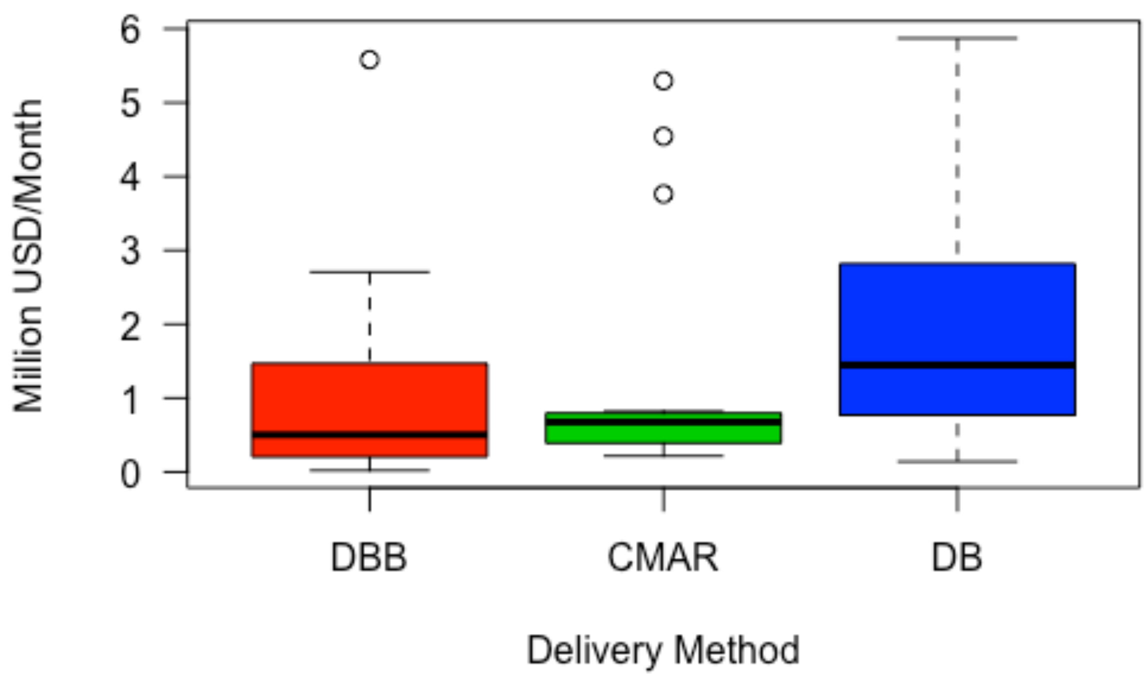

Figure 19: Intensity vs. Delivery Method

Testing for Statistical Significance

Using Tukey's detection method for outlier removal the sample size was reduced from 47 to 43 data points. A Q-Q plot was then developed and illustrated that the data was not normally disturbed. The Kruskal-Wallis test was used to test for significance and a *p*-value of 0.008 was obtained. This value signifies that the differences are statically significant, as the *p*-value acquired is <0.05.

6.3.2 Scope Changes and Warranty and Latent Defects

Scope changes during the project timeline are a major concern to project owners, therefore this research study assessed the frequency of scope changes across the obtained projects. The results were collected from the 75 responses and are illustrated in Figure 20. All projects across the three delivery methods contain fewer projects without major scope changes than ones with major scope changes. However, CMAR and DBB had higher amount of major scope changes compared to DB.

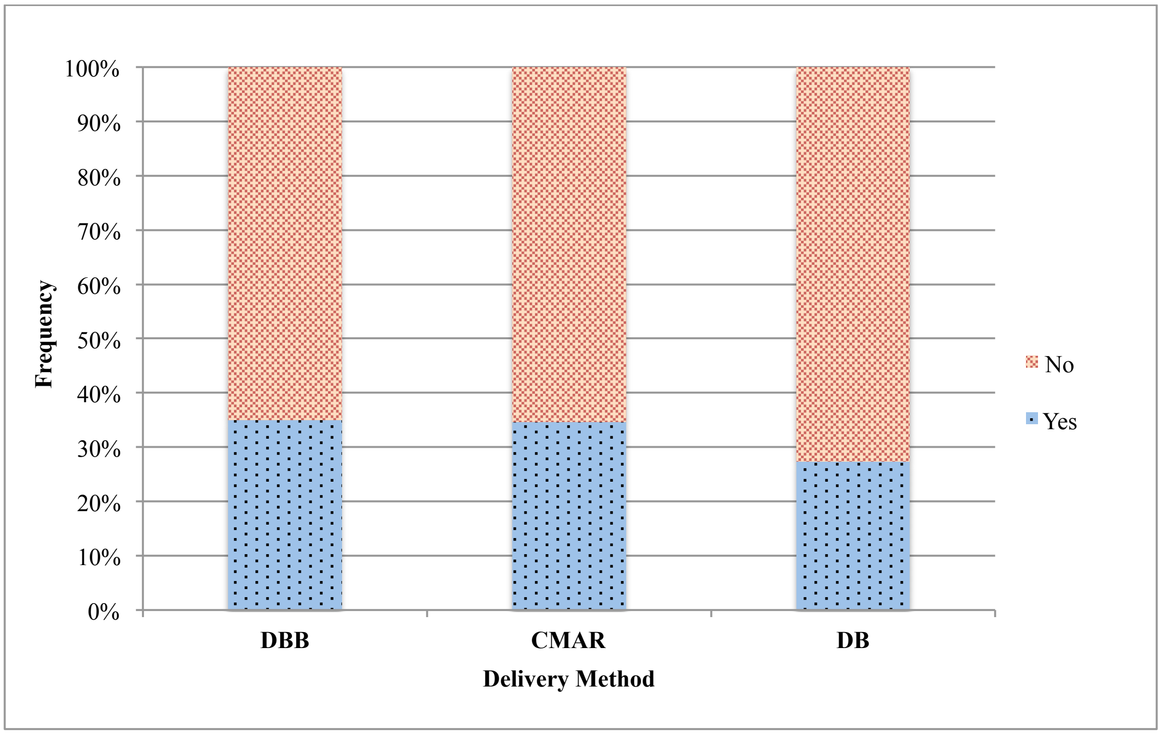

Figure 20: Major Scope Changes

The survey also measured total changes for each project as a total percentage out of 100%, and grouped these sources for project related changes into four categories: 1. Owner-driven and related to added/detailed scope or quality, 2. Contractor-driven and related to added/deleted scope or quality, 3. Due to design issues, deficiencies, errors, and omissions, and 4. Due to unforeseen or external conditions. The respective boxplots for each of the four categories can be seen in Figure 21. In terms of owner-driven changes, DB had the highest average percentage of changes at 71.45%, followed by CMAR at 53.1%, and DBB at 45.9%. For contractor-driven changes, CMAR had the highest average percentage at 18.19%, trailed by DBB at 11.05%, and DB at 9.91%. For design-issues, deficiencies, errors and omissions, DBB had the highest average percentage at 15.3%, with CMAR at 10.57%, and DB at 7.82%. Finally, for changes due to unforeseen or external conditions, DBB had the highest percentage at 22.9%, followed by CMAR at 14.48%, and DB at 10.82%. These numbers are in line with the literature, particularly in the third and fourth category, for which DBB had the highest changes due to design-issues, deficiencies, errors and omissions, and for changes due to unforeseen or external conditions. This is may be due to the lack of a collaborative environment in DBB, especially during the early project development and design stages.

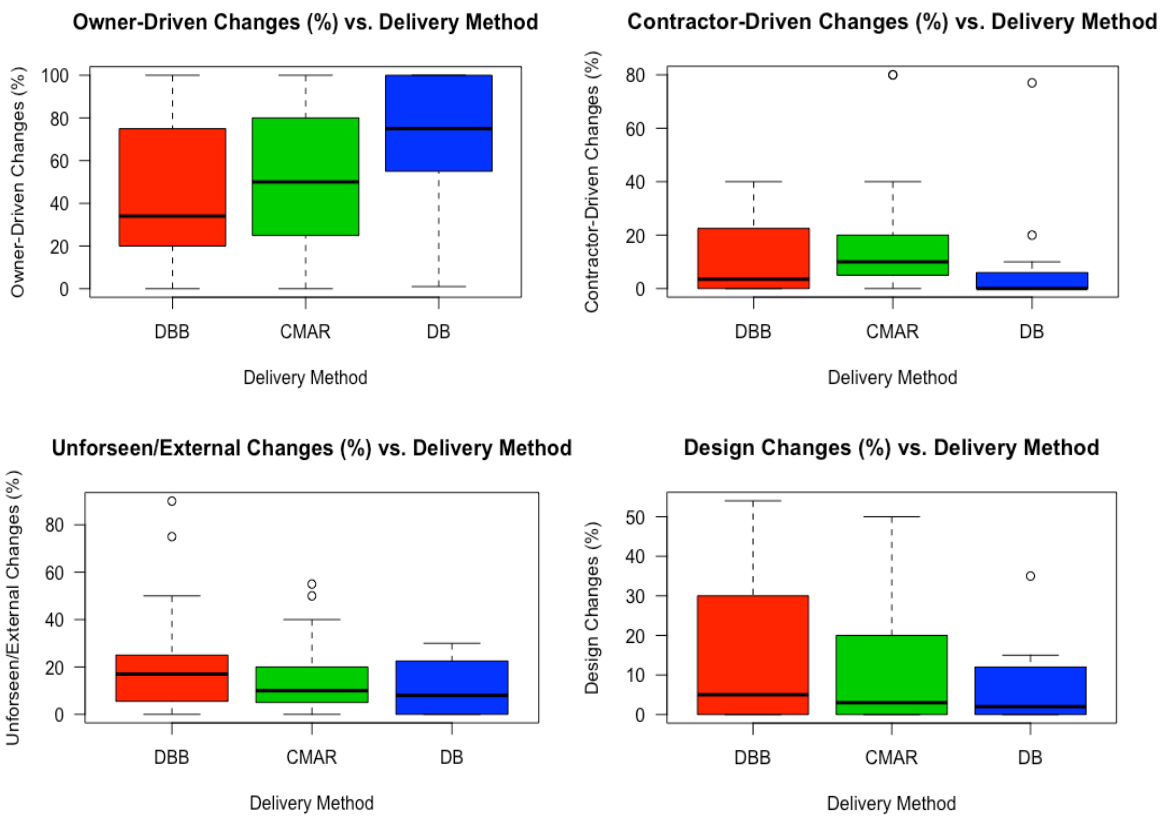

Figure 21: Changes vs. Delivery Method

This study also aimed to observe the frequency of warranty and latent defects after project completion for different delivery methods. This metric was used to attempt to gauge the overall quality of a project. A selection of potential warranty and latent defects were developed for the respondents to select from and included: inadequate materials, under performance of facility, leaks, equipment failure, and other issues. The results were compiled and are presented in Figure 22. Respondents were also asked if their projects were still under the contractor's warranty period, of which 54% of DBB, 38% of CMAR, and 29% of DB projects were still under warranty.

By observing Figure 22, it can be deduced that DBB projects have the highest frequency of warranty issues and latent defects, followed by CMAR, and then DB. Based on the literature, these obtained results for DBB projects, could be due the lack of stakeholder collaboration and involvement of the operations team during design and construction phase.

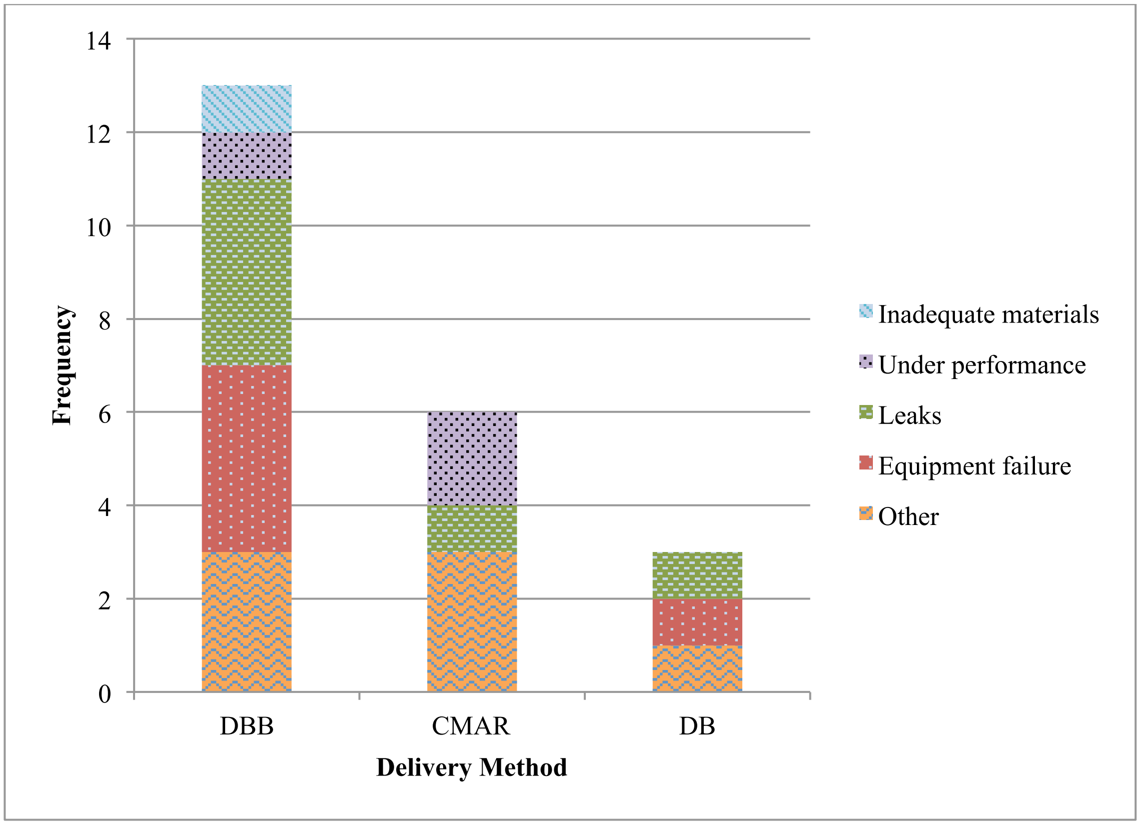

Figure 22: Warranty and Latent Defects

6.3.3 Unresolved Claims, Project Meeting Specifications, and Maintenance Requirements

In terms of unresolved claims between stakeholders after final acceptance, results revealed that 100% of DB respondents stated that there were no unresolved claims after the completion of their projects, compared to 96% for DBB and CMAR. In general, all three delivery methods performed well in this category and resolved all claims before project completion.

This research study also investigated whether the completed projects functioned according to their specifications, which also included reliability. To which 100% of DBB, CMAR, and DB respondents agreed that they did. This result could imply that all three delivery methods can ultimately lead to a successful project that meets owner's project specifications and requirements.

Another metric that was evaluated to assess a projects quality, inquired if the completed project required more than the reasonable amount of maintenance. For this metric, 100% of DBB respondents claimed that their projects required a normal amount of maintenance, compared to 93% for both CMAR and DB. However, this slight difference between DBB and APDM is case-specific, and may not be related to the project delivery method itself. For example, some respondents stated that equipment malfunction was a general maintenance issue; however, this concern may be due to a supplier's manufacturing malfunction, regardless of the delivery method.

6.3.4 Meeting Owners Life Cycle Cost Expectations, Room for Innovation, & Appropriateness of Delivery Method

The survey also included questions to gauge whether or not the used project delivery method had met an owner's life cycle cost (including operations and maintenance) expectations, allowed room for innovation, and if it was the appropriate project delivery method for their projects. Respondents were offered three choices to select from for each question which included: "Yes," "Somewhat," and "No." The responses were obtained from a sample of 71 projects and are presented as a percentage of total projects for each delivery method, as seen in Table 6.

By observing Table 6, it can be inferred that APDM outperformed DBB in terms of meeting an owner's life cycle expectations. It is also important to note that 100% of APDM projects had the required operation manuals delivered, compared to 86% of DBB projects. However, when it came to the delivery method that allows the most room for innovation, despite being in contradiction to the literature, DBB was superior. This may be due to the nature of the projects themselves, and not directly associated to the delivery methods. Moreover, all DB project owners felt that it was the appropriate delivery method for their project with 100% of respondents choosing "Yes." The majority of DBB and CMAR owners also felt it was the appropriate delivery method for their project with "Yes" being selected for 95.83% of DBB projects and 92.31% for CMAR.

Table 6: Meeting Owner's Life Cycle Expectations, Room for Innovation, and Appropriateness of Delivery Method

Delivery Method	**Project Meeting Owner's Life Cycle Expectations**			**Room for Innovation**		**Appropriate Delivery Method for this Projects**	
	Yes	**Somewhat**	**No**	**Yes**	**No**	**Yes**	**No**
DBB (N=24)	80.00%	20.00%	0%	58.33%	41.67%	95.83%	4.17%
CMAR (N=26)	92.86%	7.14%	0%	41.67%	58.33%	92.31%	7.69%
DB (N=21)	92.86%	7.14%	0%	45.00%	55.00%	100%	0%

6.3.5 Owner Satisfaction and Reusing Delivery Method on Future Projects

Owner's overall satisfaction with the chosen delivery method after project completion was measured using a 5-point Likert scale, with 1 representing "no or little satisfaction" and 5 representing "highly satisfied." After evaluating the results, DB received an average score of 4.57, followed by DBB with 4.42 and CMAR with 4.19. Statistical analysis was then performed, and Q-Q plots were drawn to test for normality. The plots showed that the data was not normally distributed; therefore a Kruskal-Wallis test was used to obtain the *p*-value. The test resulted in a *p*-value of 0.227, which signifies that the differences are not significant.

This study also desired to evaluate whether the project delivery method chosen by the respondents would be reused for their future water and wastewater treatment plant projects. The responses were collected and presented in terms of total project percentage out of 100% as seen in Figure 23. The majority of project owners responded by stating that they would reuse this project delivery method on future projects, with DBB receiving the highest score of 96%, DB with 92%, and finally CMAR with 82%.

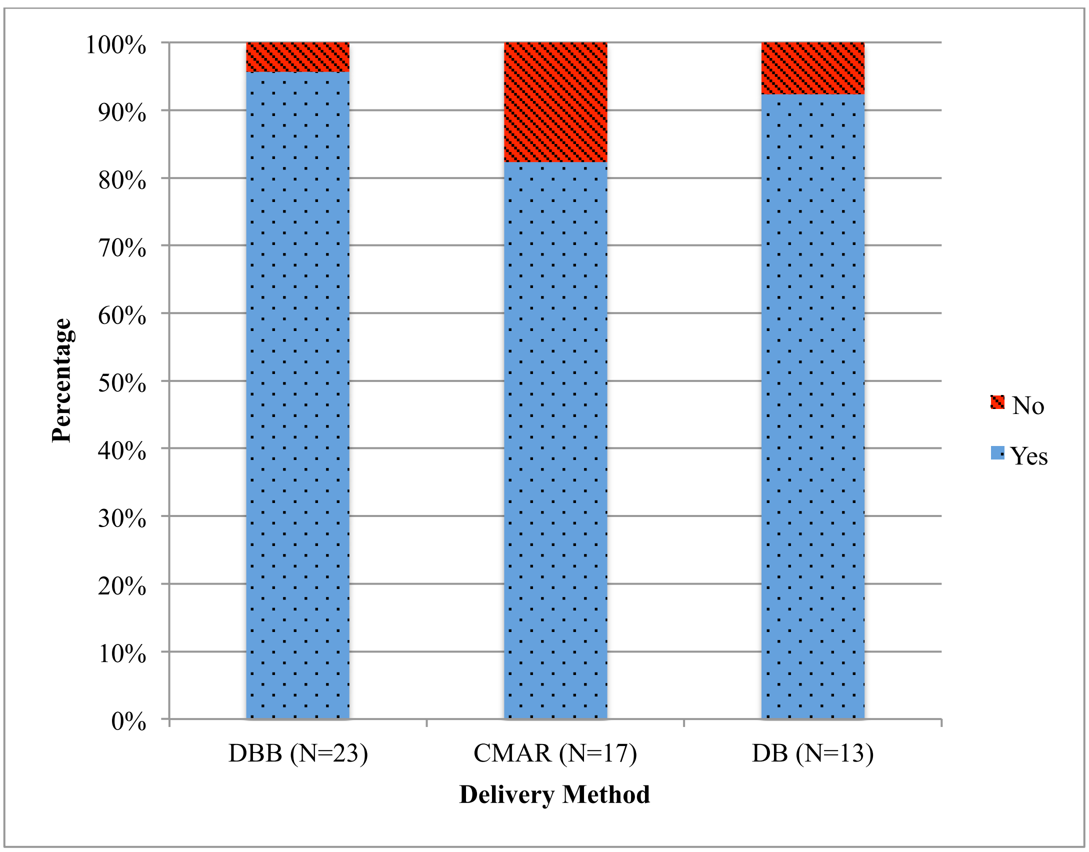

Figure 23: Reusing Delivery Method on Future Projects

CHAPTER 7

CONCLUSION

Water and wastewater industry decision-makers must choose the appropriate project delivery method that yields the most benefit. This study consisted of a performance evaluation for project delivery methods in the water and wastewater industry. A national survey was conducted and collected relevant data from a total of 75 completed DBB, CMAR, and DB projects. The data analysis revealed that some performance metrics contained differences with statistical significance, while other metrics did not.

In terms of average design, construction, and total cost growth, the data analysis showed that APDM had outperformed DBB; with DB having the lowest cost growth for all cost growth metrics, including unit cost; however the results were not statistically significant. In terms of schedule, both CMAR and DB had negative average design schedule growth and outperformed DBB. However, for average construction and total schedule growth, APDM were not superior to DBB. But this data was not statistically significant; therefore, APDM cannot be assumed to have lower performance when compared to DBB. Nonetheless, some performance metrics did have statistical significance. APDM outperformed DBB in terms of project intensity and speed and obtained *p*-values less than 0.05. These results may imply that APDM may be better suited to handle projects that have significant schedule constraints. Other qualitative and quantitative metrics were also discussed and analyzed, and may serve as a reference to assist decision-makers in this industry when making a project delivery method selection decision.

The findings in this study were predominantly consistent with the literature. Particularly through obtaining statistical significance in the performance metrics of project speed and intensity. However, in terms of the raw data of the average construction and total schedule growth there were some discrepancies between the literature and the results of the study. This can be due to various factors, such as the possibility of APDM still facing various contractor-owner related executional challenges in the water and wastewater industry. The major contribution of this study was that it was capable of showing that for the same project cost, water and wastewater treatment plants could be delivered under a faster schedule and with higher quality through the utilization of APDM.

A limitation of this study is that the survey data set contains a small sample size (less than 100 projects). Another limitation is that this study only focuses on the three delivery methods of DBB, CMAR, and DB. However, other project delivery methods may be also used in the water and wastewater industry, such as job-order-contracts (JOC) and integrated project delivery (IPD).

Future research can build on this study’s findings, such as by further improving the accuracy of results by increasing the data set sample size and measuring other qualitative and quantitative performance metrics that may have not been addressed in this study. Moreover, this study was conducted with water and wastewater treatment plants in-focus. Future work may also conduct similar investigations and measure the performance impacts of APDM for water and wastewater pipeline projects and for other industries as well.

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APPENDIX A

NATIONAL DATA COLLECTION SURVEY QUESTIONS

The following section presents the 67 survey questions that were presented in the data collection survey. It is important to note that the questions were not uniformly provided to all respondents, and the questions arrangement was dependent on previous answers selected by the respondent as the survey progressed. Therefore, in the list below, a "if applicable" at the start of a question signifies that a question may or may have not been presented to the respondent.

Additionally, some questions required the respondents to select their answer(s) from available options that were prepared beforehand. While other questions utilized a 5-point Likert scale, and were used to gauge the respondents' agreement or disagreement to the applicable question. Certain questions were also combined in this list, but were essentially asked independently in the actual survey, for example this includes the actual and planned cost and schedule related questions.

List of Survey Questions:

Q1. Respondent name.

Q2. Email address.

Q3. Telephone.

Q4. Organization name.

Q5. Organization role.

Q6. Does your organization have in-house engineering?

Q7. Does your organization have in-house construction?

Q8. What role did the respondent have on the project?

Q9. Project owner.

Q10. Project name.

Q11. Brief project description.

Q12. Project's location (City, State).

Q13. Project site.

Q14. Did the facility stay in service during construction?

Q15. Project construction type.

Q16. What was the plant's original capacity (in million gallons per day) before commencing with the project?

Q17. What was the plant's final capacity (in million gallons per day), after project completion?

Q18. What the project for a water or wastewater treatment plant?

Q19. Plant type.

Q20. What was the type of delivery method used for this specific project?

Q21. How many projects has your organization completed using this delivery method (approximately)?

Q22. Why was this delivery method chosen? Check all that apply.

Q23. Will this delivery method be used on future projects?

Q24. How experienced is the owner organization with the delivery method used on this project? (Using a 5-point Likert scale).

Q25. How experienced is the construction team with the delivery method used on this project? (Using a 5-point Likert scale).

Q26. How experienced is the design team with the delivery method used on this project? (Using a 5-point Likert scale).

Q26. Does the utility have the required staff with the availability, experience, and capability/training needed for the chosen delivery method?

Q27. Which selection process was used for this specific project? Check all that apply.

Q28. What was the compensation type for the construction team? Check all that apply.

Q29. We are trying to gauge this project's complexity. Please check all that apply in this project.

Q30. What were the owner's key driving metrics that mostly defined success for this project?

Q31. Please rate the owner's level of involvement in the design of the project. (Using a 5-point Likert scale).

Q32. Please rate the owner's level of involvement in the construction of the project. (Using a 5-point Likert scale).

Q33. Please rate how well the different project stakeholders communicated. (Using a 5-point Likert scale).

Q34. What was the total project contingency in $USD?

Q35. How was this contingency shared? (if applicable).

Q36. Was there an agency in-house design cost?

Q37. Did the project use separate construction contracts through multiple work packages?

Q38. If applicable (if the project is CMAR), please indicate contracted total design cost, contracted pre-construction cost, contracted construction cost, and contracted total project cost.

Q39. If applicable (if the project is CMAR), please indicate final total design cost, final pre-construction cost, final construction cost, and final total project cost.

Q40. If applicable (if the project is DB), please indicate contracted owner RFP cost, contracted DB design cost, contracted construction cost, and contracted total project cost.

Q41. If applicable (if the project is DB), please indicate final owner RFP cost, final DB design cost, final construction cost, and final total project cost.

Q42. If applicable (if the project is DBB), please indicate contracted total design cost, contracted construction cost, and contracted total project cost.

Q42. If applicable (if the project is DBB), please indicate final total design cost, final construction cost, and final total project cost.

Q43. If applicable, please indicate the approximate level of design (in percentage) completed prior to engaging the CMAR firm, design-builder, or contractor.

Q44. If applicable, please indicate the associated costs for the design completed prior to engaging the CMAR firm, design-builder, or contractor.

Q45. Please provide the owner's administrative and oversight cost for this project. This is the total cost of the owners' advisor and the owner's employees assigned to the project (including RFP, RFQ and procurement phase, if applicable).

Q46. Was there a major scope change in the project?

Q47. In percentage of total changes, please fill out the following: (the percentages in the four sections must sum up to 100% or less: Approximately, what portion was owner-driven and related to added/deleted scope or quality, contractor-driven and relates to added/deleted scope or quality, due to design issues, deficiencies, errors & omissions, due to unforeseen or external conditions?

Q48. What was the project’s planned and actual start date?

Q49. What was the project’s planned and actual design contract start date?

Q50. If applicable (if the project is CMAR), what was the project’s planned and actual pre-construction services start date?

Q51. If applicable (if the project is DB), what was the project’s planned and actual construction notice to proceed date?

Q52. What was the project’s planned and actual construction start date?

Q53. What was the project’s planned and actual substantial completion date?

Q54. What was the project’s planned and actual final acceptance date?

Q55. If applicable (if the project is DB), what was the duration between the Request for Proposal (RFP) solicitation and the contract award date?

Q56. Is the plant still under contractor's warranty period?

Q57. What warranty issues did the plant face? Check all that apply.

Q58. What latent defects (post-warranty) did the plant face? Check all that apply.

Q59. Were there unresolved claims between stakeholders after final acceptance?

Q60. Does the plant function according to the specifications, including reliability? (please explain if needed).

Q61. Does the plant require more than the reasonable or normal amount of maintenance? Please explain if needed.

Q62. Did the plant meet the owner's expectations with respect to Life Cycle Costs including O&M costs of the plant?

Q63. Were operation manuals delivered for the plant?

Q64. Did the project team come up with any innovations?

Q65. Rate your organization's overall satisfaction with the project. (Using a 5-point Likert scale).

Q66. Knowing what you know now, was this the appropriate delivery method for this project?

Q67. Would you like to share any additional critical information, such as major regulatory, safety, or permitting issues that impacted the project?