Performance of the Construction Manager at Risk (CMAR) Delivery Method

Applied to Pipeline Construction Projects

by

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ABSTRACT

Much of the water and wastewater lines in the United States are nearing the end of their useful life. A significant reinvestment is needed in the upcoming decades to replace or rehabilitate the water and wastewater infrastructure. Currently, the traditional method for delivering water and wastewater pipeline engineering and construction projects is design-bid-build (DBB). The traditional DBB delivery system is a sequential low-integration process and can lead to inefficiencies and adverse relationships between stakeholders. Alternative project delivery methods (APDM) such as Construction Manager at Risk (CMAR) have been introduced to increase stakeholder integration and ultimately enhance project performance. CMAR project performance impacts have been studied in the horizontal and vertical construction industries. However, the performance of CMAR projects in the pipeline engineering and construction industry has not been quantitatively studied.

The dissertation fills this gap in knowledge by performing the first quantitative analysis of CMAR performance on pipeline engineering and construction projects. This study's two research objectives are:

(1) Develop a CMAR baseline of commonly measured project performance metrics

(2) Statistically compare the cost and schedule performance of CMAR to that of the traditional DBB delivery method

A thorough literature review led to the development of a data collection survey used in conjunction with structured interviews to gather qualitative and quantitative performance data from 66 completed water and wastewater pipeline projects.

Performance data analysis was conducted to provide performance benchmarks for CMAR projects and to compare the performance of CMAR and DBB.

This study provides the first CMAR performance benchmark for pipeline engineering and construction projects. The results span across seven metrics in four performance areas (cost, schedule, project change, and communication). Pipeline projects delivered using CMAR have a median cost and schedule growth of -5% and 5.10%, respectively. These results are significantly improved from DBB baseline performance shown in other industries. To verify this, a statistical analysis was done to compare the cost and schedule performance of CMAR to similar DBB pipeline projects. The results show that CMAR pipeline projects are being delivered with 6.5% less cost growth and with 12.5% less schedule growth than similar DBB projects, providing owners with increased certainty when delivering their pipeline projects.

I dedicate this dissertation to my loving parents Brian and Lindy and sister Jordan. I am

eternally grateful for your love, unwavering support, and continuing guidance. Without

you this would not have been possible.

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1. INTRODUCTION

1.1 Background

The United States has a failing water and wastewater pipeline infrastructure. In 2013, the American Society of Civil Engineers (ASCE) released a report card grading 16 categories of America's infrastructure. In this report, ASCE gave both the water and wastewater infrastructure a grade of a "D," which is considered poor and at risk. ASCE defines a D as; "The infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of significant concern with strong risk of failure" (ASCE 2013). Failures in water and wastewater pipeline infrastructure have many impacts on the public, including water disruptions, impediments to emergency response, water pollution, and damage to roadways and other types of infrastructure (ASCE 2013). Due to aging of the water and wastewater lines, a significant reinvestment is needed in the up coming decades to replace or rehabilitate the pipelines. According to ASCE, "Not meeting the investment needs of the next 20 years risks reversing the environmental, public health, and economic gains of the last three decades" (ASCE 2013). Two studies by the Environmental Protection Agency (EPA) estimated a need of approximately $632.8 billion is needed for water and wastewater systems, with $281.6 billion of those funds allocated to pipelines by 2028 (EPA 2007; EPA 2008). Some of the major concerns surrounding the water and wastewater infrastructure are the increase in water main breaks and discharge of untreated sewage.

In the United States there are nearly 170,000 water systems that contain more than one million miles of water mains. Within these systems, there is an estimated 240,000

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water main breaks per year (ASCE 2013). These breaks can have significant social and economic impacts. The cost of an emergency repair of a waterline and roadway after a catastrophic water main break is typically much higher than if that line was rehabilitated or repaired before failure. This cost does not factor in the disruption of the public while a repair is taking place. In a study completed on water infrastructure in 2007, the EPA reported a 20-year capital investment need of $334.8 billion. Of the $334.8 billion investment, nearly 60% or $199 billion is needed for transmission and distribution systems. The buried pipes of a transmission and distribution network generally account for most of a system's capital value and are the least visible component of a public water system (EPA 2007).

There are between 700,000 and 800,000 miles of public sewer mains located throughout the 19,739 wastewater systems scattered around the U.S. The aging and under designed wastewater pipelines lead to the discharge of an estimated 900 million gallons of untreated sewage each year (ASCE 2013). The discharges typically flow into a nearby river or body of water and are a major water pollution concern. In another study completed in 2008, the EPA reported that a 20-year capital investment of $298 billion is needed for aging wastewater infrastructure, with wastewater pipeline repair and new pipelines accounting for $82.6 billion (EPA 2008).

These studies highlight the aging water and wastewater infrastructure is in critical need of replacement or rehabilitation. This is going to require a serious investment from the federal, state, and local governments. To maximize the money invested, engineering and construction must be completed efficiently, on time, and without additional costs. Alternative project delivery methods (APDM) have shown to provide superior

performance in delivering construction projects in other industries (Konchar and Sanvido 1998; Molenaar et al. 1999; Shane et al. 2013; El Asmar et al. 2013).

The traditional method for delivering water and wastewater pipeline engineering and construction projects is design-bid-build (DBB). The DBB delivery system is a sequential process and can lead to inefficiencies and adverse relationships between owners, design engineers, and contractors. These adverse relationships are often caused by a lack of communication and stakeholder integration. APDM have been introduced to increase stakeholder integration and ultimately enhance project performance (Konchar and Sanvido 1998; Molenaar et al. 1999; El Asmar et al. 2015). Some of the prevalent APDM methods used in the water and wastewater pipeline industry are construction manager at risk (CMAR), job order contracting (JOC), and design-build (DB). This study focuses specifically on the project performance of CMAR for delivery of water and wastewater pipeline projects.

Project delivery methods are most commonly distinguished by two key characteristics: (1) the contractual relationships between project stakeholders and (2) their timing of engagement in the project (El Asmar et al. 2013; Sanvido and Konchar 1998). Figure 1(a) shows the relationships between key stakeholders for the two delivery methods discussed in this dissertation: DBB and CMAR. In both project delivery methods, the owner signs separate contracts with the engineer and the contractor. Figure 1(b) highlights the contractor's timing of engagement. In DBB, the contractor is typically engaged after the design is complete and is unable to provide input during the design. To maximize the benefit of collaboration during the design phase and minimize redesign, the

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CMAR firm is best engaged between 30 and 60 percent of the design development (Shorney-Darby 2012).

Figure 1: Relationships and Timing of Engagement Between Key Stakeholders in DBB and CMAR

Additional key differences between the two delivery systems were found in the literature (Gransberg and Shane 2010; Shorney-Darby 2012) and include the following:

A. In CMAR, the design engineer and CMAR firm are often contractually required to coordinate during the design phase of the project. This level of interaction often does not take place in the traditional DBB method.

B. During a CMAR project, the contractor often has two contracts. The first is a preconstruction contract that will be completed during the design phase for services such as design reviews, constructability reviews, cost estimation, value engineering, and scheduling. The second contract is for the construction of the project.

C. The contractor selection process varies between DBB and CMAR. DBB often

uses a selection process where the owner will typically select the lowest

responsible bidding contractor, regardless of their experience or qualifications. In

contrast, in CMAR the owner often selects the contractor based on a combination

of cost and qualifications.

These differences highlight the increased timing of engagement of the CMAR firm and

the ability to provide more coordination and communication during the design phase.

There are currently no studies that investigate and provide a baseline of

performance metrics for pipeline projects completed using CMAR. This dissertation will

fill this gap in knowledge but completing the first quantitative performance analysis of

CMAR on pipeline engineering and construction projects.

1.2 Research Objectives and Method

The primary objectives of this dissertation are twofold: (1) provide a comprehensive

study of CMAR project performance to develop a baseline of commonly measured

performance metrics; and (2) statistically compare the cost and schedule performance of

CMAR to that of the traditional DBB delivery method. The hypothesis of this study is

that the use of CMAR can positively affect commonly measured performance metrics and

provide superior performance when compared to DBB for pipeline engineering and

construction projects. This will provide owners with a valuable alternative to the

traditional DBB delivery method.

The research study is separated into four phases as shown in Figure 4. After

which, the phases will be expanded upon individually.

Dissertation Chapter	Research Steps	Contributions
All Chapters	**Phase A: Literature Review** **APDM Literature** • Review relevant literature in all construction industries (vertical, horizontal, industrial, pipelines etc.) **Pipeline Literature** • Review relevant performance study literature	**Body of Knowledge** • APDM and pipeline industry literature and previous studies • Foundation for Journal Papers 1, 2, and 3 **Commonly Used Performance Metrics** • Metrics and variables studied in both the APDM and pipeline industry
Chapter 2	**Phase B: State of Practice** **Qualitative Survey** • Development • Data collection • Analysis of utilization rate, comfort level, and perception of APDM **Meta-Analysis of Literature** • Analysis of cost savings of pre-published projects	**Journal Paper #1: Industry Perceptions of Alternative Project Delivery Methods Applied to Trenchless Pipeline Projects** • APDM are being used and perceived to perform well in the pipeline industry • Meta-analysis showed a potential for cost savings when using APDM. • Motivation for large quantitative study
Chapter 3	**Phase C: Case Study** **Quantitative Survey** • Development • Reviews by faculty and industry **Pilot Testing** • Four projects • Used to refine survey in preparation for large data collection	**Journal Paper #2: Construction Manager at Risk (CMAR) for Pipeline Rehabilitation: A Case Study on CMAR Performance Benefits** • Longitudinal case study of CMAR performance on pipeline projects • Further motivation for larger quantitative study based on shown performance benefits
Chapter 4	**Phase D: Quantitative Performance Assessment** **Data Collection** • CMAR and DBB project performance data **Data Analysis** • Descriptive statistics • Univariate statistics	**Journal Paper #3: Performance of Construction Manager at Risk (CMAR) on Pipeline Engineering and Construction Projects: A Quantitative Benchmarking Study** • Quantitative performance analysis of CMAR pipeline projects • Baseline for CMAR performance metrics • Statistically compare performance of CMAR and DBB projects

Figure 2: Research Method and Journal Publications

1.2.1 Phase A: Literature Review

Phase A is a comprehensive assessment of the literature in both APDM performance and pipeline performance that will provide a foundation for the rest of the study. This phase

consisted of two objectives: the first determines the current state of knowledge and use of APDM in the pipelines industry. The second identified common performance metrics that are studied in both alternative project delivery and pipeline engineering and construction research.

1.2.2 Phase B: State of Practice

The second phase began with developing a qualitative survey. The purpose of the survey was to determine the utilization rate, industry comfort level, and perceptions of performance of APDM in the trenchless pipeline construction industry based on a sample of industry leaders. The survey was combined with a meta-analysis of literature that explored the cost savings achieved on a small sample of pre-published trenchless construction projects. The survey results indicated the trenchless industry perceived APDM to offer better performance than DBB and that APDM was being used to deliver a portion of projects. The meta-analysis showed the potential for APDM to impact the cost performance on trenchless construction projects. This phase provided motivation for a large quantitative data collection effort to investigate the performance of APDM in the trenchless industry. During this phase the authors made the decision to focus the study on the CMAR delivery method in the entire pipeline industry due to identified public water and wastewater projects.

1.2.3 Phase C: Case Study

Two stages needed to complete Phase C are a quantitative survey development and pilot testing of the survey. The survey included metrics identified in the literature review, and then went through a series of revisions. Construction and Engineering Management faculty members conducted the first revision. The second revision completed by industry

experts, representing owners, engineers, and contractors. After the iterative revision and development process, the survey was pilot tested using a small sample of projects to further refine the questions and maximize their effectiveness. This led to a concise 18-question survey that allowed for data collection of performance metrics on completed CMAR pipeline projects.

The aforementioned stages were combined to produce a case study of CMAR performance benefits on four pipeline projects from the pilot testing. These benefits will be further examined in Phase D, which is an analysis of CMAR performance on pipeline projects.

1.2.4 Phase D: Quantitative Performance Assessment

Using the refined quantitative performance survey data was collected and analyzed on a large sample of CMAR pipeline projects. The compiled data was then coded for two different analyses. The first analysis developed a baseline of performance metrics for pipeline projects being delivered with CMAR. The second analysis statistically compared the performance of projects using CMAR to projects delivered using the traditional DBB system. The DBB data was collected in addition to the author's CMAR project surveys. This provides the first quantitative study that provides a baseline for CMAR performance metrics and compares the performance of CMAR and DBB in the pipeline industry.

1.3 Dissertation Format

The dissertation is organized in three journal paper format. The objective of **Chapter 1** is to introduce the research problem statement, overall methodology, and provide a brief description of each phase of the dissertation. Each of the three subsequent chapters represents an independent article that has been accepted or is being peer-reviewed for

academic journals. Therefore, each chapter will have its own abstract, introduction, literature review, objectives, methodology, discussion of results, and conclusions.

The qualitative survey of APDM in the trenchless pipeline industry and meta-analysis are presented in **Chapter 2**. This study provided motivation for a large quantitative study of APDM performance metrics in the pipeline industry. The findings of this phase were published in the ASCE *Journal of Pipeline Engineering Systems and Practice*.

The case study completed in Phase C is presented in **Chapter 3**. This provides an in depth analysis of the pilot tested pipeline projects completed using CMAR and provides further evidence of the benefits of using CMAR on pipeline engineering and construction projects. The findings were submitted to the ASCE *Journal of Construction Engineering and Management*.

Chapter 4 presents the comprehensive quantitative data collection and analysis completed in Phase D. The two results are presented in this chapter are (1) a baseline for CMAR performance metrics in the pipeline industry and (2) a statistical comparison of the performance of CMAR and DBB pipeline projects. The findings from this phase were submitted to the ASCE *Journal of Pipeline Engineering Systems and Practice*.

Chapter 5 summarizes the major findings, limitations, and contributions of the dissertation and provides recommendations for future research. Following this chapter are the references and appendices.

2. INDUSTRY PERCEPTIONS OF ALTERNATIVE PROJECT DELIVERY METHODS APPLIED TO TRENCHLESS PIPELINE PROJECTS

2.1 Abstract

The majority of trenchless pipeline projects delivered today use the traditional design-bid-build (DBB) system. Alternative Project Delivery Methods (APDM) have been introduced to increase stakeholder integration and ultimately enhance project performance. The complex nature of trenchless pipeline projects renders them ideal candidates for APDM because of the gap that is often created by an inherent lack of technical knowledge exchange between design engineers and contractors when using DBB delivery. The use of APDM is only beginning to gain acceptance for trenchless pipeline projects. This paper has two objectives: 1) to examine the current usage, comfort level, and stakeholder perception of APDM through a survey of the trenchless industry; and 2) to investigate the published cost performance of completed trenchless projects that employed APDM. The results from the industry survey are threefold: 1) the most used project delivery system in the trenchless industry is design-bid-build; 2) the comfort level of stakeholders in implementing each project delivery method is influenced by the amount each method is used; and 3) the industry respondents perceive APDM to impact certain performance metrics more than others. The initial results from the meta-analysis demonstrate the possible performance impact of APDM on trenchless construction projects, as realized through cost savings ranging from 2% to 44%. This study provides a contribution to the body of knowledge by assisting project stakeholders in better understanding the overall industry perceptions of APDM-related performance improvements. This understanding can guide stakeholders in selecting the most suitable delivery system for their trenchless projects.

2.2 Introduction

Since its inception, trenchless pipeline construction has been delivered predominantly with the traditional design-bid-build (DBB) delivery system (Doherty and Kurzeja 2015). This delivery system is a sequential process that can lead to inefficiencies and adverse relationships between design engineers and contractors, which are often generated by a lack of stakeholder integration. Alternative Project Delivery Methods (APDM) have been introduced to increase stakeholder integration and ultimately enhance project performance (El Asmar et al. 2013). Project delivery methods are generally distinguished by two key characteristics: 1) the contractual relationships between project stakeholders and 2) their timing of engagement in the project (El Asmar et al. 2013). The aforementioned APDM allow earlier engagement of project stakeholders and have the ability to create more collaborative relationships, as shown in Figure 3.

Figure 3: Typical Project Delivery Methods Timing of Engagement and Contractual Relationships

The traditional DBB method begins with the owner procuring design services from an engineer who will completely design the project. The engineer produces design documents that the owner then uses to procure construction services. The lowest responsible bidding contractor is typically awarded the contract to complete the construction of the project. This sequential and segregated process has the potential to create a disconnect between engineers and contractors. This disconnect is typically attributed to the lack of technical information exchanged between engineers and contractors during the design phase. Although many engineers consult with contractors during the design phase, in DBB it is not a required process. However, when using APDM the trenchless contractor is engaged before the design is fully complete and is able to provide input on design and appropriate installation methods (Guy 2007).

There are several APDM currently being used in the architecture, engineering, and construction (AEC) industry. These include: construction manager as agent (CM Agent); construction manager at risk (CMAR); job order contracting (JOC); design-build (DB); and integrated project delivery (IPD). While there are some limitations to using each of these APDM (e.g. each state has its own legislation governing when and how they may be used), this paper will discuss the project delivery methods most commonly used in the AEC industry. The predominant delivery systems are defined follows:

- DBB: The traditional project delivery system in the U.S. construction industry, where the owner contracts with a designer and a contractor separately. The owner first contracts with a design company to provide "complete" design documents. The owner or owner agent then solicits fixed price bids from construction contractors to perform the work. One contractor is selected and enters into an

agreement with the owner to construct a facility in accordance with the plans and specifications (Konchar and Sanvido 1998).

- CM Agent: A delivery method wherein an architect or engineer is selected to design the project. At the same time a separate selection is made for a construction manager to serve as an agent for the owner, providing administration and management services. The CM Agent provides design phase assistance but neither holds subcontracts nor provides bonding for the construction of the project (Mahdi and Alreshaid 2005). The contractor is an agent of the owner and assumes no risk in the project. This delivery method is also referred to as *Pure CM* (it is sometimes regarded as a management strategy rather than a delivery method).

- CMAR: A project delivery system where the owner still contracts separately with a designer and a contractor. The owner contracts with a design company to provide a facility design. The owner selects a contractor to perform construction management services and construction work, in accordance with the plans and specifications, for a fee. The contractor usually has significant input in the design process and generally guarantees the maximum construction price (Konchar and Sanvido 1998).

- JOC: A delivery method to procure design and construction services for small to medium size maintenance, repair and minor new construction projects. A contract is typically valid for a set period of time for multiple design and construction projects that are delivered on an on-call basis (Francom et al. 2014).

- DB: A delivery method where the owner contracts with a single entity that is responsible for the completion of both design and construction phases, which often overlap (Molenaar and Gransberg 2001).

- IPD: A delivery system distinguished by one multiparty agreement between all key stakeholders, including major subcontractors, and their very early involvement in the project before any design has been completed (El Asmar et al. 2013).

APDM has been studied considerably in other industries such as vertical construction (Bennett et al. 1996; Konchar and Sanvido 1998; Molenaar et al. 1999; and El Asmar et al. 2013) and horizontal roadway construction (Songer and Molenaar 1996; Molenaar and Gransberg 2001; El Asmar et al. 2010; and Shrestha et al. 2012). APDM are continuing to gain substantial popularity due to the documented ability to improve project performance, as shown in the studies cited above. However, the use of APDM is only beginning to gain acceptance for trenchless pipeline projects.

Trenchless construction is defined as a family of methods that are used for the installation or rehabilitation of underground infrastructure with minimal disruption to surface activities such as traffic and business. There exist various types of trenchless technologies including: horizontal directional drilling (HDD); microtunneling; lining; pipe bursting; and auger boring. A comprehensive overview of trenchless methods can be found in Najafi (2012).

Based on performance studies in other sectors in the AEC industry, it appears the use of APDM may have the potential to improve the performance of trenchless pipeline projects. This paper explored this claim by: 1) conducting a qualitative survey of

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professionals in the trenchless industry; and 2) conducting a meta-analysis of case studies that have reported the cost performance of trenchless projects using APDM. The first objective of this study is to use the industry survey to collect data and understand the market share, comfort level in APDM implementation, and which performance areas are most affected by the use of APDM. The second objective is to analyze the data from the meta-analysis to investigate some of the published cost savings being realized on APDM trenchless projects completed in the last decade.

2.3 Previous Research

There has been little published research targeting the benefits of using APDM to deliver trenchless pipeline projects. A comprehensive review of literature was performed to analyze available information on this topic; this produced three studies that were considered relevant and used as a foundation for this paper. Additionally, the performance metrics that have the potential to be most affected by implementing APDM were collected.

Hassan (2010) evaluated the pros and cons of project delivery systems used on trenchless construction projects. A survey of industry professionals was used to evaluate different delivery systems. The author stated that project delivery systems are no longer seen as mere procedures to follow in order to move a project from the design and planning stages to the execution and commissioning stages. Instead, delivery systems have become instruments that are being used to save time and money, while developing innovative design solutions to address the unique challenges of trenchless projects. Industry professionals including owners, designers/engineers, contractors, and project managers were surveyed. Ten projects were evaluated resulting in the following

conclusions: 1) DBB is the most frequently used project delivery method in trenchless construction; 2) the trenchless construction industry is slowly beginning to adopt DB as it realizes the value that all APDM have to offer; 3) DB is most suited for projects with schedule constraints; 4) the choice of project delivery method used on a trenchless construction project is governed by the cost, risk, quality, and schedule requirements of the project; and 5) experts in the trenchless construction industry believe that the choice of a project delivery method on a trenchless construction project considerably affects the success of that project. The lack of responses from the survey was a limitation for this study, subsequently the results could not be considered statistically significant.

Guy (2007) discussed how the pairing of DB with trenchless solutions could produce a powerful synergy. Most important to the DB process, trenchless companies are ideal DB partners because they are capable of assisting the entire DB team in the current technical capabilities of a highly specialized industry. They also have been researching, engineering, and manufacturing their products to meet customized design parameters for years. Guy (2007) concluded that using trenchless technologies with DB brings numerous advantages regarding owner and design costs, design and construction schedules, critical path impacts and risk, and project profit advantages.

Kramer and Meinhart (2004) provided insight on the effectiveness of using APDM for pipeline and trenchless projects by stating the use and acceptance of APDM for pipeline and trenchless projects will likely expand as more owners, contractors, and engineers become familiar with these methods. The authors then discussed the appropriateness of APDM combined with trenchless construction through four case

studies to demonstrate that the use of ADPM could offer significant benefits to all parties involved in trenchless construction projects.

The first case study presented by Kramer and Meinhart (2004) was a traditional DBB public project for the design and construction of a water main extension using HDD. The schedule did not demand evaluating alternatives and the municipality did not have regulations that easily allowed for the use of APDM. The project was completed several weeks ahead of schedule and $200,000 below budget, and thus was considered to be very successful.

The second case study presented by Kramer and Meinhart (2004) was a public DB project replacing intake and outfall lines for a heating and refrigeration plant using microtunneling. Using the DB approach allowed for an integrated project team with the owner, providing innovative solutions and quick resolution of issues, expediting the review of design documents and allowing for real-time decision-making on proposed changes. This resulted in a reduction of project schedule and construction costs.

The third case study presented by Kramer and Meinhart (2004) was a modified DB contract for a development company to install a sewer line using microtunneling. The modified DB process consisted of the engineer preparing 75% design documents within 90 days from the Notice to Proceed, then issuing the documents to three local general contractors for proposals. The project team benefited by obtaining a constructability review during the design by requiring each general contractor to submit recommendations for design modifications that would reduce cost while still meeting the overall project goal. By using the modified DB delivery approach the project team was

able to significantly reduce the design and construction schedule, while also completing the project $2,000,000 below the original contract budget.

The final case study presented by Kramer and Meinhart (2004) was an Engineer-Procure-Construct-Manage (EPCM) contract for a utility company to install an electrical line using HDD. The project had to be completed prior to the peak of the summer months. An APDM was selected to help overcome the critical schedule constraints. Another benefit of using EPCM is the constructability reviews conducted during the design process to determine potential cost saving alternatives. The cost savings for this project were not reported; the authors stated the critical driver for using APDM was the critical schedule. Utilizing APDM enabled the project to be completed approximately two months sooner than a traditional DBB method.

Today, owners are seeking methods to expedite construction, control cost, and manage risk. Several delivery methods have been proven successful when used in the correct environment. Every project requires a unique and rigorous evaluation of the pros and cons for each available delivery method. A particular method may be the best fit for a specific project depending on the unique project variables. The drivers towards a particular method often will be dictated by the schedule urgency, cost pressures, risk elements, and local regulations.

To summarize the existing literature, a few studies discuss the advantages of APDM for trenchless construction projects. APDM has the ability to impact trenchless pipeline project performance. This paper builds upon these studies with an industry survey and meta-analysis in order to investigate the use, comfort level, and industry perception of APDM performance on trenchless construction projects.

2.4 Problem Statement

The traditional DBB delivery system has been used successfully in the construction industry for decades. This delivery system is especially successful for projects where the work is well defined and there is relatively low uncertainty (i.e., projects that are repetitive, with low complexity). Trenchless construction, however, is a specialized and complex type of construction. Moreover, unknown geotechnical conditions can be especially impactful because unlike most types of construction, trenchless projects are completed without seeing the environment in which they are being constructed (e.g. installing a water line under a river or roadway, microtunneling a sewer main through a congested area). Most general contractors typically do not self-perform trenchless construction. Upon design completion, a specialized trenchless contractor is typically contracted to perform the work. However, this process often prohibits the experienced and specialized trenchless contractor to provide input prior to the design being finalized. Gokhale (2011) concluded that complex or large trenchless projects often result in substantial cost and schedule increases, in part due to the separation of design and construction, as well as pressure resulting from the low-bid environment. Frequently, these increases occur in a non-productive, inefficient, and adversarial work environment leading to claims, disputes and costly litigation (Gokhale 2011).

Cohen (2013) found that design engineers and contractors today face a real challenge because the new innovative methods for installing and rehabilitating pipelines give them more options than ever before. Additionally, it is critical for successful project planning to understand issues beyond the technical requirements of the work itself, such as the surrounding environment, the technologies appropriate for the given situation, and

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how the facility will be constructed (Cohen 2013). When using the traditional DBB delivery system, the engineer typically does not allow the trenchless contractor input into the design of the project. In contrast, APDM enable a trenchless contractor to be consulted during the design phase to assist the engineer with the selection of the best installation method. In fact, Doherty (2013) found that technical risks associated with the failure of a specific trenchless method are often related to improper specifications or inappropriate means and methods employed by the contractor. These risks often are associated with (1) poor communication of owner preferences and (2) poor communication by the engineers in the design documents. In some cases, the engineer has a lack of understanding of existing conditions or means and methods, which can result in selecting the wrong trenchless method or overlooking specific tooling requirements (Doherty 2013).

The complex nature of trenchless pipeline projects renders them ideal candidates for APDM because of the lack of technical knowledge exchange traditionally seen between engineers and contractors. APDM can be used to bridge this gap by enabling specialized and experienced contractors to provide knowledge and insight early in the design stage of trenchless projects. This early integration of project stakeholders and more collaborative relationships has the potential to improve project performance.

2.5 Objectives and Methodology

To start understanding how APDM can improve performance of trenchless projects, it is important to   (a) appreciate how APDM are currently being used in the trenchless industry; and (b) investigate the documented performance of historical APDM trenchless projects. The performance of these projects will help provide insights regarding the

possible benefits of using APDM on trenchless projects. This paper has two objectives: 1) to examine the current usage, comfort level, and stakeholder perception of APDM through a survey of the trenchless industry; and 2) to investigate the published cost performance of completed trenchless projects that employed APDM.

2.5.1 Industry Survey

The research methodology involved developing a survey to collect data from trenchless industry leaders. The five-question survey was used to collect data on market share, industry comfort level in APDM implementation, and stakeholder perception of which performance metrics are most impacted by each project delivery system. The survey collected data representing the three key stakeholders (owners, engineers, and contractors) and various leadership positions.

2.5.2 Meta-Analysis

Glass (1976) defines meta-analysis as "the analysis of analyses, the statistical analysis of a collection of results from individual studies for the purpose of integrating the findings." Similarly, Hunt (1997) states a meta-analysis offers a systematic means of integrating and accumulating the findings of individual studies to achieve an authoritative position regarding the issue under investigation. The research methodology involved conducting a meta-analysis of literature to compile data published in different case studies of completed projects. Case studies of past trenchless construction projects were reviewed through searching conference proceedings, engineering journals, and various trade magazines. The meta-analysis specifically focused on project cost because it was the only metric for which adequate data has been published. The data collected and analyzed included the initial budgeted cost and the final installed cost of the project. The cost

savings of each project were then calculated by finding the difference between the initial budgeted cost and the final installed cost. The meta-analysis produced reliable data for ten trenchless projects using APDM. The project data was collected from the following studies: Ablin and Kinshella (2002), Bantz and Melcher (2008), Benner (2010), Bueno (2012), CH2M Hill (2004), Flatt and Kirby (2013), Henning (2011), Orton et al. (2009), Rush (2003), and Scott and Timberlake (2013). The case study projects originate from five states in the U.S., as well as Toronto, ON, in Canada. The types of trenchless technologies varied, but the majority utilized HDD and lining technologies. The next section presents the results from both the industry survey and the meta-analysis.

2.6 Results and Discussion

2.6.1 Industry Perceptions

Thirty-four (34) owners, engineers, and contractors completed the survey, which was shared with a total of 57 professionals in the trenchless construction industry. The response rate was approximately 60 percent. Figure 4(a) shows the distribution of organizations that responded to the survey. The "other" category consisted of 9% of the respondents, and included pipe vendors, trade association members, and research and development professionals. Figure 4(b) shows the positions of respondents in their respective organizations. The most represented position was project manager (26%). The "other" category included positions such as City Associate Commissioner; City Director/Engineer; Chairman of the Board of Directors; and National Practice Leader for Trenchless Construction.

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(a)   (b)

Figure 4: Respondent Characteristics (N=34)

Respondents were asked about the percentages of their projects that use each of the six project delivery methods previously defined. Figure 3 shows the responses in a boxplot format. A boxplot is a nonparametric graphical summary of data that displays the lower quartile, median, and upper quartile. The black line dividing the dataset in half represents the median value. The rectangle represents the 50% of the data around the median, whereas the remaining 50 percent of the data are divided equally above and below the rectangle. Figure 5 shows 68 percent of the projects are being delivered by DBB. The second highest value is twelve percent for DB. Next, CMAR and JOC hold approximately the same market share with approximately eight percent of projects for each. Respondents rarely used CM Agent and IPD in the trenchless industry. Overall, the survey indicates DBB holds about two-thirds of the trenchless construction market, and all APDM combined hold the remaining third of the market.

The survey also gauged the comfort level of the respondents in implementing the six delivery methods, using a Likert scale. Figure 5 shows the distribution of the responses with respect to the y-axis placed on the right side of the figure and denoted by

the dashed line. The x-axis represents the level of stakeholder integration in different delivery methods, increasing from left to right, beginning with DBB and ending with IPD. The dashed line represents the average comfort level with each project delivery system.

As expected, the respondents expressed a high comfort level in using DBB. DB represents the highest comfort level for APDM, followed by JOC. The previous two questions were presented on the same figure to show how comfort level is closely related to the market share for each delivery method. Using a specific delivery method allows the industry to become more comfortable in adopting it, and vice versa. For example, IPD and CM Agent are both rarely used in the trenchless industry, and subsequently the industry has a low comfort level in adopting these delivery methods.

Figure 5: Market Share and Comfort Level of the Industry with Different Delivery Methods (N=34)

The last question in the survey prompted respondents to select the project delivery method they perceive to offer the best performance for the nine following performance areas: 1) meeting cost and budget expectations; 2) meeting target schedule; 3) quality of the delivered project; 4) project safety; 5) project changes and modifications; 6) labor productivity; 7) environmental benefits; 8) profit and return business; and 9) level of communication of involved parties. Figure 6 illustrates the results for each of the nine performance areas.

The five APDM are being used as alternatives to DBB. Next, the industry's perception of APDM performance will be compared to DBB. The results indicate the industry respondents perceive APDM combined can impact project performance more than DBB in all performance areas with the exception of cost and profit. Fifty percent of the industry respondents perceived DBB to offer better performance with regards to meeting cost and budget expectations, and 53% perceived DBB to offer better performance with respect to profit and return business. For the remaining seven performance metrics, only about a third of the respondents perceived DBB offers better performance. This finding highlights the fact that different delivery systems can be used depending on the priorities of a given project.

	Cost	Schedule	Quality	Safety	Change	Productivity	Environment	Profit	Comm.
IPD	0%	9%	3%	9%	9%	0%	10%	6%	15%
DB	24%	18%	15%	22%	15%	35%	19%	16%	24%
JOC	9%	15%	12%	9%	21%	18%	6%	3%	9%
CMAR	12%	24%	18%	19%	15%	18%	16%	22%	21%
CM Agent	6%	0%	18%	6%	9%	0%	6%	0%	3%
DBB	50%	35%	35%	34%	32%	29%	42%	53%	29%

Figure 6: Project Delivery Perceived Performance

After examining how the survey respondents perceive the potential impact of APDM on project performance, the data from the final question was divided by stakeholder type. The data was separated into owners, engineers, and contractors, to understand if the various stakeholders had different perceptions of APDM performance impacts on trenchless projects. The results are presented in Table 1.

There appears to be a clear disconnect between the contractors' and the engineers' responses. Contractors perceive APDM to offer better performance in all metrics, with a 100% unanimous response for communication, schedule, quality, and changes. Conversely, engineers perceive DBB to provide better performance on cost and profit metrics. Owners are fairly neutral with respect to half of the metrics, and perceive APDM to offer improved schedule, quality, productivity, and change performance.

Table 1: Delivery System Performance Perception by Stakeholder

Performance Metric	Delivery	Stakeholders			Total
		Owners	Engineers	Contractors	
Cost	APDM	50%	44%	71%	52%
	DBB	50%	56%	29%	48%
Schedule	APDM	63%	56%	100%	68%
	DBB	38%	44%	0%	32%
Quality	APDM	75%	56%	100%	71%
	DBB	25%	44%	0%	29%
Safety	APDM	50%	63%	86%	65%
	DBB	50%	38%	14%	35%
Change	APDM	63%	63%	100%	71%
	DBB	38%	38%	0%	29%
Productivity	APDM	75%	69%	86%	74%
	DBB	25%	31%	14%	26%
Environment	APDM	50%	50%	86%	58%
	DBB	50%	50%	14%	42%
Profit	APDM	50%	25%	86%	45%
	DBB	50%	75%	14%	55%
Communication	APDM	50%	75%	100%	74%
	DBB	50%	25%	0%	26%

There are several possible reasons for the disconnect between the contractors' and the engineers' responses. One reason is contractors may have less low-bid competition when pursuing APDM projects, which may lead to a greater potential for return business if the owner is satisfied. Another possible reason is the risk transfer that is associated with using APDM; engineers may be assuming more risk when using APDM, which could potentially affect their perception of performance. The authors discussed and confirmed the issue of increased risk with several engineers at the 2015 North American Society of Trenchless Technologies (NASTT) No-Dig Show. Next, the paper discusses the results of the meta-analysis.

2.6.2 Meta-Analysis

To gain a better perspective on the use of APDM for trenchless pipeline projects, projects from published case studies were analyzed. The meta-analysis produced adequate and reliable data for ten trenchless projects using APDM. Seventy percent of the projects in the dataset were delivered using DB; the remaining 30% were delivered using CMAR. The main focus of the meta-analysis was to collect published cost savings data from completed projects in order to determine potential the cost benefits of using APDM. These projects are described in Table 2.

Table 2: Meta-Analysis Data

Year	Location	Trenchless Technology	Utility Type	Delivery System
2002	Phoenix, AZ	CIPP	Wastewater	CMAR
2003	Alexandria, VA	HDD	Wastewater	DB
2004	Winter Park, FL	HDD	Wastewater	DB
2005	Phoenix, AZ	Pipe Bursting	Wastewater	CMAR
2007	Military Base	CIPP	Wastewater	DB
2008	Toronto, CAN	HDD	Water	DB
2010	North Bay Village, FL	HDD	Wastewater	DB
2011	Orange County, CA	Sliplining	Wastewater	DB
2012	Durham, NH	Microtunneling	Stormwater	DB
2012	Miami, FL	HDD	Water	DB
2012	Roanoake Island, NC	Sliplining	Water	CMAR

Project data was divided into two subsets: 1) projects delivered using DB; and 2) projects delivered using CMAR. The cost savings were then compared for all projects, as illustrated in Figure 7. Trenchless construction projects using APDM had an average cost savings of 27%. The average cost savings for the CMAR projects was 13%, while DB projects revealed an average cost savings of 33%. These results stem from the meta-analysis of 10 previously published case studies on APDM trenchless construction

projects. While the sample may not be representative of the whole industry, the results clearly show the potential of APDM to greatly increase trenchless projects' cost performance.

Figure 7: Cost Savings of Trenchless Projects using DB and CMAR

The minimum cost savings for projects using DB and CMAR were 20% and 2%, respectively. The nonparametric Mann-Whitney-Wilcoxon (MWW) test was performed to determine if the differences in performance between CMAR and DB are statistically significant. The MWW test is more powerful than the t-test when data cannot be assumed to be normally distributed (Lehmann 2006), which was the case with the cost data. The resulting p-value from the MWW test was 0.0563, on the verge of being statistically significant when using the common threshold of 0.05. Although the results are not shown

to be statistically significant for this small sample, the data shows a noteworthy difference between the cost savings of projects using DB and projects using CMAR.

The meta-analysis suggests there is great potential to improve cost performance when using APDM on trenchless projects. APDM performance benefits have been documented for other construction types including buildings, infrastructure, and industrial facilities. According to the Design-Build Institute of America, DB projects average 6% in cost savings (DBIA 2011). Similarly, Konchar and Sanvido (1998) showed DB projects have a 5.2% less cost growth when compared to DBB. The results from the meta-analysis presented in this paper also show cost savings, but the preliminary values are higher than those in the literature. The small sample size and the lack of projects that reported cost overruns are two possible reasons for the reported large cost savings in this meta-analysis.

Schedule performance data was not available in the published case studies; however, all the projects were completed on or before the anticipated completion dates. The only case study documenting quantitative schedule performance data showed a 25% schedule savings. All the case studies stated completion dates continually decreased due to time savings achieved using APDM. For example, a decrease in design time was attributed to the experience of contractors in assisting the engineer during the design phase.

2.7 Conclusions

The results of the industry survey indicate the most utilized project delivery system in the trenchless industry is still the traditional DBB system, followed by DB as the most prevalent APDM. The comfort level of the stakeholders in implementing each project

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delivery method is influenced by their past experience using each method. The industry respondents perceive APDM to impact certain project performance metrics more than others. These metrics include: schedule (68%), quality (71%), and productivity (74%). For the majority of the performance areas, the respondents perceived the collective use of APDM offers increased performance compared to traditional DBB. When broken down by individual stakeholders, the results reveal a distinct disconnect between the perceptions of engineers and contractors. Contractors perceive APDM to offer better performance for all metrics. On the other hand, engineers perceive DBB to provide better performance for two of the nine metrics. Overall, the industry respondents perceive APDM to provide superior performance when adopted on trenchless pipeline projects.

The meta-analysis quantified these potential improvements, specifically for project cost. Trenchless projects using APDM were found to exhibit an average cost savings of 27%. DB and CMAR showed an average cost savings of 33% and 13%, respectively. These results build upon the findings of the industry survey to show performance benefits are being realized in the trenchless industry when using APDM.

This study has some limitations: the small sample size may not be representative of the entire trenchless industry. Another limitation is the previously published data used for the meta-analysis may be biased towards successful projects. To address these limitations, future research will include collecting original data from a large number of recently completed pipeline construction projects to allow for multivariate statistical analysis of APDM impact on the performance of trenchless pipeline projects. The dataset will include projects covering all currently used APDM in the pipeline industry, and

using various installation technologies. The quantitative results will be compared to the industry perceptions documented in this paper.

This study provides a contribution to the body of knowledge by assisting project stakeholders better understand the overall industry perceptions of APDM-related performance improvements. This understanding can guide stakeholders in selecting the most suitable delivery system for their trenchless projects.

3. CONSTRUCTION MANAGER AT RISK (CMAR) FOR PIPELINE REHABILITATION: A CASE STUDY ON CMAR PERFORMANCE BENEFITS

3.1 Abstract

The traditional design-bid-build (DBB) delivery system is a sequential process and can lead to inefficiencies and adverse relationships between owners, design engineers, and contractors, which are often caused by a lack of stakeholder integration. Several alternative project delivery methods (APDM) have been introduced to increase stakeholder integration, examples of these include: construction manager at risk (CMAR), job order contracting, (JOC), and design-build (DB). The ability to use alternative project delivery methods to deliver public construction projects is governed by legislation that may vary from state to state. A large and representative industry group working together out of Arizona State University (ASU) helped the State of Arizona revise its statutes in 2000 to allow municipalities, such as the City of Phoenix, to use alternative delivery methods (CMAR, JOC, and DB) for their construction projects. This paper studies the use of the CMAR delivery system by the City of Phoenix to deliver a critical ten-year pipeline rehabilitation program: the Val Vista Water Transmission Main. This paper combines a case study and quantitative analysis of each of the four phases of the rehabilitation program. The findings demonstrate the performance benefits of using CMAR, which include a cumulative cost reduction of 2.75% and schedule reduction of 3.4% over the four phases of the program, as well as improved change and communication performance. This study offers a key contribution to the construction body of knowledge: it uncovers CMAR benefits through (a) performing a longitudinal study on a large diameter water main rehabilitation program and (b) analyzing the performance effects of the CMAR delivery method on pipeline rehabilitation. The results

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can help owners better understand the potential performance benefits CMAR has on pipeline engineering and construction projects.

3.2 Introduction

The U.S. engineering and construction industry employs several project delivery methods, such as design-bid-build (DBB), construction manager at risk (CMAR), job order contracting (JOC), and design-build (DB) to deliver construction projects. The traditional DBB delivery system is a sequential process and can lead to inefficiencies and adverse relationships between owners, design engineers, and contractors, which are often caused by a lack of stakeholder integration. Alternative Project Delivery Methods (APDM) have been introduced in the construction industry to increase stakeholder integration and ultimately enhance project performance (e.g.; Konchar and Sanvido 1998; Molenaar et al. 1999; El Asmar et al. 2015). This study focuses on the use of one specific delivery method – CMAR – by the City of Phoenix (herein after referred to as the City) to deliver a water pipeline rehabilitation program.

Project delivery methods are distinguished by two key characteristics: (1) the contractual relationships between project stakeholders and (2) their timing of engagement in the project (El Asmar et al. 2013). First, Figure 8(a) shows the relationships between key stakeholders for the two delivery methods discussed in this study: DBB and CMAR. In both project delivery methods, the owner signs separate contracts with the engineer and the contractor. Second, Figure 8(b) highlights the contractor's timing of engagement. In DBB the contractor is typically engaged after the design is complete, and is unable to provide input during the design. To maximize the benefit of collaboration during the design phase and minimize redesign, typically the CMAR firm is best engaged at about

30 percent design development and not later than 60 percent design development (Shorney-Darby 2012).

Figure 8: Relationships and Timing of Engagement Between Key Stakeholders in DBB and CMAR

Additional differences between the two delivery systems include the following:

A. In CMAR the design engineer and CMAR firm are often contractually required to coordinate during the design phase of the project. This level of interaction does not take place in the traditional DBB method (Shorney-Darby 2012; Gransberg and Shane 2010).

B. The CMAR firm often has two contracts during a CMAR project: the first is a design services contract that is completed during the design phase for services such as design reviews, constructability reviews, cost estimation, value engineering, and scheduling; and the second contract for the construction of the project (Shorney-Darby 2012; Gransberg and Shane 2010).

C. Another key difference between DBB and CMAR is the contractor selection process. When using DBB the owner typically selects the lowest responsible bidding contractor, regardless of their experience or qualifications. With CMAR the owner often selects the CMAR firm based on a combination of cost and qualifications (Shorney-Darby 2012; Gransberg and Shane 2010).

The ability to use CMAR to deliver public infrastructure projects is governed by local legislation and varies from state to state. Many states have specific requirements for using CMAR. For example, in the State of California the Department of Transportation (DOT) may only use CMAR on no more than six projects per fiscal year, at least five of which shall have construction costs great than ten million dollars (State of California 2012). The State of Arizona is one of the more progressive states in terms of delivery systems, and allows all public agencies to use CMAR for all project types. In 2000 a large and representative industry group working together out of Arizona State University (ASU) helped the State of Arizona, through House Bill 2340, revise the statutes that dictate which procurement methods each government entity is able to use to deliver public projects. These changes allowed water and wastewater utilities in the State of Arizona to use innovative delivery methods, such as CMAR, for the construction of new pipelines or the rehabilitation of existing pipelines. Prior to the revision of the statutes, the City of Phoenix delivered all pipeline engineering and construction projects using the traditional DBB method. Following the revision of the statutes, the City of Phoenix used CMAR for a portion of water and wastewater pipeline projects.

CMAR has been studied and used successfully in other industries including vertical construction (buildings) and horizontal construction (roadways). CMAR is

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continuing to gain substantial popularity in these industry segments due to its ability to improve project performance. In fact, Engineering News Record (ENR) recently published its latest list of Top 100 CMAR firms and stated the Top 100 CMAR firms exhibited a domestic revenue of $86.77 billion in 2014, an 11.5% increase compared to 2013 (ENR 2015). The performance of CMAR has not been documented comprehensively in the pipeline industry. This study aims to provide insight into the use and expected performance of CMAR for pipeline projects through a detailed case study and data analysis from the ten-year Val Vista Water Transmission Main (WTM) rehabilitation program delivered by the City of Phoenix.

3.3 Literature Review

The authors performed a comprehensive review of the literature to analyze the body of knowledge covering the use and performance of CMAR. In this portion of the paper, a first subsection discusses CMAR in the general design and construction industry. Second, the authors highlight studies that specifically targeted CMAR for pipeline projects. The third subsection is a summary of previous research completed by this paper's same authors on APDM in the pipeline industry. These three components act as a point of departure and solid foundation for the problem statement and objectives presented in this paper.

3.3.1 CMAR in the General Design and Construction Industry

With studies documenting CMAR's performance benefits for design and construction projects, CMAR continues to gain interest from both practitioners and academics. Konchar and Sanvido (1998) empirically compared cost, schedule, and quality performance of DBB, DB, and CMAR using 351 U.S. building projects. The results

demonstrated CMAR projects realize an increase in performance over DBB in unit cost, construction speed, delivery speed, and schedule growth. The only metric in which DBB outperformed CMAR was managing cost growth. The study concluded CMAR had significant advantages over DBB in delivering vertical projects. A decade later, Rojas and Kell (2008) compared the performance of 273 DBB and 24 CMAR public school projects constructed in Oregon and Washington. The study found that CMAR projects (4.74%) have a lower change order ratio (COR) than DBB projects (6.29%). However, these results were not statistically significant.

In another study, Shane and Gransberg (2010) looked at CMAR from a different perspective and performed a study to determine the advantages and disadvantages of CMAR innovation on transportation projects. Data from 19 case studies concluded the top five advantages of CMAR innovation are: (1) the ability of the contractor to make substantive/beneficial input to the design; (2) the enhanced ability to accelerate the project's delivery schedule; (3) enhanced cost certainty at an earlier point in design than DBB; (4) the ability to bid early work packages as a means to mitigate the risk of construction price volatility and accelerate the schedule; and (5) owner control of the design details (Shane and Gransberg 2010).

3.3.2 CMAR for Pipeline Projects

Although not as prevalent as in the building and transportation industries, CMAR has been successfully employed in the pipeline engineering and construction industry. However, its performance is not studied comprehensively. In fact, the majority of the research on APDM in the pipeline industry is qualitative in nature and focuses on the use of DB (Hassan 2010; Guy 2007; Kramer and Meinhart 2004). The literature on CMAR in

the pipeline industry mainly includes technical case studies of individual projects (Leskinen et al. 2007; Ambroziak et al. 2009; Ambroziak et al. 2010; Vergara et al. 2013; Payne and Taylor 2013; Roth and Horn 2013; DeGrande et al. 2014; Maughn et al. 2014) and typically does not specifically examine the benefits of using CMAR. These case studies instead focus on the design, construction methods, pipeline materials, and technical aspects of the project. There is little research focusing specifically on the quantitative performance benefits of CMAR on pipeline projects.

3.3.3 The Author's Previous Work on APDM in the Pipeline Industry

Realizing the gap in knowledge on APDM's performance impact for pipeline projects, the authors initiated studies to investigate this topic. In fact, this paper builds upon previous research, which investigated cost performance and industry perceptions of APDM on pipeline projects (Francom et al. 2015). In the previous work, the authors completed a meta-analysis of literature to determine if APDM are successfully used in the pipeline industry. The meta-analysis specifically focused on project cost because it was the only metric for which data was published. The results stemmed from ten completed projects and showed DB and CMAR can potentially offer cost savings benefits ranging from 2% to 44%. Specifically, the average cost savings for the CMAR projects was 13%. The results originated from a small sample of pre-published data – enough to show there is a potential, but not enough to draw significant conclusions on the performance improvement. The authors built on that knowledge in this current paper.

Moreover, the authors developed and implemented a survey of pipeline industry stakeholders to investigate the utilization rate, industry comfort level, and perceptions of performance of APDM. The results of the pipeline industry survey indicated the most

utilized project delivery system is still the traditional DBB system, followed by DB and CMAR as the most prevalent APDM. Although many of the respondents showed a moderate comfort level with most APDM, DBB is the project delivery method that the respondents are still most comfortable using. The comfort level of the stakeholders in implementing each project delivery method is influenced by their past experience using each method. Intuitively, the more a project delivery method is used, the more comfortable the industry will be when implementing it. A Likert scale measured the comfort level from 1-5, with 1 being very uncomfortable and 5 being very comfortable. The respondents had an average comfort level of 3, which is a medium comfort level, to implement and use CMAR on their projects.

The results indicate industry respondents perceive APDM to impact some project performance metrics (i.e., schedule, quality, and productivity) more than others. The respondents perceived CMAR to most impact schedule, return business and profit, and communications between stakeholders. For most performance areas, the respondents perceive the collective use of APDM to offer increased performance compared to the traditional DBB when adopted on pipeline projects. Understanding the industry perceptions on performance helped the authors focus their scope of work for this current paper, which will collect actual (as opposed to perceived) performance data.

To summarize the state of knowledge on the topic, there have been CMAR studies completed in other industry segments, providing evidence for CMAR performance benefits. However, this knowledge is limited for the pipeline industry, where there only exist a few case studies on individual CMAR projects.

3.3.4 Problem Statement

As shown in the literature review, no studies have comprehensively measured the performance benefits of CMAR on pipeline projects and provided supporting evidence of these benefits. The existing case studies focus mostly on the pipeline construction details (e.g. installation, technology used, geotechnical conditions, construction issues and resolutions, etc.) of a single project, and do not specifically investigate and quantify the impact of CMAR on performance. To build on the existing literature, the case study presented in this paper concentrates on investigating the quantitative performance impacts of CMAR on pipeline projects.

3.4 Research Objective and Method

The specific research objective of this paper is to understand how CMAR affects the performance of pipeline engineering and construction projects. The authors accomplish this objective by performing a longitudinal study of a ten-year CMAR pipeline rehabilitation program. The program included four phases that were completed along a single large diameter pipeline. The results will demonstrate how the use of CMAR affects project performance in several commonly used metrics, including; cost, schedule, change and communication. This study includes both qualitative and quantitative analyses using established case study methodology. First, the case study motivation and methodology will be presented. This is followed by a discussion of the Val Vista WTM program. Finally, a description of the quantitative survey will be presented.

3.4.1 Case Study Motivation

The case study research method has a distinct advantage over other methods when the question being asked is a "how" question about events over which the researcher has no

control (Yin 1984). The authors selected a case study approach because the research objective focuses on "how" a particular project delivery method – CMAR – affects the performance of pipeline engineering and construction projects.

Yin (1984) defines a case study as an empirical inquiry that: (1) investigates a contemporary phenomenon within its real life context, especially when (2) boundaries between the phenomenon and context are not clearly evident. In a different study, Yin (1994) states case studies are generally preferred for explanatory research because this type of research deals with actions traced over time and is not concerned with the statistical frequency of events. This is often the case with engineering and construction research. Engineering and construction projects are too large and costly to be used for full-scale research studies where the researcher requires control over the actions on the site. The use of case studies does not require the researchers to have control over the actual events (Molenaar et al. 2004).

Typically, collecting comparable data across multiple projects can be extremely difficult in the engineering and construction context where projects studied may be a significant distance from one another, and often involve different networks of firms and individuals. All of these reasons make construction projects particularly challenging for conducting comprehensive case study research. It also is important to consider that most engineering and construction projects are unique, compared to other industries such as manufacturing where the same project (i.e. Toyota Corolla) is manufactured repeatedly. Therefore, case-to-case differences in engineering and construction projects are likely to vary more than in some other industries and consequently studying multiple cases is particularly important to generate insights that can be generalized (Taylor et al. 2011).

3.4.2 The Val Vista WTM Project

Based on the above definitions, the City of Phoenix's Val Vista WTM rehabilitation program is ideal to employ the case study methodology. This ten-year program is unique in the fact that continuity between the major stakeholders was kept relatively intact. Table 3 shows the major stakeholders for each phase of the project. The owner, program manager, and CMAR firm were kept constant throughout the four phases of the project. However, the City decided to award design contracts to different engineering firms, possibly to allow more firms to familiarize themselves with rehabilitation of pre-stressed concrete cylinder pipe (PCCP); this is due to the City potentially having a significant amount of future sliplining work that needs to be designed (Leskinen et al. 2007). After the pilot Phase A, two engineering firms divided the full design, with Wilson Engineers performing the design throughout the City of Tempe and Dibble Engineering performing the design throughout the City of Mesa.

Table 3: Project Stakeholder Continuity

Phase	Year	Owner	Engineer	Program Manager	CMAR
A	2005-2006	City of Phoenix	Brown and Caldwell	Brown and Caldwell	Kiewit Western Co.
B	2008-2009	City of Phoenix	Wilson Engineers / Dibble Engineering	Brown and Caldwell	Kiewit Western Co.
C	2010-2011	City of Phoenix	Wilson Engineers / Dibble Engineering	Brown and Caldwell	Kiewit Western Co.
D	2014-2015	City of Phoenix	Wilson Engineers / Dibble Engineering	Brown and Caldwell	Kiewit Western Co.

This degree of continuity would not have been achieved using the traditional DBB method. The owner can retain the program manager and select the design engineer based on experience and qualifications. However, in DBB when selecting the contractor the

owner would typically select the lowest responsible bid for each phase of the program, irrespective of prior experience on previous phases. This often results in different contractors for each phase of the rehabilitation program. By using CMAR with a qualifications-based selection, the owner is able to retain the same contractor. Moreover, the owner is able to add additional scope to the original contract, as will be discussed later in the paper.

Another aspect that makes this program ideal for a case study is the fact that the rehabilitation occurred along a single pipeline. This constant factor allows for relatively similar working conditions, designs and specifications, labor pool, soil conditions, legislation, weather conditions, and issues that arise during construction. Constant factors help decrease the learning curve that the stakeholders have during construction projects. Combining the continuity between stakeholders and rehabilitation along a continuous pipeline significantly reduces the amount of variables typically seen in construction case study research.

The program includes four separate phases (A, B, C, and D) to compare and analyze commonly measured performance metrics. The authors conducted the case study according to procedures outlined by Taylor et al. (2011) in a study regarding the use case study research in the engineering and construction field. Taylor et al. (2011) adapted these procedures for engineering and construction research from accepted case study methodology from Yin (1984), Yin (1993), Yin (1999), and Yin (2013). The case study presented here involves both qualitative interviews and quantitative surveys used to enable the collection of project characteristics and performance data.

3.4.3 *Quantitative Survey*

To facilitate the case study analysis, the authors developed an 18-question quantitative survey to collect data on the completed pipeline rehabilitation phases. The survey was completed in two major stages: survey development and data collection. The survey development began with a thorough review of both the APDM and pipeline industry literature. This review identified the key performance metrics commonly used and studied in both alternative project delivery research and pipeline engineering and construction research. The studies used for the foundation of the data collection survey included: El Asmar et al. 2013; Bogus et al. 2013; Shane et al. 2013; Shrestha et al. 2012; Molenaar et al. 2004; Allouche et al. 2000; Molenaar et al. 1999; Konchar and Sanvido 1998; Songer and Molenaar 1996.

The data collection survey was then developed based on the identified variables from the literature review and designed to gather data on quantitative and qualitative project performance metrics. The authors implemented two review stages before the survey was used to collect data. The first stage consisted of individual reviews by construction engineering and management faculty members; the second stage consisted of reviews by industry experts, representing contractors, designers, and owners. The data collection for this study included meeting with the City of Phoenix Water Services Department staff and with Central Records staff within the Public Works Department to collect publicly available information for each phase of the Val Vista WTM program. The authors used this information to begin populating the survey and gaining a better understanding for each phase of the project prior to meeting with the CMAR firm. Then, a meeting was conducted with the project sponsor, project manager, and project engineer

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from the CMAR firm to collect the remainder of the data. These steps resulted in the completion of quantitative surveys for all four phases of the rehabilitation program, in addition to receiving important qualitative information from the interview conducted during the data collection phase. The following section discusses the Val Vista WTM program in detail and subsequently presents a discussion of each individual phase.

3.5 Case Study: Val Vista Water Transmission Main

The Val Vista WTM is a non-redundant pipeline that runs nearly 15 miles through the Phoenix, AZ metropolitan cities of Mesa and Tempe. The pipeline originates from the Val Vista Water Treatment Plant in Mesa, the largest treatment plant in the Phoenix metropolitan area, and ranges in diameter from 72 to 108 inches. The line is gravity fed and delivers up to 190 million gallons per day to Phoenix and 100 million gallons per day to Mesa at a maximum operating pressure of 70 pounds per square inch (Leskinen et al. 2007).

The original PCCP pipeline was constructed under a series of five separate design and construction contracts between 1973 and 1975. The pipeline was initially installed along a largely undeveloped alignment with a design depth of 12 to 35 feet of cover. However, vast expansion in the Phoenix metropolitan area brought commercial and residential development along the original easement, significantly increasing both the congestion and depth of cover along portions of the pipeline. This growth caused several realignments of the original water line. During a 1,000-foot realignment of a 72-inch section of pipe in 1999, significant signs of deterioration of the PCCP were discovered (Ambroziak et al. 2010).

Due to these signs of deterioration, the City began an extensive condition assessment of the entire Val Vista WTM in the fall of 2003. The condition assessment began with the following state-of-the-art inspection techniques: electromagnetic inspection; sound and visual inspection; metallurgical analyses of the prestressing wire; petrographic sampling to identify carbonation of the mortar coating; and extensive soil analysis along the alignment (Leskinen et al. 2007).

After the condition assessment was completed in 2004, the City determined the water main was in need of a long-term rehabilitation program. The City and design engineer began to research and explore methods of rehabilitation. All feasible methods were considered including: replacement, hand-applied carbon fiber, mechanically applied carbon fiber, tendon reinforcement, concrete encasement, and two types of steel sliplining, solid can and split can. There were many factors that complicated the selection of the appropriate rehabilitation method, including: commercial and residential development adjacent to and above the entire pipeline alignment; pipeline depth in excess of 40 feet in some locations; location of the pipeline outside of the City of Phoenix boundaries; and pipeline capacity restrictions.

After thorough research and considerations, it was ultimately decided to use steel split can sliplining as the method for rehabilitating the pipeline. This method was chosen due to the ability to meet the aforementioned factors while also being cost effective. Split can liners are typically steel plate rolled to the required pipe diameter, but not factory welded longitudinally. The split cans are collapsed and banded to a diameter about 10 inches less than the host pipe diameter, which allows the liners to negotiate curves and pulled joints. The bands are cut after the liners are in place in the host pipe. The expanded

liners are fitted into place and welded together both circumferentially and longitudinally. The annular space between the host PCCP and liner is then grouted using grout couplings in the liner. After the annular space is grouted, a half-inch mortar lining is then applied to the interior of the pipeline (Leskinen et al. 2007).

The steel slipliners are installed through access pits spaced at approximately 2,500-foot to 3,000-foot intervals. Access pit spacing is determined by surface improvements along the pipeline alignment, pipeline geometry, and the length of welding leads available to the contractor. Typically two of the PCCP pipe sections are removed at each access pit, and steel liners are installed in each direction from the access pit using a pipe cart to transport them to the correct location.

Approximately half (7.2 miles or 38,050 L.F.) of the Val Vista WTM was rehabilitated during a 10-year rehabilitation program from 2005-2015. Due to the high water demands through the hot Phoenix summers, shutdowns and startups of the large diameter pipelines are only scheduled between October and April (Ambroziak et al. 2010). Therefore, all construction activities for each phase occurred within this seven-month window.

The program consisted of installing 38,050-feet of steel split can pipe at a final cost of $72,859,827. The program was completed in four different phases that included eight separate guaranteed maximum price (GMP) packages. The program details are shown in Table 4.

Table 4: Four Phases of Construction

Phase	GMP Packages	Length (LF)	Cost ($)	Cost (%)	Schedule (Days)	Schedule (%)
A	1-4	9,700	$17,321,630	24%	396	50%
B	5-6	18,500	$38,096,510	52%	108	14%
C	7	3,600	$5,241,978	7%	131	17%
D	8	6,250	$12,199,709	17%	153	19%
Total		**38,050**	**$72,859,827**		**788**	

Each phase of the rehabilitation program faced its own challenges; the following sections will first present background information, then discuss both cost and schedule performance for each of the phases individually, and finally end with detailed benefits of using CMAR for each phase. The cost performance is calculated in terms of cost growth or cost savings, as the relative difference between the final GMP proposal value and the final installed cost. Similarly, the schedule performance is calculated by using the notice to proceed as a starting point, and finding the relative difference between the intended substantial completion and the actual substantial completion of each individual phase. The discussion starts with Phase A.

3.5.1 Phase A

Phase A of the Val Vista WTM rehabilitation began in 2004 as a pilot program to test the split can sliplining method for the rehabilitation of the City's PCCP water mains. The City chose to use four GMP packages for Phase A. GMP package #1 was issued for the procurement of the steel split can pipe; GMP package #2 consisted of inspecting, cleaning, and emergency repair of critical failing sections using carbon fiber wrap; GMP package #3 was used for a pilot steel split can rehabilitation that included the installation

of 6,300-feet of pipe; and GMP package #4 was issued to install an additional 3,300-feet of pipe.

As its first ever large diameter water transmission main rehabilitation project, the City of Phoenix chose to rehabilitate a relatively short, straight section of pipeline located along a less developed area of the alignment (Leskinen et al. 2007). This section was included in GMP package #3, a 6,300-foot pipe of 72-inch diameter located through the City of Tempe and completed during the fall of 2005. Three access pits were used for the liner installation with depths of cover ranging from 12 to 14 feet. This 6,300-foot pilot project in Phase A was completed on schedule and 5.3% under the contract amount. Due to this success the City elected to continue using steel split can sliplining to rehabilitate the entire pipeline.

The next installation in Phase A (GMP package #4) was completed during the allowed shutdown period in the fall of 2006. The scope of the project was to rehabilitate 3,300-feet of 72-inch PCCP located just to the east of the previously completed project. Due to the relatively short distance to be rehabilitated, only one access pit was required. The project was again completed on schedule and had a cost savings of 7%.

During the completion of Phase A, the owner experienced some unexpected benefits of using CMAR. In October 2006, during the sliplining included in GMP package #4, the City had a catastrophic failure of a separate PCCP water main, the Superior Waterline. This is a 3.2-mile 60-inch PCCP line that is fed by the Val Vista WTM. The Superior Waterline was also constructed during the late 1970s and early 1980s. After the pipe failure, the City conducted an electromagnetic inspection of the entire pipeline and the results of this investigation identified extensive wire damage in

multiple locations that mandated repair or replacement of 528-feet of pipeline. The line needed to be placed back into service by February 2007 to meet the high summer demand for water. The City therefore decided to repair these sections with carbon fiber and continue monitoring the pipeline for wire breaks in the areas of highest concern. In the first three months of operation, February to May, the monitoring system recorded over 200 wire breaks. This further verified the need for a complete rehabilitation of the Superior Waterline (Ambroziak et al. 2009).

This rehabilitation necessitated an emergency repair contract. The City determined that the only available shutdown timeframe for the rehabilitation work was between January 2008 and April 2008. This left less than six months to complete the design and begin the pipe manufacturing (Ambroziak et al. 2009). It was determined that the limits of the project included 3,300-feet of pipeline rehabilitation. Due to the expedited schedule the project team decided to use solid steel can sliplining. This allowed for a quicker installation and a lower cost, both attributed to the elimination of the longitudinal welding that is needed on split can sliplining.

The project team stated that the CMAR delivery method was ideal for this type of emergency project because the contractor, engineer, and owner are involved from the first design meeting through the final punch list of the project (Ambroziak et al. 2009). The owner was able to amend the existing contract with the engineer and contractor familiar with the rehabilitation of PCCP using sliplining methods. This ability would be more difficult when using the traditional DBB delivery method.

Overall, Phase A of the Val Vista WTM rehabilitation program, including the Superior Pipeline emergency project, was completed with a cost savings of 5% and a

schedule growth of 4%. The following section will discuss the observed performance and CMAR benefits relative to Phase B.

3.5.2 Phase B

Phase B of the rehabilitation program was the longest and most complex of the four phases. This phase was completed during the 2008-2009 shutdown period. It consisted of GMP package #5 and GMP package #6 with a scope of rehabilitating 18,500-feet of 72, 90, and 96-inch PCCP with steel split can sliplining. At the time of construction, this phase resulted in the largest steel split can rehabilitation of PCCP in the U.S. (Ambroziak et al. 2010). The phase required ten access portals to install the 925 twenty-foot pipe segments.

Due to the magnitude of this phase, the shutdown was scheduled for six months of the seven-month shutdown window allowed during the low demand season. However, because of emergency work being completed at another water treatment plant in October 2008, the shutdown of the Val Vista Water Treatment Plant ended up being shortened to five months as the contractor was mobilizing on site. Fortunately, this reduced schedule was absorbed in the construction schedule by the use of techniques employed by the contractor, such as multi-shifting work and value engineering (Ambroziak et al. 2010). To combat the extra cost of shortening the construction schedule, the City issued a change order for $400,000, of which the contractor used $304,495. This schedule reduction contributed to both a schedule decrease and cost growth for the phase.

One major benefit of using CMAR for the rehabilitation of the Val Vista WTM is the ability of the City to move cost savings from one phase to be used on another. During Phase B, there was several additional change orders issued for various reasons including:

unforeseen conditions, requests from the City or the engineer, and permit requirements; these will be discussed further in the results section. The change orders resulted in additional costs of $1,078,284, 2.91% of the original contract value. The City was able to use the cost savings from Phase A to pay for $919,460 of these changes, while funding the remaining cost with their contingency for the phase. This would not have been possible using the traditional DBB method; the City would have to get additional funding to cover the change order amount. This would involve submitting the documentation to the city council for approval.

Overall, Phase B was completed on the original substantial completion date with a 21% schedule savings caused by the City delaying the start date of the project by a month. The decreased schedule and various change orders discussed above resulted in a 2.7% cost growth for the phase. The project performance and CMAR benefits during Phase C will be discussed next.

3.5.3 Phase C

The third phase of the rehabilitation program was constructed during the 2009-2010 shutdown period. It consisted of installing 3,521-feet of steel split can slipliners beneath a parking lot on the ASU Campus. This phase required only one 40-foot deep access portal, with sliplining being deployed in both directions.

Phase C of the rehabilitation program was completed smoothly with minimal changes during construction. After finishing the more complex Phase B, the project team was able to coordinate and plan for unforeseen conditions they had encountered in the previous phases. This allowed Phase C to be successfully completed without any major issues. Moreover, the project team stated CMAR presented significant benefits,

including: flexibility, coordination, and early stakeholder integration. The portal for this phase was located just north of the Sun Devil football stadium on ASU's Tempe campus. During the time of construction there were several events held in Tempe, including the Iron Man triathlon competition and the college football Cactus Bowl. In order to avoid impacting these events, the contractor had to coordinate with the City of Tempe and ASU. This coordination was completed before the construction phase (which would not have been possible using DBB) and the phase did not severely impact these events. Phase C was completed on time and achieved a cost savings of 11.2%. The next section will present the performance and CMAR benefits of the most recent phase, Phase D.

3.5.4 Phase D

The final phase of the Val Vista WTM rehabilitation was completed during the 2014-2015 shutdown period. The scope of this phase was to rehabilitate 6,262-feet of 90-inch PCCP with split can slipliners. This project was located just to the east of Phase C, running through Tempe, AZ.

Similar to Phase C of the program, Phase D was completed smoothly without any major issues. This again can be attributed to the previous experience of the project team. Still, the use of CMAR had the same significant benefits during this phase as those experienced with Phase C. One of the main concerns of the City of Tempe during Phase D was the impact of the holiday shopping season at the nearby Tempe Marketplace shopping center. The location of the portal was near a major intersection adjacent to the shopping center. The contractor used existing relationships with the City of Tempe to address concerns and develop traffic control plans to mitigate the impact to the traffic during the busy holiday season. The early integration of the contractor during Phase D

proved beneficial again: the contractor detected a waterline that had been installed after the final design was completed, and proceeded to assist the engineer with the plan to relocate the waterline. This waterline was detected by the contractor during the design phase and did not impact construction because of its early detection.

Phase D was another successful phase being completed with a cost savings of 10.8% and schedule savings of 14% The next section will present CMAR performance benefits to the entire rehabilitation program.

3.6 Discussion of Findings

The case studies of the four phases of the Val Vista WTM provide background information for each individual phase. The performance results also were analyzed collectively to provide a broader understanding of how the use of CMAR affected the entire rehabilitation program, and how the continuity of the project team attributed to performance benefits. The discussion of findings starts with an overview of cost and schedule performance, leading to an in-depth analysis of the Phase B cost performance; and then the authors also discuss the change and communication performance.

3.6.1 Cost and Schedule Performance

The first two metrics analyzed are cost growth and schedule growth, illustrated in Figure 9. The range of cost and schedule growth for the four phases was -11.2% to 2.7% and -21% to 4%, respectively. The cumulative cost and schedule growth for the rehabilitation program were -2.75% and -3.4%, respectively.

Figure 9: Rehabilitation Program Cost and Schedule Growth

The cumulative cost savings of the rehabilitation program was $2,059,633 or 2.75% of the total cost, as shown in Table 5. The Val Vista WTM program was schedule critical due to the high water demand during the summer months in Phoenix. Each of the phases were required to be completed during their allotted shutdown period in a 7-month window coinciding with the City's low demand season. Also shown in Table 5 is that even with a schedule overrun of 17 days during Phase A, the entire rehabilitation program realized a schedule savings of 28 days or 3.4% of the total schedule.

Table 5: Total Cost and Schedule Savings

Phase	Budgeted Contract Cost ($)	Final Cost ($)	Cost Growth ($)	Cost Growth (%)	Target Schedule (Days)	Actual Schedule (Days)	Schedule Growth (Days)	Schedule Growth (5)
A	$18,249,461	$17,321,630	($927,830)	(5%)	379	396	17	+ 4%
B	$37,100,000	$38,096,510	$996,510	2.7%	131	108	-23	- 21%
C	$5,900,000	$5,241,978	($658,022)	(11.2%)	131	131	0	0%
D	$13,670,000	$12,199,709	($1,470,291)	(10.8%)	175	153	-22	- 14%
Total	**$74,919,461**	**$72,859,827**	**($2,059,633)**		**816**	**788**	**-28**	

As shown in Figure 9 and Table 5, the cost growth for Phase B is directly related to the schedule decrease. To account for the decrease in schedule, the contractor used methods such as additional crews and longer work schedules. The construction speed of Phase B, in feet per day of installed pipe, was greater than that of the other phases. This increase in installation speed allowed the contractor to complete the phase on schedule despite having a one-month reduction in the schedule by the City. Since Phase B is the only phase that exhibited a positive cost growth, the authors will examine its cost performance more closely, focusing on the reasons for this cost growth.

3.6.2 In Depth Analysis of Phase B

With the exception of Phase B, three of the four phases were delivered under the guaranteed maximum price. Phase B incurred a cost growth that can be attributed to a decrease in schedule time and unforeseen conditions that occurred during construction. This analysis will show the funding for Phase B, the cost of all changes incurred, and the basis and reasoning behind each of these changes.

The original contract funds from GMP packages 5 & 6 are the primary sources of funding for Phase B. The City also used the remaining contract funds from Phase A, including unused owner and contractor contingencies. Additional funding was provided through three COs by the City; however, only CO #2 increased the contract value, as it was not funded by the savings from Phase A.

Table 6: Phase B Cost Changes

Change Order No.	City WCD No.	Cost ($)	City Request	Engineer Request	Unforeseen Site Condition	Permit Requirement	Reason
1	WCD No. 1	$130,654	X				Agency Permit Fees
	WCD No. 3	$304,424	X				Install Turbidity Station at Portal #9 & Emergency Chlorination Station at Booster Station 1-B4
	WCD No. 5	$37,506	X				Hayden Rd. Pipeline Inspection Support
2	WCD No. 2	$400,000	X				Acceleration Costs Due to 30 Day Reduction of Schedule
	WCD No. 10a	$344,144	X		X		Emergency Fiber Wrap Repair of 40 ft. of PCCP
	WCD No. 11	$165,981	X	X	X	X	Schedule and Location Adjustment to Portal #6W
3	WCD No. 13	$95,576	X				Security Fencing and Sample Station at Valve Station 602 and Extended Maintenance of Project Site and Lay-Down Yard

There were three COs issued during the construction of Phase B. Each are broken down into specific work change directives (WCD) shown in Table 6. The total amount for the change orders was $1,478,286, however, the only increase to the contract for Phase B was CO #2 for $400,000. As previously discussed, this CO was issued to cover the costs of reducing the construction schedule by 31 days. CO #2 accounted for 31% of the cost changes on the phase. The remaining 69% of the cost changes were funded from three sources: (1) the owner's contingency from GMP packages 5 & 6; (2) the remaining contract funds from Phase A; and (3) unused allowances and quantity under-runs from GMP packages 5 & 6. By using these three sources to fund the change orders, the City did not have to go through the process of requesting for additional funds, as was the case for CO #2. The ability for the owner to use remaining funds from the previous phase attributed to the four phases being delivered under the same program and to the use of CMAR.

The City designates a basis of change and reason for each WCD included in a CO, also shown in Table 6. The basis for change includes: city request, engineer's request, unforeseen Site condition, and permit requirement. The initiator of the WCD selects all the bases that apply and provides a reason for each WCD.

WCD No.1 was issued for the cost of permit fees for the City of Tempe and the City of Mesa. These were not included in the design or construction contracts and the city directed the contractor to pay them and allow the phase to begin. This WCD was designated as a city request due to it not being in the original contract and having to be completed before the phase could begin.

As another example, WCD No. 10a was issued for unforeseen conditions and a city request. During the sliplining, the contractor discovered two 20-foot sections of the 72-inch pipe to be partially collapsed. The City directed the contractor to conduct emergency repairs using carbon fiber wrap methods prior to completing the sliplining.

The City issued WCD NO. 13 for two reasons. The first reason was for security fencing and building of a sample station at valve station 602. The Water Operations Section requested that a new water sampling station be added and that all newly installed equipment at the valve station be enclosed with security fencing. The second reason was for the contractor to maintain field offices and lay-down yard until the start of the Phase C. The contractor estimated the complete de-mobilization of the current work and the mobilization for Phase C to be approximately $250,000. The additional $63,360 to maintain the field offices was significantly offset by this cost savings of not having to de-mobilize and re-mobilize again for the next phase. The ability for the City to do this again originates from the continuity of the project team. By using the same contractor for both phases, the de-mobilization and mobilization costs were significantly decreased. After having discussed cost and schedule performance, the following section presents the change and communication performance of the rehabilitation program.

3.6.3 Change and Communication Performance

In addition to cost and schedule performance metrics, the survey targeted change and communication performance metrics. The change performance metric collected was the average change order processing time. This is defined as the period of time between the initiation of the change order and the owner's approval of the change order. Figure 10(a) shows the average change order processing time for each phase. Phase A had an

approximate average processing time of four weeks; this time decreases to three weeks for Phases B and C, and finally to one week for Phase D. One possible reason for this steady decrease in processing time is the continuity of the project stakeholders. A CO is initiated by the contractor, Kiewit Western Co., and then given to the program manager, Brown and Caldwell, to review and send to the owner, the City of Phoenix. When the continuity of the stakeholders is maintained, the duration of the process has the ability to be decreased because of familiarity and a decreased learning curve. El Asmar et al. (2013) showed similar performance benefits on vertical projects when using integrated project delivery methods.

The communication performance metric collected was the average request for information (RFI) processing time, defined as the period of time between the initiation of the RFI and the owner's or engineer's response to it (El Asmar et al. 2013). Requests for information are considered a communication performance metric because they can be an important source of waste for projects. The reason is simple: crews lose productivity while waiting for information, especially when it takes weeks for other project parties to respond. Often, these crews have to demobilize and remobilize more than once, which can add costs to the project (El Asmar et al. 2013). Figure 10(b) shows the average RFI processing time during each phase of the program. The processing time is held constant at three weeks for Phases A, B, and C. Then, the processing time decreases to one week for Phase D.

Figure 10: Average Change Order and RFI Processing Times

One possible reason for this decrease in comparison to the change order processing time is the differing design engineers for the phases. The contractor initiates

the RFI and submits it to the program manger for review and then typically the design engineer for that phase will be contacted for a response. This process does not have the same continuity as the change order process and could explain the processing time not decreasing as drastically.

The Val Vista WTM program is a successful example of using CMAR for the delivery of a large pipeline rehabilitation program. The project team incurred performance benefits in several commonly used metrics. There are numerous possible causes of the increase in performance. One of the possible explanations is the benefits come from the continuity of the project team. This could decrease the learning curve typically seen on construction projects. After the completion of the first phase the team is familiar with the process and the subsequent phases would have a significantly decreased learning curve. This has the possibility to increase performance on the following phases. However, as discussed previously, this continuity can be attributed to the use of CMAR. If the program had been delivered using DBB, the project team most likely would have been different and the benefits of continuity, including a decreased learning curve, would not be realized.

3.7 Conclusions

This study aimed to illustrate how CMAR can affect the performance of pipeline rehabilitation projects. The Val Vista WTM rehabilitation program was studied using both a case study and quantitative survey. The case study provided background and phase specific schedule and cost performance on each phase of the ten-year program. Phase A was completed with a schedule growth of 4% and a cost savings of 5%. This included the emergency rehabilitation of the Superior Waterline completed as an amendment to the

original phase. This was made possible by adding this scope to the original CMAR contract for both the engineer and contractor. Phase B was completed with a 21% schedule savings and a cost growth of 2.7% cost growth. These were attributed to a decrease in the construction schedule by the City due to an emergency repair at a separate facility. The contractor was able to absorb the schedule decrease by increasing man-hours and through value engineering, which led to a portion of the cost growth. Phase C of the rehabilitation program was finished with no schedule growth and a cost savings of 11.2%. Phase D was completed with a schedule savings of 14% and cost savings of 10.8%. Both Phases C and D benefited from the use of CMAR by allowing the project team to have more flexibility, better coordination, and increased stakeholder involvement.

The case study assisted in contextualizing the results of analyzing the entire rehabilitation program. The range of cost and schedule growth for the four phases of the program was -11% to 2.7% and -21% to 4%, respectively. The whole program had a cost savings of $2,059,633 or 2.75% of the total costs, and a schedule savings of 28 days or 3.4% of the total schedule. An in-depth analysis of the cost performance of Phase B showed in detail some of the benefits the City realized by using CMAR. These benefits included: paying for needed changes during Phase B by using the cost savings form Phase A; dealing with unforeseen conditions with more ease; and decreasing costs of de-mobilization and re-mobilization of future phases by allowing the contractor to simply maintain the field office and laydown yard.

The quantitative survey also analyzed the change and communication performance. The change order processing time was shown to decrease significantly from

Phase A to Phase D. One possible explanation for this decrease is the continuity between the project stakeholders. The authors also analyzed the RFI processing times, which showed a similar decrease. This is possibly attributed to continuity of the design engineers who typically provide answers to RFIs.

Overall, the Val Vista WTM rehabilitation program was successful in providing the City of Phoenix a solution to rehabilitate a critical waterline. The program highlights the potential benefits of using CMAR for pipeline rehabilitation. One limitation of this study is typical to case studies, and consists of the small sample size. However, this study is part of a larger research effort that includes three major phases.

The first phase was completed through a preliminary survey that investigated the market utilization, industry comfort level, and performance perceptions of CMAR and other APDM based on a survey of industry leaders. The survey results indicated the pipeline industry perceived APDM to offer better performance than DBB and that APDM were being used to deliver a meaningful portion of projects. The results were paired with a meta-analysis that explored the cost savings being realized on completed projects. The first phase showed the potential for CMAR and other APDM to impact the cost performance on pipeline engineering and construction projects, also laying the foundation for the second phase of the study.

The second phase is the case study presented in this paper, and used to demonstrate and discuss the performance of a four-phase CMAR rehabilitation program. The data was collected through a detailed survey that allowed for the collection data for several commonly used performance metrics. The case study method also provided qualitative information regarding each phase of the program, which would not have been

possible with the quantitative data analysis alone. However, due to the limited number of projects studied, no statistical analysis was completed to compare the performance of CMAR to that of DBB.

Future work includes the third phase of the described research thread, which will use the quantitative performance survey to collect data on large sample of pipeline engineering and construction projects using CMAR. The data will then be used to statistically compare the performance of projects using CMAR to projects delivered using other delivery systems. The anticipated third phase will provide the first large empirical study that compares the performance of CMAR and DBB in the pipeline industry.

This study offers a key contribution to the construction body of knowledge: it uncovers CMAR benefits through (a) performing a longitudinal study on a large diameter water main rehabilitation program; and (b) quantitatively analyzing the performance impact of CMAR on the program. The results can help owners better understand the potential performance benefits CMAR has on pipeline engineering and construction projects.

3.8 Acknowledgments

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success of this study. Without their valuable contributions this research would not have

been possible.

4. PERFORMANCE ANALYSIS OF CONSTRUCTION MANAGER AT RISK (CMAR) ON PIPELINE ENGINEERING AND CONSTRUCTION PROJECTS

4.1 Abstract

Much of the water and wastewater pipelines in the United States are nearing the end of their useful life. A significant reinvestment is needed in the upcoming decades to replace or rehabilitate the water and wastewater pipeline infrastructure. Currently, the traditional method for delivering water and wastewater pipeline engineering and construction projects is design-bid-build (DBB). The traditional DBB delivery system is a sequential low-integration process and can lead to inefficiencies and adverse relationships between stakeholders. Alternative project delivery methods (APDM) such as construction manager at risk (CMAR) have been introduced to increase stakeholder integration and ultimately enhance project performance. CMAR project performance impacts have been studied in the horizontal and vertical construction industries. However, the performance of CMAR projects in the pipeline engineering and construction industry has not been quantitatively studied. This paper fills this knowledge gap by achieving two objectives: (1) provide a comprehensive study of CMAR project performance to develop a baseline of commonly measured performance metrics; (2) and statistically compare the cost and schedule performance of CMAR to that of the traditional DBB delivery method. A thorough literature review led to the development of a data collection survey used in structured interviews to gather qualitative and quantitative performance data from completed water and wastewater pipeline projects. The results provide a performance benchmark for seven metrics in four performance areas (cost, schedule, project change, and communication). The major contribution of this paper is demonstrating the superior cost performance (by 6.5%) and schedule performance (by 12.5%) of CMAR projects

when compared to similar DBB projects. The results can aid decision makers when choosing the appropriate delivery method for their water and wastewater pipeline projects, and provide stakeholders with more certainty in their project performance.

4.2 Introduction to Project Delivery Systems and Pipeline Infrastructure

The water and wastewater infrastructure in the United States is failing. In 2013, the American Society of Civil Engineers (ASCE) released a report card grading 16 categories of America's infrastructure. In this report, ASCE gave both the water and wastewater infrastructure a grade of a "D," which is considered poor and at risk. ASCE (2013) defines this grade as follows: "The infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of significant concern with a strong risk of failure." Failures in water and wastewater pipeline infrastructure have many impacts on the public, including water disruptions, impediments to emergency response, water pollution, and damage to roadways and other types of infrastructure (ASCE 2013). Due to aging of the water and wastewater lines, a significant reinvestment is needed in the up coming decades to replace or rehabilitate the pipelines. According to ASCE, "Not meeting the investment needs of the next 20 years risks reversing the environmental, public health, and economic gains of the last three decades" (ASCE 2013). Two studies by the Environmental Protection Agency (EPA) estimated a need of approximately $632.8 billion is needed for water and wastewater systems, with $281.6 billion of those funds allocated to water and wastewater pipelines by 2028 (EPA 2007; EPA 2008). Some of the major concerns surrounding the water and

wastewater infrastructure are the increase in water main breaks and discharge of untreated sewage.

In the United States there are nearly 170,000 water systems that contain more than one million miles of water mains. Within these systems, there is an estimated 240,000 water main breaks per year (ASCE 2013). These breaks can have significant social and economic impacts. The cost of an emergency repair of a waterline and roadway after a catastrophic water main break is typically much higher than if that line was rehabilitated or repaired before failure. This cost does not factor in the disruption of the public while a repair is taking place. In a study completed on water infrastructure in 2007, the EPA reported a 20-year capital investment need of $334.8 billion. Of the $334.8 billion investment, nearly 60% or $199 billion is needed for transmission and distribution systems (EPA 2007).

There are between 700,000 and 800,000 miles of public sewer mains located throughout the 19,739 wastewater systems scattered around the U.S. The aging and under designed wastewater pipelines lead to the discharge of an estimated 900 million gallons of untreated sewage each year (ASCE 2013). The discharges typically flow into a nearby river or body of water and are a major water pollution concern. In another study completed in 2008, the EPA reported that a 20-year capital investment of $298 billion is needed for aging wastewater infrastructure, with wastewater pipeline repair and new pipelines accounting for $82.6 billion (EPA 2008). This study, along with the aforementioned study, highlights the critical need of replacement or rehabilitation for the aging infrastructure. This is going to require a serious investment from the federal, state, and local governments. To maximize the money invested, engineering and construction

must be completed efficiently, on time, and without additional costs. Alternative project delivery methods (APDM) have the potential to assist owners in delivering their projects economically and on schedule.

Currently, the traditional method for delivering water and wastewater pipeline engineering and construction projects is design-bid-build (DBB). The traditional DBB delivery system is a sequential process that can lead to inefficiencies and adverse relationships between owners, design engineers, and contractors. These adverse relationships are often caused by a lack of stakeholder integration and communication. APDM have been introduced to increase stakeholder integration and ultimately enhance project performance (Konchar and Sanvido 1998; Molenaar et al. 1999; El Asmar et al. 2015). Some of the commonly used APDM are construction manager at risk (CMAR), job order contracting (JOC), and design build (DB). This study focuses specifically on the project performance (cost, schedule, project change, and stakeholder communication metrics) of CMAR attained by the City of Phoenix in Arizona on its water and wastewater pipeline projects.

Project delivery methods are generally distinguished by two key characteristics: (1) the contractual relationships between project stakeholders and (2) their timing of engagement in the project (Konchar and Sanvido 1998; El Asmar et al. 2013), shown in Figure 11. The owner signs separate contracts with the engineer and the contractor in both DBB and CMAR. In DBB, the contractor is typically engaged after the design is complete and is rarely able to provide input during the design. In contrast, the CMAR firm is engaged before the design in complete, typically between 30 and 60 percent of the

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design development, maximizing the benefit of collaboration and minimizing redesign (Shorney-Darby 2012).

Figure 11: CMAR and DBB Stakeholder (a) Relationships and (b) Timing of Engagement (Francom et al. 2015b)

Additional key differences between the two delivery systems were found in studies by Gransberg and Shane 2010; Shorney-Darby 2012 that include the following:

D. In CMAR, the design engineer and CMAR firm are often contractually required to coordinate during the design phase of the project. This level of interaction often does not take place in the traditional DBB method.

E. During a CMAR project, the contractor typically has two contracts. The first is a preconstruction contract that will be completed during the design phase for services such as design reviews, constructability reviews, cost estimation, value engineering, and scheduling. The second contract is for the construction of the project.

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F. The contractor selection process varies between DBB and CMAR. DBB often uses a selection process where the owner will typically select the lowest responsible bidding contractor, regardless of their experience or qualifications. Whereas in CMAR, the owner often selects the contractor based on a combination of cost and qualifications.

These differences highlight the increased timing of engagement of the CMAR firm and the ability to provide more coordination and communication during the design phase.

Research found CMAR was successfully implemented in the vertical and horizontal construction industries. It continues to gain substantial popularity due to its documented ability to improve project performance (Sanvido and Konchar 1998; El Asmar et al. 2015). In fact, Engineering News Record (ENR) recently published its latest list of Top 100 CMAR firms and stated the top firms exhibited a domestic revenue of $86.77 billion in 2014, an 11.5% increase compared to 2013 (Tulacz 2015). This revenue is nearing the $87.74 billion seen in 2008 before the Great Recession. The ENR article states that with the end of the recession many owners are once again being attracted to the benefits associated with using CMAR. They further noted that legislative barriers are falling and public agencies are becoming more familiar with the CMAR process, and in turn CMAR is becoming more relevant in markets that have not been as receptive to straying beyond DBB. This is in stark contrast to the projects being delivered during the Great Recession. Owners were choosing to use DBB to take advantage of rock bottom pricing due to desperate engineers and contractors (Tulacz 2015).

When studying the performance of a project delivery method in a construction industry, it is essential to understand the performance of the traditional method. Through

a review of relevant literature, the authors found no studies that document and analyze project performance of DBB on pipeline engineering and construction projects. However, researchers completed many studies that investigate performance of DBB projects in the vertical and horizontal construction industries. Cost and schedule are the most commonly studied performance metrics within the literature. Every construction project has a set budget and schedule, and any overruns of these negatively impact the owner's ability to adequately plan for future projects. When delivering public construction projects, it is especially important for owners to have cost and schedule certainty. For example, these certainties allow for proper allocation of resources (e.g. budget, time, and personnel) for all ongoing and future projects within their capital improvement plan.

Figure 12 was developed by the authors to show the historical cost and schedule growth performance of 18 studies in the vertical and horizontal industries. These studies are used to create a baseline for DBB cost and schedule performance. Cost growth is measured by comparing, in percentage terms, the final construction cost to the original cost proposal. Similarly, schedule growth is defined as the percentage of time a project is completed over the original allotted contract time.

Figure 12: DBB Cost and Schedule Growth Baseline in Other Construction Industries

These metrics are particularly important because they are the deviation from the budgeted cost and allotted schedule time. A majority of the studies had a cost and schedule growth with the exception of one, which showed a cost savings. The cost growth ranges from -0.71% to 24.6% and the schedule growth ranges from 3.13% to 50%. Taking a weighted average of the cost and schedule growth of the 1,538 projects presented in Figure 2, results in an average cost growth of 4.43% and an average

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schedule growth of 15.89% (represented by the dashed lines in Figure 12). These studies show that on average an owner will have nearly a 5% increase in the cost of their projects and nearly a 16% overrun in the schedule duration. This uncertainty, in terms of cost and schedule, puts owners in the difficult position of adequately planning and budgeting for ongoing and future projects.

The use of CMAR has the potential to improve performance on pipeline construction projects, thus allowing owners to have a better certainty when planning and constructing their projects. The authors have found no comprehensive studies that have examined the performance of CMAR in the pipeline engineering and construction industry and provided a baseline for commonly studied performance metrics. This paper aims to fill this gap by completing two objectives: (1) provide a comprehensive study of CMAR project performance to develop a baseline of commonly measured performance metrics; and (2) statistically compare the cost and schedule performance of CMAR to that of the traditional DBB delivery method.

4.3 Literature Review

The authors began with a comprehensive review of literature to analyze the body of knowledge on the use and project performance of CMAR in the construction industry. There have been few research studies on the comprehensive performance of CMAR projects, with no such studies for the pipeline industry. Much of the published research on CMAR in the pipeline industry consists of qualitative analyses or case studies that discuss the advantages of using CMAR, but do not focus on quantitative performance (DeGrande et al. 2014; Maughn et al. 2014; Ambroziak et al. 2010; Hasan 2010; Guy 2007; Leskinen et al. 2007; Kramer and Meinhart 2004). First, literature on CMAR in

other construction industries is presented, followed by previous APDM studies by the authors in the pipeline industry.

4.3.1 CMAR Project Performance Literature

Konchar and Sanvido (1998) conducted a study of 351 building projects to quantify the performance of several delivery systems. One part of the study empirically compared cost and schedule performance of DBB and CMAR. The results from a univariate analysis showed that CMAR had a median cost growth of 3.37% and schedule growth of 0%. In contrast, DBB had a median cost growth of 4.83% (very close to the aforementioned baseline in Figure 12) and schedule growth of 4.44%. A multivariate analysis showed that when all other variables were held constant CMAR had a higher cost growth and lower schedule growth than DBB. However, these results were not deemed to be statistically significant. The study concluded CMAR offered significant advantages over DBB in delivering vertical projects (Konchar and Sanvido 1998).

Alder (2007) studied the performance of CMAR projects completed by the Utah Department of Transportation (UDOT). The report states that CMAR has not positively or negatively impacted the budget of a project. However, it is noted that funding saved on CMAR projects is usually reprogrammed for additional work to be accomplished, including expanding the scope when funds are available. The reprogramming of funds makes it difficult to report a true effect that CMAR has on the budget. With respect to schedule, Alder stated, "the CMAR process has reduced the schedule for most projects. Part of the reason for this is the time saved in the design effort. The contractor's participation helps to identify solutions quickly and speeds up the design process. Their participation also reduces the detail that must be communicated to the contactor in

drawings and specifications." The shortened design process allows the project to begin construction earlier, therefore, decreasing the delivery time when the contractor is initiated early in the design process. The study concluded that CMAR should be used to deliver UDOT projects because of the contractor's input to reduce risk, cost, and construction time (Alder 2007).

Rojas and Kell (2008) compared the cost performance of 273 DBB and 24 CMAR public school projects completed in the Pacific Northwest. The results show no statistical difference between CMAR and DBB in change order costs during the construction phase. However, the CMAR projects exceeded the guaranteed maximum price (GMP) in 75% of the cases, and DBB averages less cost growth than CMAR. These results counter some of the traditional expectations of the ability of CMAR to better control cost than DBB.

Shane and Gransberg (2010) showed a comprehensive literature review documenting the advantages and disadvantages of CMAR innovation in correlation with case studies involving structured interviews of project practitioners in the building and transportation sectors. The study presents the intersection of the literature content analysis with the case study project structured interviews. Within the top seven advantages of using CMAR, five are directly related to cost and schedule. The advantages include: (1) ability to fast-track a project; (2) early knowledge of costs; (3) ability to bid early work packages (in turn decreasing construction time by overlapping with design); (4) guaranteed maximum price (GMP) proposals create a cost control incentive; (5) and reduced design costs. The authors concluded that CMAR showed cost and schedule benefits throughout the literature and during the structured interviews (Shane and Grandsberg 2010).

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4.3.2 The Author's Previous Work on APDM in the Pipeline Industry

Realizing the gap in knowledge on APDM's performance impact for pipeline projects, the authors initiated studies to investigate this topic. In fact, this paper builds upon two previous research studies.

The first study investigated cost performance and industry perceptions of APDM on pipeline projects (Francom et al. 2015a). In the previous work, the authors completed a meta-analysis of literature to determine if APDM are successfully used in the pipeline industry. The meta-analysis specifically focused on project cost because it was the only metric for which data was published. The results stemmed from ten completed projects and showed DB and CMAR can potentially offer cost savings benefits ranging from 2% to 44%. Specifically, the average cost savings for the CMAR projects was 13%. The results originated from a small sample of pre-published data – enough to show there is a potential, but not enough to draw significant conclusions on the performance improvement. The authors built on that knowledge in this current paper.

Moreover, the authors developed and implemented a survey of pipeline industry stakeholders to investigate the utilization rate, industry comfort level, and perceptions of performance of APDM. The results of the pipeline industry survey indicated the most utilized project delivery system is still the traditional DBB system, followed by DB and CMAR as the most prevalent APDM. Although many of the respondents showed a moderate comfort level with most APDM, DBB is the project delivery method that the respondents are still most comfortable using. The comfort level of the stakeholders in implementing each project delivery method is influenced by their past experience using each method. Intuitively, the more a project delivery method is used, the more

comfortable the industry will be when implementing it. A Likert scale measured the comfort level from 1-5, with 1 being very uncomfortable and 5 being very comfortable. The respondents had an average comfort level of 3, which is a medium comfort level, to implement and use CMAR on their projects.

The results indicate industry respondents perceive APDM to impact some project performance metrics (i.e., schedule, quality, and productivity) more than others. The respondents perceived CMAR to most impact schedule, return business and profit, and communications between stakeholders. For most performance areas, the respondents perceive the collective use of APDM to offer increased performance compared to the traditional DBB when adopted on pipeline projects. Understanding the industry perceptions on performance helped the authors focus their scope of work for this current paper, which will collect actual (as opposed to perceived) performance data.

In a second study, the authors performed a longitudinal case study of the use of CMAR to deliver a critical ten-year rehabilitation program by the City of Phoenix (Francom et al. 2015b). This paper was a combination of a qualitative case study and quantitative analysis of each of the four phases of the rehabilitation program. The four phases within the program were used to pilot test the performance survey used in this quantitative assessment and benchmarking paper (this will be discussed in the following section). The pilot testing allowed the authors to refine the survey questions and maximize their effectiveness prior to conducting a large data collection effort. The case study allows for a more in depth understanding of the project and the ability to contextualize the results from the quantitative performance analysis. The findings demonstrate the performance benefits of using CMAR, which include a cumulative cost

reduction of 2.75% and schedule reduction of 3.4% over the four phases of the program, as well as improved change and communication performance. These results provide even further motivation for the need of research in this area and a large comprehensive performance study.

To summarize the literature, there is a lack of quantitative research or baseline of performance metrics on CMAR pipeline projects. However, several studies demonstrated the use of CMAR on other types of construction projects has the ability to positively impact performance. This paper builds upon these studies to investigate and quantify performance specific to pipeline engineering and construction projects delivered using CMAR.

4.4 Research Objective and Method

With CMAR gaining popularity in pipeline engineering and construction industry, there is a need to understand its performance. The objectives of this study are twofold: (1) provide a comprehensive study of CMAR project performance to develop a baseline of commonly measured performance metrics; and (2) statistically compare the cost and schedule performance of CMAR to that of the traditional DBB delivery method. These objectives are accomplished in three phases.

4.4.1 Phase A

Phase A is a comprehensive literature review of both APDM performance and pipeline performance that provided a foundation for the rest of the study. The literature review assisted the authors in first determining the current state of knowledge and use of APDM in the pipelines industry. Secondly, to identify common performance metrics that are studied in both alternative project delivery and pipeline engineering and construction

research. In addition to the studies presented in the *Literature Review* section, the following performance research was reviewed for comprehensiveness: El Asmar et al. 2013; Bogus et al. 2013; Shane et al. 2013; Shrestha et al. 2012; Molenaar et al. 2004; Allouche et al. 2000; Molenaar et al. 1999; Konchar and Sanvido 1998; Songer and Molenaar 1996. Coupled with the metrics found in the literature, the authors consulted with industry partners to ensure only useful metrics with available data were included in the research. The completion of this stage served as a solid foundation for the development of a quantitative performance survey.

4.4.2 Phase B

Two steps were needed to complete the Phase B. Beginning with developing a data collection survey using the identified metrics from the literature review and input from industry partners. The survey aims to collect data on quantitative and qualitative performance metrics. The survey went through two stages of reviews prior to being used to collect data: the first by construction and engineering management faculty members at Arizona State University (ASU); and secondly industry partners, representing owners, engineers, and contractors. The survey was then pilot tested using a small sample of projects (as previously discussed in the *Literature Review* section) to refine the questions and maximize their effectiveness. These iterative review steps led to a concise 18-question survey that allowed for data collection of performance metrics on completed CMAR pipeline projects. The survey was then used to facilitate data collection during structured interviews with the identified industry participants, specifically the project manager from the CMAR firm.

4.4.3 Phase C

Phase C was also completed in two steps. The first step included collecting the CMAR data needed to create a performance baseline. The second step gathered DBB project performance data to compare to the CMAR data collected in the first step.

4.4.3.1 CMAR Baseline

Phase C began with identifying nationwide pipeline engineering and construction projects delivered using CMAR. It became evident during an extensive search for applicable projects that several project case studies (DeGrande et al. 2014; Horn and Roth 2013; Ambroziak et al. 2010; Ambroziak et al. 2009; Leskinen et al. 2007) were published on completed CMAR pipeline projects in Arizona. Upon further discussion with several of the publication authors and industry partners, it was determined that the majority of the CMAR pipeline projects completed in Arizona were delivered by the City of Phoenix. To limit the variation in the dataset and increase the certainty in the results, the research team (with advice from industry partners) elected to use the City of Phoenix as a source for the data. Keeping the owner organization consistent throughout helped decrease variables such as different owner organizations, experience of all stakeholders with CMAR, location variability and factors, the number of contractors and design engineers used, and different legislative laws and requirements. The next step involved meeting with the City of Phoenix to identify projects that were suitable to the framework of this study. This began with examining he records from all water and wastewater projects to find only the projects delivered using CMAR. Then a discussion with staff in the City of Phoenix verified these projects.

After identifying the projects, project documents were obtained from the Central Records staff within the Public Works department. The project documents contained: contracts, guaranteed maximum price (GMP) proposals, payment applications, change order documentation, notices to proceed, final completion approvals, request for council actions, and general correspondence. These documents were analyzed for information to begin populating the data collection survey for each project. The information taken from the project documents included the project characteristics (e.g. project name, length, diameter, utility, etc.) and the cost and schedule data. This rich dataset from the owner's side allowed the research team to have an increased familiarity with the projects, as well as the ability to complete approximately half of the survey prior to meeting with the CMAR firm representative.

Then the authors conducted structured interviews with the CMAR firm project manager for each individual project to ensure consistency in the collected data. After the completion of the surveys, the data was compiled and coded for analysis. The performance data was analyzed using descriptive statistics and univariate statistical techniques. The Mann-Whitney-Wilcoxon (MWW) test was used to compare the two sample medians and determine statistical significance between different samples in the dataset (e.g. performance of water projects versus wastewater projects). Among tests based on ranks, the MWW test is the most widely used because it is known to be extremely robust against non-normality and to have asymptotic power of at least 86% of that of the t-test over all distributions (Lehmann 2006). The MWW test results in a p-value that is compared to the common threshold for statistical significance of 0.05. A p-value smaller than 0.05 indicates the differences observed between the two samples is

statistically significant. The descriptive statistics and results from the MWW tests were used to create a baseline for seven performance metrics on CMAR pipeline projects.

The authors then performed a comprehensive analysis of the performance data to evaluate outliers. This analysis included performing normality tests, distribution plots, and statistical tests. The data points considered outliers were then investigated to determine the specific cause of the outlier value. The complete performance data set (outliers included) is presented for comprehensiveness and objectivity. However, discussion of results without the outliers will be presented and compared to the performance with outliers included. After completing the data analysis, the authors met with the City of Phoenix to verify, validate, and contextualize the findings.

4.4.3.1 CMAR and DBB Cost and Schedule Performance Comparisons

During the CMAR data collection effort, the authors also identified similar DBB pipeline projects delivered during the same timeframe. The project documents for each DBB project were analyzed to gather cost and schedule performance metrics. The entire data collection survey was not completed for each DBB project; therefore, only cost and schedule metrics were collected and analyzed. This resulted in 41 DBB projects that met the criteria of this study. The cost distribution of the CMAR and DBB projects were then plotted to understand the distribution of cost between the two delivery systems. The datasets were then truncated to include only similar size projects. This allowed for an accurate comparison analysis of cost and schedule performance. The following section first presents and discusses the characteristics of the CMAR dataset and then discusses the characteristics of the DBB projects.

4.5 Data Characteristics

4.5.1 CMAR Performance Baseline Data

Through collaboration with the City of Phoenix, 66 CMAR pipeline projects were identified to fit the scope of this study. The projects' dates ranged from 2003 to 2015 and totaled slightly over $400 million in 2015 equivalent dollars. Each of the project cost was converted to 2015 equivalent dollars using the latest Bureau of Labor Statistics (BLS) inflation information provided in the Consumer Price Index (CPI). This allows for similar comparison and distribution of project cost across the 13 years. Figure 13 shows the cost and schedule distribution for the projects. The projects' costs ranged from $500,000 to slightly over $60 million, with the majority under $10 million dollars and delivered in less than 250 days. Most projects took around five to six months to complete. In contrast, vertical construction projects are typically completed over the course of a year to several years. The typical duration of projects is a major difference between the pipeline industry and other construction industries.

Figure 13: City of Phoenix CMAR Project Cost (N=66) and Schedule Distribution (N=57)

Figure 14 provides further project characteristics including the distribution of diameter, utility type, and construction type. The pie charts on top in Figure 14 show the percentage based on number of projects and on bottom of Figure 14 show the percentage based on cost. The majority (in terms of number) of the projects were wastewater pipelines projects, however, the total cost of the wastewater and water projects was nearly identical. This is due to the City delivering several sizeable water projects using CMAR. Nearly 70% of the projects were for rehabilitation or installation of large diameter (>24") pipelines totaling approximately $350 million (88% of the total cost). Roughly half of the projects (both in number and cost), were rehabilitation of deteriorating pipelines using trenchless construction methods such as slip lining, cured in place pipe (CIPP), and pipe bursting. The other half of the projects were new construction installed using traditional open cut methods.

Figure 14: Data Characteristics – Project Utility Type, Diameter, and Construction Type – Percentages by Number of Projects (Top) and by Cost (Bottom) (N=66)

The structured interviews with the CMAR firms resulted in complete surveys for 41 of the 66 (a 62% response rate) identified projects. This provided data for questions the authors were unable to complete using the project documents. One question in the survey aimed to understand at what stage during the design the contractor became involved.

City of Phoenix CMAR Projects (N=41)

Figure 15: CMAR Firm Involvement in Design (N=41)

The boxplot in Figure 15 shows that the majority of the CMAR firms are involved between 30% and 60% design development (with an average time of 50% design completion), which is consistent with the range presented by Shorney-Darby (2012). A boxplot is a nonparametric graphical summary of data, displaying the sample minimum, lower quartile, median, upper quartile, and maximum. A thick black line, dividing the dataset in half, represents the median value. The rectangle represents the 50% of the data around the median, whereas the remaining 50% of the data are divided equally above and below the rectangle.

This dataset is used to provide a baseline for CMAR performance on communication, change, schedule, and cost performance metrics. The following subsection discusses the characteristics of the dataset used for the CMAR and DBB cost and schedule performance comparison.

4.5.2 CMAR and DBB Cost and Schedule Comparisons Data

With assistance from the City, the authors collected cost and schedule data on 41 DBB pipeline projects completed between 2003 and 2015. To ensure that the DBB and CMAR datasets are comparable (i.e. similar size based on cost distribution) the 2015 equivalent cost distributions of both delivery systems (66 CMAR projects and 41 DBB projects) were plotted to determine the overlap, seen in Figure 16. The distribution shows that the City has not delivered any of their pipeline projects over $8 million using DBB, all of these larger projects were delivered using CMAR. For this reason the dataset was reduced to only comparable sized projects for the comparison of cost and schedule performance. From the overlap of the distributions, it was determined that the maximum project cost to be included is $5.5 million.

Figure 16: DBB and CMAR Cost Distribution (N=107)

This resulted in 89 projects (49 CMAR and 40 DBB) for the statistical comparison. The cost distribution of the truncated dataset can be seen on the right plot in Figure 16. The total cost of the CMAR and DBB projects is $135 million and $95 million, respectively. This dataset is used to provide the statistical comparison of cost and schedule performance between CMAR and DBB.

4.6 Results and Discussion

The following subsections present the CMAR performance baseline for change, communication, schedule, and cost performance metrics. The cost and schedule

performance comparison of the CMAR and DBB projects is shown after the performance baseline in the cost and schedule subsections.

4.6.1 Communication Performance Metrics

The first performance metrics studied are the communication between the major stakeholders involved in the project. The metrics collected focus on the number of requests for information (RFI) and the RFI processing time. The number of RFI has been normalized by dividing by the project cost in order to compare projects of different sizes. The projects have a median value of two RFI per million dollars, shown in Figure 17(a). This value is very close to the median value of 1.81 RFI per million dollars for CMAR and DB vertical building projects presented in El Asmar et al. (2013). This study shows a significant decrease in the number of RFIs when compared to traditional DBB projects.

(a) City of Phoenix CMAR Projects(N=41)   (b) RFI Processing Time (weeks)

Figure 17: CMAR Communication Performance (a) RFI per Million Dollars and (b) RFI Processing Time (N=41)

The second communication metric studied is RFI processing time; it is defined as the period between the initiation of the RFI by the contractor and the response by the owner

or engineer. Shown in Figure 17(b) is the distribution of RFI processing time. The majority of the RFIs were responded to within one week and no longer than three weeks, with the median being 1.5 weeks. Again, the results of RFI processing time are nearly identical to the median processing time of 1.5 weeks for CMAR and DB vertical building projects in El Asmar et al. (2013). The DBB projects in this study have a median RFI processing time of 2 weeks, with a much larger distribution than CMAR and DBB projects. The distribution of processing time is significantly narrowed when using more integrated delivery methods such as CMAR and DB.

4.6.2 Change Performance Metrics

The project change metrics studied include the causes for changes and the average processing time for change orders. First the causes of changes are presented. The causes include the approximate scope changes and unforeseen condition changes for each project. Figure 18 shows that the median percentage of changes due to a change in scope by the City is notably higher than the percentage of changes caused by unforeseen conditions.

(a) Scope Changes (N=41)

(b) Unforeseen Condition Changes (N=41)

Figure 18: CMAR Change Performance Metrics (a) Percentage of Scope Changes, (b) Percentage of Changes Due to Unforeseen Conditions (N=41)

One likely reason for this distribution of changes, as discussed with the City, is that using a more integrated delivery method (CMAR) where a contractor is consulted earlier in the design process decreases the amount of surprises during construction (unforeseen conditions). The larger value for scope changes can be attributed to cost savings during the project. These savings are then repurposed for additional scope items such as increasing the length of pipeline installed or replacing a deteriorating line adjacent to the construction, as previously discussed.

The second change metric collected was the average change order processing time, defined as the period of time from contractor initiation of a change order and the owner's approval, shown in weeks in Figure 19. The average processing time is approximately four and half weeks. This value is slightly higher than the processing time presented by El Asmar et al. (2013) where change order processing time for CMAR and DB projects ranged from one to five weeks, with a median value of 3.5 weeks.

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Figure 19: CMAR Change Order Processing Time (N=41)

As shown by Figure 17(b) and Figure 19, the processing time for change orders is much longer than that of RFIs. This increased processing time can be attributed to the amount of documentation and the approvals needed for each. Change orders must have supporting documentation that provides justification for the increase in cost or schedule. This documentation must then be reviewed by the owner and approved. The level of approvals for a change order depends on the size. If it is large enough, the owner must obtain approvals from the City Council, which can take a significant amount of time.

4.6.3 Schedule Performance Metrics

4.6.3.1 CMAR Schedule Performance Baseline

The schedule performance data collected includes: (1) the notice to proceed date; (2) the targeted substantial completion date; and (3) the actual substantial completion date. Using these dates, the difference between targeted schedule days and actual schedule days is

calculated. Then, schedule growth is found by dividing this difference by the targeted schedule days. Figure 20 shows a set of boxplots of schedule performance for projects delivered using CMAR by the City of Phoenix. Complete and accurate schedule data was available for 57 of the 66 identified projects. Figure 20(a) shows the projects had a range of schedule growth from -48.7% and 186.4%, with a median schedule growth of 5.10% and mean schedule growth of 10.17%. Nearly half of the projects were delivered on time or with a schedule reduction. This shows a noteworthy performance increase when compared to the 15% weighted average schedule growth for DBB projects from the literature shown in Figure 12.

Figure 20(a) shows four outliers for schedule growth. Outliers shown on the boxplot are defined as being 1.5 times the interquartile range below the first quartile or above the third quartile. The four outliers in the schedule data have a large impact on the mean and median values. The analysis without the outliers resulted in a median value of 1.5% and a mean schedule growth of 1.77%. This decrease demonstrates the impact that the few outliers can have on the results. Each of these outlier schedule growth values was associated with a unique scenario during the construction. For example, one project had a cost growth of 111% that can be attributed to the Arizona Department of Transportation (ADOT) not allowing traffic restrictions along a major interstate during the holiday season. Therefore, the City of Phoenix was forced to delay the 90-day project by 107-days to meet the requirements imposed by ADOT. This project also incurred a scope change that included adding 30-days to complete the rehabilitation of another sewer line not included in the original contract. Even with this additional rehabilitation, the contractor completed the project prior to the adjusted substantial completion date.

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Figure 20: CMAR Project Schedule Growth (a) Schedule Growth for All Projects, (b) by Utility Type, (c) by Diameter, and (d) by Construction Type (N=57)

Figure 20(b) compares the schedule growth between wastewater and water projects. The results show the median values for water and wastewater projects are very close. The MWW test was completed to test the difference of the sample means and resulted in a p-value of 0.75, indicating there is not significant schedule performance difference when using CMAR to install different utilities. The difference in the range may be due to the different sample sizes for each subset.

The bottom left boxplot, Figure 20(c), compares the schedule growth between large diameter (> 24") and small diameter (<24") pipelines. The large and small diameter pipelines were delivered with a median schedule growth of -3.24% and 10.74%, respectively. The MWW test resulted in a p-value of 0.032, which shows a statistically significant difference in schedule performance when installing large or small diameter pipelines. The potential causes of this interesting result were discussed with a representative from the City of Phoenix. Some of the potential explanations include: the City being able to completely shutdown large diameter pipelines and not have as many disruptions during construction; and small diameter pipelines are typically in more congested areas (neighborhoods) that can cause delays due to right-of-way concerns, holidays, traffic control issues, and any delays by the hook up of services by a plumbing company.

Finally, Figure 20(d) shows the schedule growth of rehabilitation and new construction projects. The median schedule growth values of the rehabilitation and new construction projects were -2.69% and 6.77%, respectively. The MWW test resulted in a p-value of 0.099. Although a difference can be seen visually, this performance difference is not statistically significant. One potential reason for the visual difference is that 95% of the rehabilitation projects were of large diameter pipelines, which ties back into the aforementioned results seen in Figure 17(c).

4.6.3.2 Comparing CMAR and DBB Schedule Performance

The schedule growths of both delivery methods are compared to determine which offers superior performance when delivering pipeline projects, shown in Figure 21. Complete and accurate schedule data was collected for 35 DBB projects and 45 CMAR projects.

The median schedule growth for the DBB projects was 18.33% and for the CMAR projects was 5.83%. For illustration purposes, the authors zoomed in on the boxplots and three extreme outliers in both datasets were not shown in the figure to display an improved visual representation for the distributions and the differences between the medians. Due to these extreme outliers, the mean schedule growth for were vastly different than the medians, the DBB projects had a mean schedule growth of 62.77% and CMAR projects had a mean schedule growth of 12.06%.

Figure 21: Comparison of DBB and CMAR Schedule Growth (N=80)

The MWW test conducted to determine if the schedule growth between CMAR and DBB is significant resulted in a p-value of 0.011. This result shows there is a statistically significant difference between the schedule performance of DBB and CMAR for delivering pipeline projects. The outliers were removed from the dataset and the MWW test was completed on the remaining dataset. This analysis resulted in similar median schedule growth values and a p-value of 0.0089, showing that the large outliers in the DBB projects did not skew the schedule performance conclusion. The City of Phoenix is delivering CMAR projects with greater schedule certainty than their DBB

projects. These results show CMAR provides 12.5% better schedule certainty for pipeline projects than the traditional DBB.

4.6.4 Cost Performance Metrics

4.6.4.1 CMAR Cost Performance Baseline

Data for the cost performance metric construction cost growth was available from the project data gathered through the City. As previously defined, construction cost growth is measured by comparing, in percentage terms, the final construction cost to the original cost proposal. The GMP proposal generated the original cost and the final pay application provided the final cost of each project.

Figure 22 presents the cost growth in terms of boxplots for the 66 CMAR projects delivered by the City of Phoenix. Figure 22(a) shows the cost growth of all the projects having a range between -45% and 19%, with the median and mean value being -5% cost growth for all projects. In total, 54 of the 66 projects had no cost growth or a cost savings (value below 0%). As shown by the boxplot, 50% of the projects had a cost savings between 0% and -10%.

Figure 22(a) also shows the cost growth data has six outliers. Each of these projects either encountered unforeseen conditions or had significant scope changes during construction. The project with the largest cost growth (19.23%) had a substantial scope addition due to right-of-way issues. The project team was forced to find another route along a protected mountain range. Rather than rerouting the entire waterline, the project team made the decision to tunnel under the mountain and keep the waterline on the original route. The outlier values were removed from the dataset and the analysis was completed again to ensure the outlier values do not skew the mean and median cost

growth. This resulted in mean and median values similar to those of the data with the outliers included.

Figure 22: CMAR Project Cost Growth (a) Cost Growth for All Projects, (b) by Utility Type, (c) by Diameter, and (d) by Construction Type (N=66)

Similar to the schedule growth results, Figure 22(b)-22(d) displays the cost growth separated by utility type, diameter, and construction type. The MWW test was used to determine if there is any statistical difference between the separated data. The results of the MWW tests provide evidence that the cost growth performance seen by the City of Phoenix is similar for all projects in the dataset.

This subsection shows that the mean construction cost growth of -5% for the CMAR pipeline projects is significantly less than 4.43% DBB baseline from literature presented in Figure 12. Furthermore, this mean cost growth is 8.37% less than the 3.37% presented in the comparable CMAR study on vertical building by Konchar and Sanvido (1998).

4.6.4.2 Comparing CMAR and DBB Cost Performance

Similar to schedule growth, the cost growths of both DBB and CMAR delivery methods are compared to determine which offers superior performance when delivering pipeline projects. Figure 23 shows a boxplot of the cost growth of DBB and CMAR. Prior to performing any statistical analyses, one can see that CMAR projects experience significantly less cost growth than their DBB counterparts. The DBB projects had a mean and median cost growth of 0.55% and the DBB projects had a mean and median cost growth of -6.0%. These results show CMAR provides 6.55% more certainty in the project cost, which is beneficial for all stakeholders involved.

Figure 23: Comparison of DBB and CMAR Cost Growth (N=89)

A MWW test was conducted to statistically verify the visual results shown in Figure 23. The test resulted in a p-value of 0.001. This result is statistically significant and indicates that CMAR pipeline projects have less cost growth than comparable DBB projects. Similar to the previous section, the outliers in the data were removed to determine if they skewed the univariate analysis. The exclusion of the outliers resulted in comparable median cost growth values and a p-value of 0.0003, which shows a larger difference between CMAR and DBB. The analysis provides the first quantitative evidence that CMAR offers superior cost performance compared to traditional delivery methods for pipeline projects. CMAR pipeline projects are being delivered with 6.5% less cost growth than similar DBB projects.

4.7 Conclusions

This study provides the first quantitative analysis of the CMAR delivery system applied to pipeline projects. A performance baseline is created for seven metrics in four performance areas. These baselines can be used to assist owners in gauging their project performance when implementing CMAR on pipeline projects.

Most interestingly, the pipeline projects delivered with CMAR had a median cost growth of -5% and a median schedule growth of 10.17%. The major contribution of this paper is demonstrating CMAR cost performance is superior to DBB by 6.5%, and CMAR schedule performance is superior to DBB by 12.5%. These findings emerge from an analysis of similar CMAR and DBB projects of comparable size, type, owner, location, labor, and so forth, to minimize the variation in the data set. The use of CMAR on pipeline projects allows owners and other project stakeholder to have greater cost and schedule certainty when compared to the DBB performance.

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This research offers two major contributions to the construction engineering and management body of knowledge: (1) CMAR performance baseline for seven metrics in four performance areas; (2) and a demonstration of superior performance by CMAR pipeline projects when compared to DBB projects. CMAR delivers pipeline projects under budget and with significantly less schedule growth than the traditional delivery method. These results can guide owners when choosing the appropriate delivery system for their pipeline engineering and construction projects.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Research Methods

This dissertation provides the first comprehensive performance study on the use of CMAR for pipeline engineering and construction projects. This began with a qualitative perception survey and meta-analysis to determine if CMAR is being used and how it is performing in the pipeline industry. The results provided motivation for a large quantitative performance assessment of CMAR on pipeline projects. Next, a case study was conducted to pilot test a quantitative performance survey and to further provide motivation for a large data collection effort. The findings from the case study further indicated the ability of CMAR to impact project performance. The pilot testing of the survey led to a large data CMAR collection effort with the City of Phoenix in Arizona. Analyses on qualitative and quantitative performance data provide a performance baseline for seven metrics in four performance areas. The study also compared the cost and schedule performance of CMAR projects to similar DBB pipeline projects to determine whether CMAR provides superior performance. The following sections provide a summary of the key results and contributions to the body of knowledge, a discussion of the limitations of this study, and recommendations for future research.

5.2 Summary of Results and Contributions

Two primary objectives presented in the beginning of this dissertation were:

(1) Quantify performance of the CMAR delivery method on pipeline projects and provide a baseline for CMAR performance metrics;

(2) Statistically compare the cost and schedule performance of CMAR to that of the traditional DBB delivery method.

Through data collection and project performance analysis both of these objectives were met.

The analysis presented in *Chapter 4* provides a performance baseline for CMAR on seven metrics in four performance areas: cost, schedule, project change, and communication. CMAR performance on cost and schedule metrics is shown to be superior to DBB baselines and CMAR performance research from other industries. A majority of the projects were completed with cost and schedule savings, providing the owner with greater certainty for both metrics. The average cost growth was -5% and the average schedule growth was 10%. The City of Phoenix is completing their water and wastewater projects under budget and with significantly less schedule growth than what is shown by DBB baselines in other industries. While cost and schedule are typically the most studied metrics, they were not the only metrics to be positively affected by the use of CMAR. Project change and communication performance is shown to be similar to benchmarked performance of APDM in the vertical construction industry. These previous studies noted that a more integrated delivery system, such as CMAR, provides the owner with increased project change and communication performance. Most notably, the amount of changes due to unforeseen conditions is shown to be less than changes associated with addition or reduction of scope. By using a more integrated delivery system, the unforeseen conditions are identified during the design phase and not during the construction phase when they become much costlier. These findings allow for a baseline value that project stakeholders can compare the performance of their CMAR pipeline projects to.

In addition to comparing CMAR with baseline DBB studies in other industries, *Chapter 4* also provides the first analysis to determine whether CMAR projects are outperforming comparable DBB pipeline projects. The results show that CMAR provides statistically significant performance differences when compared to similar DBB pipeline projects. The CMAR projects were delivered with 6.5% less cost growth and 12.5% less schedule growth. Project stakeholders can use these findings to help make informed decisions when selecting the appropriate delivery system to use on their water and wastewater pipeline projects. These findings can also be used to inform lawmakers and potentially change legislation in states that do not currently allow for the use of CMAR.

5.3 Recommendations for Future Research

This study provides the first comprehensive quantitative assessment of CMAR performance on pipeline projects. Additional follow-up studies can validate the findings or build upon this study. This study focused on one geographical location and owner, the City of Phoenix. This was a scoping decision that allowed for the decrease of variables when analyzing the performance impacts of CMAR on pipeline projects. One way to build upon this study is to identify and collect data on projects nationwide to compare with the performance realized by the City of Phoenix.

Another approach is to use the quantitative survey shown in *Appendix B* to collect DBB project data for all of the same performance areas as the CMAR projects. This will allow for additional analyses to compare the performance of CMAR and DBB in metrics other than cost and schedule. While cost and schedule are the primary metrics owners are interested in, other benefits from using CMAR can assist them in choosing the delivery system that most fits their project objectives.

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Another recommendation is to collect larger (in terms of cost) DBB projects to compare with the CMAR dataset. The City of Phoenix made the transition to CMAR for all of their large projects after legislation was passed that allowed for the use of CMAR. No DBB pipeline projects greater than $7 million were delivered after 2001. Collecting data on larger projects will allow for a comparison of cost and schedule for the entire distribution of CMAR projects and give a better representation of project performance.

One last recommendation is to use the framework of this study to collect pipeline project performance data on other APDM such as job order contracting (JOC). This delivery system has potential to provide owners with improved performance for small rehabilitation and construction projects. For example, the City of Phoenix has utilized JOC to deliver a substantial portion of their pipeline projects under $1 million. This performance can be compared to the CMAR and DBB results from this dissertation.

Addressing these recommendations will provide a better understanding of the performance of CMAR and potential benefits of using other APDM to deliver pipeline projects. This understanding can better help project stakeholders when deciding which delivery method to use when completing their water and wastewater pipeline projects.

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APPENDIX A

QUALITATIVE SURVEY

Name:

Company:

Email Address:

Phone Number:

1. Please indicate your organization type:

Owner ☐

Designer/Engineer ☐

General Contractor ☐

Subcontractor ☐

If other, please specify:

2. Please indicate your position within the organization:

President ☐

Vice President ☐

Engineer ☐

Project Manager ☐

Project Engineer ☐

Superintendent ☐

If other, please specify:

3. What is the approximate percentage of projects your organization is involved in under each of the following project delivery systems?

	0%	0%-10%	10%-25%	25%-40%	40%-60%	60%-75%	75%-90%	90%-100%	100%
Design-Bid-Build (DBB)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Construction Manager as Agent (CM Agent)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Construction Manager at Risk (CM Risk)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Job Order Contracting (JOC)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Design Build (DB)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Integrated Project Delivery (IPD)	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. What is your comfort level in implementing the following alternative project delivery methods?

	Very Low	Low	Medium	High	Very High
Design-Bid-Build (DBB)	☐	☐	☐	☐	☐
Construction Manager as Agent (CM Agent)	☐	☐	☐	☐	☐
Construction Manager at Risk (CM Risk)	☐	☐	☐	☐	☐
Job Order Contracting (JOC)	☐	☐	☐	☐	☐
Design Build (DB)	☐	☐	☐	☐	☐
Integrated Project Delivery (IPD)	☐	☐	☐	☐	☐

5. Based on your experience, which project delivery method typically has offered the best performance on your trenchless construction projects? For each performance metric, please select one project delivery method:

Performance Metrics	DBB	CM Agent	CM @ Risk	JOC	DB	IPD
1-Meeting Cost and Budget Expectations	☐	☐	☐	☐	☐	☐
2-Meeting Target Schedule	☐	☐	☐	☐	☐	☐
3-Quality of the Facility	☐	☐	☐	☐	☐	☐
4-Project Safety	☐	☐	☐	☐	☐	☐
5-Project Changes and Modifications	☐	☐	☐	☐	☐	☐
6-Labor Productivity	☐	☐	☐	☐	☐	☐
7-Environmental Benefits	☐	☐	☐	☐	☐	☐
8-Profit and Return Business	☐	☐	☐	☐	☐	☐
9-Level of Communication of Involved Parties	☐	☐	☐	☐	☐	☐

Alternative Project Delivery Methods (APDM) Definitions

- **Design-Bid-Build**: The traditional delivery method where an owner procures design and construction services separately, and where the construction phase only starts after the design phase is fully completed.
- **Construction Manager as Agent**: A delivery method where the owner procures design and construction services through separate contracts; however, the construction management firm can be involved in the design phase by providing preconstruction services that include evaluating cost and schedule implications of alternative designs, systems, and materials. The contractor is an agent of the owner and assumes no risk in the project. This delivery method is also referred to as Pure CM.
- **Construction Manager at Risk**: A delivery method where the owner procures design and construction services through separate contracts; however, the construction management firm can be involved in the design phase by providing services that include evaluating cost and schedule implications of alternative designs, systems, and materials. A CM@ Risk firm typically guarantees the cost and schedule of the project.
- **Job Order Contracting**: A delivery method to procure design and construction services for small to medium size maintenance, repair and minor new construction projects. A contract is typically valid for a set period of time for multiple design and construction projects that are delivered on an on-call basis.
- **Design-Build**: A delivery method where the owner contracts with a single entity that is responsible for the completion of both design and construction phases, which overlap.
- **Integrated Project Delivery**: A delivery system that is distinguished by a multiparty agreement between all key stakeholders and their very early involvement in the project before any design has been completed.

APPENDIX B

QUANTITATIVE SURVEY

Survey on Alternative Project Delivery Methods for Pipeline Construction Projects
Tober Francom, Samuel Ariaratnam, and Mounir El Asmar

We truly appreciate all your time and effort to complete this survey. Your response will be kept confidential. At the end of the process, we will share with you our comprehensive findings, which we predict will be useful for the success of your future projects.

Section I: Project Characteristics

Please Select ONE Past Pipeline Project (Completed in the past 10 years):

Project Name: _____
Project Location: _____
Company Name: _____

1. For this project, your company acted as:

Owner ☐
Engineer ☐
General Contractor ☐
Trenchless Contractor ☐
Other (Please Specify): _____

2. Installation Method:

Open Cut ☐
HDD ☐
Microtunneling ☐
Pipe Bursting ☐
Lining ☐
Other (Please Specify): _____

3. Pipeline Project Details:

    a. Total Length of Project (ft.): _____
    b. Pipeline Diameter: < 24" ☐   > 24" ☐
    c. Pipeline Material (Select one):

    HDPE ☐   PVC ☐   PCCP ☐
    Steel ☐   Clay ☐
    Ductile Iron ☐   Concrete ☐
    Other (Please Specify): _____

4. Primary Soil Encountered:

Clay ☐
Silt ☐
Sand ☐
Gravel ☐
Cobbles ☐
Hard pan ☐
Sandstone ☐
Bedrock ☐
Other (Please Specify): _____

5. Utility Type:

Water ☐
Wastewater ☐
Electrical ☐
Oil/Gas ☐
Communications ☐
Other (Please Specify): _____

Section II: Project Performance

6. Compared to an average project of the same type, this project's complexity was:
   Low ☐   Average ☐   High ☐

Cost Performance

7. Please specify the following project costs.

	Design Contract Cost	Construction Contract Cost
Originally Budgeted		
Final/Actual Costs Incurred		

Schedule Performance

8. Please provide the following schedule information:

	Target (mm/yy)	Actual (mm/yy)
Design Start Date		
Construction Start Date (Notice to Proceed)		
Construction End Date (Substantial Completion)		

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Changes

9. How much of the cost differences resulted from scope changes? (approx.) _____% of changes

10. How much of the cost differences resulted from unforeseen conditions (approx.) _____% of changes

11. On average, the *change order processing time* (the period of time between the initiation of the change order request and the approval of the change order) was:

1-7 days ☐   8-14 days ☐   15-21 days ☐   22-28 days ☐   < 28 days ☐

Productivity

12. What is the average productivity (feet/day*) of installed pipeline for the project? (*based on an 8 hr. day)

<150 ft. ☐   <300 ft. ☐   <600 ft. ☐   <900 ft. ☐   <1200 ft. ☐   >1200 ft. ☐

Profit and Return Business

13. Overall, how would you rate the effect of this project on your organization image (for owners) and/or potential for return business (for contractors)?
Very negative ☐   negative ☐   neutral ☐   positive ☐   very positive ☐

Level of Communication

14. What was the total number of request for information (RFI) on the project?

_____ RFIs

15. The *RFI processing time* (the period of time between your submittal of a RFI and the response by the appropriate party), on average, was:

1-7 days ☐   8-14 days ☐   15-21 days ☐   22-28 days ☐   < 28 days ☐

Section III: Project Delivery System

16. What percentage of the design was complete when each of the following parties became involved in the project?

GC/CM	_____ %
Trenchless Contractor	_____ %
Pipe Suppliers	_____ %
Other Key Stakeholders (Please Specify): _____	_____ %

17. What Project Delivery System was used on this project?

Design-Bid-Build (DBB)   ☐
Job Order Contracting (JOC)   ☐
Construction Manager at Risk (CMAR) ☐
Design-Build (DB)   ☐
Other (Please Specify): _____

18. Would you consider using the same project delivery system for this project if you completed it again? If not, why and which delivery system would you choose?

   Yes ☐   No ☐

_____
_____
_____