Innovative Delivery of Water Infrastructure Projects

by

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ABSTRACT

Water utilities across the United States are facing numerous challenges, such as limited funding and increasing project complexity, in constructing and upgrading their aging infrastructure. One innovative method to overcome these challenges is through the use of alternative project delivery methods (APDM), such as construction management at-risk (CMAR) and design-build (DB). Previous research has shown that APDM have the potential to deliver higher performing water infrastructure projects when compared to the traditional design-bid-build (DBB) method. However, there is a need to further examine APDM practices and develop tools that may support utilities in the delivery of their APDM water infrastructure projects.

This study fills the knowledge gap by conducting several studies that may support public and private utilities in improving the delivery of their APDM water infrastructure projects. First, APDM implementation practices for water infrastructure projects are identified by assessing the state of practice, particularly during project procurement and execution. Second, DB project administration best practices are determined to support utilities seeking to add DB to their organization's project delivery toolbox. Third, a pioneering web-based project delivery method decision-support tool was developed to aid utilities in selecting the appropriate delivery method for their water project. Finally, project-specific factors and attributes that impact project delivery performance are investigated through exploratory modeling and analysis.

The study collected data on 75 completed treatment plant projects, conducted interviews with ten utilities that successfully deliver their water projects using DB, and worked closely with several industry experts through industry workshops and panels. Key findings related to water infrastructure project delivery revealed in this study included: (1) guaranteed maximum price (GMP) is the preferred compensation type for APDM projects; (2) utilities statistically having the lowest comfort level with delivering CMAR projects; (3) qualifications-based procurement is an effective DB project delivery practice; (4) the identification of 13 key project delivery method selection factors; and (5) the three highest predictors that impact unit cost performance are project complexity, project team chemistry and communication, and project size.

I dedicate this dissertation to my late father, who has sacrificed everything for his family.

Thank you for instilling in me a love and passion for education.

To my mother, Marleine, you are my strength and resilience.

To my brothers, Julien and Joey, you are my drive.

To my partner, May, you are my perseverance.

Thank you all for always supporting me.

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CHAPTER 1

INTRODUCTION

1.1 Background

The American Society of Civil Engineers (ASCE) released the 2017 Infrastructure report card, which graded the condition of America's infrastructure. The ASCE gave water infrastructure an unsatisfactory grade of "D" and wastewater infrastructure a grade of "D+" (ASCE 2017). Many elements of US water infrastructure are approaching the end of their service life. As a result, significant reinvestment is needed to replace or rehabilitate these deteriorating and aging infrastructure components.

The American Water Works Association (AWWA) estimates that $1 trillion is needed over the next 25 years to sustain current services and expand to meet future demands (AWWA 2016). However, a study by the CBO (2015) has indicated that federal funding for water utilities has dropped from $16 billion in 1976 to $4.4 billion in 2014. Therefore, state and local governments are required to cope with growing water infrastructure demands with limited funding.

As result of these constraints, utilities must ensure that their projects are completed on time and budget. One innovative approach to improve project delivery performance is through the utilization of alternative project delivery methods (APDM), such as construction management at-risk (CMAR) and design-build (DB). APDM projects have been extensively studied and applied across various industries and revealed substantial performance benefits over the traditional design-bid-build (DBB) method (Konchar and Sanvido 1998; Migliaccio et al. 2010; Park and Kwak 2017). Additionally, APDM performance studies have also been conducted specifically for the water industry and have shown performance benefits for water infrastructure projects (Bogus et al. 2010; Francom et al. 2016a and 2016b; Shrestha et al. 2018; Feghaly 2018).

A project delivery method can be defined as the process that will be utilized by the project owner (e.g., water utility) through agreements with other project stakeholders and entities to commence with the planning, financing, design, construction, start-up and operation of a construction project. However, two commonly shared elements within diverse definitions of project delivery methods are: (1) contractual relationships between project stakeholders; and (2) their timing of engagement in the project (Konchar and Sanvido 1998; Molenaar et al. 1999; El Asmar et al. 2016).

DBB is often referred to as the traditional project delivery method, as it is the most widely understood project delivery method in the construction industry (ACRP 2009). In DBB, an owner manages two independent contracts, one with the designer and one with the contractor. DBB projects are often awarded on a low-bid process and contractor selection tends to be based entirely on cost (Bearup et al. 2007). DBB also grants the owner significant control and influence over a project, requiring the owner to be heavily involved in monitoring the contractor’s adherence to contract requirements (Khalil 2002). Often seen as a linear process, construction in DBB begins once design is 100% complete, the project has been successfully bid, and the contract has been awarded.

Similarly to DBB, in CMAR the owner also manages two independent contracts with both a contractor and a designer. However, in CMAR the construction manager is required to coordinate with the designer and be heavily involved during the design phase.

According to Bearup et al. (2007), CMAR is ideal for owners who seek to accelerate a project's delivery time by overlapping both design and construction, as construction activities may initiate before project design is 100% complete. Unlike DBB, on a CMAR project the owner may evaluate a contractor's qualifications before awarding a contract. A key advantage of having the contractor on board before the initiation of construction is the benefits that come from obtaining preconstruction services during the design phase (Sullivan et al. 2017). These benefits include cost engineering, constructability reviews, and assistance in developing subcontractor bid packages (ACRP 2009).

DB is a project delivery method that allows an owner to obtain both design and construction services through one single entity, commonly referred to as the design-builder (Molenaar and Songer 1998). DB, similarly to CMAR, is typically also awarded based on contractor qualifications (Bearup et al. 2007). Design-builders, like CMAR firms, can also offer valuable preconstruction services due to their earlier engagement in the project and allow opportunities for schedule compression (Bearup et al. 2007). However, in DB the owner tends to have less control and influence over a project (Culp 2011). For example, an owner that pursues DB may not directly own the details of the design; therefore, design liability may be transferred to the design-builder (Culp 2011).

1.2 Research Objectives and Method

As stated earlier, previous research has shown that APDM has the potential to deliver higher performing water infrastructure projects when compared to the traditional DBB method. However, there is a need to further examine APDM practices and develop tools that may support utilities in the delivery of their APDM water infrastructure projects.

This need has been echoed by numerous industry stakeholders and the Water Research Foundation (WRF), which helped form the motivation of this dissertation. The dissertation aims to fill this gap in knowledge by conducting APDM studies that may support public and private utilities in improving the delivery of their water infrastructure projects. This research study consisted of four independent phases, as shown in Figure 1. Each phase will be briefly summarized in the following sections.

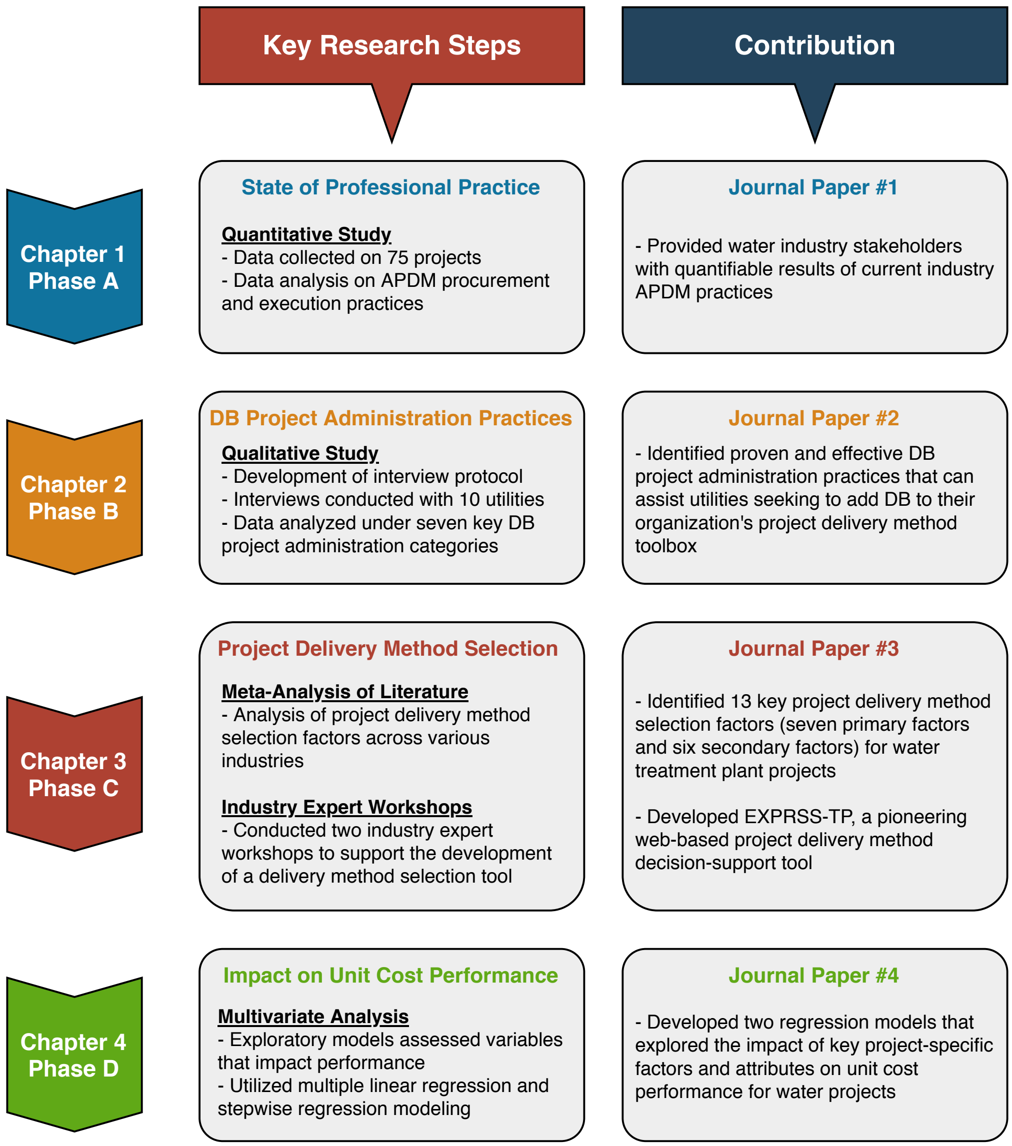


Figure 1: Key Research Steps and Contributions

1.2.1 Phase A: State of Practice

The objective of the first phase of this study is to assess current APDM implementation practices for water infrastructure projects by conducting a state of professional practice. An extensive survey, developed through the support of an industry workshop, analyzes practices for both the CMAR and DB method alongside the DBB method. Data was collected from 75 recently completed water and wastewater treatment plant projects across the United States. In total, information on 25 DBB projects, 27 CMAR projects, and 23 DB projects was collected. The data was then analyzed using various data visualization tools and statistical testing. GMP was shown to be the most selected compensation type for APDM projects. Qualifications-based was the most selected procurement process for APDM projects. The findings indicated that both DBB and APDM projects have similar procurement durations. Additionally, results of the study showed that project teams had the lowest experience score in delivering DB projects, when compared to CMAR and DBB projects. This finding served as the motivation for the second phase of this study, where DB project administration practices can be identified to support inexperienced project teams facing challenges in delivering DB water infrastructure projects.

1.2.2 Phase B: Design-Build Project Administration Practices

The objective of the second phase of this study is to provide effective DB project administration practices specifically for the water industry. An elaborative interview protocol was developed, though an extensive literature review and support of a panel of industry experts, to collect information from utilities that are experienced with delivering

DB water projects. Interviews were conducted with 10 utilities in the United States and Canada. DB practices were identified under seven key DB project administration categories. The collected data was analyzed using thematic content analysis, a research method for qualitative analysis. This analysis approach allowed for the quantification of the qualitative data obtained. The study identified effective DB practices for water projects in the following categories: (1) procurement; (2) DB roles and responsibilities; (3) risk and quality management; (4) design; (5) design and submittal review; (6) cost and schedule estimates; and (7) communication and information flow.

After this phase was concluded, the next phase aimed to continue building on the findings of the previous study, and identify key project delivery method selection factors to develop a project delivery method selection tool. This tool aims to support utilities in selecting between the DBB, CMAR, and DB delivery method; based on their water infrastructure project's unique characteristics and constraints.

1.2.3 Phase C: Project Delivery Method Selection

The objective of the third phase of this study is to identify key project delivery method selection factors to assist water industry decision-makers in selecting the most appropriate delivery method for their water treatment plant projects. The selection factors were identified by compiling and validating key project delivery selection factors across various industries through an extensive literature review and two industry expert workshops. This effort resulted in the development of a pioneering web-based decision-support tool to facilitate project delivery method selection within the water industry. The tool improves the tradaitional project delivery method selection process and provieds evidence-based project delivery method selection recommendations.

1.2.3 Phase D: Impact on Unit Cost Performance

The objective of the fourth and final phase of this study is to explore project-specific factors and attributes that impact a water infrastructure project's delivery performance. A dataset of 75 completed water treatment plant project was used to conduct multivariate analysis to obtain an understanding on the behavior of project-specific factors and attributes on unit cost performance. Six factors and attributes from the literature were assessed and included: (1) use of a GMP for their project; (2) project team experience with delivery method; (3) level of design completion before contractor engagement; (4) project complexity; (5) project team chemistry and communication; and (6) project size. A multiple linear regression model and a stepwise regression model were developed and the findings were analyzed.

1.3 Dissertation Format

This dissertation is organized in four journal paper formats. As discussed earlier, each chapter consists of a phase of this study. **Chapter 1** of this dissertation provides a background on APDM and introduces the problem statement, overall methodology, and provides a high-level description of the phases of the dissertation. Each following chapter consists of academic journal articles that have been published, accepted, submitted and currently under peer-review, or in preparation for submission. As a result, each chapter will have its own introduction, literature review, methodology, results, and conclusions.

Chapter 2 presents current APDM implementation practices for water infrastructure projects as a result of a state of professional practice. This study provided key findings, which motivated the following three phases of this dissertation. The findings of this study resulted in a journal paper, which has been accepted and currently in press in the ASCE *Practice Periodical on Structural Design and Construction.*

Chapter 3 provides a detailed study on the identification of effective DB project administration practices specifically for the water industry. The findings of this study may support utilities seeking to add the DB delivery method to their organization's toolbox. The findings of this study were submitted to the ASCE *Journal of Pipelines Engineering Systems and Practice* and the journal paper is currently under peer-review.

Chapter 4 presents key project delivery method selection factors specific to the water industry. This research resulted in the identification of 13 key selection factors and the development of a pioneering web-based project delivery method selection tool. The findings of this study were published in *Engineering, Construction, and Architectural Management.*

Chapter 5 explores project-specific factors and attributes that impact unit cost delivery performance in the water industry. The study practically supports utilities in understanding the impact of key factors and attributes on unit cost performance. The findings of this study may support water utilities in their project delivery decisions, improving the overall performance of their water projects. This journal paper is currently in preparation and will be submitted to a reputable academic journal.

Chapter 6 recapitulates the major findings, limitations, and contributions resulting from this dissertation. Moreover, recommendations for potential future research are discussed. The references for this dissertation are provided following Chapter 6.

CHAPTER 2

STATE OF PROFESSIONAL PRACTICE FOR WATER INFRASTRUCTURE PROJECT DELIVERY

2.1 Introduction

Water infrastructure in the United States is aging and investments are incapable of keeping up with growing needs. Major renovations are needed to improve the overall efficiency of these systems as they mature. In order to sustain current services and expand to meet future demands, the American Water Works Association (AWWA) estimates that $1 trillion is needed over the next 25 years (AWWA 2016). This forecasted financial challenge is only intensified by other difficulties facing this industry such as the need for funding capital improvement projects, water scarcity/supply, government regulations, and climate change. As a result of these complications, utilities require innovative project delivery solutions for the delivery of their water infrastructure projects (which consist of both water and wastewater infrastructure as part of the integrated One Water approach of the US Water Alliance (USWA 2016)).

Traditional design-bid-build (DBB) is the most widely used project delivery method for the construction of water infrastructure projects. This delivery method is suitable for utilities that have high-level in-house construction management capabilities and for well-defined projects. Alternative project delivery methods (APDM), such as design-build (DB) and construction management at-risk (CMAR), have been growing in popularity across the construction industry. APDM are being chosen by utilities due to their potential performance impact on a project’s cost, schedule, and quality. However, various project delivery methods have their distinct advantages and disadvantages. For example, APDM engages the constructor earlier in the design phase and improves opportunities for collaboration; however, it may cost the utility a slightly higher upfront investment. Research reveals this investment to be more than recovered through improved project performance (El Asmar et al. 2013 and El Asmar et al. 2016).

There are numerous project delivery methods used across various industries. This study only focuses on the application of DBB, CMAR, and DB for the delivery of treatment plant projects in the water industry. The results of this study should support water stakeholders with the procurement and execution of their water infrastructure projects.

2.1.1 Project Delivery Methods

DBB is the most established and utilized delivery method within the construction industry (ACRP 2009). In a DBB project the utility (owner) has two separate and independent contracts, one with the designer and one with the constructor. DBB is a linear process, in which the constructor is selected only after the design has been 100% completed. The lack of involvement and input from the constructor during the design phase may also lead to potential obstacles during the construction phase, as any design changes will have to be handled as change orders by the utility (Shrestha and Mani 2014). In DBB, the constructor is typically selected based on a low-bid process. In CMAR the utility also holds two independent contracts; one with the designer and one with the constructor. However, a key difference between DBB and CMAR is that CMAR firms are engaged earlier in the design phase and provide valuable pre-construction services.

The collaborative environment between the CMAR firm and the designer initiates opportunities for successful project delivery. Unlike DBB, a CMAR firm is not solely selected based on their bid, but also through an assessment of their qualifications. In DB the utility only manages one contract, with one single point of responsibility, with the design-builder. The design-builder is the entity that is responsible to act both as the designer and the constructor throughout the project delivery process (Hale et al. 2009). In line with CMAR, DB also provides the utility with valuable preconstruction services. In order to select a design-builder for a given project, similarly to CMAR, a utility will assess the qualifications of the DB team before awarding the project.

2.2 Previous Research

Numerous publications have evaluated APDM performance for water infrastructure projects (Shane et al. 2013; Bogus el al. 2013; Shrestha et al. 2018). However, no research publications have conducted a state of professional practice for water infrastructure project delivery with a large geographically dispersed sample of DBB, CMAR, and DB projects.

Flora et al. (1998) assessed DB project delivery satisfaction by conducting a case study with a general contractor that focuses on delivering projects for the water industry. This study evaluated field-level management perceptions rather than that of corporate management. Key DB advantages revealed in this study included: greater owner satisfaction; risk sharing; and improved communication between the project teams. This study evaluated the DB method from a single company's perspective.

The adoption of APDM in the water industry has substantially grown over the past two decades. The City of Phoenix, Arizona used the Design-Build-Operate (DBO) project delivery method for the Lake Pleasant Water Treatment Plant project, which was one of the nation's first large-scale DBO water projects (City of Phoenix 1999). DBO was selected for its ability to minimize operating costs and maximize efficiency throughout design, permitting, construction and operations. This decision resulted in savings of approximately $30 million. Additionally, DBO enabled the adoption of innovative technologies to create operational flexibility. This study focused on the DBO method for one water infrastructure project.

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 DB project delivery. The study also found widespread growth for the use of DB for water and wastewater treatment facilities. This study primarily focused on identifying industry best practices for the DB method.

Rao (2009) conducted a case study analysis of four water treatment plants in California and noted several benefits of using DB delivery over traditional DBB in the water and wastewater industry. DB 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: (1) the notion that DB project teams are formed between engineers and contractors to seek out the best cooperation; (2) DB project teams can potentially offer cutting edge technology or innovation solutions to the project; and (3) DB project teams are more likely to meet the owner's objectives due to improved project team alignment. 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. This study focused on four treatment plant projects and did not discuss CMAR.

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. CMAR was selected due to its ability to support risk funding allocation, risk allocation/mitigation, project implementation, and commissioning priorities. This study focused on one CMAR water infrastructure project.

AWWA (2010) stated advantages and disadvantages of using DB delivery method for water and wastewater utility construction. DB advantages included: a single point of contact and single source of responsibility for design, construction and performance; the financial cost is known before project commencement; the ability to fast track and compress delivery schedules; and overall cost reduction and guaranteed performance. DB disadvantages included: the fact that State law may limit the use of the DB method; proposal evaluation is time consuming and more complex than traditional bid evaluation; and DB does not eliminate the cost for design reviews or inspection. This study shared advantages and disadvantages of DB, and did not compare results to DBB and CMAR.

Bogus et al. (2010) conducted a study to investigate the performance of water and waster projects using various contract payment methods. A national survey collected information on 252 completed water and wastewater projects. Results of the study revealed an increase in the water and wastewater industry's use of DB delivery with a guaranteed maximum price (GMP). The study concluded that projects using a GMP do not experience as much schedule and cost growth as projects using a lump sum contract.

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. 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. This study focused on one water infrastructure DB project.

Bogus et al. (2013) later examined the relationship between procurement duration and performance of water and wastewater projects. Statistical analysis revealed that there is no statistical correlation between cost growth and procurement duration, and no correlation between procurement period and project performance. The study also found that providing a longer procurement period was unlikely to result in improved project performance, while allowing a short procurement period could result in poor schedule performance. These studies did not evaluate CMAR.

Kajimo-Shakantu et al. (2014) studied the perception of water stakeholders for using Public-Private-Partnership (PPP) as an approach to deliver a desalination plant in Namibia. Data was collected from 70 respondents in the water industry. The results revealed that the majority of respondents perceive that their institutions do not provide them with sufficient financial resources to develop and maintain new water infrastructure.

This study showed that there is room to explore APDM for improving water infrastructure delivery in Namibia.

Francom et al. (2016a) conducted a survey on 34 completed trenchless projects to assess industry perceptions on APDM utilization. The authors found that DBB is still the most prevalent delivery method in the trenchless industry, followed by DB. The majority of respondents also perceived APDM to offer increased performance compared to DBB. However, contractors perceived APDM to have better performance for all metrics assessed in this study; compared to engineers who perceived DBB offers better performance on cost and profit metrics. This study did not focus on water and wastewater treatment plants.

Shrestha et al. (2016) evaluated the satisfaction levels of utility managers and project managers that have applied APDM for water and wastewater infrastructure projects. There were 153 responses collected and analyzed. Best value was the preferred procurement process for 57% of the respondents, followed by qualifications only representing 31%, and the remaining 12% using price selection. A key finding in this study included observing that project-level staff experienced significantly higher performance benefits than management-level staff on their APDM projects. This study did not include the DBB method in the comparison.

El Asmar and Ariaratnam (2018) investigated the performance of DBB, CMAR, and DB project delivery methods for water infrastructure projects. Data was collected from 34 completed water and wastewater treatment plant projects. Resulted indicated that

APDM showed improved construction cost growth and speed performance when compared to DBB. However, the results of this study were not statistically supported.

Shrestha et al. (2018) analyzed the differences in the perceptions of DB and CMAR for water and wastewater projects. The study measured utility satisfaction levels with APDM, investigated cost and schedule performance, identified and ranked APDM selection factors, and explored APDM project advantages. The APDM benefit with the highest frequency was level of owner's involvement in the design process, followed by project quality. The authors also found that the main motive for APDM selection for utilities was schedule advantages. Similarly to Shrestha et al. (2016), this study did not incorporate DBB in the assessment.

Dithebe et al. (2019) assessed critical success factors for water infrastructure projects under the PPP method. The researcher of this study administered a questionnaire to 150 water stakeholders. Critical success factors for water infrastructure projects under the PPP method were identified as having: (1) thorough planning for project viability; (2) high levels of transparency and accountability; and (3) a legal framework stipulating policy continuity. This study identified key success factors that can improve water infrastructure delivery.

Based on the review of the literature, various publications cited benefits of using APDM for water infrastructure projects. However, there is a need to evaluate the three commonly used delivery methods of DBB, CMAR, and DB in one study and conduct a state of professional practice for water infrastructure project delivery, focusing particularly on the procurement and execution phase. Additionally, the literature review supported the development of a detailed data collection survey for this study and is used as a basis of comparison for the authors' findings.

2.3 Objective and Methodology

The objective of this research is to study APDM implementation practices for water infrastructure projects by assessing APDM state of practice during procurement and execution. The study consisted of four sequential steps: (1) review of literature; (2) development of data collection survey and industry workshop; (3) national data collection; and (4) data analysis.

After completion of the literature review, the authors developed a data collection survey. An industry workshop with 20 industry experts was assembled to review and validate the composition of the survey. A selection of industry experts' pilot-tested the survey and confirmed that industry interests and concerns were reflected. The survey was administrated nationally and sent to around 200 professionals in the water industry. Finally, the authors analyzed the findings and highlighted key APDM procurement and execution implementation practices.

2.3.1 Survey Development and Expert Workshop

The survey was designed to collect pertinent information on a respondent's completed project. Qualtrics, an online survey and data collection tool, was used to design and administer the survey. General information of a project that was gathered included: (1) location; (2) site condition; (3) type of project (e.g., new construction, renovation); (4) plant capacity before and after construction; and (5) project delivery method used. Other project specific questions included: (1) reasons for delivery method selection; (2)

procurement process (e.g., low-bid, best value); (3) compensation types (e.g., lump sum, unit price, GMP); and (4) approximate level of design completed before engaging the constructor. Qualitative questions included: (1) opinions on utility, constructor, and designer experience with the chosen delivery method; (2) utility's involvement in design and construction; (3) overall stakeholder communication; and (4) utility satisfaction with the project.

An industry expert workshop was assembled with the support of 20 industry experts representing: nine utilities; three design firms; three construction general contractors; and three research organizations. These experts have over 400 years of combined experience in supporting the delivery of water infrastructure projects. The industry experts supported the development of the survey (e.g., identifying a list of potential key factors for project success), and provided their review and feedback on survey questions prepared by the research team. The experts also shared contact information of individuals in their professional networks that may potentially provide information on their completed projects during the data collection phase.

The authors revised the survey to reflect the feedback obtained by the industry experts, with the final survey consisting of 67 questions. The survey was pilot-tested by a limited number of utilities that were involved in the workshop. The experts provided additional feedback on the survey's interface and confirmed that the survey is simple to use.

2.3.2 National Data Collection

The survey was administrated electronically using *Qualtrics,* an online data collection tool. Convenience sampling was used and augmented by a network of utilities, conference rosters, professional associations, and water infrastructure stakeholders, as discussed next. The survey was primarily directed to water utilities, as they typically have the broadest understanding of the project; however, designers and builders were not discouraged to provide information. To further develop the list of potential survey respondents, the research team acquired and reviewed participant rosters from several national water infrastructure conferences. Individuals on the list of potential respondents included industry experts that extensively contribute to the delivery of their respective utilities' water projects.

Surveys were accessed electronically by the respondents through an email distribution. Respondents were asked to only provide information on their water and wastewater plant projects if they have been recently completed. The scope of the study was limited to water and wastewater treatment plant projects completed between 2005 and 2018. Moreover, the survey strictly advised the respondents to only submit data if they had been intimately involved with their project. For example, respondents included project managers, senior staff members, and chief estimators. The final survey was sent to about 200 project delivery decision-makers and professionals in the water industry. Responses were collected for 75 completed projects (response rate of about 38%). The data collection phase spanned a period of 11-months.

After project information was submitted by a respondent, returned surveys were reviewed by the research team and validated by verifying the responses through online publications, news articles, and other resources that contain publicly accessible information on completed water and wastewater treatment plant projects. The validation process improved the accuracy and quality of the source data acquired prior to analyzing the data. Additionally, in the case key information was missing from the returned survey, the research team contacted the concerned respondent through email or phone to request and obtain the missing data.

2.3.3 Data Analysis

The data was analyzed through the support of different data visualization tools and underwent various forms of statistical testing. This included using: frequency charts; boxplots; descriptive statistics (e.g., median; mean); and both the Kolmogorov-Smirnov (K-S) and Shapiro-Wilk test were used to observe the statistical distribution of the variables of interest and test for normality, which informs the use of either parametric statistical tests (e.g., one-way analysis of variance (ANOVA) test) or non-parametric statistical tests (Kruskal-Wallis test or Pearson's chi-square test) for hypothesis testing.

The one-way ANOVA test is used to determine if there are any statistically significant differences between the means of two or more independent (unrelated) groups. The one-way ANOVA is a parametric test, and can be used only if the data is normally distributed. If the data is not normally distributed, then the non-parametric Kruskal-Wallis test can be used to determine if there are statistically significant differences between two or more groups. Pearson's chi-square test is also a non-parametric test;

however, it is used to test significant association between two or more categorical variables.

In this study, the null hypothesis of statistical tests stated there are no significant differences: between the mean for the ANOVA test; the median for the Kruskal-Wallis test; and in proportions for the chi-square test. In the contrary, the alternate hypothesis for each test stated that there are statistical differences between the delivery methods. In this study, all variables were tested at a 95% confidence interval (α=0.05). Moreover, in the K-S and Shapiro-Wilk test, the null hypothesis states that a variable is normally distributed and the alternate hypothesis states that is not normally distributed. A null hypothesis is rejected and the alternate hypothesis is accepted only when a *p*-value of 0.05 or less is achieved for a given statistical test.

2.4 Data Characteristics

The collected data relating to the 75 projects were distributed between 25 DBB (33%), 27 CMAR (36%), and 23 DB (31%) projects. Utilities represented 70% of the survey responses, with constructors representing 20%, and designers representing the remaining 10%. 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 responses that were received by utilities, 72% perform in-house engineering and design, and 24% perform in-house construction. All constructors perform in-house construction and do not perform in-house engineering. The projects obtained through this survey originated from all major regions of the United States and represented a total of 15 US states. About 62% of these projects were water treatment plant 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. Total project costs ranged from $0.430 million to $438 million. The total dollar amount of all projects represented was about $4.1 billion, with water treatment plants representing a combined value of about $1.7 billion and wastewater treatment plants representing a combined value of approximately $2.4 billion. The average total project cost was approximately $64 million for water treatment plants and $82 million for wastewater treatment plants.

Respondents shared that 85% of their projects were constructed on project sites that were 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 responses were new construction projects, 25% were retrofit/expansion, and the remaining 25% were renovation/rehabilitation projects.

2.5 State of Practice on Water Infrastructure Procurement

State of practice of water infrastructure procurement consists of many factors that can influence a project's delivery. In this section, seven key factors of the state of water infrastructure procurement will be discussed. There seven factors are: (1) project team past experience; (2) delivery method comfort level; (3) factors for project delivery method selection; (4) percent design complete before constructor engagement; (5)

procurement process; (6) compensation type; and (7) duration between request for proposal (RFP) and contract award date.

2.5.1 Project Team Past Experience

A 5-point Likert scale measured respondents' opinions on the project team's past experience with the selected delivery method. This included: (1) utility experience; (2) constructor experience; and (3) designer experience. The 5-point Likert scale was labeled to have 1 represent "no or few previous projects completed" to 5 represent "having completed many previous projects."

Both the K-S and Shapiro-Wilk test revealed that the data collected for all three project team experience categories was not normally distributed (*p*-value <0.01). This permitted the use of the Kruskal-Wallis test to determine if there are any statistically significant differences between the delivery methods. The differences for utility experience, constructor experience, and designer experience were observed to be statistically significant (*p*-values less than 0.05), as shown in Table 1.

Table 1: Results of Kruskal-Wallis Test for Project Team Past Experience

Category	Delivery Method	Sample Size	Mean Value (Scale 1 to 5)	Median Value (Scale 1 to 5)	*p*-value
Utility Experience	DBB	25	4.92	5	<0.01*
	CMAR	27	2.89	3	
	DB	23	2.70	2	
Constructor Experience	DBB	25	4.96	5	<0.01*
	CMAR	27	3.85	5	
	DB	23	4.17	4	
Designer Experience	DBB	25	4.84	5	<0.01*
	CMAR	27	4.19	5	
	DB	23	4.09	4	

**Statistical significance at p-value <0.05*

These findings entail that utilities are statistically far less experienced with the APDM, as CMAR and DB have average utility experience scores of 2.89 and 2.7 respectively; compared to DBB projects where the average utility experience score is 4.92 out of 5. Constructor experience and designer experience also followed the same trend. Similarly, to Francom et al. (2016b), where DBB was revealed to have the largest market share in the trenchless industry, this study showed that utilities are statistically more experienced in delivering their projects using DBB in water industry as well.

2.5.2 Delivery Method Comfort Level

The study explored utility comfort level (e.g., having the required staff with the availability, experience, and capability/training needed) with their project's chosen delivery method. DBB projects had the highest frequency related to delivery method comfort level at 96%, followed by DB at 95%, and CMAR at 85%. The values underwent statistical testing to reveal if these differences were statistically significant. Both the K-S test and Shapiro-Wilk revealed that the data was not normally distributed (p-value <0.01), subsequently the chi-square test was used and resulted in a p-value of 0.01. This indicated that the differences were statistically significant and that utilities statistically have lower comfort levels delivering their water infrastructure projects using CMAR. These results are in parallel with that of Francom et al. (2016a), where respondents also expressed the highest level of comfort level in using DBB for their trenchless projects and the lowest comfort level in using CMAR.

2.5.3 Factors for Project Delivery Method Selection

There are several factors that influence project delivery selection and potentially make one delivery method more favorable to a utility over another for a given project. Respondents were asked to identify selection factors that motived the selection of their project's delivery method. The selection factors cited in this study were developed by first identifying key selection factors from the literature and then further developing a list of factors during the industry expert workshop. For example, some of the selection factors of this study included: expedited schedule; utility's experience with delivery method; cost certainty; and other (e.g., project team approach; improved lifecycle costs). Figure 2 shows the compiled selection factors for all collected responses.

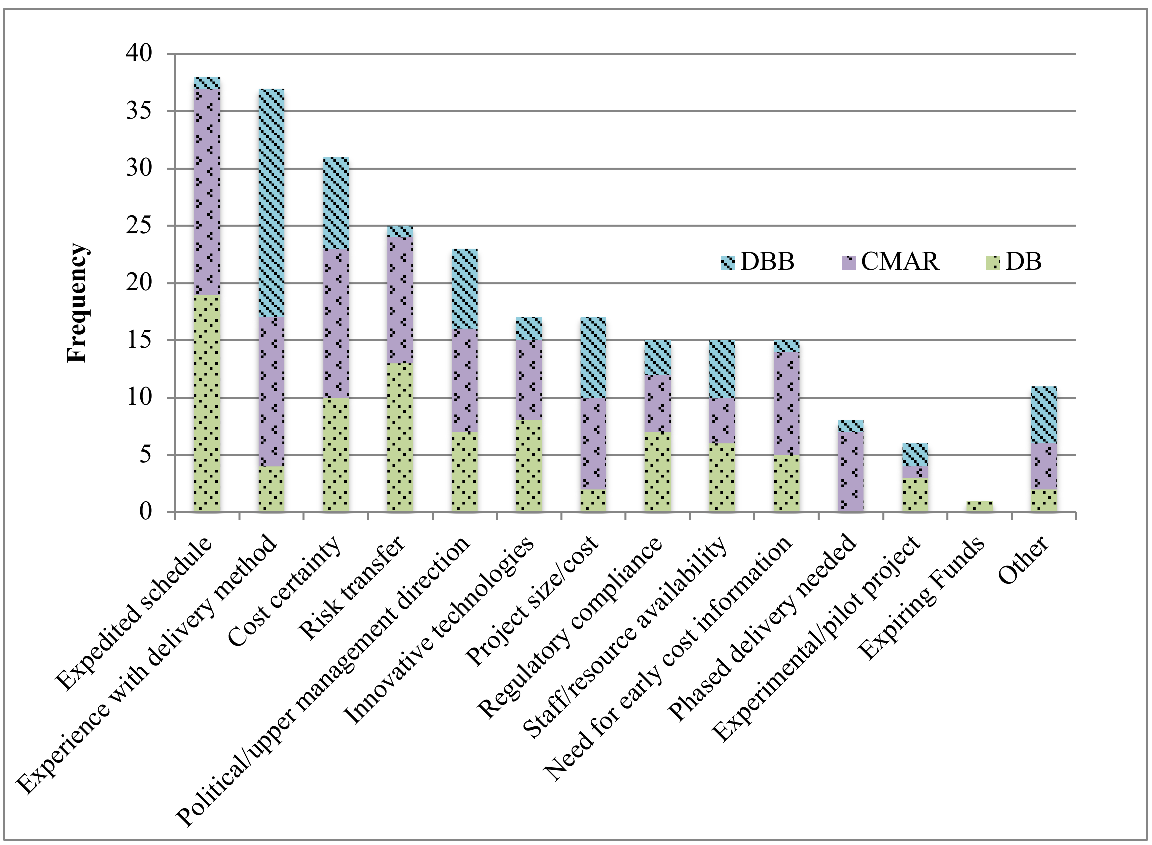


Figure 2: Factors for Project Delivery Method Selection

The selection factor with the highest frequency amongst all three delivery methods was "expedited schedule", and 97% of the respondents that selected this factor represented an APDM project. 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 and is the method that utilities are most experienced in managing (Minchin et al. 2010). Respondents that shared information on their CMAR and DB projects in this study also selected their respective delivery methods due to factors such as: (1) transferring risk; (2) using innovative technologies; (3) strict regulatory compliances; (4) a need for early cost determination; and (5) requiring phased project delivery. These factors for APDM selection are aligned with the findings of the literature and are mentioned as key advantages of APDM for water infrastructure projects (Rao 2009; Bogus et al. 2010; AWWA 2010).

2.5.4 Percent Design Complete Before Constructor Engagement

Respondents were asked to provide the percentage of design completion before constructor engagement for their respective projects. This data was plotted using a boxplot, where the median (horizontal solid lines) and mean (black diamond) are identified, as shown in Figure 3.

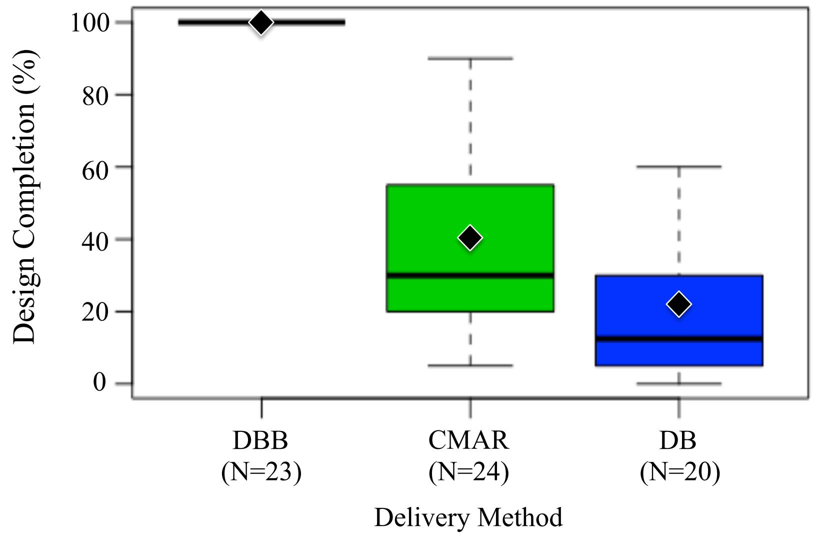


Figure 3: Design Completion Before Constructor Engagement.

The results indicated that the average constructor is typically engaged at 100% design completion for DBB, earlier in the design phase for CMAR (39%), and at an even earlier stage for DB (22%). The data is aligned to the literature and shows that constructors are engaged earlier in the design phase for APDM projects, which allows the utility to leverage the constructor's experience during design (El Asmar et al. 2013).

2.5.5 Procurement Process

It is important for utilities to identify the most appropriate procurement process, based on their project's internal and external influencing factors, before selecting the most suitable project delivery method for their project. Procurement processes options included: (1) low bid; (2) best value; and (3) qualifications-based. The respondents' selected procurement processes are illustrated in Figure 4. Low bid is the most popular procurement process for DBB in this study, as nearly 75% of DBB projects opted for this process. It is important to note that all CMAR and DB projects did not utilize low bid procurement at all, and opted for qualification-based or best value procurement. For APDM projects in this sample, qualifications-based was the clearly favored procurement process representing 76% of the collected responses, followed by best value for the remaining 14%.

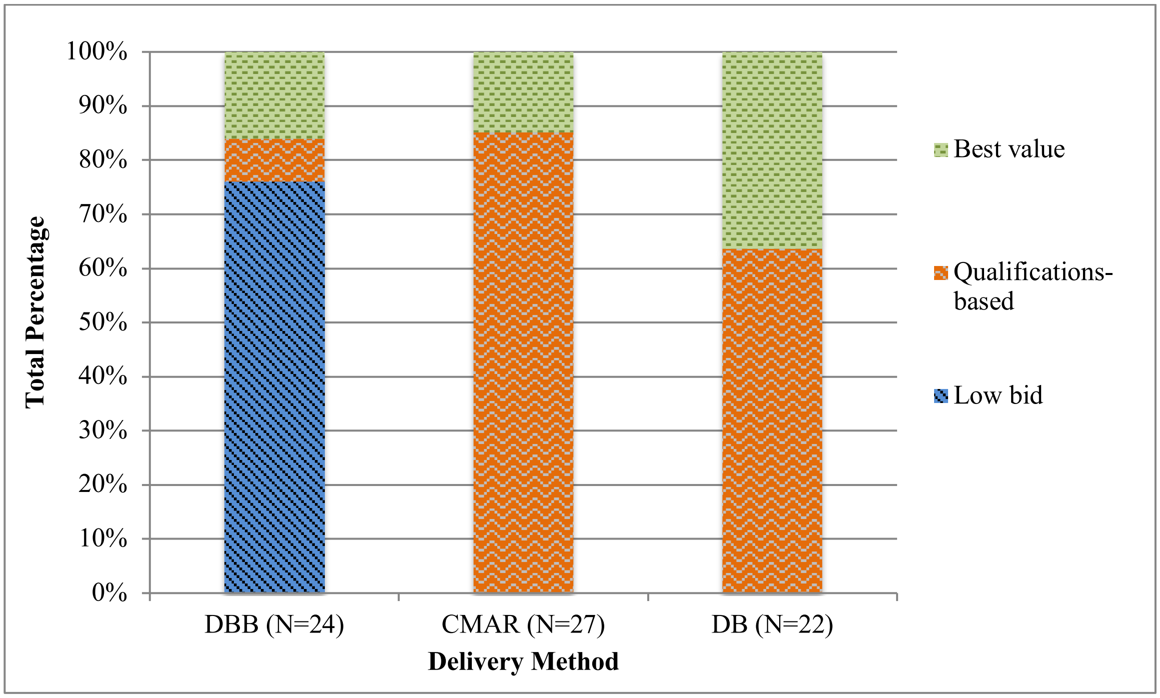


Figure 4: Procurement Process

The results of this study are different from the findings of Shrestha et al. (2016), where best value (57%) was the highest selected procurement method for APDM projects of their sample, followed by qualifications-only procurement (31%). These differences may show that water utilities are now shifting their APDM procurement decision basis from having a bid price component, to one that is focused on qualifications without factoring in the bid price.

2.5.6 Compensation Types

Similarly to selecting the appropriate procurement type, the project team must have the most suitable compensation type(s) for the payments of their contracts. Selection options of compensation types included: (1) unit price; (2) lump sum; (3) negotiated; (4) guaranteed maximum price (GMP); (5) cost plus percentage; and (6) cost plus fixed fee. A frequency chart of compensation types used for each delivery method is illustrated in Figure 5. The respondents used combinations of compensation types, with some utilities choosing a mixture of two or three different types.

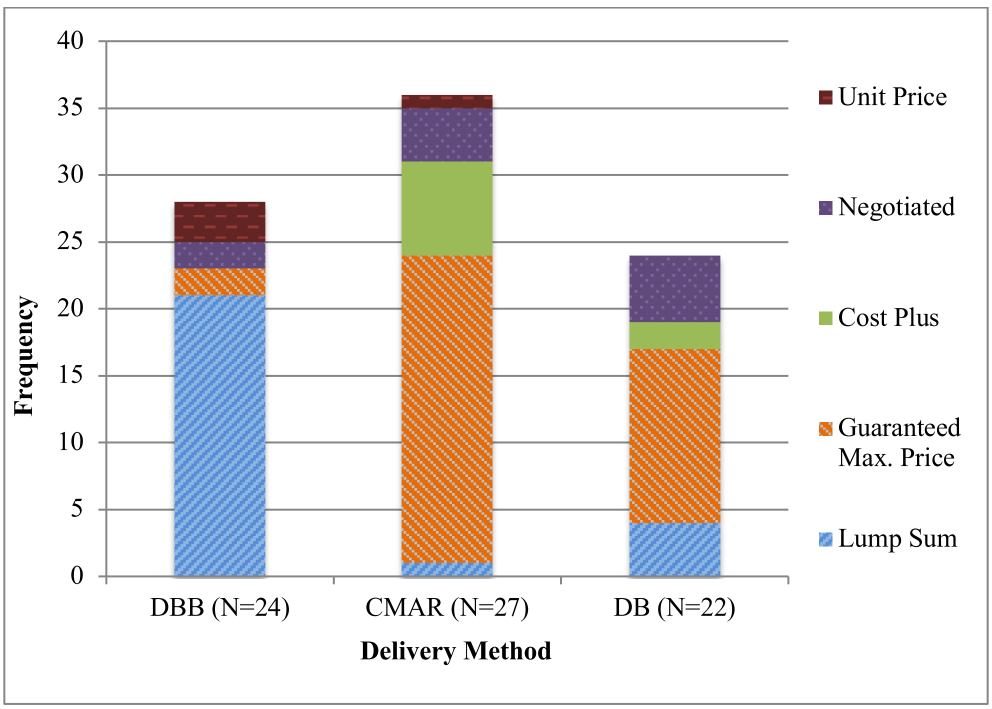


Figure 5: Compensation Types

Utilities that selected DBB clearly favored the lump sum method, with 84% DBB projects opting for this mode of compensation. Cost plus compensation was selected for both CMAR and DB, but was not chosen for any of the DBB projects. Additionally, using a GMP was the most popular compensation type chosen for the APDM projects in this study, with about 85% of CMAR projects and 60% of DB projects choosing this compensation type. Utilizing a GMP as a compensation type for APDM projects is in parallel to the literature, as a study by Bogus et al. (2010) determined that APDM projects that used a GMP performed better in terms of schedule and cost growth than those that used a lump sum contract.

2.5.7 Duration between Request for Proposals and Contract Award Date

Procurement duration, between the request for proposals (RFP) solicitation and the contract award date, was examined across the delivery methods, as shown on Figure 6. The authors conducted the non-parametric Pearson's chi-square to explore if there are statistically significant differences in procurement duration between the three delivery methods. The results of this test resulted in a *p*-value of 0.967 (greater than 0.05) and did not show any statistically significant differences,. This result confirmed that no delivery method contained a faster procurement duration within this sample.

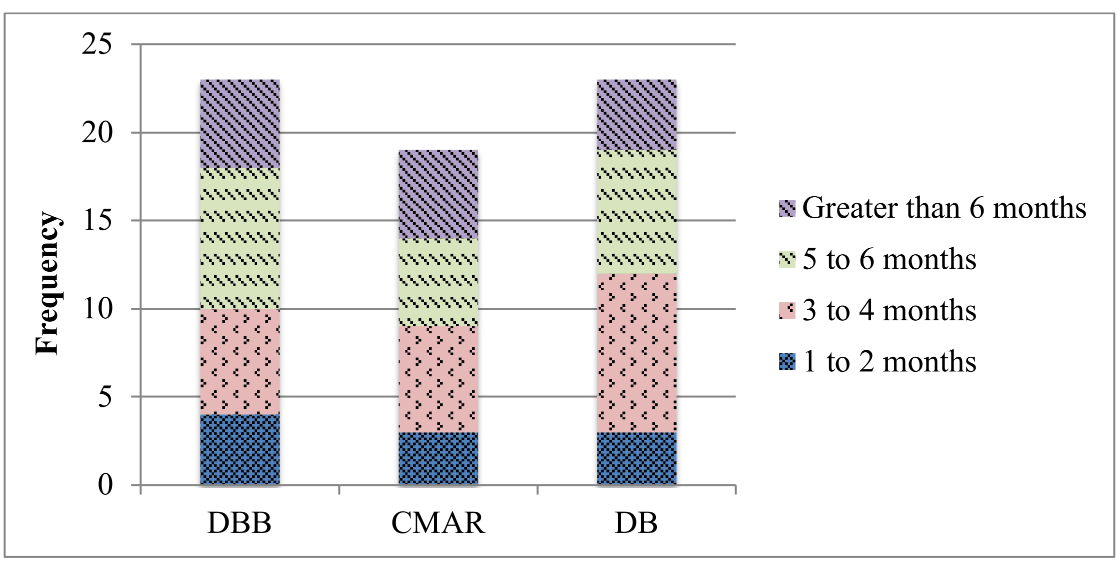


Figure 6: Duration Between RFP and Contract Award Date

Unlike the studies by Rao (2009) and AWWA (2010), which revealed that a disadvantage of DB is that it requires a longer procurement duration; this study was capable of showing that the differences between the three delivery methods in terms of procurement duration were not statistically significant and that APDM water infrastructure projects do not require a longer procurement duration than that of DBB.

2.6 State of Practice on Water Infrastructure Execution

State of practice of water infrastructure execution comprises of several factors that influence project delivery. Five key factors of the state of water infrastructure execution will be discussed. There five factors are: (1) project contingency; (2) utility administrative and oversight costs; (3) project complexity; (4) utility involvement, communication, and satisfaction; and (5) driving metrics for successful project delivery.

2.6.1 Project Contingency

Total project contingencies were examined across the delivery methods of interest from the sample of 75 projects. The average total project contingency of DBB projects was 6.4%, 5.9% for CMAR, and 4.6% for DB. This contingency was either shared by the utility and the contractor (e.g., utility's contingency equal to 75% of total contingency and contractor's contingency accounting for the remaining 25%), or solely allocated as part of the utility's contingency. The K-S test and Shapiro-Wilk test indicated that the data for total project contingencies was normally distributed (p-value>0.05); therefore, the ANOVA test was used to determine if there are any statistically significant differences between the delivery methods. The ANOVA test resulted in a p-value of 0.129, demonstrating that the differences were not statistically significant. However, in terms of the raw data, these findings show that DBB had the highest average percentage of total project contingency, specifically about 2% more than that of DB. These results are aligned with the literature, a study by Collins and Parrish (2014), evaluated that contingencies allocated by DBB project owners have been observed to be less than sufficient to cover shortcomings that arise on a DBB project. Due to the lack of project team collaboration and constructor input, higher contingencies must be put in place on DBB projects to protect the project from the risk of claims, delays, and unknowns. On APDM projects, these savings in project contingencies may be used to deliver a higher quality project.

2.6.2 Utility Administrative and Oversight Costs

The utility's administrative and oversight cost was also examined between the three delivery methods. However, in terms of the raw data, the average owner overhead and administration cost was highest for DBB at 6.3%, followed by DB at 4.2%, and CMAR at 3.1%. The K-S and Shapiro-Wilk test indicated that the data was not normally distributed (p-value <0.05); therefore, the Kruskal-Wallis test was used. The test resulted in a p-value of 0.338, meaning that the differences were not statistically significant. However, in terms of the raw data, these findings are aligned with the literature. Culp (2001) discusses that the benefits of APDM include hiring the design-builder or CMAR firm based on their qualifications. This allows the utility to hire project team members based on their personnel, past experience on similar projects, and project approach (Culp 2011). APDM also allow room for transferring project risks to the party that is best suited to handle it. These benefits allow utilities to reduce their direct costs associated to administrative staff and oversight for their projects. Similarly to the APDM-related savings in project contingencies mentioned earlier, these savings can also be used to deliver a higher quality APDM project.

2.6.3 Project Complexity

Respondents selected project complexity issues that were encountered either during the delivery their respective projects. The authors wanted to observe if specific complexity issues were more or less common depending on the delivery method chosen. The survey selection choices consisted of a diverse range of 16 internal and external issues, which were developed and validated through the industry expert workshop. The respondents were presented these 16 complexity issues and requested to select the issues that are applicable to their projects. The compiled results obtained from the survey are shown in Table 2.

Table 2: Observed Project Complexity Issues

Complexity Issues	DBB (N=25)	CMAR (N=27)	DB (N=22)
Integration to Existing Systems	88%*	67%	50%
Operational Constraints	80%	63%	59%
Schedule Constraints	48%	82%*	68%*
Project Size/Cost	76%	67%	46%
Constructability Challenges	60%	52%	50%
Project Footprint	60%	56%	23%
Permitting	56%	22%	55%
Plant Capacity	64%	26%	36%
Aggressive Scheduling	16%	44%	55%
New Technology	32%	33%	41%
Environmental Constraints	20%	33%	41%
Weather Constraints	20%	26%	32%
Challenging Project Participants	20%	11%	36%
Project Location	20%	22%	23%
Market Constraints	4%	4%	9%
Litigation	4%	4%	5%

**Highest frequency of complexity issues per delivery method*

For DBB projects "integration with existing systems" was the highest frequency issue of complexity for this delivery method. This finding reveled that 88% of all DBB projects from this sample reported complexity issues with integration to existing systems either during their respective project's procurement or execution. In line with the literature, a noted disadvantage of DBB is the minimal input from constructors and facility operators during the design phase (Dahl et al. 2005); this lack of collaboration can lead to potential challenges related to existing systems integration during the project delivery process. The most common complexity issue faced for APDM projects in this study was "schedule constraints." Additionally, "aggressive scheduling" was reported for 44% of CMAR projects and 55% of DB projects, compared to only 16% of DBB projects. The obtained values are consistent with the literature that states that APDM are ideal for projects that require aggressive scheduling (Shrestha et al. 2018).

2.6.4 Utility Involvement, Communication, and Satisfaction

A utility's involvement in design was gauged, with 1 representing "no or little involvement" to 5 representing "significant involvement." Respondents' perception of overall stakeholder communication in their project was also measured, with 1 representing "no or little communication" to 5 representing "significant communication." Utility satisfaction with the project was assessed with 1 representing "extremely unsatisfied" to 5 representing "extremely satisfied."

Similarly to the statistical rigor used earlier to gauge project team past experience, the K-S and the Shapiro-Wilk test indicated that the data was not normally distributed for these categories (p-value<0.01). Therefore, the Kruskal-Wallis test was used to determine if there are any statistically significant differences between the delivery methods. The differences in the utility's involvement in design were observed to be statistically significant, as shown in Table 3.

Table 3: Results of Kruskal-Wallis Test for Utility Involvement, Stakeholder Communication, and Utility Satisfaction

Category	Delivery Method	Sample Size	Mean Value (Scale 1 to 5)	Median Value (Scale 1 to 5)	*p*-value
Utility Involvement in Design	DBB	25	4.56	5	0.032*
	CMAR	27	4.44	5	
	DB	23	3.83	4	
Utility Involvement in Construction	DBB	25	4.04	4	0.504
	CMAR	27	4.11	4	
	DB	22	3.77	4	
Stakeholder Communication	DBB	25	4.00	4	0.972
	CMAR	27	3.96	4	
	DB	23	4.05	4	
Utility Satisfaction	DBB	25	4.42	4	0.227
	CMAR	27	4.19	4	
	DB	23	4.57	5	

**Statistical significance at p-value <0.05*

These results revealed that utilities that deliver their projects using DB are statistically less involved in the design process when compared to DBB and CMAR projects. This finding is in parallel to the literature, as DB allows utilities to transfer design liability to the design-builder and enables them to be less involved in the design-phase (Culp 2011). This study quantified this metric for water infrastructure projects.

No statistically significant differences were observed for overall stakeholder communication (Table 3). However, in terms of the raw data, all delivery methods had an average score of about 4; potentially implying that stakeholder communication is not a major drawback for any specific delivery method. Similarly, no statistically significant differences were observed for utility satisfaction, possibly indicating that all delivery methods could lead to successful projects that meet their utilities' expectations.

2.6.5 Utility's Driving Metrics for Successful Project Delivery

The intent of this investigation was to identify key driving metrics for successful project delivery after project completion. These metrics were assessed for water infrastructure project, regardless of the selected delivery method. Industry experts defined the need to conduct this investigation during the workshop and supported the authors in developing the survey questions' selection choices for this question, which included: utility involvement; project functioning to specifications; early cost certainty; reduced cost; safety; and more. The results of the 75 responses were compiled and are shown in Figure 7. The driving metric for successful project delivery that contained the highest frequency was "project functioning to specifications (61 responses)", followed by "utility involvement (51 responses)", and "time to completion (50 responses)." These findings are aligned with the literature, a study by (Hwang and Lim 2013) ranked the top critical success factors for construction projects as: (1) as adequacy of place and specifications, followed by (2) adequate planning and control techniques (for cost and time).

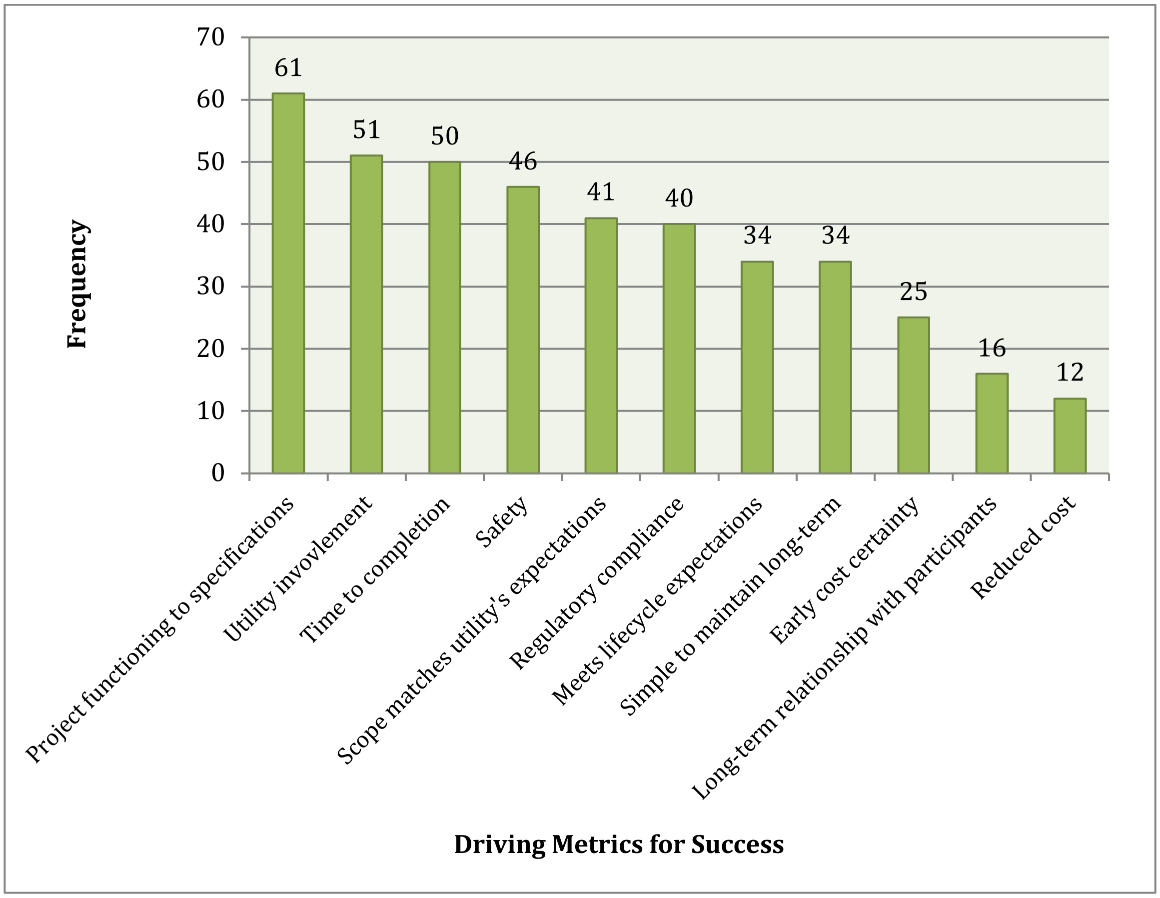


Figure 7: Driving Metrics for Successful Project Delivery

The results of this study indicate that utilities' uppermost criterion of success is having the project meet its specifications. Reasonably, this criterion is more critical than having a well performing project that is under schedule or budget, but far from the expectations and specifications of the utility. Respondents in this study provided information on their perception of plant maintenance and reliability after project execution. The analysis of the data showed that almost the majority of DBB, CMAR, and DB project respondents: (1) considered that their treatment plants are functioning according to specifications; (2) do not require more than reasonable or normal amount of maintenance; and (3) meet the utility's expectations with respect to life cycle costs (e.g., O&M costs of the plant). However, only one CMAR and one DB project respondent faced maintenance issues with specific equipment (e.g., solid transfer equipment malfunction) at their plant. These responses indicated that all delivery method may deliver a project that may meet a utility's expectation for plant maintenance and reliability. It also indicates that specific issues that arise may have not stemmed from the utility's choice of delivery method.

Additionally, to gauge uncertainty in the project delivery process, this study measured total changes for each project as a total percentage out of 100% of all changes. These sources for project-related changes were grouped 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. In terms of owner-driven changes, DB had the highest average percentage of changes at 71.45%, followed by CMAR at 53.10%, and DBB at 45.90%. For contractor-driven changes, CMAR had the highest average percentage at 18.19%, with 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%, 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%. The reason for DBB having the highest percentage of changes due to unforeseen or external conditions, when compared to APDM projects, may be due to the lack of a collaborative environment (especially during the early project development stage). APDM allow the builder to be engaged earlier in the design process and offer the utility valuable preconstruction services. Moreover, these findings are in line with the literature, which reveals the ability of cost and schedule uncertainty to be reduced in through the utilization of an APDM approach (Sullivan et al. 2017).

2.7 Conclusions

This study presented critical information on APDM implementation practices for water infrastructure projects by assessing APDM state of practice during procurement and execution. Utilities need to select the most appropriate delivery method for their infrastructure projects and this study contributes to the body of knowledge by providing water industry stakeholders with quantifiable results of current industry practices. Key findings revealed in this study specific to APDM water infrastructure delivery include: (1) guaranteed maximum price (GMP) is the preferred compensation type; (2) qualifications-based is the preferred procurement method; (3) expedited schedule is the highest selection factor; (4) utilities having the least experience with the DB method; (5) water stakeholders statistically have the lowest comfort level using CMAR; (6) owner involvement in design is lowest for DB projects; and (7) DBB and APDM have similar procurement durations for water infrastructure projects.

This study contributes to the existing body of knowledge by presenting evidence-based APDM implementation practices that may support utilities with the delivery of their water infrastructure projects. Findings of this study revealed that different delivery methods have unique characteristics that amplify their applicability and opportunities for success. Decision-makers must be aware of all internal and external factors, unique to this industry, which may influence their delivery method selection decisions before initiating a project. A limitation of this study is that the sample size analyzed may not be representative of the entire water industry. Future work can build on this study's findings and collect information from a larger sample size of completed water and wastewater treatment plant projects.

CHAPTER 3

DESIGN-BUILD PROJECT ADMINISTRATION PRACTICES FOR THE WATER INDUSTRY

3.1 Introduction

It has become well accepted that water infrastructure in the United States is aging and requires replacement (ASCE 2017). Pipeline deterioration and failure have significant safety and economic implications to the general public; therefore, utilities may need to seek integrated and innovative solutions to avoid these challenges. Moreover, rapid urbanization and population growth also contributes to the increase of water demands. As a result, the renewal and development of water infrastructure assets becomes a requirement of water utilities.

An innovative approach utilities are using to address increasing project delivery challenges is by identifying and implementing appropriate alternative project delivery methods (APDM), such as job order contracting (JOC), construction management at-risk (CMAR), and design-build (DB). Water utilities were traditionally required to deliver their projects using the traditional design-bid-build (DBB) method. However, changing public policies and state legislation have allowed APDM to gain popularity, mainly as a result of their ability to optimize risk management, improve cost efficiencies, and accelerate project schedules.

Numerous research studies have specifically shown the project delivery performance benefits of utilizing DB for the delivery of water infrastructure projects. Bogus et al. (2010) studied 47 completed water projects and revealed that the average schedule growth for DB projects (one month) was half of the schedule growth for DBB projects (two months). Shrestha et al. (2018) interviewed 109 utility managers, project staff, and policy makers in the water industry to compare the performance of DB and CMAR projects. Results of the study indicated that DB water projects experienced lower cost growth (0.26% vs. 2.44%) and schedule growth (0.65% vs. 1.06%). Francom et al. (2016a) collected data on 10 completed DB trenchless projects and revealed that DB projects exhibited an average cost savings of 33%. Additionally, the authors found that DB had the highest comfort level for APDM pipeline projects.

Two key characteristics generally distinguishing project delivery methods are: (1) the contractual relationships between key project stakeholders; and (2) their timing of engagement in the project (El Asmar et al. 2013 and 2016; Molenaar and Franz 2018). DB is unlike the traditional DBB method, as the utility only deals with one entity that is responsible for both the design and the construction of the project (Molenaar and Songer 1998). In DB, the design-builder is engaged early in the design phase and provides the utility valuable preconstruction services. Design-builders are typically procured based on their qualifications and technical expertise through a request for qualifications (RFQ). For water projects that have challenging design and construction requirements due to complex equipment and technologies, RFQs allow utilities to evaluate potential design-builders and select the most qualified for the job (Culp 2011). In summary, design-builders are selected through an evaluation of their qualifications; whereas constructors of DBB projects are often awarded a project based solely on their bid price.

Many utilities now have several project delivery methods to select from for their water infrastructure projects. Research studies have also shown the project delivery performance superiority of DB on water projects. Therefore, as the DB method continues to grow in use within the water industry, it is essential to identify effective DB project administration practices that can assist utilities seeking to add DB to their organization's project delivery toolbox. The objective of this study was to present proven water industry specific effective DB project administration practices. In order to highlight the most successful and prominent DB practices, elaborate interviews were conducted with utilities that have extensive experience delivering their projects using DB. The study also aimed to examine proven effective DB administration practices across the entire DB project delivery process, ranging from procurement, design, construction, and operations and maintenance.

3.2 Review of Water Industry Design-Build Project Administration

The literature review assessed the current body of knowledge for DB project administration in the water industry and examined academic publications and industry guides that discussed DB project administration practices. The literature review was conducted to inform the development of an interview protocol for this study.

3.2.1 Design-Build Administration Literature in the Water Industry

This section of the review assessed current DB administration literature in the water industry and highlighted key DB administration practices. Overall, six studies were examined with the majority focusing on case studies with a limited sample size of DB projects.

Molenaar et al. (2004) conducted a survey and case studies on three completed water and wastewater treatment plant projects and aimed to benchmark DB best practices for the water and wastewater industry. In their study, the authors identified an extensive list of best practices that may assist owners and practitioners using DB for the first time. A selection of DB best practices included: (1) identifying risks early on and allocating them appropriately; (2) using best-value evaluations; and (3) requesting that regulators provide partial approvals before design is 100% complete. The authors of this study focused on a limited sample of completed DB water infrastructure projects.

Hill et al. (2007) conducted a case study on the San Diego County Water Authority 100 MGD Twin Oaks Valley Water Treatment Plant. The project used the design-build-operate (DBO) delivery method. The paper presented the challenges faced and lessons learned from the designer, contractor, and pipe suppliers' point of view during the design and construction of the large diameter yard piping for the facility. A lesson learned from the use of DBO on this project included conducting plant inspections at the beginning of pipe fabrication and not after completion. This study shared lessons learned of a single DBO water project.

The Design-Build Institute of America (DBIA) (2015b) released DB best practices for the water and wastewater industry and highlighted the main differences of managing DB project delivery in the water industry compared to other industries. A selection of best practices consisted of: (1) using a competitive DB procurement that establishes an evaluation and selection process that is fair, open, and transparent and that values both technical concepts and price; (2) having all DB team members educated and trained with the DB process; and (3) developing a process to facilitate timely and effective communication, collaboration, and issue resolution at the beginning of the project. A comparison with DBIA's best practices with the findings of this study will aim to reinforce the development of effective DB practices for the water industry.

The Water Design-Build Council (WDBC) (2016) developed a handbook to assist owners and design-builders in the water and wastewater industry in facilitating a successful DB project. The handbook shares several DB best practices across the project delivery timeline, which included: (1) performance warranties in the DB contracts, which guarantees to the owner that the project will meet owner-defined specifications; (2) encouraging communication between the project teams through different platforms to manage project documentation, such as building information modeling (BIM), site visits, meetings, and electronic document-control systems; and (3) having the DB team prepare the operations and maintenance (O&M) manuals, through online submittals and hard copies, and conducting the required training of the O&M staff before handover. Similar to DBIA (2015b), a comparison with WDBC's DB practices with the study's findings will further support the development of effective DB practices for water projects.

The Washington State Capital Project Advisory Review Board (WSCPARB) (2017) published guidelines defining DB best practices to be used by Washington State public agencies. A selection of these DB practices consisted of: (1) the use of an external consultant team to support in developing the project criteria and in managing the RFQ and RFP (request for proposals) process; (2) the project team should discuss and identify the anticipated level of owner involvement after agreement on a project's final design and cost; and (3) using an owner's contingency of at least 5% of the project budget to accommodate for unknown project conditions and changes. The WSCPARB (2017) guidebook identified DB best practices across all industries and was not specific to the water industry.

In a study by Feghaly (2018), the author examined APDM (CMAR and DB) in the water industry by conducting a survey on 75 completed water projects. The author observed, on average, a design-builder was first engaged at 22% of a DB project's design completion. Moreover, qualification-based procurement was the most selected procurement method for DB projects (about 60%) and guaranteed maximum price (GMP) was the most used compensation type for DB projects (about 60%). This study did not highlight specific effective DB project administration practices for the water industry.

Shrestha et al. (2020) conducted interviews with 15 project managers in the water and wastewater industry to capture lessons learned in CMAR and DB project delivery. The authors specifically asked the respondents on how APDM projects can be procured and executed in a method that reduces project disputes or claims. A selection of key positive lessons learned included procuring the CMAR or DB team based on qualification and having owners involved in the design phase. This study focused on disputes and claims reduction for APDM water projects.

3.2.2 Other Important Design-Build Literature in the Water Industry

This section reviews other important DB related literature in the water industry. Three studies were identified and detailed in the following paragraphs. Key DB literature that may not be DB administration specific, but is significant to the development of the interview protocol for this study, is detailed in the paragraphs below.

Rao (2009) conducted a case study analysis of four water treatment plants in California and noted several benefits of using DB delivery over traditional DBB in the water and wastewater industry. These benefits involved: (1) single source responsibility for design and construction; (2) lower life cycle costs; and (3) schedule compression. This study shared advantages of DB delivery, but did not identify DB project administration best practices.

Comstock (2011) discussed the use of DB to build a water reuse facility on the Johns Creek Environment Campus. Project limitations included site constraints, stringent guarantees, effluent limits, and a long-term reuse plan. The author claimed that all objectives were achieved through the use of DB, with benefits including a collaborative design and construction team, time and money savings, and reduced costly disputes between designers and contractors. This study focused on lessons learned of a single DB water project.

Gates et al. (2015) interviewed utilities to elicit the lessons learned using APDM (such as DB) over traditional DBB for water projects. The authors reported the benefits of using APDM resulted in higher quality projects, increased communication among the parties, incorporated innovative ideas into the project, reduced the number of claims and change orders, and promoted a smooth transition of the constructed project to the operations team. This study did not identify best practices for DB project administration in the water industry.

After completing the literature review, the authors acknowledged that DB use in the water industry is growing. Although the body of knowledge on DB procurement is rich, literature on DB project administration for water infrastructure is limited, especially for water transmission pipeline projects. This gap in the literature motivated the authors to identify effective DB project administration practices that can assist water utilities seeking to add DB to their organization's project delivery toolbox. A selection of key DB benefits that were identified in the literature consisted of improved: (1) project team communication; (2) project delivery cost and schedule performance; and (3) risk transfer and management. The authors documented these key findings and aimed to develop an interview protocol that can highlight effective DB practices used by water utilities to achieve these benefits. In the following section, the authors detail the research methodology used to achieve the study's objective.

3.3 Research Methodology

The research team conducted structured interviews with experienced water utilities that have successfully delivered their water infrastructure projects using DB. The research methodology for this study consisted of five steps, as seen in Figure 8.

Figure 8: Research Methodology

A review of the literature was first conducted, assessing both academic and industry publications. The literature review served as the foundation for the development of an interview protocol and as a source of comparison to the DB practices highlighted in this study. Subsequently, the research team compiled a list of water utilities to administer an initial screening survey to identify experienced utilities in DB delivery. A comprehensive interview protocol was developed to organize the data collection process. The protocol was organized into seven different categories, based on an extensive review of the literature and support of four industry experts. The final interview protocol consisted of 67 questions. Interviews were conducted with ten utilities that were identified to be experienced with delivering DB water infrastructure projects. Finally, the data was analyzed using thematic content analysis, a research method for qualitative analysis. The analysis advanced the research team's efforts to quantify the qualitative data obtained and reported findings on the most effective DB project administration practices for the water industry.

3.3.1 Initial Screening Survey

An initial survey was developed to screen potential water utilities to interview, allowing the research team to identify the most experienced utilities in DB delivery. The survey was designed to be user-friendly and to be completed in less than one minute. The survey consisted of three questions and inquired respondents on the following: (1) the amount of DB projects a respondent's organization had completed so far; (2) the number of projects the respondent had been personally involved in; and (3) the respondent's willingness to provide further information on their utility's DB project administration practices.

The research team acquired participant rosters from several national water infrastructure conferences. In total, 181 potential respondents from more than 100 water and wastewater utilities were identified. Individuals on the initial list included industry experts who contribute to the project delivery decisions of their utility. The screening survey was administered online using the Qualtrics survey platform over a three-week period, to which 21 individuals responded (response rate of about 12%).

3.3.2 Development of the Interview Protocol

Interviews are typically conducted when performing qualitative research and when the researcher is exploring attitudes, behaviors, and experiences of interviewees (Dabbs 1982). According to Rowley (2012), interviews are valuable when: (1) the research objectives center on understanding experiences, opinions, attitudes, values, and processes; (2) there is insufficient knowledge about the subject to be able to draft a questionnaire; and (3) the potential interviewees might be more receptive to an interview than other data gathering approaches. Interviews are generally classified based on their level of structure. The researchers conducted semi-structured interviews for this study. Semi-structured interviews vary in design, quantity, presentation, and structure of the interview questions based on how an interview is unfolding (Rowley 2012).This structure was selected as different utilities will have varying approaches for delivering their DB projects, and some questions in the protocol may or may not be applicable to their utility.

The research team first developed a list of 30 potential interview questions relating to key DB practices mentioned in the literature. These interview questions were vetted through the support of four water industry experts. The industry experts have extensive experience delivering water infrastructure projects from their respective utilities and play a crucial role in their utilities' decision-making process (e.g., project managers; senior engineers). The experts supported the research effort by providing valuable industry insight and aggregated the interview questions under eight DB project administration specific categories related to the various components of a DB project's delivery. The categories consisted of: (1) procurement; (2) DB roles and responsibilities; (3) risk and quality assurance; (4) design; (5) design review; (6) cost and schedule estimates; (7) submittal and submittal review; and (8) communication and information flow. The industry experts reviewed each question carefully and validated its composition and necessity.

During the interview protocol's final review stage by the authors and the industry experts, the eight categories were reduced to seven, due to the merging of two similar categories ("Category 4: design" and "Category 7: submittal and submittal review" formed one new category called "design and submittal review"). The industry experts also supplemented the interview protocol by adding additional questions that highlight specific valuable DB practices. The final interview protocol consisted of 67 questions organized into seven key categories, each consisting of several specific subcategories. By identifying subcategories within the larger categories, the research team honed in on a diverse set of specific DB practices. Table 4 shows a summary of the seven key categories and their respective subcategories.

Table 4: Summary of Interview Protocol Categories and Subcategories

Key Category	Subcategories of Interest	Number of Questions
Procurement	• In-house design completion • Design and construction management services • Percentage of total costs allocated for design • Project delivery method selection process • Procurement method, proposal evaluation, and basis of price • Selection of subcontractors • Compensation types • Incentives/Disincentives • Owner and contractor contingencies	16
DB Roles and Responsibilities	• Project team size • Key staff and roles • Distribution of responsibility with design-builder • Owner level of involvement and control • Responsibility matrices • Public relations • Permitting • Substitution of DB team members	11
Risk and Quality Management	• Development of risk assessment skills and risk registers • Inspections • Quality assurance and quality control • Specifications	7
Design	• Scope validation • Geotechnical and environmental investigations/reports • Technical specifications and Design package standards • Sustainable design and innovative technologies	9
Design and Submittal Review	• Consistency of design review • Level of design review • RFI and submittal review process • Streamlining the submittal process	10
Cost and Schedule Estimates	• Schedule of cost estimates and GMP • Schedule development • Pre-Construction cost control	6
Communication and Information Flow	• Stakeholder collaboration and co-location of project team • Minimizing impact on existing operations • Handover of operation manuals, as-built drawings, and warranties • Knowledge transfer and lessons-learned	8

3.3.3 Data Sources

After concluding the initial survey screening process, utilities experienced with DB were identified and contacted to schedule interviews. The research team found excellent and diverse experiences in the identified group of utilities and succeeded in interviewing ten utilities (seven public and three private) with DB projects in 13 states across the US and in the Canadian province of Alberta, as shown in Figure 9.

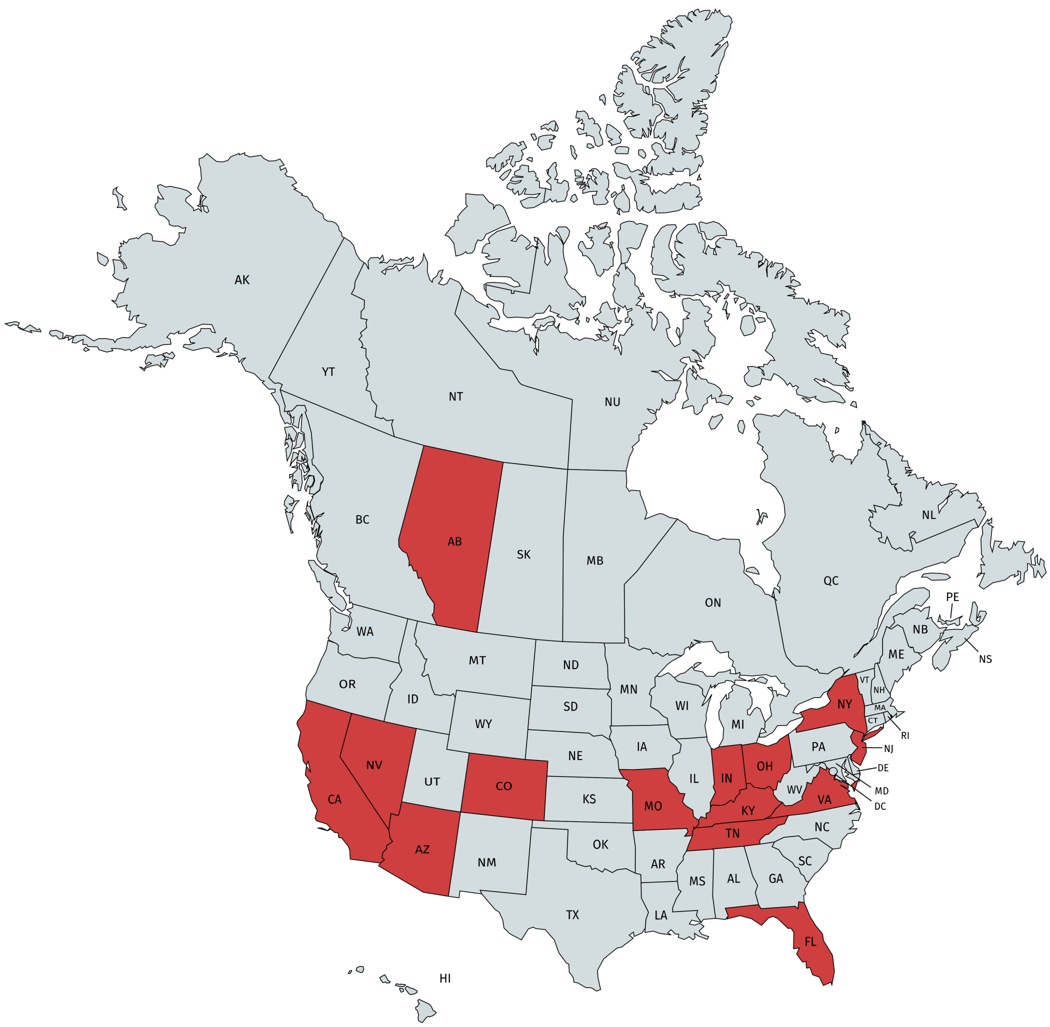


Figure 9: Represented States/Territories in the United States and Canada

The number of DB projects delivered by the utilities ranged from four completed DB water projects to over 30 completed DB water projects. In order to capture the most effective DB project administration practices used by these utilities, the interview process included simultaneously meeting with a number of a utility's key staff, such as: project managers, senior executives, contract administrators, and utility engineers. The interviews were conducted in a face-to-face setting at the utilities' workplace or via a video/phone conference call, depending on the respondent's availability and geographical location. Two interviews were conducted face-to-face at the utilities' workplace, with the remaining eight interviews conducted over a video/phone conference call. The interview duration averaged one hour. During the interview process, the research team directly transcribed the responses to all questions through the support of commercial software.

3.3.4 Data Analysis Approach

Numerous methods can be used to analyze qualitative data (e.g., thematic content analysis; cross case synthesis process mapping) (Swarup et al. 2010). Each method has its own procedure for conducting, documenting, and evaluating data analysis processes (Nowell et al. 2017).

Thematic content analysis is a qualitative research method that is used for identifying, analyzing, organizing, describing, and reporting themes found within a body of information (Braun and Clarke 2006). Thematic content analysis is a practical tool for examining perspectives of different interviewees, identifying similarities and differences, and gaining unforeseen insights (Braun and Clarke 2006; King 2004). Burnard et al. (2008) stated that thematic content analysis is arguably the most common data analysis approach for qualitative research. Thematic content analysis is used when researchers are attempting to identify themes from transcribed interviews. Therefore, to conduct the required qualitative data analysis in this study, the authors selected the thematic content analysis method shared by Burnard et al. (2008).

The six-step thematic analysis approach defined by Braun and Clarke (2006) consists of the following procedure: (1) become familiar with the data; (2) generate initial codes; (3) search for themes; (4) review themes; (5) define themes; and (6) write-up.

Coding was used to condense the longer responses into smaller meaningful terms that relate to the questions. Open coding was selected for analyzing the data of this study, which implies that the researchers did not utilize predefined codes, but rather developed and modified the codes as coding progressed (Braun and Clarke 2006). The codes were generated based on the researchers' observations from the data. To illustrate an example of the open coding process, if a question is presented by the interviewer to the interviewee: "How does your organization enhance the understanding and assessment of risk in DB projects?" Hypothetically, the research team can identify the codes "risk-register" and "risk workshop" based on the assessment of all responses. The research team will then be capable of identifying utilities that used a risk register or conducted a risk workshop for their projects and the utilities that did not.

To obtain quantifiable results, the research team calculated the frequency of each code per interview question (Chi 1997). Referring the prior example, if eight out of ten interviewees mentioned using a "risk-register" for their DB projects, then the research team will be able to report the majority (80%) of utilities use "risk-registers" and the majority illustrates an effective practice of "risk-register" use for the interviewed utilities. It is also important to note that some questions in the interview protocol were not coded, as they contained straightforward "Yes" or "No" responses. The results from these direct questions were easily quantifiable.

Once the results had been quantified and organized, the final phase of this process consisted of reporting on the interview findings. These findings will be detailed in the next section of this paper.

3.4 Water Industry Effective Design-Build Project Administration Practices

The interviewed utilities provided findings relevant to current DB project administration practices. The following section organizes and details the findings into seven categories.

3.4.1 Category 1: Procurement

The majority (70%) of interviewed utilities revealed that they complete less than 10% of the design (concept design) in-house before design-builder engagement, as shown in Figure 10.

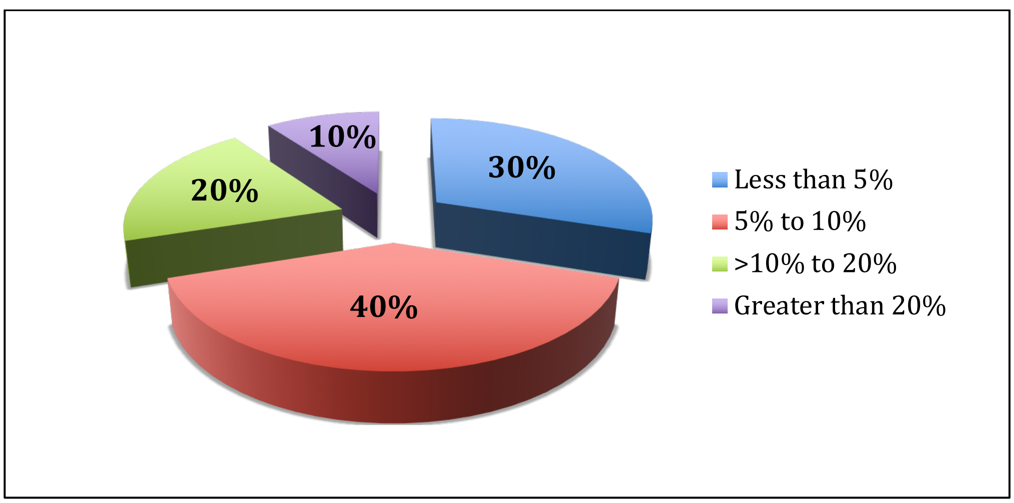


Figure 10: Percentage of Design Complete Before Design-Builder Engagement

The average value for percent of design completion before design-builder engagement obtained in this study (12%) is lower than the findings presented in Feghaly (2018), where the average design-builder was engaged at 22% of a project's design completion. This finding indicates that utilities are involving the design-builder even earlier in the design process. The interviewed utilities shared that by engaging the design-builder earlier, they reached the final design faster, obtained cost estimates of higher accuracy, and allowed the design-builder to implement innovative designs. These findings are consistent with the literature, confirming the positive relationship between early contractor engagement and improved project outcomes.

The interviewees were asked if they procure the services of an owner agent or representative for their DB projects, to which 60% of the utilities mentioned they do or have done so in the past. The remaining 40% of utilities stated they have the required design and construction management skills internally; therefore, do not need the support of an owner's agent or representative. Overall, interviewees claimed an owner agent or representative is useful when the project is complex and the utility does not have the in-house managerial expertise. This finding is similar to WSCPARB (2017), which mentions hiring DB-experienced consultants during the RFQ/RFP process is valuable until there is enough in-house DB experience.

Utilities were also asked if they have adapted other utilities' or organizations' documents, tools, or templates for their DB water projects. In response, 60% of utilities stated they adapt peer utilities' or organizations' documents, especially for the development of their RFPs and DB contracts. Some of these organizations included the

Engineers Joint Contract Documents Committee (EJCDC) and the Water Design-Build Council (WDBC). The remaining 40% of utilities mentioned having in-house project team experts developing their templates and documents. The authors recommend starting with templates that have been tested and worked successfully for others and to adapt them if needed.

The interviewees were asked to describe their proposal evaluation process and criteria. One-step best-value procurement is typically used by 50% of interviewed utilities, followed by one-step qualifications-only procurement for 30% of utilities. A two-step best-value procurement is used by the remaining utilities (20%). It is important to note that in a best-value procurement approach, the utility values both technical concepts and price. The price component can be on the front-end (e.g., design) cost or on construction costs, depending on the level of design completed at builder engagement. For example, one utility mentioned that they have the design-builder initially price the project only for construction and design supervision costs. Moreover, the utility states that as the project's scope develops, a target cost is achieved through design progression.

Different utilities used different criteria for proposal evaluation. The compilation of these criteria include reviewing the design-builder's: (1) past experience in similar type of work; (2) individual experience of project team members; (3) communication and organizational structure; (4) previous project performance; (5) ability to meet project goals; (6) proposed project cost; (7) previous experience working with the utility; (8) subcontractor selection process; and (9) disparity programs (e.g., small and disadvantaged businesses). These criteria are consistent with those used in DB procurement in other industries (e.g., building and transportation industries) (ACRP 2009; TCRP 2009). Identifying the DB team that is best fit for the utility's needs for a given project is an advantage of this delivery method, as utilities can select the most qualified design-builder for their complex water projects. DB prevents utilities from risking the selection of the lowest bidder that may not fit all the needed criteria for the project at hand.

Utilities evaluate proposals based on project-specific characteristics that vary from one project to another. Most utilities stated that the proposal evaluation criteria and scoring procedure is detailed in their RFP or RFQ. For example for utilities that use a best-value approach, one utility mentioned cost evaluations account for 15% to 20% of the proposal evaluation score and qualifications account for 80% to 85% of the remaining score. Another utility stated that costs typically account for 40% of their proposal evaluation score and qualifications for the remaining 60%. The utilities also mentioned that detailing the criteria and their weights in the RFQ/RFP is an effective DB practice and significantly reduces the risk of a protest by an unsuccessful bidder. For the study, the findings on proposal evaluation criteria aligned to DBIA (2015b) stating that proposal evaluation should value both technical concepts and price.

There are different compensation practices used across project delivery methods. GMP (55%) is the most used compensation type, followed by lump sum (35%) and finally cost-plus (10%). These results are very similar to that of Feghaly (2018) findings, where GMP was the most frequently used compensation type (about 60%) among DB projects analyzed in the study's sample of 75 completed water projects. The use of a

GMP is an effective DB practice and will be elaborated further in the following sections of this paper.

3.4.2 Category 2: Design-Build Roles and Responsibilities

In the interview, the utilities discussed the responsibilities they manage in-house and the ones that they either hand to or share with the design-builder. Responsibilities typically managed by the utilities consist of: (1) property acquisition; (2) environmental reviews; (3) cultural resource clearances; (4) inspections (may be shared); and (5) contentious issues (e.g., project team disputes; change order management). On the other hand, responsibilities that are managed by the design-builder include: (1) flood plain/washes/scours planning; (2) coordination of external utilities; (3) construction permitting (may be shared with owner); (4) right-of-way; (5) environmental permits (may be shared with owner); (6) PR (may be shared with owner); and (7) the risks associated with the design. This study identified key DB project responsibilities that are effectively managed by utilities alone and responsibilities either shared or distributed to the design-builder. DB allows for the distribution of project responsibilities, a practice not offered in traditional DBB.

Having reduced overall control of a project is a common concern for utilities when implementing DB, particularly for the first few times. However, only 30% of the utilities mentioned that this is a challenging issue for their organization. Further 70% of utilities felt they are in control of their DB projects or are faced with minimal issues. The utilities stated their level of involvement and control in the DB process is often project-specific. For example, if a project is highly complex then the design-builder has a more active role. However, the utilities' role does not diminish. Generally, a good practice has 100% of the utilities project team heavily involved across all phases of their projects.

This study identified a selection of effective practices to support utilities' management of project involvement and control on their DB water projects, which included: (1) using clear benchmarks during the design phase (e.g., using 30%, 60%, and 90% design review milestones) and providing detailed owner review and input; (2) establishing at the beginning of the project the specific roles of each stakeholder; (3) specifying the amount of meetings (e.g., daily; weekly; monthly) in the RFP; (4) developing a clear process in the RFP for design and construction control; (5) involving the O&M team early in the planning phase; and (6) being actively involved in all major steps of the delivery process. Additionally, some utilities also mandate partnering meetings in the initial stages of the project. Partnering meetings promote the discussion of roles and expectations of the utility and the design-builder, align the project team, and identify the project challenges and plans to overcome them. The literature shares that partnering is a good practice on all types of delivery methods, not just for DB projects (Harper and Waldrop 2016).

3.4.3 Category 3: Risk and Quality Management

The utilities were asked to share their established practices for enhancing DB project teams' risk understanding and assessment. Findings showed that 70% of utilities use a risk register early on in their projects to gauge the amount of risk related to various project concerns. The remaining 30% do not use a formal tool or register; they depend on their project team's expertise to identify project risks and the most suitable party to address each risk.

Before awarding the project, three utilities develop their risk registers internally to then provide the registers to the design-builder for monitoring. Three other utilities do not begin with developing a risk register in-house; rather the utilities assign risk management responsibilities to the design-builder in the early stages of the project. The final two utilities develop and maintain their risk-registers internally and do not involve the design-builder, as they prefer to be solely involved in monitoring and managing their key project risks. In the authors' experience, risk assessment is one area that can benefit considerably from the design-builder's experience and the utility's own input. Moreover, a study by Molenaar et al. (2004) revealed that identifying risks early on and allocating them appropriately to the party that is best suited to handle them is an effective DB practice.

In order to incorporate potential risk impacts or risk mitigation processes into their schedule and budget, utilities allocate owner and/or contractor contingency for their projects. Two utilities mentioned that they typically place an owner contingency of at least 10% of the project cost, depending on project complexity, for their DB water projects. These finding are similar to WSCPARB (2017), which recommends using an owner's contingency of at least 5%. Moreover, 60% of utilities do not allocate a contractor's contingency for their projects with the other 40% allocating a contractor's contingency. From the four utilities that use a contractor's contingency for their projects, one utility allocates around 8% to 10% of the project's cost as part of the contractor's contingency. Only two utilities specify cost sharing of the unused contractor's contingency (e.g., providing an incentive for the DB team to complete the project under the agreed upon GMP).

A good practice is to have both a utility (owner) contingency and a contractor contingency. The two parties can agree on which contingency to use depending on which risks materialize. During the GMP negotiations, the utility can see where the contractor is adding cost, due to risks that may or may not materialize, to counter with suggestions to reduce the cost. This method of negotiations in DB is critical as the utility can suggest moving the contingency to the contractor's contingency bucket, most of which can return to the utility if unused. Another good practice includes incentivizing the design-builder by sharing unused contingency at the end of the project (with the utility keeping at least half of the unused funds).

Of the ten utilities interviewed, 30% outsource all quality assurance/quality control (QA/QC) responsibilities to the design builder, 30% assign QC duties to the design-builder but manage QA responsibilities internally, 20% utilize assistance of a consultant or owner advisor, and 20% handle QA/QC responsibilities in-house. This study revealed that utilities have varied approaches to manage their DB project's QA/QC responsibilities.

The interview consisted of having utilities share practices they implement to ensure that the DB team's design specifications are consistent with the utility's expectations. These practices include: (1) developing a detailed RFP including all project specifications and design standards; (2) performing detailed design reviews at project milestones; (3) involving all stakeholders (e.g., end-users and O&M team) in the design review and approval process; (4) reviewing shop drawings before execution; (5) evaluating daily site reports; (6) having experienced DB staff in the project team; and (7) reviewing and approving all submittals. This study identified effective DB practices to ensure that a design-builder's specifications are consistent with that of the utility.

3.4.4 Category 4: Design

For 80% of the interviewed utilities, the responsibility of geotechnical investigations are led by the design-builder. Of the 80%, half of utilities mentioned this responsibility is solely the design-builder, but the other 40% stated the responsibility may be shared with the utility depending on project type (e.g., complex pipeline project that requires extensive design-builder input). The remaining 20% of interviewed utilities prefer to direct all of their geotechnical investigations' responsibilities to external consultants/advisors.

Half of the interviewed utilities share the responsibility of environmental investigation processes/reports, permits, and notifications with the design-builder, where the party that is best suited to handle those risks is appointed the responsibility. Only one utility stated that it hands these responsibilities are directed solely to the design-builder to manage.

The majority of interviewed utilities (90%) have not pursued sustainable certifications (e.g., ENVISION; LEED) for their water projects; the single utility using sustainable certifications demands the ENVISION rating system's evaluation for their projects. Moreover, two utilities use in-house sustainable performance goals during the design phase (e.g., installing solar panels to meet energy goals or improving energy efficiencies) when designing their projects. One utility also described that the potential benefits of sustainable design may include improved public relations. The findings indicate potential opportunity for utilities to improve and meet sustainability goals for their DB water projects. Comstock (2011) shares that DB methods incorporate an environment where innovative ideas, such as sustainability goals, can be achieved for projects.

3.4.5 Category 5: Design and Submittal Review

The utilities shared their methods for ensuring different individuals within their organization are reviewing at the same level of design detail. Five of the utilities stated design review consistency is an ongoing challenge they tend to face with project teams. Discussed further in the interviews, several practices to counter this challenge were revealed and include: (1) assembling a workshop with the project team and all stakeholders to review the designs from a high level (e.g., page by page); (2) assigning the Project Manager to support the design review staff to advance their skills over time; and (3) communicating to the design-builder any missing details in the design. This study identified the DB design review process as an ongoing challenge for water utilities and compiled a list of effective practices to overcome these difficulties.

The majority of utilities (60%) perform their design reviews at 30%, 60%, and 90% design completion milestones. Other variations shared by the utilities consisted of: (1) 10%, 30%, 60%, and 90%; (2) 30%, 50%, and 90%; and (3) 30%, 50%, 75%, and 98%. The reviews are typically performed in-house and depend heavily on the project teams' expertise. Moreover, 100% of utilities actively include the O&M teams in the design review process, an effective practice. A study by Lapinski et al. (2016) reinforces this findings and states that including the O&M team eases downstream bottlenecking of the project delivery process.

To streamline the submittal process, one utility oversees all formal communication between the designer and the constructor; however, the utility is only involved, directly, in the submittal process when absolutely needed. For three utilities using an online platform or software effectively, the process has streamlined the submittal process. The use of an online submittal management platform is line with the recommendations of WDBC (2016), which states an online platform for submittal management is an effective practice. Other shared practices by the interviewed utilities include: (1) setting an agreed-upon allocated time for submittal response; (2) identifying a single point of contact for the DB team with the utility; and (3) preparing an extensive pre-approved materials list by the utility so that the utility can speed up the approval process. It is important to have a well-structured submittal management framework in the early stages of a project to streamline the submittal process and improve the delivery of a DB project.

3.4.6 Category 6: Cost and Schedule Estimates

The majority of the utilities (60%) develop their cost estimates early on and revisit the estimates with the design-builder's support as the design progresses, since cost estimates become accurate as the design advances. The remaining utilities (40%) set their GMP or project budget, during or after bid award, and have the design-builder commit to this figure.

From the six utilities that typically use a GMP, five utilities specified varying times for agreeing on the GMP, as shown in Figure 11. Most utilities provided a range, in terms of percentage of project design complete, at which the GMP is typically finalized for their DB projects. However, one interviewee, Utility 5 identified in Figure 11, mentioned reviewing the initial GMP during the 30% and 60% design review milestones before finalizing the GMP at the 90% design review milestone. This is a good DB practice to prevent locking in price until a significant portion of design is complete; such DB practices reduce the risks identified and related contingency costs. Setting a GMP too early may lead to increased contingencies, surprises, and costs. Additionally, three of the six utilities (50%) that use a GMP for their DB projects agree the average time to negotiate a GMP is an estimated two to three weeks. For the remaining three utilities the time spans differ; one utility reports negotiations take about three to four weeks, a second utility averages around four to six weeks, and a third utility estimates twelve weeks. This study quantified GMP management practices for DB water infrastructure projects.

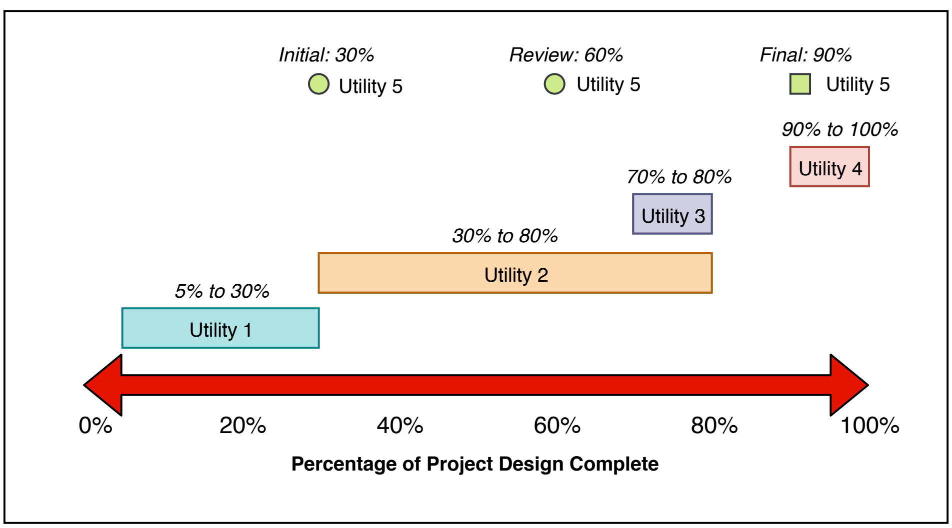


Figure 11: GMP Agreement Based on Percentage of Project Design Complete

For 90% of the utilities, their internal project team sets the substantial completion date, which the design-builder must abide by. These completion dates are mostly influenced by an operational need and are developed based on the internal project team's experience. The utilities stated the practices they use to set a schedule do not differ between their DB and DBB projects. The schedule is typically set through a backwards approach and the constructor must schedule their milestones accordingly. However, only one utility requests the design-builder to set the schedule for their projects, based on their technical construction expertise.

3.4.7 Category 7: Communication and Information Flow

In the interviews the utilities revealed their methods for collaborating with different project stakeholders involved in the DB process. Various practices were shared by the utilities, such as: (1) scheduling daily/weekly/monthly stakeholder meetings with key project team members; (2) adhering to review milestones; (3) developing a work plan early on and detailing the communication flow during the project kick-off meeting; (4) ensuring that all forms of communication involve the key project stakeholders; (5) inviting all stakeholders to participate in design review workshops; and (6) partnering with internal and external stakeholders to improve project team alignment.

Three utilities mentioned that minimizing the impact on existing operations is similar for both their DBB and DB projects. Different practices to control and minimize impact on operations were discussed and include: (1) specifying exact outage schedules in the RFQ and RFP; (2) enforcing liquidated damages as disincentives in case the project impacts existing operations (e.g., due to extended operational shutdown); and (3) collaborating extensively with the O&M team and requiring their approval on activities that may impact existing operations. In line to this study's findings, DBIA (2015b) shares that DB allows the project team to collaborate and resolve potential issues early in the project as a result of earlier design-builder engagement.

To ensure knowledge transfer, DB practices by the utilities include: (1) holding a lessons learned meeting after the completion of projects and documenting on paper or electronically; (2) writing a detail final construction report by key members of the project team, detailing the project's lessons learned, at project closeout; and (3) utilizing a specific checklist and sign-off to ensure knowledge and lessons learned are captured from each member of the project team. This study identified effective practices utilized by utilities to improve communication and information flow on their DB water projects.

3.5 Recommendations and Conclusions

To recommend the most effective DB practices to water industry stakeholders, the authors highlighted key DB project administration practices revealed in this study. These DB practices are detailed under the seven key categories in the following paragraphs.

Category 1: Procurement: (1) engage the design-builder as early in the design as possible; (2) procure an owner agent or representative if you are new to, or unfamiliar with, the DB delivery process; (3) consider using qualification-based procurement (if allowed), or best-value procurement with the majority of the weight for qualifications; and (4) incentivize the design-builder by sharing a portion of the unused contingency at the end of the project.

Category 2: DB Roles and Responsibilities: (1) initiate projects with a kick-off meeting where all stakeholders are involved and specific roles are established early on; (2) consider sharing key project responsibilities with the design-builder and distribute each responsibility to the party that is best suited to handle it; and (3) remain heavily involved in the project across all of it phases.

Category 3: Risk and Quality Management: (1) develop and use a risk-register early on in the project to gauge and allocate project risks to the party that is best suited to handle it; (2) consider providing the risk-register to the design-builder to maintain during the project delivery process; (3) utilize both an owner contingency and a contractor contingency; and (4) perform plant and manufacturer's inspections collaboratively with the design-builder when possible.

Category 4: Design: (1) allow the design-builder to lead the management of geotechnical investigations when applicable; and (2) share the responsibility of acquiring environmental investigation processes/reports, permits, and notifications with the design-builder.

Category 5: Design and Submittal Review: (1) require design reviews at 30%, 60%, and 90% design review milestones; and (2) To streamline the submittal review process; the utility can consider setting up an agreed-upon allocated time for response, identify a single point of contact for the DB team, prepare an extensive pre-approved materials list, and utilize an online platform or software.

Category 6: Cost and Schedule Estimates: (1) develop project cost estimates early on and revisit at each design milestone with the support of the design-builder; (2)

require the internal project team to set the substantial completion date of a project and ensure that the design-builder can establish their project schedule to meet this deadline; and (3) consider using a GMP and finalizing it near completion of the project.

Category 7: Communication and Information Flow: (1) heavily involve the O&M team in the design review process and ensure that they are required to approve any plan that may impact existing operations; and (2) hold a lessons-learned meeting after the completion of the project and document this session on paper or electronically.

This study identified effective DB project administration practices that will allow a water utility to leverage DB experiences of utilities that successfully deliver DB water projects. Utilizing these project administration practices alone will not guarantee a successful DB project but are a valuable starting point for the implementation of DB. The main contribution of this study is the identification of effective DB project administration practices. Moreover, effective practices are identified across a DB water project's delivery timeline (from project initiation, design, construction, handover, and operations).

A limitation of this study is the sample size of the interviews conducted. However, given the complexity of the adapted research framework, this study identified DB project administration practices in the water industry from industry practitioners representing ten large utilities across major regions of the United States and a Canadian province. Future work can build on the findings of this study and document additional DB practices from other utilities that successfully deliver DB water projects.

CHAPTER 4

SELECTING PROJECT DELIVERY METHODS FOR WATER TREATMENT PLANTS

4.1 Introduction

Across the United States, water and wastewater treatment plants are aging and in dire need of renovation. According to an assessment performed by the American Society of Civil Engineers (ASCE), United States water and wastewater infrastructure systems received an unsatisfactory grade of "D" and "D+" respectively on the 2017 ASCE Infrastructure Report Card (ASCE 2017).

The growing problem of deteriorating water infrastructure (which consist of both water and wastewater infrastructure as part of the integrated One Water approach of the US Water Alliance) has now fallen under the responsibility of individual states and municipalities, due to a significant drop in federal funding from $16 billion in 1976 to $4.4 billion in 2014 (USWA 2016; CBO 2015). Therefore, it is vital for decision-makers in the water industry to select the most appropriate project delivery methods that may maximize their opportunities for successful projects.

Different project delivery methods contain their own advantages and disadvantages based on several unique project-related characteristics and factors. Despite traditional design-bid-build (DBB) prevailing as the most applied project delivery method within the construction industry, decision-makers are now also choosing to deliver their projects using alternative project delivery methods (APDM). APDM such as design-build (DB) and construction management at-risk (CMAR) have been gaining popularity due their acclaimed schedule and cost performance superiority. This paper will focus on the application of DBB, CMAR, and DB project delivery within the water industry.

Project delivery method selection is an intricate process that tends to consume a great amount of an organization's resources and time. Decision-makers at times may not be well equipped with the required knowledge for APDM selection, and in turn are hesitant to adopting APDM for the delivery of their water treatment plant projects. Therefore, it is important to identify key project delivery method selection factors to assist these decision-makers in this extensive process.

To confirm that stakeholder needs are met, the authors of this paper substantially involved industry professionals in the research process. Two industry workshops were held at the beginning and the end of the research effort; ensuring that the identified critical selection factors are also vetted by the industry.

4.2 Research Objective and Methodology

There exist numerous project delivery selection models and frameworks with distinctive selection factors across various industries such as transportation, airport, transit, and education. However, these methods are not always consistent with one another, and none focus on selecting the right delivery method for water projects. This gap in knowledge was identified by the Water Research Foundation and formed the motivation for this study. Therefore, the main objective of this study was to address this gap by contributing to the body of knowledge, but also contribute to the state of practice by ensuring the new information is disseminated and used in industry.

After identifying key selection factors, the authors embarked on the development of a user-friendly, web-based decision-support tool that can appropriately serve the water industry. This tool aims to encompass and prioritize project delivery method selection knowledge presented in the literature from across available academic and industry decision-support models. As a result, this study presents a holistic framework that contains all collected key project delivery selection factors in existence in the literature and state of practice.

The methodology of this paper comprised of three main phases: (1) identifying the point of departure; (2) key selection factors and tool development; and (3) tool review and testing.

Phase 1 is a two-stage process, where the first stage performed a systematic review of academic literature and an industry state of practice to assess the current knowledge of project delivery method selection. The second stage then identified all project delivery method selection factors obtained from the reviewed literature.

Phase 2 of this research paper comprised of a three-stage process. The first stage involved the formation of a holistic decision-support model that encompassed all selection factors obtained across the reviewed literature. This stage also extracted selection questions, and the logic behind each, for each factor of interest. The second stage encompassed an industry workshop to assess all compiled project delivery selection factors from the literature and identify key selection factors for the water industry. The concluding stage of Phase 2 consisted of programming and developing the decision-support tool using a java-based platform, as a result of the identified key selection factors of this study.

Phase 3 of this paper comprised of reviewing and testing the new model through the support of a supplementary industry workshop and industry panel. The authors utilized the panel's expertise in the water industry to review the composition of the model and validate its overall integrity and quality.

4.3 Identifying the Point of Departure through a Review of Literature & State of Practice

4.3.1 Existing Project Delivery Method Decision-Support Models: Macro-Level Review

The first stage of Phase 1 consisted of a macro-level analysis that reviewed about 40 relevant academic research papers and 15 decision-models used by industry organizations. The industry decision-models are obtained from various industries such as water, transportation, education, airport, and transit.

A wide selection of tools for project delivery were cited in the academic literature; however, the two most common tools cited for project delivery selection were multi-attribute analysis and analytical hierarchy process (AHP), as presented in Table 5.

Multi-attribute analysis is used to obtain an objective value from a subjective data set, such as project delivery method selection criteria. In short, multi-attribute analysis helps in reducing the variability of results that usually occur from using subjective criteria in a model. AHP consists of developing a list of criteria essential to the decision at issue and then arranging those factors into a hierarchy of importance to the ultimate decision.

Table 5: Overview of Project Delivery Method Selection Tools

Model Type/Name	Gordon (1994)	Kumaraswamy & Dissanayaka (1998)	Love et al. (1998)	Molenaar and Songer (1998)	Skitmore and Marden (1998)	Alhazmi and McCaffer (2000)	Ribeiero (2001)	Luu et al. (2003a)	Luu et al. (2003b)	Molenaar et al. (2004)	Luu et al. (2005)	Mahdi and Alreshaid (2005)	Luu et al. (2006)	Oyetunji and Anderson (2006)	Chan (2007)	Mafakheri et al. (2007)	Ghavamifar (2009)	Chen et al. (2011)	Cheung et al. (2001)	Touran et al. (2011)	Al Khalil (2012)	Shane et al. (2013)	Tran (2013)	Mogerman et al. (2016)	Tran et al. (2016)	**Total**
Multiattribute analysis	x		x	x	x					x				x					x							7
Analytical hierarchy process						x						x				x			x		x					5
Case-based reasoning							x		x		x		x													4
Multivariate analysis				x																x		x				3
Artificial neural networks		x																x								2
Project procurement selection model						x		x																		2
Parker's alternative						x																				1
Fuzzy procurement selection model															x											1
Data envelopment analysis - bound variable																		x								1
Decision support system																	x									1
Fuzzy sets											x															1
Case-based procurement selections											x															1
Delphi method																								x		1
Simple multiattribute rating technique														x												1
NEDO multiattribute approach					x																					1
Discriminant analysis					x																					1
Cross-impact analysis																									x	1

In total, 15 industry decision-support models were also obtained by the authors and are listed in Table 6. Additionally, the highlighted decision-support models in Table 6 are the primary literature sources used for the development of the holistic decision-support framework during Phase 2 of this paper. The reason the authors chose these models over the others is due to certain criteria that will be clarified in the upcoming sections of this paper.

The five project delivery decision-support models highlighted in Table 6 will be briefly summarized in the following paragraphs. These models allow decision-makers in their respective industries to evaluate the advantages and disadvantages of certain project delivery methods by assessing them against specific selection factors.

Table 6: Existing Project Delivery Selection Decision-Support Models

Organization (Organized Alphabetically)	Year	Application Industry	Title of Publication
Airports Council International-North America (ACI-NA), Airport Consultants Council (ACC) and the Associated General Contractors of America (AGC)	2012	Airport	Airport Owners' Guide to Project Delivery Systems
*Airport Cooperative Research Program (ACRP)	2009	Airport	A Guidebook for Selecting Airport Capital Project Delivery Methods
Association of California Construction Managers (ACCM)	2017	Education	Project Delivery Handbook: A Guide to California School and Community College Facility Delivery
*Alaska Department of Education and Early Development (ADEED)	2017	Education	Project Delivery Method Handbook
American Institute of Architects/Associated General Contractors of America (AIA/AGC)	2011	Multi-Industry	Primer on Project Delivery
Construction Management Association of America (CMAA)	2012	Multi-Industry	An Owner's Guide to Project Delivery Methods
Design-Build Institute of America (DBIA)	2015	Multi-Industry	Choosing A Project Delivery Method: A Design-Build Done Right Primer
Orange County Public Works Department (OCPWD)	2017	Multi-Industry	Project Delivery Method Selection Tool Guide
*Transit Cooperative Research Program (TCRP)	2009	Transit	A Guidebook for the Evaluation of Project Delivery Methods
*Colorado Department of Transportation (CDOT)	2014	Transportation	Project Delivery Selection Matrix
Minnesota Department of Transportation (MnDOT)	2014	Transportation	Project Delivery Method Selection Workshop
Nevada Department of Transportation (NDOT)	2011	Transportation	Project Delivery Selection Approach
*Washington State Department of Transportation (WSDOT)	2016	Transportation	Project Delivery Method Selection Guidance
Texas Water Development Board (TWDB)	2002	Water	Alternative Project Delivery
Water Design Build Council (WDBC)	2016	Water	Water and Wastewater Design-Build Handbook

**Highlighted organizations are primary sources used for the development of the water project delivery decision-support tool*

The ACRP (2009) provides a two-tier system for project delivery selection, allowing airport decision-makers to select the most appropriate project delivery method for their projects between DBB, CMAR, and DB. The ACRP decision-support model identifies 19 key project delivery method selection factors.

Based on the ACRP's (2009) two-tier approach, the TCRP's (2009) framework further introduces a third tier consisting of a risk analysis section for project delivery selection in the transit industry. This decision-support model assists transit project owners in selecting between DBB, CMAR, DB, and Design-Build-Operate-Maintain (DBOM). The TCRP decision-support model identifies 24 selection factors.

CDOT developed a project delivery selection matrix that comprises of an extensive three-stage project delivery method evaluation framework for the transportation industry (CDOT 2014). The delivery methods identified in this matrix are DBB, CMAR, and DB. Stage 1 consists of documenting project attributes, goals, and constraints. Stage 2 involves assessing five primary project delivery method selection factors. Finally, Stage 3 concludes the evaluation process and evaluates three secondary selection factors.

The WSDOT adopted the CDOT's decision-support model and modified it to be in accordance with their existing practices (WSDOT 2016). Likewise, this model also assists decision-makers in selecting the most appropriate delivery method between DBB, CMAR, and DB. WSDOT utilizes a two-stage project delivery selection model. Stage 1 is the probable delivery method determination process and Stage 2 is the revision and validation stage.

The ADEED (2017) project delivery method handbook establishes a decision-support model to assist decision-makers in the educational facilities industry with selecting the most appropriate delivery method for their projects by choosing between DBB, CMAR, and DB. ADEED identifies project delivery selection factors by categorizing them under six need selection factors and four success selection factors.

4.3.2 Identifying of Project Delivery Method Selection Factors: Micro-Level Review

This stage of the literature review and state of practice phase comprised of a micro-level analysis, where project delivery method selection factors were compiled for all identified models during the Macro-Level Review. This effort led to the compilation of 44 selection factors acquired from the literature. Some of the selection factors that were common across the literature and played important roles in project delivery selection across the different industries are: project delivery schedule/speed; project complexity/innovation; and project risk avoidance/strategy. A list of all 18 academic publications and industry decision-models from 2011 onward along with all 31 (of the 44) factors that appear in these 18 references are displayed in Table 7. The remaining 13 factors (of the 44) were referenced in sources published in 2010 and prior, and include: flexibility, maintainability, utility relocation, and others. A rank-ordering of these key factors based on frequency supported the identification of those that are most prominent and important for delivery method selection.

Table 7: Summary of Literature from 2011 to Present vs. Selection Factors

#	Selection Factors	Comstock (2011)	Culp (2011)	Touran et al. (2011)	ACI-NA, ACC, AGC (2012)	CMAA (2012)	AIA-AGC (2012)	Shorney-Darby (2012)	Benson et al. (2013)	CDOT (2014)	Liu et al. (2014)	DBIA (2015a)	Gates et al. (2015)	Giachino et al. (2015)	Cannon and Hildebrand (2015)	WSDOT (2016)	WDBC (2016)	Fredell et al. (2016)	ADEED (2017)	**Total**
1	**Schedule/Speed**		x	x		x	x		x	x		x	x	x	x	x	x	x	x	14
2	**Size/Budget**			x	x	x	x	x		x		x	x	x	x	x	x	x		13
3	**Risk Avoidance/Strategy**		x	x	x	x	x			x	x	x	x	x	x	x				12
4	**Scope/Clarity**			x	x	x		x	x	x					x	x	x		x	10
5	**Permitting Issues**			x	x	x	x	x					x	x		x			x	9
6	**Owner Involvement**				x	x					x	x	x	x	x		x		x	9
7	**Quality**	x	x						x				x	x	x			x		7
8	**Capital Costs**	x	x		x				x				x	x			x			7
9	**Project Characteristics**	x	x		x	x					x					x				6
10	**Complexity/Innovation**	x		x				x		x					x	x				6
11	**Communication**		x										x	x	x		x	x		6
12	**Contractor Needs/Capabilities/Input**			x	x					x			x						x	5
13	**Owner Experience**			x	x				x						x				x	5
14	**Lifecycle Costs**			x	x								x			x				4
15	**Owner/Builder Characteristics**				x					x	x								x	4
16	**Project Certainty**				x											x			x	3
17	**Dispute Resolution**			x					x										x	3
18	**Responsibility**										x			x	x					3
19	**Funding/Financial Issues**															x			x	2
20	**Competition**									x									x	2
21	**Existing Facility Impacts**				x											x				2
22	**Market Attributes**			x		x														2
23	**Design Control**										x				x					2
24	**Sustainability Goals**				x															1
25	**Third-Party Agreements**															x				1
26	**Value Engineering**																	x		1
27	**Pre-construction Issues**													x						1
28	**Environmental Concerns**															x				1
29	**Constructability**				x															1
30	**Technological Capabilities**				x															1
31	**Amount of Overlapping Design/Construction**																		x	1
32	**Flexibility**																			0
33	**Disadvantaged Business**																			0
34	**Maintainability**																			0
35	**Efficient Decision-making**																			0
36	**Stakeholders Input**																			0
37	**Labor Unions**																			0
38	**Contract Pricing**																			0
39	**Client Satisfaction**																			0
40	**Commissioning**																			0
41	**Safety Concerns**																			0
42	**Culture**																			0
43	**Project Type**																			0
44	**Utility Relocation**																			0

4.4 Selection Factors and Tool Development

The selection factors and respective selection questions undertook several iterations during the three major phases of this research effort, as seen in Figure 12. The process for identifying key selection factors for the water industry and the tool development process will be detailed in the upcoming sections.

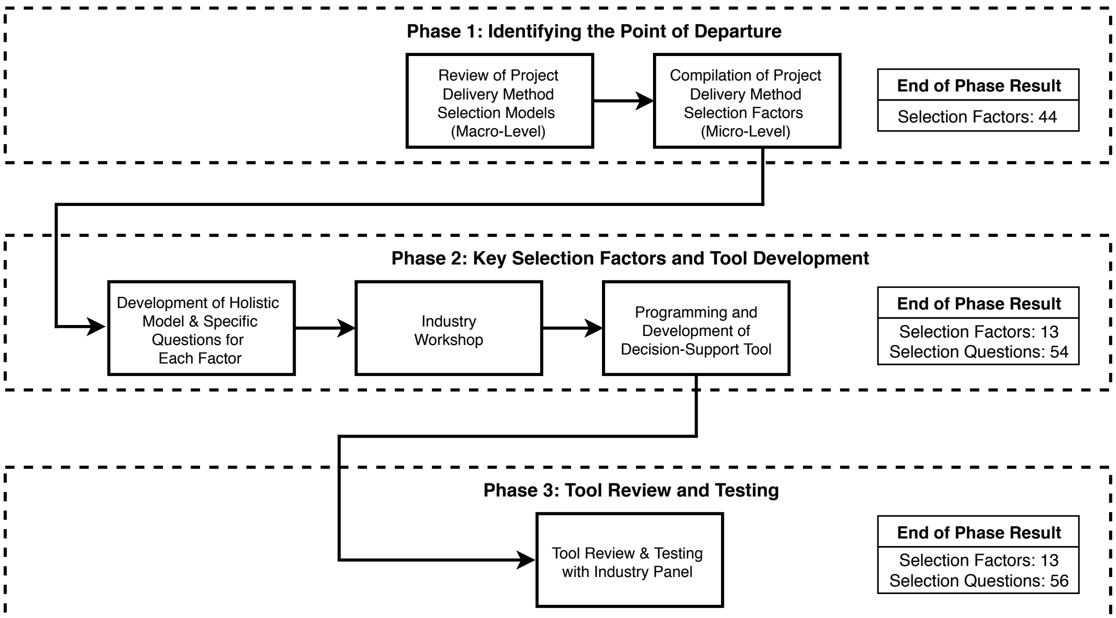


Figure 12: Research Methodology

4.4.1 Development of Holistic Decision-Support Model and Specific Questions for Each Factor

The purpose of the holistic decision-support model was to develop a comprehensive framework to extract relevant project delivery method selection factors questions from. The ACRP and TCRP models were predominantly chosen as they presented the highest frequency of selection factors amongst the 15 acquired models, with 19 and 24 selection factors respectively. The CDOT model was also chosen due to it being the earliest project delivery selection publication developed for the transportation industry between the models that the authors had obtained. However, the WSDOT model had some significant modifications from the CDOT model and contained additional features of interest; therefore, it was also chosen. Finally, the ADEED model was selected for being the most recent industry-utilized model between the 15 obtained decision-support models. The authors also included information found in two water-specific guidebooks, TWDB (2002) and WDBC (2016), specifically focusing on the advantages and disadvantages of different project delivery methods in the water industry.

The initial comprehensive model encompassed the 44 project delivery selection factors obtained after completing the review of the literature. The authors further combined some of the 44 selection factors and reduced them to 36 by merging similar factors together. For example, "owner involvement" and "owner control" were merged into one factor labeled as "owner involvement and control."

The resulting 36 individual factors led to the formation of a model that includes a total of 133 initial selection questions. The questions were primarily inherited from the various acquired models of the literature review. These selection questions were to be used for calculating the most favorable delivery method based on "Yes" or "No" responses. By answering these selection factor questions, decision-makers will be capable of quantifying the most favorable delivery method based on their responses. For example, if water industry stakeholders selected "Yes" to the question "are you seeking to include the construction team's qualifications as part of the procurement selection process," then CMAR and DB would be the recommended delivery methods and points would be allocated to them. In the case the stakeholders selected “No” and did not want to include the construction team’s qualifications, then DBB would be the recommended delivery method and points would be allocated to this method instead, and so on for each of the 133 questions while the points keep adding up for each method until all questions have been answered.

4.4.2 Industry Workshop

The authors held a workshop with a diverse representation of 20 water industry professionals, representing 18 organizations: three design firms; three general contractors; nine utilities; two industry associations; and one research organization. These experts have way over 400 years of combined experience in supporting the delivery of capital projects in the water industry. This workshop was conducted at the Arizona State University’s School of Sustainable Engineering and the Built Environment. During the workshop, the authors provided a brief background of the research project to the participants and shared the research objectives. The workshop consisted of a breakout group discussion that reviewed and conferred the 36 desired selection factors that resulted from the analysis of literature.

This industry experts’ revision process refined and validated the selection factors and their questions, warranting their relevance for water treatment plant projects. Some selection factors were omitted, while others were further merged or removed due to their inapplicability to water projects. This water industry vetting exercise reduced the selection factors from 36 to 13 critical factors, and their associated questions from 133 to 54 critical questions. The intent of this research workshop was to narrow down the wealth of literature knowledge to the most important factors that are critical to making the correct delivery method decision, while at the same time ensuring that the number of factors and questions is small enough to be manageable by decision-makers.

After the 13 key project delivery method selection factors were identified, the industry partners requested that a web-based decision-support tool be created by the authors to embed these factors and their associated questions in an industry-friendly format for decision makers. The purpose of the tool is to facilitate project delivery method selection using the idenfied project delivery method selection factors.

With the support of industry workshop participants, selection factors were further organized into different levels in terms of importance and were categorized in sections within the tool as 7 Primary Factors and 6 Secondary Factors, as shown in Table 8. The reasoning behind this organization is detailed later in this section.

Table 8: Decision-Support Tool Primary and Secondary Selection Factors

Category	Selection Factor No.	Selection Factor	No. of Questions
Primary Factors	1	Level of Design Complete	4
	2	Procurement	3
	3	Project Delivery Schedule	2
	4	Owner Involvement, Experience, & Control	5
	5	Risk Management & Allocation	2
	6	Project Cost Control & Early Cost Estimate	6
	7	Project Complexity and Innovation	6
Secondary Factors	8	Maintainability & Quality	5
	9	Staffing Requirements and Capabilities	4
	10	Funding, Site, & Impact on Existing Operations	4
	11	Sustainability Goals & Security	2
	12	Third-party Involvement & Community & Stakeholder input	4
	13	Adversarial Relationships, Construction Claims, & Potential for Change During/After Construction	4

The tool also contained a Documentation Section and a Prerequisite Factors Section. The Documentation Section requests decision-makers to describe various key project characteristics. This section aimed to improve project team alignment before initiating the tool evaluation process.

The Prerequisite Factors Section assesses whether a project delivery method should be eliminated from the evaluation process. This section evaluates project delivery methods against constraints related to: legislation and regulation (such as state laws that prevent alternative project delivery methods type of projects); the utility's capability to manage/outsource APDM projects; and the amount of design completed when the construction team will be awarded the contract (if design is highly complete, then APDM will not be as beneficial). An example of a Prerequisite Factors Section question from the finalized version of the developed tool is shown in Figure 13(a).

The industry workshop participants selected from the 13 selection factors the most essential factors (seven factors) for project delivery method selection and placed them in their own group called Primary Factors. The remaining six factors were grouped into Secondary Factors and were deemed to be important for project delivery selection, but unanimously agreed upon by workshop participants to be not as critical as the identified Primary Factors. Therefore, the Primary Factors Section acts as the primary project delivery method evaluator. The Secondary Factors Section follows the Primary Factors Section and further supplements the project delivery method evaluation process.

The industry experts concluded that Primary Factors and Secondary Factors within each group may or may not be as important as one another for project delivery method selection and that selection factors are dependent on a project's unique set of characteristics and goals. Therefore, after a thorough discussion between workshop participants, consensus was reached for the allocation of points between the two groups. The industry panel agreed that all selection factors within each section (Primary Factors and Secondary Factors) should impact the decision-making process equally, as they are potentially as important to one another in their respective categories. Therefore, each selection factor was given an equal weight of 1 point in terms of the scoring process.

4.4.3 Programming the Web-Based Tool

The final arrangement of the tool's evaluation stages consisted of: Stage 1: Documentation Section; Stage 2: Prerequisite Factors Section; Stage 3: Primary Factors Section; and Stage 4: Secondary Factors Section. After completion of Stage 1 (Documentation) and Stage 2 (Prerequisite Factors) of the tool, the decision-makers are required to either consider DBB, CMAR, or DB for completing Stage 3 (Primary Factors) of the tool's assessment; or will consider any two delivery methods in the case one of the three methods is not applicable. If only one delivery method is determined favorable at the end of Stage 2, then the tool evaluation process will conclude as there would only be one feasible delivery method.

Depending on the number of questions within a given factor, each selection question provides a portion of its points to the delivery method(s) selected. For example, a selection factor that has two selection questions under its category contributes an equal 0.5 points to each answer and to each corresponding delivery method. In the case an answer relates to two or three project delivery methods, each applicable delivery method would receive the same aggregate of points. The equation for calculating the points allocated per answer is displayed in Equation 1.

$$Points\ Per\ Answer = \frac{Total\ Selection\ Factor\ Point\ (1\ Point)}{Number\ of\ Questions\ within\ Selection\ Factor} \quad (1)$$

During the evaluation process within the Primary Factors Section, points are collected for each delivery method across the entire evaluation process and a live circular gauge containing a needle indicates the most favorable delivery method. After all Primary Factors are assessed, the delivery method with the highest percentage of total points over the maximum allowable Primary Factor points (which is 7 points in Stage 3) is the most favorable method. The total percentage of points per delivery method is calculated using Equation 2.

$$Total\ Percent.of\ Points\ Per\ Deliv.Method = \frac{Total\ Points\ Obtained\ Per\ Delivery\ Method}{Maximum\ Total\ \ Points\ (7\ Primary\ Points)} \times 100 \quad (2)$$

The Primary Factors Section assessment concludes with providing the decision-makers a summary of the results obtained. This section contains both a gauge that displays the most favorable project delivery method and total percentage of points for each project delivery method. The gauge's needle is programmed to indicate both the most favorable and second most favorable delivery method depending on the overall score. For example, if the needle is pointing to a delivery method zone, but not to its center, then this method is the most favorable, and the method that the needle is leaning towards is the second most favorable, as shown in Figure 13(b). This option gives decision-makers a wider selection of delivery method opportunities that they may consider pursuing. It is also important to note that having the live gauge move freely and displaying the live scoring while the evaluation process is ongoing may create some form of bias, as decision-makers may deliberately answer questions to alter the results and sway the scores based on their own delivery method preferences. Therefore, the scores are displayed only at the end of the sections, in order to reduce bias while the tool evaluation process is ongoing.

If the decision-makers did not determine the most appropriate project delivery method at the end of the Primary Factors Section, then they will have the choice to continue the assessment and move onto Stage 4 (Secondary Factors). Stage 4 evaluates the project delivery methods against Secondary Factors and runs similarly to Stage 3. However, in this stage there are only six Secondary Factors, therefore the total percentage of points per delivery method calculation equation at the end of the assessment is adjusted, as seen in Equation 3.

$$Total\ Percent. of\ Points\ Per\ Deliv. Method = \frac{Total\ Points\ Obtained\ Per\ Delivery\ Method}{Maximum\ Total\ \ Points\ (6\ Secondary\ Points)} \times 100 \qquad (3)$$

At the end of the Secondary Factors Section, similarly to the conclusion of the Primary Factors Section, the gauge indicates the most favorable delivery method and the tool evaluation process is concluded. Additionally, at the end of both the Primary Factors and Secondary Factors Section, decision-makers will have the opportunity to print the tool's evaluation results (including all questions and answers). This allows decision-makers to document the entire delivery method selection process and grants their organizations opportunities for future continued discussions.

On a technical level, the decision-support tool was programmed using several web-development technologies, such as: Schematic, React JS, Nginx WebServer, and Docker. Schematic is a programming tool that is used to design and represent a flowchart that consists of events and decisions. Events are used to show the information, while decisions are used to provide choices to the user. Upon selection of different choices, different events can be linked and so on. React JS was utilized as a front-end library, and Nginx, WebServer, and Docker were used for the development and deployment of the decision-support tool.

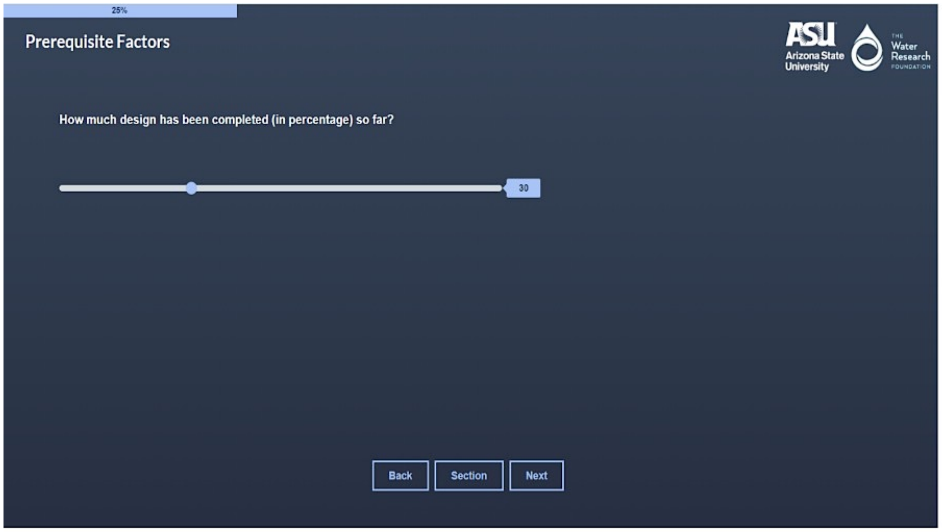
4.5 Tool Review and Testing

The name selected for the water industry web-based project delivery decision support tool was EXPRSS-TP: EXtensive PRoject delivery decision Support System for Treatment Plants; highlighting the research comprehensiveness supporting this tool and the accelerated pace of project delivery selection which it provides.

In order to test the results of this effort, a supplementary industry workshop was assembled with the support of 13 industry experts representing: two design firms; one general contractor; six utilities; one research organization; and one water industry association. These industry experts have over 200 years of combined experience in project delivery in the water industry. This industry workshop was conducted at the 2018 American Water Works Association Annual Conference & Exposition.

The workshop aimed to validate the research findings and contributions, as well as the resulting tool’s effectiveness for water project delivery selection. The purpose of this workshop was to review the 13 key factors and their associated questions, critique the model and tool, and discuss possible enhancements and recommendations. Workshop participants reassessed each specific selection question under each factor. Attendees reviewed the scoring basis of each question and answer, and modified the wording of questions wherever it was applicable. The panel also approved the tool's final sequence and flow. Moreover, a few selection questions that were deemed necessary were added by the participants, bringing the total number of questions from 54 to 56. Participants provided valuable feedback after reviewing the tool. For example, participants asked the authors to include short introductions at the beginning of each of the tool's sections; serving the purpose of keeping the tool user-friendly.

Overall, the industry panel was impressed with the comprehensiveness of the key selection factors while at the same time maintaining efficient ease of use of the tool. The authors and industry workshop participants developed EXPRSS-TP with the notion of creating a practical interface for industry decision-makers, as shown in Figure 12(b). The research process followed in this study led to both a contribution to the body of knowledge while also contributing to industry practice.



(a) Prerequisite Factors Section Sample Question

(b) EXPRSS-TP's Interface in Primary Factors Section

Figure 13: EXPRSS-TP Interface

4.6 Conclusions

This paper's contribution consists of identifying and prioritizing the 13 key project delivery method selection factors for the water industry, emerging from a systematic literature review, industry project delivery method selection models, and significant industry input through organized workshops. As a bi-product of the effort, EXPRSS-TP, a comprehensive decision-support model, was also developed to disseminate the findings through a simple-to-use interface that can be operated by decision-makers in the water industry.

Determining the most appropriate project delivery method to utilize is one of the most critical decisions utilities must take for their projects. The identification of 13 key factors most critical for the delivery of water treatment plants will allow decision-makers in this industry to select the delivery method that is most aligned with their project's unique objectives and characteristics. Utilities using the findings of this work will be able to gauge which project delivery method best positions their current project for success, based on their organization attributes and resources available at the time.

A project delivery method selection process is typically an informal process that may range from days to weeks at a time. Based on this work, the assessment can now be completed in about one hour and provides decision-makers with the most favorable delivery method for their project. And with the new tool that encompasses the new knowledge, not only is the decision reached at an accelerated pace, EXPRSS-TP also documents the entire selection process, allowing for a written and retained record of this key decision and its procedure.

Regarding the limitations of the work, the research study was designed, conducted, and reviewed with the intent of assisting water industry decision-makers for their water treatment plant projects only. Although some aspects of the work may be applicable to projects in other industries, one limitation is its focus on the water industry solely, as it has not been tested in other industries and adapted appropriately. Future research work can be conducted to adapt and test the findings to fit other project types (e.g., pipeline projects) or even other industries (e.g., building projects) that could also use support with project delivery method selection.

CHAPTER 5

EXPLORING IMPACTS ON UNIT COST PERFORMANCE FOR WATER INFRASTRUCTURE PROJECT DELIVERY

5.1 Introduction

Water utilities are now facing numerous challenges in upgrading and repairing aging water infrastructure (AWWA 2019). These challenges are only intensified by major demographic shifts, with some cities facing population decline and others significant population growth. Population decline leaves utilities with fewer ratepayers and funds from tax collection. On the other hand, population growth requires utilities to expand their water infrastructure's current capacity to meet additional consumption needs. According to a report by the Environmental Protection Agency (EPA) (2018), $472.6 billion USD is needed over the next 20 years to maintain and upgrade water infrastructure to meet future water needs.

Utilities heavily depended on federal funding in the past to finance the development of water infrastructure projects. However, today, funding for water infrastructure primarily originates from revenue generated by ratepayers (ASCE 2017). A study by the Value of Water Campaign (VWC) (2017) revealed that federal contributions to water infrastructure has declined from 63% of total capital spending in 1977 to about 9% in 2017. A large portion of water infrastructure systems in the United States are currently aging and exceeding their expected lifespan. Therefore, it is vital for policymakers to finance and invest in their nation's water infrastructure systems.

Water utilities are now seeking solutions to overcome rising financial complications. One innovative approach to face this challenge is through the use of alternative project delivery methods (APDM), such as construction management at-risk (CMAR) and design-build (DB). APDM differ from the traditional design-bid-build (DBB) method, which is the most used delivery method within the construction industry. DBB is generally a linear project delivery process that can lead to inefficiencies due to a lack of project team integration (Francom et al. 2016a). In DBB, the utility (owner) first engages with a designer to produce complete design documents. The design documents are then used to procure construction services, typically from the lowest bidding contractor. This process leads to a lack of collaboration between the designer and contractor. However, on APDM projects, the contractor is engaged earlier in the design phase and can offer a utility valuable preconstruction services such as constructability reviews and value engineering (Feghaly et al. 2019).

Utilities have limited resources and need to ensure that they can deliver projects on or under a project's allotted budget to maximize existing funds for water infrastructure systems maintenance and construction. The performance benefits of APDM projects have been studied extensively across various industries (Migliaccio et al. 2010; El Asmar et al. 2016; Molenaar and Franz 2018), and as well as in the water industry in specific (Bogus et al. 2010; Francom et al. 2016a and 2016b; Shrestha et al. 2018). Research has shown that APDM has the potential to deliver higher performing water infrastructure projects when compared to the traditional DBB method. However, selecting an APDM delivery method alone is not the sole factor that may influence a water infrastructure project's cost and schedule performance. Other factors such as a project team's experience or the complexity of a project may also influence the overall delivery performance of a project. Therefore, this study aims to explore how potential project-specific factors and attributes may impact a project's delivery performance for DBB, CMAR, and DB water infrastructure projects through the support of mathematical models. The findings of this paper may allow water stakeholders to obtain a clearer understanding in how certain project-specific factors and attributes can impact the unit cost performance of their water infrastructure projects.

5.2 Review of Literature

In the last few decades, several studies have explored the cost and schedule performance of construction projects using APDM. Researchers have studied project delivery performance across numerous industries, such as the transportation, industrial, building, and the water industry. Sullivan et al. (2017) assessed two decades of APDM performance knowledge by analyzing 30 existing studies and 4,623 completed projects. The authors were able to evaluate APDM project performance under five key performance metrics, which included: cost growth, unit cost, schedule growth, delivery speed, and quality. In line to the existing body of knowledge, the authors were able to observe that APDM projects typically performed better than DBB projects in terms of the performance metrics of interest. However, the study showed that there was no superior delivery method in terms of unit cost. Based off the findings of this study, the authors of this paper determined that unit cost would be an appropriate performance metric to explore how project-specific factors and attributes may impact a project's delivery performance. Moreover, this approach allows for bias reduction when observing the behavior of project-specific factors and attributes that impact water infrastructure projects, regardless of the delivery method chosen.

In the following sections, unit cost performance studies in the existing body of knowledge are reviewed to assist the authors in identifying the gaps in the literature. Moreover, a review on studies that explore project-specific factors and attributes that impact project delivery performance is also detailed.

5.2.1 Unit Cost Performance Studies

Col Debella and Ries (2006) collected data on completed educational facilities from 105 district superintendents. The projects were completed using DBB, either with a single prime contractor or through multiple primes. Statistical analysis revealed that there was no significant difference between single prime or multiple primes in terms of unit cost performance.

Allen (2001) studied the performance of 110 DBB and DB military construction projects. The author measured unit cost as cost per square foot of finished facility. DB ($117.23) outperformed DBB ($134.41) in terms of average unit cost. However, the results of the statistical testing showed no statistically significant differences between the two delivery methods.

Hale et al. (2009) conducted a study that evaluated the performance of 38 DB and 39 DBB military projects. Unit cost was measured as cost per bed in this study. The average DB project (53.1 $K/bed) had lower unit cost than the average DBB (56.4 $K/bed) project. An analysis of variance (ANOVA) test was performed to determine statistical significance; however, the results revealed no statistical differences between the two delivery methods.

Shrestha et al. (2007) compared the performance of DBB and DB highway projects. The authors evaluated 17 DBB projects and eight DB projects. Unit cost was assessed as cost-per-lane mile. The average unit cost for DBB projects ($3.68 million) outperformed that of DB projects ($4.56 million). Single factor ANOVA testing revealed that there were no observable significant differences between the delivery methods. Shrestha et al. (2012) also conducted a study that compared the performance of DBB and DB highway projects. The authors evaluated 16 DBB projects and six DB projects. Unit cost was also assessed as cost per lane distance. Similarly to Shrestha et al. (2007), the results showed that DBB (4.3 Million USD/Lane Mile) outperformed DB (5.1 Million USD/Lane Mile) in terms of average unit cost. However, statistical testing revealed that there were no observable statistical differences between the two delivery methods.

Rosner et al. (2009) analyzed the performance of 557 DBB and 278 DB military construction projects. Unit cost ($USD/square meters) performance analysis showed that DB projects (3,041.1) had a higher unit cost on average when compared to the DBB method (2,706.5). However, statistical testing showed that the differences were not significant. The study also indicated that, depending on the facility type, the DBB or DB delivery method may perform better in terms of average unit cost.

Feghaly (2018) studied the performance of completed DBB, CMAR, and DB water projects. The author investigated performance metrics such as unit cost, schedule growth, cost growth, project speed, and project intensity. No statistical differences were observed between the three delivery methods for unit cost performance. However, the average unit cost was highest for CMAR at 9.93 million USD/million gallon per day, followed by DB at 7.16 million USD/million gallon per day, and DBB at 6.62 million USD/million gallon per day.

Molenaar and Franz (2018), with the support of the Construction Industry Institute (CII) and the Charles Pankow Foundation, conducted a study that analyzed 212 completed DBB, CMAR, and DB projects from a variety of building uses, such as light industrial and high technology. The authors updated the performance benchmarks of a distinguished performance evaluation study by Konchar and Sanvido (1998). The results showed that after two decades, when compared to the DBB and CMAR method, DB projects still possessed lower unit cost for their projects when compared to CMAR (by 1.9%) and DBB projects (by 0.3%).

The review of literature revealed that unit cost performance has been mostly studied by comparing the DBB and the DB method. However, there is a need to further benchmark the unit cost performance of CMAR projects, specifically for the water industry. Additionally, unit cost performance studies have mostly targeted various industries such as education, military, transportation, and mixed-use. However, there is a need to further explore unit cost performance for the water industry. A study by Feghaly (2018) investigated the unit cost performance of water treatment plant projects. However, the author did not explore the impact of key project variables on unit cost performance, a clear gap in the body of knowledge.

5.2.2 Project-Specific Factors and Attributes that Influence Performance

As seen in the previous section, research studies have shown that both APDM and DBB have superior project delivery performance benefits based on different industries and project types. However, there are a number of explanatory variables that may affect a project's delivery performance other than the delivery method itself. Therefore, this section will review the literature and identify key project-specific factors and attributes that influence a project's delivery performance across varying delivery methods.

Molenaar and Songer (1998) developed predictive models for public-sector DB projects to measure success based on 122 completed projects. Regression models were developed to estimate cost growth, schedule growth, conformance to expectations, administrative burden, and overall satisfaction. Statistically significant factors that influenced project success included: (1) scope, schedule, and budget definition; (2) project complexity; (3) owner experience; (4) design-builder prequalification; and (5) method of design-builder selection (e.g., price only; qualifications only.

A study by Mafakheri et al. (2007) used the analytical hierarchy process (AHP) to develop a framework to support project owners with their project delivery decisions. The authors identified 13 key factors for project delivery selection, which consisted of: (1) project complexity; (2) project size; (3) owner experience; (4) value engineering; and (5) financial guarantee.

Touran et al. (2011) identified key project delivery method selection factors for the transit industry. Nine in-depth case studies were conducted on completed DBB, CMAR, and DB projects. The authors identified 24 factors for project delivery method selection and categorized them under five key categories: (1) project-level issues; (2) agency-level issues; (3) public policy regulatory issues; (4) life cycle issues; and (5) other issues. A selection of factors revealed by the authors included: (1) project size/complexity; (2) schedule; (3) agency experience; (4) stakeholder/community input; (5) sustainable design goals; and (6) adversarial relationships.

Shane et al. (2013) studied 69 DBB and 31 DB completed water projects and found that utility owners selected the DB delivery approach over DBB due to a number of project delivery performance related benefits. Key performance benefits shared by the respondents of this study included: (1) time savings/speed of delivery; (2) construction quality/problems with low-bid work; (3) cost savings/price certainty; (4) single-point accountability; and (5) builder's earlier involvement in the design process.

Tran et al. (2016) used cross-impact analysis to develop a model that can evaluate project performance for highway projects. The authors conducted an extensive literature review and identified 39 risk factors that impact project delivery. A questionnaire was distributed to 137 qualified industry respondents and statistical analyses showed that 31 delivery risk factors had the highest impact on project delivery. A selection of these risk factors included: (1) project complexity; (2) staff/owner experience; (3) delays in delivery schedule; (4) constructability in design; (5) construction sequencing/phasing; and (6) design completion.

Abi Shdid et al. (2018) developed a project performance-rating model using data from 43 completed water and wastewater projects. To develop the model, the authors identified nine key performance factors, which fall under five key project performance success criteria. The five criteria consisted of: (1) project cost; (2) project schedule; (3) quality; (4) customer satisfaction; and (5) early involvement. The nine key performance factors are: (1) cost overrun; (2) change order costs; (3) time overrun; (4) request for information (RFI); (5) errors and omissions change orders; (6) total cost of claims; (7) RFI response time; (8) total cost of field rework; and (9) owner requested change order costs.

In the study by Molenaar and Franz (2018), the authors identified factors that have the most influence or impact on key project performance metrics. To reduce cost growth and unit cost it was revealed that the most influential conditions included: (1) using the DB delivery method; (2) having improved team chemistry; (3) using open book contracting terms, such as a guaranteed maximum price (GMP); and (4) involving the builder earlier in the design. For reducing schedule growth and improving delivery speed, the authors stated that owners are recommended to follow conditions such as: (1) reducing project complexity; (2) requiring the designer and builder to participate in project goal-setting; and (3) using an APDM approach for their project. The authors also noted that successful projects repeatedly used the same designer and/or builder for their projects. On the other hand, the least successful projects where ones where the project team did not have sufficient experience with the delivery system.

There are numerous explanatory project-specific factors and attributes that may affect a project delivery method's cost and schedule performance, and there exists no single measure of project performance applicable to all utilities (Franz et al. 2017). Each utility will have its own unique and independent set of performance measures. Based on the review of the literature, the authors selected a set of six key factors and attributes that influence performance for this study. These factors and attributes statistically impact project delivery performance, as revealed primarily by the study conducted by Molenaar and Franz (2018) and supported by several research studies in the literature. The list of seven key factors and attributes is shown in Table 9.

Table 9: Key Factors and Attributes from the Literature Review

No.	Key Factors and Attributes	Source
1	Earlier Price Certainty/Use of a Guaranteed Maximum Price	Mafakheri et al. (2007); Shane et al. (2013); Molenaar and Franz (2018)
2	Project Team Experience	Molenaar and Songer (1998); Mafakheri et al. (2007) Touran et al. (2011); Tran et al. (2016); Molenaar and Franz (2018)
3	Early Involvement of Builder in Design	Shane et al. (2013); Tran et al. (2016); Abi Shdid et al. (2018); Molenaar and Franz (2018)
4	Project Complexity	Molenaar and Songer (1998); Mafakheri et al. (2007); Touran et al. (2011); Tran et al. (2016); Molenaar and Franz (2018)
5	Project Team Chemistry/Communication	Molenaar and Songer (1998); Molenaar and Franz (2018)
6	Project Size	Mafakheri et al. (2007); Touran et al. (2011); Molenaar and Songer (1998)

5.2.3 Gaps in the Literature

The existing body of knowledge revealed that unit cost is an effective method of analyzing a project's cost performance and is widely used by researchers and industry to measure the performance of a project. Moreover, there is a need to further explore unit cost performance for water infrastructure projects, which is a clear gap in the literature. The study by Molenaar and Franz (2018) identified key variables that impact project performance across various industries. However, there is a need to explore how these factors and attributes impact project performance for treatment plant projects in specific, as shown in Table 10. The objective of this study is to bridge the gaps and contribute to the body of knowledge by developing exploratory mathematical models to detect the impact of project-specific factors and attributes on a water infrastructure project's unit cost performance.

Table 10: Gap in Existing Body of Knowledge

#	Key Variable	Molenaar and Songer (1998)	Mafakheri et al. (2007)	Touran et al. (2011)	Shane et al. (2013)	Tran et al. (2016)	Abi Shdid t al. (2018)	Molenaar and Franz (2018)	Gap in Literature
1	Use of GMP		x		x			x	*
2	Project Team Experience	x	x	x		x		x	*
3	Early Involvement of Design-Builder				x	x	x	x	*
4	Project Complexity	x	x	x		x		x	*
5	Project Team Chemistry/Communication	x						x	*
6	Project Size	x	x	x				x	*
	Treatment Plant Projects	x			x		x		*

**This paper addresses a gap in the literature and explores the impact of the identified six project variables for water treatment plant delivery performance.*

5.3 Research Method

The research methodology of this study consisted of four key steps, as shown in Figure 14. A literature review was first performed to identify key explanatory factors and attributes that have the highest impact on a project's unit cost performance. The literature review also served as the foundation for the development of an initial survey questionnaire to collect information on the performance of completed water treatment plant projects.

After completion of the initial survey questionnaire, an industry expert workshop was held to support the authors reviewing and further developing he data collection questionnaire. The expert workshop consisted of 20 water industry experts from both the public and private sectors. Participants consisted of water industry professionals that represent several utilities, design firms, and construction firms. These experts contained over 400 years of combined experience in water infrastructure project delivery. Additionally, the experts' pilot-tested the survey and helped ensure the practicality of the data collection tool. The final survey consisted of 67 questions and collected information such as: (1) respondent contact information; (2) general project characteristics (e.g., project location; type of project); (3) project initial and final budget; (4) treatment plant capacity before and after construction; (5) project delivery method used; (6) the use of a GMP; and (7) percent design completion at time of contractor engagement.

After concluding the development of the data collection tool, the survey was then administered and information was collected on recently completed water and wastewater treatment plant projects across the United States. The survey was administrated using *Qualtrics*, and online surveying platform. The survey was sent out to about 200 water industry professionals and administered over an 11-month period. Data was collected on 75 completed water treatment plant projects (response rate of about 38%). Respondents were instructed to provide information on their completed projects only if they were heavily involved. For example, respondents included: project managers, senior executives, and chief estimators.

The final step of the research methodology consisted of cleaning the data and completing a multivariate data analysis to explore the impact of project-specific key factors and attributes (independent variables) on unit cost performance (dependent variable). Two regression modeling techniques were selected and the results were then compared. The regression techniques used in this study are the multiple linear regression technique and the stepwise regression technique. Both regression techniques are used in construction performance modeling studies within the construction industry (Ling et al. 2004; Molenaar and Franz 2018).

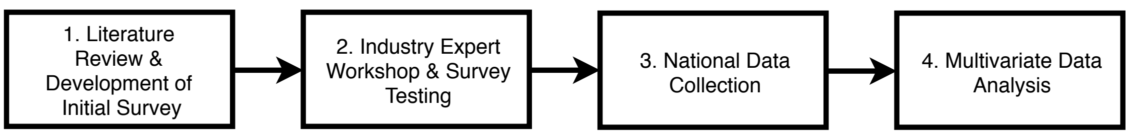


Figure 14: Research Methodology

As mentioned in the literature review section earlier, there are numerous ways that researchers across various industries have measured unit cost performance. This metric is typically adjusted to fit the context of the industry and project type being analyzed. In this study unit cost is assessed by measuring a treatment plant's total project cost in million USD divided by its increased capacity in million gallons per day, as shown in Equation 4.

$$Unit\ Cost\ = \frac{Total\ Project\ Cost\ \ (Million\ USD)}{Increased\ Plant\ Capacity\ (Million\ Gallons\ Per\ Day)} \tag{4}$$

5.3.1 Exploratory Modeling and Analysis

Using exploratory modeling and analysis is unalike using predictive modeling and analysis, where regression models are developed based on known facts (Hodges 1991). Since there are numerous unique factors and attributes that may influence a project's performance, and are judged differently by various utilities, constructing a predictive model that adheres to a broad set of utilities' unique needs may be unreliable. However, exploratory modeling and analysis can allow researchers to observe the data and formulate new hypotheses, based on key explanatory variables. Explanatory modeling identifies variables that have a scientifically meaningful relationship with the outcome. This form of modeling can provide practical benefits, as industry stakeholders will be able to understand how certain commonly-used project-specific factors and attributes may positively or negatively influence the impact of unit cost performance on water projects. In this study, multivariate analysis is used to develop two regression models, one through multiple linear regression and one through stepwise regression. The following sections will provide further detail on the exploratory modeling and analysis process of this study.

5.3.1.1 Multivariate Regression Analysis

Multiple linear regression is a statistical technique used to develop a linear equation that can relate two or more independent variables to a specific dependent variable, as seen in Equation 5.

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon \qquad (5)$$

Where Y = dependent variable; α = intercept; β_i = regression coefficients; X_i = input variables; and ε = error.

Regression analysis is used for prediction, hypothesis testing, and modeling of casual relationships (Ji et al. 2010). An important component for using multiple regression analysis is the assumption that multicollinearity does not exist. It is critical to ensure that there is no high degree of negative or positive correlation between two or more independent variables. One common approach to examine multicollinearity is through the use of a correlation matrix; however, a more reliable approach is by the variance inflation factor (VIF) (Neter et al 1990; Yoo et al. 2014). A correlation matrix depicts if a linear relationship between the independent variables exists, indicting multicollinearity issues. The VIF estimates the amount of increase of variance of a regression coefficient due to multicollinearity in the model. Typically, if a VIF value of an independent variable is greater than 10, then there are multicollinearity issues that need to be diagnosed before proceeding with model development (Yoo et al. 2014).

Stepwise regression is a specific regression technique, useful in reducing the number of input variables and in identifying highest predictors. There are several variations of stepwise regression that can be used (e.g., forward; backward). In forward stepwise regression, the model is empty at first and sequential iterations occur by adding an independent variable only if it improves the accuracy of the model. On the other hand, in backward stepwise regression, the model is first saturated with all independent variables and at each step gradually removes independent variables from the regression model to find a reduced model that best explains the data. Stepwise regression is useful in reducing the number of input variables and in identifying highest predictors. In this study, backward selection was selected. The reason the backward stepwise approach was selected is due to its ability of dealing with predictors in the models that may have collinearity problems (Hwang 2009).

The backward stepwise regression approach implies that an independent variable will be removed from the model only if the model will achieve a larger R^2 value, where R^2 is represents the portion of the dependent variable that is explained by the independent variable being investigated. R^2 is measured on a scale of 0% to 100%, with a higher R^2 value indicating better predictive power. In the backward step approach, the model will continue running until the point where removing an independent variable form the model will not improve the R^2 value. At this point, the independent variables that remain would typically have a p-value lower than 0.05, when tested at a confidence interval of 95%, and are ones that are statistically significant. This approach can reveal the independent variables that have statistically significant correlations with the dependent variable in question. Moreover, the adjusted R^2 is a modified version of the R^2 that is adjusted for the number of predictors in the model. The adjusted R^2 only increases if the removal or addition of a new predictor improves the model's accuracy.

5.3.1.2 Establishment of Key Factors and Attributes

Key factors and attributes cited in the literature were used for the development of the data collection survey and as the independent variables in the exploratory regression models. The factors and attributes from the literature were slightly modified to fit the context of water infrastructure projects. As shown in Table 11, this included: (1) use of a GMP; (2)

project team experience with delivery method; (3) level of design completion before contractor engagement; (4) project complexity; (5) project team chemistry and communication; and (6) project size.

Table 11: Key Factors that Influence Unit Cost Performance and their Definition

Variable Number	Factor	Definition
V1	Use of GMP on Project	1=Yes; 0=No
V2	Project Team Experience with Delivery Method	1 to 15 (summation of owner, designer and constructor experience); *Likert Scale 1 to 5* Owner Experience: 1=no experience; 5=highly experienced; Designer Experience: 1=no experience; 5=highly experienced; Constructor Experience: 1=no experience; 5=highly experienced
V3	Level of Design Completed Before Constructor Engagement	0% to 100% of design completion
V4	Project Complexity	Score ranging from 0 to 16 (summation of all applicable complexity issues on respondent's project)
V5	Project Team Chemistry/Communication	*Likert Scale 1 to 5* 1=Very low; 5=Very high
V6	Project Size	Increased plant capacity in million gallons per day (MGD)

These variables were developed through the support of the industry experts during the industry expert workshop. For example, project complexity was gauged by having respondents select complexity issues that were applicable to the delivery of their projects from a list of common complexity issues identified by the experts. In total, 16 common project delivery complexity issues were identified for water infrastructure projects, as seen in Table 12. The workshop participants did not rank the impact of the 16 complexity issues. The experts agreed that different complexity issues may have importance on a project's delivery depending on a project's unique characteristics.

Table 12: Project Delivery Complexity Issues for Water Infrastructure Projects

No.	Complexity Issue	No.	Complexity Issue
1	Project Cost	9	Integration to Existing Systems
2	Plant Capacity	10	Operational Constraints
3	Permitting	11	Schedule Constraints
4	New Technology	12	Market Constraints
5	Litigation	13	Project Location (Rural vs. Urban)
6	Challenging Project Participants	14	Weather Constraints
7	Environmental Constraints	15	Aggressive Scheduling
8	Project Footprint	16	Constructability Challenges

By observing Table 11, it can be seen that these key variables of interest in this study have different measures and definitions. Therefore, based on a similar approach used by El Asmar (2012), standardization is also considered to transform the regression coefficients to their equivalent values on the standard normal distribution. Standardization refers to the process of subtracting the mean and dividing by the standard deviation. This allows the coefficients to be assessed on the same scale if needed. In this paper, both the unstandardized coefficients (β) and standardized coefficients (b) of the regression models will be reported.

5.4 Data Characteristics

Data was collected on 75 completed treatment plant projects, distributed between 25 DBB (33%), 27 CMAR (36%), and 23 DB (31%) projects. Water utilities comprised of 70% of survey respondents, with constructors comprising of 20%, and designers comprising of the remaining 10%. Data was acquired on completed projects from 15 States from all four major region of the United States. Water treatment plants represented 62% of the collected data, with wastewater treatment plants representing the remaining 38%. Total project costs ranged from $1 million USD to $400 million USD. Total project schedules ranged from one month to 13 years. Treatment plant capacities ranged from one million gallons per day to 600 million gallons per day. The total combined value of all projects was $4.1 billion USD, with water treatment plant projects representing $1.7 billion USD and wastewater plant projects representing $2.4 billion USD. Water treatment plants had an average project cost of $64 million USD and wastewater treatment plants had an average project cost of $82 million USD. All projects in the study's sample were completed from 2005 onwards.

5.5 Model Estimation and Discussion

Before commencing with the development of the regression models, both the correlation matrix and VIF approach was used to test for potential multicollinearity issues. All six independent variables were examined through both approaches. The correlation matrix did not present any strong linear correlation between any set of variables. In terms of the VIF approach, all six variables contained a VIF lower than the common cut off point of 10 (Yoo et al. 2014).

The regression modeling in this study was conducted using the support of Statistical Package for Social Sciences (SPSS) software. Since the dataset was relatively small in sample size, a 90% to 10% randomized data splitting was used to train and test the data respectively (Marchionni et al. 2016). Information on the 68 completed water treatment plant projects (90% of the available data) was used to develop both of the multiple linear regression and stepwise regression models. However, since unit cost measured a plant's increased capacity, multiple data points in the sample were deemed unacceptable. This occurred as several data points consisted of renovation or rehabilitation type of projects, where the plant capacity stayed constant. In total, the model was built with about 15 projects. The results of these regression models for unit cost performance are shown in Table 13. Despite the sample size being rather small, the regression models successfully explored project-specific factors and attributes that impact unit cost performance. The R^2 for the multiple regression model was 0.846, indicating that the independent variables selected can explain 84.6% of the variation in unit cost performance within the data set. The R^2 for the stepwise regression model was 0.776 for the stepwise regression model, indicating that the independent variables can explain 77.6% of the variation in unit cost performance. Both regression models in this study contained a high R^2 value ($R^2 \geq 0.7$), showing a strong linear association (Ling et al. 2004). Additionally, an ANOVA test for the multiple linear regression model showed a p-value of 0.029, and a p-value of <0.01 for the stepwise regression model. These results indicated that the six independent variables within both models could statistically explain the dependent measure (unit cost).

Table 13: Regression Model Results Exploring Unit Cost Performance

Variable	β	σ	b	*t* value	*p*-value
Multiple Linear Regression					
$R^2 = 0.846, \text{Adj.} R^2 = 0.691$					
Constant	14.913	5.300	-	2.814	0.031*
Use of GMP on Project	-1.437	2.012	-0.130	-0.714	0.502
Project Team Experience	-0.250	0.463	-0.138	-0.540	0.609
Level of Design Completed Before Constructor Engagement	0.039	0.036	0.291	1.078	0.322
Project Complexity	0.828	0.357	0.387	2.319	0.059
Team Chemistry/Communication	-3.56	0.899	-0.677	-3.959	0.007*
Project Size	-0.016	0.011	-0.278	-1.467	0.193
Stepwise Regression					
$R^2 = 0.776, \text{Adj.} R^2 = 0.702$					
Constant	14.128	3.927	-	3.598	0.006*
Project Complexity	0.854	0.345	0.399	2.474	0.035*
Team Chemistry/Communication	-3.720	0.852	-0.707	-4.366	0.002*
Project Size	-0.017	0.009	-0.309	-1.908	0.089

**Statistical significance at p-value<0.0.5*

Note: Regression coefficient (β) is calculated using ordinary least-squares method. Standard error (σ) estimates the standard deviation of the coefficient across cases. The standardized regression coefficient (b), allows for equal comparison of, coefficient weights when the constant is removed. The t value measures the size of the difference relative to the variation in your sample data. The p-value indicates if the relationship between the independent variables and dependent variable is statistically significant at a p-value <0.05.

5.5.1 Use of Guaranteed Maximum Price

The application of a guaranteed maximum price (GMP) for project delivery is an effective practice that owners may use to limit their project risks. When a GMP is used, the contractor is to incur any overrun costs above the GMP associated to the project. GMP is a form of open book contracting, which may improve price transparency between the utility and the builder. GMP use is growing in the water industry (Bogus et al. 2010); therefore, it is important to understand how it may impact a project's delivery performance.

In the multiple linear regression model, it was observed that a GMP can be useful in limiting the unit cost performance of a treatment plant project (β=-1.437) This finding shows that a GMP can be useful in limiting the unit cost of a treatment plant project by at least $1.437 million per increased plant capacity (in MGD). This result is aligned to the literature, as a study by Bogus et al. (2010) found that using a GMP can limit a water project's overall cost growth and schedule growth. Additionally, these findings are similar to that of the study of Molenaar and Franz (2018), which showed that using open book contracting such as a GMP could limit unit cost performance for various building uses. This paper obtained similar findings, quantifying this benefit specifically for unit cost performance of treatment plant projects.

The regression coefficient for GMP use was not statistically significant in the multiple linear regression model. However, the negative regression coefficient itself indicated the impact of this project attribute on unit cost performance. Moreover, the use of GMP variable was not a key predictor in the stepwise regression model. This indicates that other key project variables may have a larger impact on a project's unit cost performance.

5.5.2 Project Team Experience with Delivery Method

As mentioned earlier in this paper, DBB is the traditional method of project delivery across the entire construction industry. APDM has been growing in use; however, some utilities are still gaining experience in using these innovative delivery methods. Reasonably, a project team's experience can influence a project's delivery performance.

This paper explored this factor further by quantifying the impact of project team experience specifically for water infrastructure projects.

The multiple linear regression model indicated that greater project team experience can reduce unit cost performance (β=0.25). This shows that a project that contains a very experienced project team (Likert score of 5) will be capable of reducing unit cost by $1.25 million USD per MGD. The regression coefficient for project team experience use was not statistically significant in the multiple linear regression model. Moreover, the stepwise regression model showed that project team experience was not a key predictor.

In this paper, experience with delivery method included the DBB, CMAR, and DB method. However, it may not be valid to assume that utilities will have high levels of experience with all three delivery methods. A study by Feghaly et al. (forthcoming) studied project team experience with delivery method in the water industry. The authors used a Likert scale, where 1=least experience to 5=most experienced, to study utilities experience in delivering DBB, CMAR, and DB projects. The results of the study showed that utilities had on average 4.92 experience in DBB, 2.89 in CMAR, and 2.70 in DB delivery. Therefore, it is important for utilities to be experienced with these frequently used delivery methods and use the appropriate delivery method when applicable. This will allow the utility to truly leverage the performance benefits that are implied through this multiple regression model. Additionally, a study by Francom et al. (2014) showed improved project performance for trenchless project delivery resulting from a high-level of experience of the contractor. On the other hand, Molenaar and Franz (2018) found that the worse performing projects in their dataset were ones where the project team lacked experience with their selected project delivery method. On the other hand,

5.5.3 Level of Design Completed Before Constructor Engagement

One of the key benefits of APDM is through having an opportunity to leverage the constructor's expertise earlier in the design phase. Earlier engagement allows for several opportunities that may improve a project's performance, such as: (1) obtaining earlier price certainty; (2) providing constructability reviews; and (3) improving teamwork and collaboration early in the project. A study by Mollaoglu-Korkmaz et al. (2013) revealed that DBB may also improve the delivery of a project if that constructor is engaged earlier in the project. Therefore, this paper quantified the impact of constructor engagement on unit cost performance for water projects, using all delivery three delivery methods, in terms of percent design completed.

The multiple linear regression model indicated that the later a contractor is engaged in the design process, the lower the unit cost performance of a project (β=0.039). This implies that a utility that engages a constructor at 100% design competition will have an increased unit cost of $3.9 million USD per MGD. However, if a utility were to engage with a constructor at 30% design competition, the utility can expect to have an increased unit cost of $1.17 million USD per MGD. By comparing engagement at 100% design completion and that of 30% design completion, the utility that engages at the 30% design completion mark can expect a savings of $2.73 million USD per MGD. This result aligned to the findings of Molenaar and Franz (2018) that emphasized the value of brining the team together earlier in the design process.

Similarly to the first two independent variables, the regression coefficient for level of design completed before constructor engagement was not statistically significant in the multiple linear regression model. Moreover, the variable of level of design completed before constructor engagement was not a key predictor within the stepwise regression model.

5.5.4 Project Complexity

Measuring a project's complexity is a difficult value to quantify. There are numerous factors that may increase a project's complexity and can be a result of internal or external factors relating to a project's delivery. Researchers have tried to identify complexity factors that increase a project's complexity. A study by Chan (1998) identifies five factors that contribute to a project's complexity and included: (1) client's attributes; (2) site condition/site access problems; (3) buildability of project design; (4) quality of design coordination; and (5) quality management. As mentioned earlier in this study, the authors utilized the support of industry experts to identify 16 water infrastructure specific complexity issues.

In the multiple linear regression model, it was observed that the higher the complexity issues on a project, the higher the unit cost (β=0.828). If a project has all 16 complexity issues, a project's unit cost may increase up to $13.25 million per MGD. This variable was not statistically significant in the multiple linear regression model. However, it was a key predictor in the stepwise regression model and the coefficient was statistically significant with a *p*-value of 0.035. The regression coefficient in the stepwise regression model (β=0.854), slightly higher than that of multiple linear regression model

(β=0.828). This result indicated that project complexity is a key predictor for unit cost performance for water infrastructure projects. These results are similar to that of Molenaar and Franz (2018), which also found that lowering a project's complexity is highly influential in improving a project's delivery performance.

5.5.5 Project Team Chemistry/Communication

It is important for team members to communicate well early on and create a relational project culture (Molenaar and Franz 2018). In a study by Francom et al. (2016b), project team communication was identified as key performance metric that impacts the performance of trenchless projects. The study by Molenaar and Franz (2018) found that improved team chemistry between the project team has a large impact on unit cost performance in specific. This paper explored the value of improved team chemistry and communication on unit cost performance for water projects.

Project team chemistry/communication statistically had the largest impact on unit cost performance (β=-3.56). Project team chemistry and communication was the only statistically significant regression coefficient in the multiple linear regression model with a *p*-value of <0.01*. This implies that project team that has the highest team chemistry and communication (Likert score of 5) may be capable of saving up to $17.8 million USD/MGD. This finding is similar to that of Molenaar and Franz (2018), where team chemistry also had a statistically significant impact on unit cost performance. These results are also aligned to the findings of Franz et al. (2017), where the researchers observed that as team integration improved, project performance improved.

Project team chemistry and communication was also a key predictor in the stepwise regression model, with a statistically significant *p*-value of 0.002. The regression coefficient for the stepwise regression model was slightly higher than of the multiple regression model (β=-3.72). This result indicates that, by using the stepwise regression model, a Likert score of 5 in this attribute may be capable of saving up to $18.6 million USD/MGD. This value was slightly higher than that seen in the multiple regression model.

5.5.6 Project Size

A metric typically used for capturing project size for building projects is squared meter or foot of built area (Allen 2001; Molenaar and Franz 2018). In this paper the authors adjusted this metric to fit the context of water treatment plant projects by using increased plant capacity in MGD to gauge a project's size. The authors of this paper quantified this factor specifically for unit cost performance of water projects.

The multiple linear regression model revealed that increased project size resulted in improved unit cost performance (β=-0.016). To further explain this finding in a practical way, a project with an increased plant capacity of 20 MGD and one with 100 MGD will be compared. The difference between these two hypothetical water treatment plant projects is 80 MGD, this difference can amount to unit cost savings of $1.28 million USD/MGD. This value may be further increased, depending on the amount of increased capacity. One key reason the model is indicating these unit cost benefits is a result of economy of scale. This finding is consistent with that of Creedy et al. (2010), where the authors linked project cost performance to the economies of scale. The researchers were able to find that smaller dollar projects are more likely to incur cost overruns, and larger dollar projects have smaller percentages of cost overruns (Creedy et al. 2010). In brief, economies of scale appear when more units can be produced on a larger scale with fewer input costs. Additionally, in the study by Molenaar and Franz (2018), projects with larger square footage showed delivery performance benefits.

The project size variable was also a key predictor in the stepwise regression model; however, the regression coefficient was not statistically significant. The regression coefficient for this variable in the stepwise regression model (β=-0.017) was very similar to the regression coefficient value obtained in the multiple linear regression model (β=-0.016).

5.6 Exploring Threats to Validity

The remaining 10% of the data, comprising of seven randomly selected projects, was used to estimate the mean absolute error between the actual unit cost and the predicted unit cost values. The mean absolute error is defined in Equation 6 (Donkor et al. 2012).

$$Mean\ Absolute\ Error = \frac{1}{N}\sum_{i}^{N} |Actual\ Value(i) - Model's\ Predicted\ Value(i)| \qquad (6)$$

The mean absolute errors of both models were slightly high in terms of forecast accuracy. Using the unstandardized coefficients (β), the multiple linear regression model had a mean absolute error of 10.92$M/MGD and the stepwise regression model had a lower mean absolute error of 10.71 $M/MGD. These findings indicate that the models may have relatively high errors, as the average unit cost of the actual sample was 8.45 $M/MGD. This may be a result of the small sample size used to develop this model, which may also impact the generalizability of the results. However, as mentioned earlier, these are not predictive models and are not intended to measure unit cost performance. The intent of these models is to investigate the behavior of the independent variables of interest on unit cost performance.

5.7 Conclusions

This study developed exploratory mathematical models to detect the impact of project-specific factors and attributes on a water infrastructure project's unit cost performance. Unit cost is an effective project delivery metric that can be used to gauge a project's overall performance. This study collected data on 75 completed water treatment plant projects, through the support of an industry expert workshop. The data was then used for regression modeling and analysis to observe the behavior of key project-specific factors and attributes on unit cost performance. Two models were developed using both multiple linear regression and stepwise regression.

The main contribution of this work is through exploring the impact of project specific factors and attributes on unit cost performance, particularly for the water industry. The findings of this study based off two regression models demonstrated that (1) project team chemistry and communication and (2) project complexity statistically have the highest impact on unit cost performance of water projects.

This study has built on previous works that investigated project-specific factors and attributes that impact project delivery performance, particularly that of Molenaar and Franz (2018). This research effort may practically support utilities in understanding the impact of key factors and attributes on unit cost performance. The findings of this study may support water utilities in their project delivery decisions, improving the overall performance of their water projects.

A limitation of this work is that these models are not predictive and cannot be utilized to predict the performance of future water treatment plant projects. The study only focused on exploring the behavior of project-specific factors and attributes. Another limitation is that these values are only applicable to treatment plants where there is an increase in plant capacity, as the models only included information on projects with increased plant capacities. Moreover, the sample size for developing the models was somewhat small. Therefore, it may not be an accurate representation of the entire water industry. However, despite the small sample size, the authors were still capable of observing significant findings, which aligned to the existing body of knowledge. Future work aims to expand on the dataset and potentially develop predictive models that can estimate unit cost performance for water projects. Similar work can also be conducted to explore the impact of project-specific factors and attributes on other performance metrics in the water industry (e.g., schedule growth; delivery speed).

CHAPTER 6

CONCLUSIONS

6.1 Summary of Research Methods

This dissertation provides a comprehensive study for improving the delivery of APDM water infrastructure projects. First, a state of professional practice was conducted to assess current APDM practices in the water industry. A data collection tool was developed with the support of industry experts, and data was collected from 75 completed water projects. The results of this study motivated the following phases of this dissertation. The second phase consisted of interviewing ten water utilities that are experienced with DB project delivery. DB practices were highlighted under seven key DB project administration categories. Key recommendations for DB delivery were highlighted to support water utilities seeking to add DB to their organization's delivery toolbox. In the third phase, project delivery method selection factors specific to the water industry were studied through an extensive literature review and support from industry expert workshops. In total, 13 selection factors were identified specifically for the water industry. This effort resulted in the development of EXPRSS-TP, a pioneering web-based project delivery method selection tool. EXPRSS-TP is now accessible to industry stakeholders and can facilitate their project delivery method selection process. In the fourth and final phase, multivariate analysis was conducted to explore the impact of project-specific factors and attributes on impact unit cost performance. Three key factors and attributes with the highest impact on unit cost were identified. The following sections will provide a summary on the key results and contributions to the body of knowledge as a result of this dissertation.

6.2 Summary of Results and Contributions

The first phase of this study, *Chapter 2*, provided a state of professional practice on APDM implementation practices for water infrastructure projects. This study contributes to the body of knowledge by providing water industry stakeholders with quantifiable results of current industry APDM practices. Key findings highlighted in this study included: (1) GMP is the preferred compensation type for APDM water infrastructure projects; (2) qualifications-based is the preferred APDM procurement method; (3) utilities have the least experience with the DB method; (4) utilities statistically have the lowest comfort level with delivering CMAR projects; (5) owner involvement in design is lowest for DB projects; and (6) DBB and APDM have similar procurement durations for water infrastructure projects. Moreover, this study showed that different delivery methods have unique characteristics that may make them applicable for a given project.

The second phase of this study, *Chapter 3*, identified effective DB project administration practices that will allow a water utility to leverage DB experiences of utilities that successfully deliver DB water projects. The main contribution of this study is the identification of effective DB project administration practices. Moreover, effective practices are identified across a DB water project's delivery timeline (from project initiation, design, construction, handover, and operations). Key findings highlighted in this study relating to DB effective practices for water projects included: (1) using a guaranteed maximum price (GMP) and finalizing it later in the design process; (2)

providing the risk-register to the design-builder to maintain during the design and construction process; and (3) using qualification-based procurement.

The third phase of this study, *Chapter 4*, contributes to the body of knowledge by identifying and prioritizing the 13 key project delivery method selection factors specifically for the water industry. These selection factors emerged from a systematic literature review, academic and industry project delivery method selection models, and significant industry input through organized workshops. Moreover, EXPRSS-TP, a comprehensive web based decision-support model, was also developed to disseminate the findings through a simple-to-use interface that can be operated by decision-makers in the water industry. The project delivery method selection process is typically an informal process that may range from days to weeks at a time. Based on this work, the assessment can now be completed in about one hour. The tool is currently available to water industry stakeholders and can be used to facilitate their project delivery method selection process.

The fourth and final phase of this study, *Chapter 5*, explored project specific factors and attributes that impact the project delivery performance of water treatment plant projects. Unit cost was selected as the performance metric to investigate. Key performance factors and attributes were identified from an extensive literature review. The factors and attributes were explored using multivariate analysis. Two regression models, one multiple linear regression model and one stepwise regression model, were developed. The results indicated that project team chemistry and communication is the variable with the highest impact on unit cost performance and was evidenced through both models.

Previous research has shown that APDM can deliver improved project performance for water projects. However, using an APDM solely will not guarantee project success. The findings and key contributions of this dissertation will support utilities in successfully selecting the appropriate project delivery method for their projects. This dissertation can equip their utility with evidence-based research results that may improve their water project's delivery process.

6.3 Limitations of the Research and Future Work

In *Chapter 2*, a sample size of 75 completed water and wastewater projects was collected, which may be considered small when compared to academic studies conducted on projects within other industries. However, obtaining information on treatment plant projects is difficult, as they are not constructed as often as other building types (e.g., commercial; residential). Additionally, in *Chapter 3*, a small sample of interviews was conducted. However, given the complexity of the adapted research framework, this study identified DB project administration practices in the water industry from industry practitioners representing ten large utilities across major regions of the United States and a Canadian province. Future work can build on this study's findings and collect information from a larger sample size of completed water and wastewater treatment plant projects. A limitation of the study in *Chapter 4* is that the project delivery method selection factors and the decision-support tool are focused on the water industry solely. These results have not been tested in other industries and adapted appropriately; therefore, may not be directly applicable. Future research work can be conducted to adapt and test the findings of this study to fit other project types (e.g., pipeline projects) or even other industries (e.g., building projects) that could also use support with project delivery method selection. A limitation in *Chapter 5* is that the developed models are not predictive models and should not be used to predict the unit cost performance of water projects. Additionally, the sample size was somewhat small. Future work can aim to repeat the modeling and analysis on a larger dataset to obtain more accuracy in the results. Additionally, similar work can be conducted to explore the impact of project-specific factors and attributes on other performance metrics in the water industry (e.g., schedule growth; delivery speed).

Another recommendation for future work is to include other APDM in the analysis. CMAR and DB are extensively used in the water industry; however, other forms of APDM may also be used, such as job order contracting (JOC) and integrated project delivery (IPD). Future researchers can aim to conduct similar work and include these APDM in the analysis. This may allow water stakeholders in obtaining additional viable delivery method options for their water infrastructure projects.

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