Using Alternative Project Delivery Methods to Enhance the Cost Performance of Trenchless Construction Projects

Tober Francom¹, Mounir El Asmar, Ph.D.², and Samuel T. Ariaratnam, Ph.D. P.E.³

¹Graduate Student, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 870204, Tempe, AZ 85287-0204; email: tfrancom@asu.edu
²Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 870204, Tempe, AZ 85287-0204; PH (480) 727-9023; email: asmar@asu.edu
³Professor and Construction Engineering Program Chair, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 870204, Tempe, AZ 85287-0204; PH (480) 965-7399; email: ariaratnam@asu.edu

ABSTRACT
A project delivery system is defined as the comprehensive process by which a facility is designed and constructed. The traditional design-bid-build (DBB) system is sequential and often leads to inefficiencies; therefore, alternative project delivery methods (APDM) were developed to increase stakeholder integration and enhance project performance, and therefore have gained popularity in the design and construction industries. However, the use of APDM has not yet gained traction in the emerging trenchless construction industry, which focuses on the installation of underground infrastructure with minimal disruption to surface activities like traffic and business. The traditional lack of information sharing between engineers and contractors renders trenchless construction projects ideal candidates for APDM. Design engineers often are unfamiliar with trenchless construction means and methods, and constructors have not traditionally been involved during the design phase. APDM can be used to bridge this gap by enabling contractors to provide early insights, which can result in benefits over traditional methods. This paper discusses how APDM can improve the performance of trenchless construction projects through analyzing case studies of existing APDM trenchless projects. The findings demonstrate the potential performance impact of APDM on trenchless construction projects, namely cost savings ranging from two to 44 percent.

INTRODUCTION
Alternative project delivery methods (APDM) have been gaining traction in the Architecture, Engineering, and Construction (AEC) industry. Project delivery methods are generally distinguished by two key characteristics; the relationships between project stakeholders and their timing of engagement (El Asmar et al. 2013). The traditional delivery system is sequential and is known as design-bid-build (DBB). There are several APDM used in the industry today including: design-build (DB); construction management at risk (CMAR); engineer procure construct (EPC); and integrated project delivery (IPD). In the traditional DBB the contractor is engaged when the design is 100% complete, whereas the other extreme is integrated project delivery (IPD) that engages all key stakeholders at 0% complete before the design
even starts (see Figure 1). In DB the contractor is engaged when the design is somewhere around 20% complete (this value varies with each project). Projects delivered with CMAR typically engage the construction manager while the design is still being developed, but typically not as early as in DB. This paper focuses on CMAR and DB, which can be defined as follows:

- **CMAR** is an alternative 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.

- **Design-build** is a project delivery system where the owner contracts with a single entity that is responsible for the completion of both design and construction phases, which overlap.

![Figure 1. Delivery Systems’ Key Differences (El Asmar et al. 2013)](image)

The impact of APDM performance has been researched extensively for various types of design and construction projects, including building and transportation projects. APDM projects were shown to have a superior performance when compared to projects delivered using the traditional DBB method (e.g. Konchar and Sanvido 1998; Hale et al. 2009; El Asmar et al. 2013). However, there has been little research on the use of APDM for subsurface construction. Subsurface construction includes the rapidly advancing trenchless technologies, which 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 (e.g. cured-in-place pipe); pipe bursting; and auger boring. The main types of trenchless construction are defined below.

- **Horizontal directional drilling** is defined as a steerable trenchless method of installing underground pipes, conduits, and cables in a shallow arc along a prescribed bore path by using a surface-launched drilling rig.

- **Microtunneling** is a process that uses a microtunneling boring machine (MTBM) that is operated from a control panel, normally located on the surface. The system simultaneously installs pipe as spoil is excavated and removed. Personnel entry is not required for routine operations.
Cured-in-place pipe lining is defined as a rehabilitation technique whereby a flexible resin-impregnated tube is installed into an existing pipe and then cured to a hard finish, usually assuming the shape of the existing pipe.

Pipe bursting is defined as breaking the existing pipe by brittle fracture, using force from within, applied mechanically, forcing the remains into the surrounding ground. At the same time a new pipe is drawn in behind the bursting tool.

Auger boring is a technique for forming a bore from a drive pit to a reception pit, by means of a rotating cutting head. Spoil is removed back to the drive shaft by helically wound auger flights rotating in a steel casing.

Currently, the majority of trenchless construction projects are being delivered using the traditional DBB delivery system. The use of the DBB delivery method separates the engineer designing the project and the contractor building it. Conversely, APDM integrate the design and construction phases of facilities. Similar to the application of APDM for other buildings and roadways, the use of APDM for trenchless construction projects has the potential to improve project performance. This paper examines this claim by conducting a meta-analysis of case studies that have reported the cost performance of trenchless projects utilizing APDM. First, the paper provides a comprehensive literature review to summarize the state of knowledge on the use of APDM for trenchless construction projects. Then, the authors discuss the research objectives and methodology, which set the stage to presenting the findings of the study.

LITERATURE REVIEW

A comprehensive review of literature was performed to analyze available information regarding the benefits of utilizing APDM to deliver trenchless construction projects. The authors reviewed sources that included ASCE journals and other peer-reviewed publications, conference proceedings, theses and dissertations, as well as industry magazine articles.

Kramer and Meinhart (2004) provided insight on the effectiveness of using APDM for pipeline and trenchless projects. The authors discussed the appropriateness of APDM combined with trenchless construction through four case studies to demonstrate the use of APDM could offer significant benefits to all parties involved in trenchless construction projects.

1. The first case study was a traditional DBB public project for the design and construction of a water main extension. 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; it was considered very successful.

2. The second case study was a public DB project. 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.

3. The third case study was a modified DB contract for a development company. Microtunneling was selected as the preferred installation method. The general contractors teamed up with microtunneling subcontractors and submitted proposals. 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.

4. The fourth case study was an Engineer-Procure-Construct-Manage (EPCM) contract for a utilities company. EPCM is a delivery system that is primarily used in large industrial projects that require a significant amount of engineering and often include large long lead items. The project had to be completed prior to the peak of the summer months; therefore an alternative project delivery method was selected to help overcome the critical schedule constraints. The authors state that utilizing APDM allowed the project to be completed approximately two months sooner than traditionally possible with the DBB method.

Owners throughout the country are seeking methods to expedite construction, control costs, and manage risks. The paper presented several delivery methods that have been used successfully, and showed that each delivery method can beneficial in the right environment. The drivers towards a particular method often will be dictated by the schedule urgency, cost pressures, and local regulations. The authors state that the use and acceptance of APDM for pipeline and trenchless projects will likely expand as more owners, contractors and engineers become familiar with them.

Guy (2007) demonstrates how DB trenchless solutions offer numerous advantages to water and wastewater projects in terms of cost, schedule, risk, and profit, when compared to DBB. The author states the majority of DB water and wastewater projects feature state-of-the-art package treatment facilities while relying upon 19th century “dig and replace” methods of rehabilitating underground water and sanitary and storm sewer lines to renew the supply and distribution system. Dig and replace methods are completed by digging trenches to lay the pipe in, and then backfilling them to grade. This process results in a mismatch between modern facilities and older installation methods and technologies. The mismatch does not allow the project stakeholders to fully exploit the inherent benefits of DB. One synergistic aspect is trenchless contractors make great DB teaming partners, especially when incorporated early in the project planning process. Another aspect is that trenchless rehabilitation work elements are rarely on the project’s critical path. Trenchless work can typically be accomplished at any time during the project and is relatively independent from other work elements, which is ideal for the DB superposition of work packages.

More recently, Hassan (2010) evaluated the use of various project delivery systems for trenchless construction. A survey of industry professionals was used to evaluate different delivery systems for trenchless projects. The author reckoned 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. The author surveyed the industry and collected ten responses from different states in the U.S. to conclude that: (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.

To summarize the existing literature, most studies provide some qualitative evidence of the APDM benefits on trenchless construction projects. This paper combines these findings with additional quantitative results from case studies in order to investigate the effect of APDM on trenchless construction performance.

PROBLEM STATEMENT

The traditional DBB delivery method typically begins with an owner soliciting an architect or engineer to design a project. The designer produces plans and specifications for the owner, who then invites contractors to bid on the construction work. Then, the lowest bidder often is awarded the contract. This type of project delivery has been proven successful for repetitive projects or projects that are simple in nature. Conversely, trenchless construction is a relatively complex type of construction that requires very specialized and experienced personnel. Most general contractors do not self-perform trenchless construction; instead they typically hire a specialized trenchless subcontractor to complete this portion of the project. Trenchless subcontractors can verify pipeline conditions, advise on cost and timing, design and manufacture a solution specifically for the unique application at hand (Guy 2007). Design engineers often are not experienced with trenchless technologies means and methods, and therefore might not have a full appreciation of the capabilities of these technologies or how to appropriately design trenchless projects.

When performing trenchless construction under a traditional DBB delivery method, the owner is running the risk of hiring engineers that may not necessarily know which type of trenchless construction method is best used for the given situation and how to accurately complete plans and specifications that are needed for trenchless construction. By having the design complete prior to construction, DBB delivery does not provide the opportunity for upfront guidance and constructability reviews from a contractor that specializes in trenchless construction. By pairing trenchless construction with alternative project delivery methods, a trenchless subcontractor can be brought in during the design phase to assist the engineer and contractor with the design and constructability of the trenchless portion of the project.

The integration of contractors early in the design phase can be beneficial for the success of a project. In fact, the Design-Build Institute of American (DBIA) has shown, for other construction sectors, that including experienced contractors in the design phase can reduce the cost growth, schedule growth, and amount of changes and modifications seen on a project (DBIA 2011). Currently, the majority of trenchless construction projects are being delivered using traditional DBB. Similar to the application of APDM for other types of construction, the use of APDM for trenchless construction projects has the potential to improve project performance. An interesting line of research could investigate this claim and quantify the impact of APDM on trenchless project performance.
OBJECTIVES AND METHODOLOGY

This paper aims to investigate trenchless construction projects that have employed APDM in the past decade in an effort to quantify the cost performance of these projects. The paper will specifically focus on the cost metric because it was the only metric for which appropriate data was available from trenchless construction projects, and also because it is often the most important metric that project stakeholders consider. The research methodology involved conducting a meta-analysis of literature to compile data published in different case studies. The authors comprehensively reviewed case studies of trenchless construction projects through searching conference proceedings, engineering journals, and magazines. Different methods were used in order to obtain all the necessary cost information. First, a search of all published academic research related to the topic was completed, yielding a few projects with actual cost data. Then, the search was expanded to Trenchless Technologies magazine articles to find projects that have been completed using APDM. This strategy led to many such projects, a large portion of which did not have the data needed for this study. Therefore, projects that offered some cost information were investigated further to find the missing data. Lastly, the No-Dig conference proceedings from 2004 to 2013 were searched to find projects that have utilized APDM. A large portion of the data used for this paper was collected from the North American Society for Trenchless Technology’s (NASTT) No-Dig conference proceedings and Trenchless Technology magazine. The data found and collected included the final cost and the cost savings of each project. Cost savings for this research is defined as the amount of money saved between the expected cost of a project and the actual cost of that project. The next section describes the project data used in this study.

DATA CHARACTERISTICS

Adequate and reliable data was found for ten APDM trenchless projects. These projects are distributed across geographical locations, types of trenchless technologies, types of delivery systems, and market sectors, as described below:

1. The first project was a CIPP sewer rehabilitation project in Phoenix, AZ, completed in 2002 and delivered using CMAR.
2. The second project was a HDD sewer and wastewater installation project in Alexandria, VA, completed in 2003 and delivered using DB.
3. The third project was a HDD sewer and wastewater installation project in Winter Park, FL, completed in 2004 and delivered using DB.
4. The fourth project was a pipe bursting sewer and wastewater rehabilitation project in Phoenix, AZ, completed in 2005 and delivered using CMAR.
5. The fifth project was a CIPP sewer and wastewater rehabilitation project on a military base (the exact location was not given) completed in 2007 and delivered using DB.
6. The sixth project was a HDD water installation project in Toronto, Canada, completed in 2008 and delivered using DB.
7. The seventh project was a HDD sewer and wastewater installation project in North Bay Village, FL, completed in 2010 and delivered using DB.
8. The eighth project was a slip lining sewer and wastewater rehabilitation project in Orange County, CA, completed in 2011 and delivered using DB.

9. The ninth project was a slip lining water system rehabilitation project in Roanoke, NC, completed in 2012 and delivered using CMAR.

10. The last project was a microtunneling storm water rehabilitation project in Durham, NH, completed in 2012 and delivered using DB.

The projects span across five states in the U.S., as shown in the top part of Figure 2, as well as Toronto, Canada. The types of trenchless technologies used on the project varied as shown in the bottom part of Figure 2, with the majority of the projects involving HDD and lining (CIPP) technologies.

The majority of the projects in the dataset (70%) were delivered using DB. The remaining 30% were delivered using CMAR. The focus of the meta-analysis was to collect cost data for the above projects in order to determine an initial benchmark for the distribution of APDM cost performance on trenchless projects.

**Figure 2. Geographical Distribution and Trenchless Technologies Distribution**

**RESULTS AND DISCUSSION**

Project data was divided into two subsets: DB projects and CMAR projects. The percent of cost savings was then plotted for all projects, which were ordered chronologically based on their completion dates. The results are shown in Figure 3. The trenchless construction projects that utilized APDM had an average cost savings of 27%. The average cost savings for the CMAR projects was 13%, while DB projects seem to be even more successful with an average cost savings of 33%.

Figure 4 presents another visualization of the dataset using boxplots. 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. The boxplot on the right of Figure 4
shows all the APDM project data (both DB and CMAR), while the left side only shows the projects using DB. The minimum value of cost savings for projects using DB was 20% and the minimum value when using CMAR was 2%.

![Figure 3. Cost Savings of Trenchless Projects using DB and CMAR](image1)

![Figure 4. Boxplots Showing Cost Savings for DB Trenchless Projects (left) and Cost Savings for Both DB and CMR Trenchless Projects (right)](image2)

Due to the small sample size, statistically significant conclusions cannot be drawn from the data. However, this analysis of case studies clearly suggests there seems to be cost benefits when utilizing APDM on trenchless construction projects. APDM performance benefits have been greatly documented for other construction types, including buildings, infrastructure, and industrial facilities. According to the DBIA, DB projects average 6% in cost savings (DBIA 2011). The results from the analysis presented in this paper show a noteworthy increase in cost savings compared to the average of all projects using DB.

The authors attempted to find data for other performance metrics in addition to cost performance. Exact data for schedule performance was not available for this analysis; however, all the case studies stated that their projects were completed on or before the anticipated project completion dates. Many of the projects stated the completion date of the project was continually decreased due to time savings.
achieved using APDM. These time savings included a decrease in design time resulting from the experience of contractors assisting the engineer in the design phase. Another manner the schedule was shortened was the decrease in time needed to initiate and process change orders. APDM allow for a much quicker response time to change orders and requests for information. Faster processing times have been recently documented for other APDM such as IPD (El Asmar et al. 2013). APDM allow the designer and contractor to collaborate and resolve issues faster and more efficiently than with traditional DBB delivery.

CONCLUSIONS

This paper investigated the cost performance of trenchless construction projects delivered with APDM. Cost data was compiled from previous trenchless projects and case studies. The analysis shows APDM trenchless projects exhibit an average cost savings of 27%. APDM benefits have been proven for other construction types including complex buildings, infrastructure, and industrial facilities. This study offers a contribution to the construction engineering and management literature and to the AEC industry by demonstrating the possible cost benefits associated with using APDM for a new application: trenchless construction projects. The results can be used to guide project stakeholders while choosing delivery systems for projects that involve trenchless construction.

Limitations of the study include the small sample size, which directly affects the statistical significance of the results. A second limitation is the scope of the study: (a) the data collected for this project was for DB and CMAR projects only, not all APDM were considered; (b) the results mostly stem from water and wastewater projects; (c) the study only focused on cost performance and did not find published quantitative data for additional performance metrics.

Future work will include collecting actual performance data from a large dataset of recently completed trenchless construction projects, which will allow to statistically test the performance impact of APDM on trenchless construction projects. The dataset will include projects from all currently used APDM in trenchless construction, and will target projects using various trenchless technologies. Additionally, the authors plan to collect performance data that goes beyond the cost metrics to include schedule, quality, safety, and other key performance indicators used in the AEC industry.

REFERENCES


