Improving Cost and Schedule Performance on Municipal Pipeline Projects

Realizing the Benefits of the Construction Manager at Risk (CMAR) Alternative Project Delivery Method

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The water and wastewater infrastructure in the United States is failing. In its 2013 Report Card on American Infrastructure, ASCE stated: “The water and wastewater 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 can have many impacts on the public, including disruption in water delivery, impediments to emergency response, water pollution, and damage to roadways and other types of infrastructure. Significant reinvestment is needed to replace, rehabilitate, and expand the pipeline network. In fact, the U.S. Environmental Protection Agency (EPA) estimates that approximately $632.8 billion of investment is needed for water and wastewater systems, with $281.6 billion (46 percent) specifically allocated for pipeline investment by 2028.

**Alternative Project Delivery Methods**

To maximize the benefit of the money invested, engineering and construction must be completed efficiently, both with respect to cost and time. Alternative project delivery methods (APDM) have the potential to deliver projects more efficiently than conventional delivery approaches. Currently, the typical method for delivering water and wastewater pipeline engineering and construction projects is design-bid-build (DBB), 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. For example, in most DBB projects the contractor is engaged only after the engineer had completed the design of the project. APDM helps improve integration between these key stakeholders and ultimately enhances project performance.

The complex nature of pipeline projects renders them ideal candidates for APDM because when using traditional
DBB delivery, differences in project understanding can arise, often created by a lack of technical exchange between design engineers and contractors. Complexity comes from the fact that: 1) geotechnical risks are present because subsurface conditions are always uncertain; and 2) design engineers may have limited knowledge of installation methods such as trenchless technologies, which often leads to the design of pipeline projects that are unconstructable or have high risk. Furthermore, subsurface geotechnical conditions dictate the method(s) and tooling applicable to the pipeline installation. Improved integration between design engineers and contractors leads to increased project success through better recognition and management of risk. One commonly used APDM is the construction manager at risk (CMAR) method.

How do CMAR projects perform on water and wastewater pipeline projects? The authors are part of a group of researchers at Arizona State University (ASU) that conducted a two-year study to investigate. The project involved collaborating with several organizations and professionals who generously volunteered their time to provide project data by filling out surveys and participating in several interviews and research meetings. The study, titled “Performance of the Construction Manager at Risk (CMAR) Delivery Method Applied to Pipeline Construction Projects,” forms the basis for the observations in this article.

Figure 1 compares DBB and CMAR project delivery methods and highlights the contractual relationships between the stakeholders and the timing of the stakeholders’ engagement in the project. For both methods, the owner signs separate contracts with the engineer and the contractor. The major difference is the timing of the contractor’s engagement. 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 is complete, typically between completion of 30 and 60 percent of the design development, which helps to maximize the benefit of collaboration and minimize redesign. Moreover, the design engineer and CMAR firm often are contractually required to coordinate during the design phase of the project, unlike in the traditional DBB method. 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.

Another key difference is the process of selecting the contractor. DBB frequently uses a selection process where the lowest responsible bidding contractor is selected, regardless of experience or qualifications. In contrast, with CMAR the owner typically selects the contractor based on a combination of cost and qualifications. This process
leads to the owner selecting a contractor that has more experience and/or is more qualified to complete the project. The term “construction manager at risk” means the selected construction management firm guarantees to the owner a schedule and a maximum price for the project, which is in contrast to a less popular type of delivery system called “construction management (CM) agent,” where the firm typically does not guarantee the price.

Research found CMAR has been successfully implemented in the building and transportation industries, offering owners numerous benefits over DBB, including significant improvements in project cost and schedule performance. In fact, CMAR’s documented ability to improve project performance is leading to its continuous and substantial increase in popularity in these industries. The use of CMAR has the potential to improve performance over DBB on pipeline projects, too. Until our recent research, comprehensive studies comparing the performance of CMAR to DBB in the pipeline engineering and construction industry had not been performed. Our findings fill this gap in knowledge by comparing the cost and schedule performance of CMAR pipeline projects to that of projects using the traditional DBB method.

**Pipeline Industry Perceptions of APDM**

The first step in the research study was to understand the perception of APDM in the pipeline industry. Pipeline industry stakeholders were surveyed to investigate the utilization rate, industry comfort level, and perceptions of performance of APDM. Thirty-four owners, engineers, and contractors completed the survey, which was shared with a total of 57 professionals in the engineering and construction industry. The results of the survey indicate that the most utilized project delivery system is still the traditional DBB system, followed by design-build (DB), and then CMAR. Respondents had a medium comfort level for implementing and using CMAR on their pipeline projects. About a quarter of respondents perceived CMAR as the project delivery method that can offer the best schedule performance when compared to other prominent delivery methods. However, a third to a half of respondents still felt the traditional DBB delivery method offers superior performance. Given that (1) the use of CMAR in the pipeline industry is not yet widespread, and (2) these perception results are not in line with what we have learned from other industries more experienced with CMAR, these results formed a strong motivation for the next step of the research. In fact, understanding industry perceptions on performance helped focus the research scope and provided a foundation for a quantitative performance study in which we collected actual (as opposed
Measuring the Performance of CMAR Pipeline Projects

With CMAR gaining popularity in the pipeline engineering and construction industry in general, there is a need to understand its performance. Through collaboration with a large municipality in the state of Arizona, 66 CMAR pipeline projects were identified and studied. The projects ranged from 2003 to 2015, had a total construction value of slightly over $400 million in 2015 dollars, and total scope of approximately 40 miles of pipelines.

Figure 2 illustrates the characteristics of the CMAR projects, including the diameter, utility type, and construction type. The pie charts on the top of Figure 2 show percentages based on the number of projects, while the pie charts on the bottom of the figure show percentages based on total cost. The majority (by number of projects) were wastewater pipeline projects; however, the total cost of the water and wastewater projects was nearly identical. This is due to the municipality delivering several sizeable water projects using CMAR. Nearly 70 percent of the projects were for rehabilitation or installation of pipelines with diameters greater than 24 in., totaling approximately $350 million (88 percent of the total cost). Roughly half of the projects involved rehabilitation of deteriorating pipelines using trenchless construction methods such as sliplining, cured-in-place pipe (CIPP), and pipe bursting. The other half consists of new construction pipelines installed using traditional, open-cut methods.

Cost and schedule data for the 66 CMAR projects were collected, in addition to 41 comparable DBB projects. The dataset was then reduced to only similarly sized projects to allow for a fair comparison of performance for the CMAR and DBB projects. This resulted in 89 projects (49 CMAR and 40 DBB), each of which was under $5.5 million.

Project cost and schedule are two critically important metrics. Deviations from the budgeted cost or schedule can have significant impacts for the owner and the contractor. Schedule growth was calculated for each project based on the collected schedule data, and is defined as the percentage increase from the intended schedule at the time of the award, to the final actual time it took to complete the project. Figure 3 shows the schedule growth for the DBB and CMAR projects, displaying the sample lower quartile, median, and upper quartile. The thick black line, dividing the dataset in half, represents the median value. The colored box represents the 50 percent of data around the median, whereas the remaining 50 percent of data are divided equally above and below the box between the thin horizontal lines called whiskers. The small circles outside of the horizontal lines represent statistical outliers.

The median schedule growth was 18.33 percent for the DBB projects and 5.83 percent for the CMAR projects. As shown in Figure 3, that is a significant difference of 12.50 percent. In fact, statistical validation provides even greater confidence in these results and confirms that CMAR projects are being delivered with less schedule growth as compared to similar DBB pipeline projects. We learned that CMAR helps control project schedule.

Similar to schedule growth, we compared cost growth for both DBB and CMAR pipeline projects to determine which delivery system offers superior performance. Cost growth is defined as the percentage increase from the
contracted price at the time of the award to the actual final cost of the project. Figure 4 illustrates a comparison of cost growth for DBB and CMAR. Even prior to performing any statistical analyses, one can see that CMAR projects experience considerably less cost growth than their DBB counterparts. The DBB projects had a median cost growth of 0.55 percent, while the CMAR projects had a median cost savings (the opposite of cost growth) of 6.05 percent. This means CMAR pipeline projects are being delivered with 6.50 percent less cost growth than similar DBB projects. Again, the observed differences are statistically significant, indicating that CMAR offers pipeline projects a superior cost growth performance compared to DBB. Similar to the schedule performance finding, we also learned that CMAR helps control project cost.

Our analysis stemming from more than 100 comparable CMAR and DBB projects provides the first statistical evidence that CMAR offers greater performance compared to traditional delivery methods for pipeline projects. Based on additional qualitative evaluations, we believe the major reason for this observed superiority is engaging the CMAR firm before the design is complete. This allows the contractor to provide input during the design, which leads to fewer changes and rework, and ultimately better control of cost and schedule.

**Case Study: Water Transmission Main Rehabilitation**

After quantitatively measuring the performance of CMAR, we examined a case study of the use of CMAR to deliver a critical, 10-year rehabilitation program by the City of Phoenix, AZ. When deterioration became evident, the City began an extensive condition assessment of the entire Val Vista Water Transmission

### Table 1. Ten-year rehabilitation program.

<table>
<thead>
<tr>
<th>PHASE</th>
<th>LENGTH (LF)</th>
<th>INITIAL COST ($)</th>
<th>FINAL COST ($)</th>
<th>COST SAVINGS ($)</th>
<th>TARGET SCHEDULE (DAYS)</th>
<th>SCHEDULE (DAYS)</th>
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<tr>
<td>A</td>
<td>9,700</td>
<td>$18,249,461</td>
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<td>$927,830</td>
<td>379</td>
<td>396</td>
<td>(17)</td>
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<tr>
<td>B</td>
<td>18,500</td>
<td>$37,100,000</td>
<td>$38,096,510</td>
<td>($996,510)</td>
<td>131</td>
<td>108</td>
<td>23</td>
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<tr>
<td>C</td>
<td>3,600</td>
<td>$5,900,000</td>
<td>$5,241,978</td>
<td>$658,022</td>
<td>131</td>
<td>131</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>6,250</td>
<td>$13,670,000</td>
<td>$12,199,709</td>
<td>$1,470,291</td>
<td>175</td>
<td>153</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>38,050</td>
<td>$74,919,461</td>
<td>$72,859,827</td>
<td>$2,059,633</td>
<td>816</td>
<td>788</td>
<td>28</td>
</tr>
</tbody>
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Main in the fall of 2003. The pipeline originates from the Val Vista Water Treatment Plant, the largest treatment plant in the Phoenix metropolitan area, and ranges in diameter from 72 to 108 in. The gravity-fed line delivers up to 190 MGD to Phoenix and another 100 MGD to suburban Mesa, AZ, at a maximum operating pressure of 70 psi. The program consisted of phases A through D to rehabilitate the large-diameter, pre-stressed concrete cylinder pipe (PCCP) water transmission main using slilining (Figure 5).

The overall program of about $73 million and 788 days had a total schedule savings of 3.40 percent and a total cost savings of 2.75 percent under the contract amount. The details of each phase are presented in Table 1. An in-depth analysis of the cost performance of Phase B revealed some of the benefits that the City realized by adopting CMAR. These benefits include: 1) amending the CMAR contract to complete emergency repair work; 2) paying for needed changes during Phase B by using the cost savings from Phase A; and 3) improved coordination between the stakeholders to deal with unforeseen conditions (e.g., location adjustment). The Val Vista Water Transmission Main program is a successful example of using CMAR for the delivery of a large pipeline rehabilitation program, while also resulting in cost and schedule savings.

Making the Case for CMAR
This study provides a quantitative analysis of the CMAR delivery system applied to municipal pipeline engineering and construction projects. The findings show that adopting CMAR provides superior performance over DBB for the municipal pipeline projects investigated. Analysis of similar CMAR and DBB projects of comparable size, type, owner, location, and labor pool indicates that the cost growth of CMAR is about 6.5 percent better than DBB. Additionally, we found the schedule growth of CMAR to be about 12.5 percent better. The use of CMAR on municipal pipeline projects allows stakeholders to have greater control of their project cost and schedule, reducing the risk of schedule or cost growth they may not be able to afford. The results provide owners and other stakeholders with a benchmark and a sound basis for selecting an appropriate delivery system for their municipal pipeline engineering and construction project.

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