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Evaluating the Appropriateness of Project Delivery Systems for Different Trenchless Methods

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ABSTRACT:
Trenchless methods have been considered to be a viable solution for pipeline projects in urban areas. Their applicability in pipeline projects is expected to increase with the rapid advancements in technology and emerging concerns regarding social costs related to trenching methods. Selecting appropriate project delivery system (PDS) is a key to the success of trenchless projects. To ensure success of the project, the selected project delivery should be tailored to trenchless project specific characteristics and owner needs, since the effectiveness of project delivery systems differs based on different project characteristics and owners requirements. Since different trenchless methods have specific characteristics such rate of installation, lengths of installation, and accuracy, the same project delivery systems may not be equally effective for different methods.
The intent of this paper is to evaluate the appropriateness of different PDS for different trenchless methods. PDS are examined through a structured decision-making process called Fuzzy Delivery System Selection Model (FDSSM). The process of incorporating the impacts of: (a) the characteristics of trenchless projects and (b) owners' needs in the FDSSM is performed by collecting data using questionnaires deployed to professionals involved in the trenchless industry in order to determine the importance of delivery systems selection attributes for different trenchless methods, and then analyzing this data. The sensitivity of PDS rankings with respect to trenchless methods is considered in order to evaluate whether similar project delivery systems are equally effective in different trenchless methods. The effectiveness of PDS with respect to attributes is defined as follows: a project delivery system is most effective with respect to an attribute (e.g., ability to control growth in costs) if there is no project delivery system that is more effective than that PDS. The results of this study may assist trenchless project owners to select the appropriate PDS for the trenchless method selected.

Keywords: Trenchless projects, Project Delivery Systems, Decision-Making.

1. INTRODUCTION

Trenchless methods have been considered to be a viable solution for pipeline projects in urban areas. Their applicability in pipeline projects is expected to increase with the rapid advancements in technology and emerging concerns regarding social costs related to trenching methods. As a result of this increase of application, project owners such as urban municipalities and utility providers, allocate significant budgets each year to such projects. Therefore, to be confident about the success of these projects, project owners should ensure that the projects are delivered through the most appropriate project delivery systems. It has been estimated that the selection of more efficient contracting methods could reduce construction project costs by an average of 5% (Contractual, 1982).

Project delivery is a comprehensive process through which a project is designed and constructed (Dorsey, 1997). In other words, the delivery system is the framework through which the project is executed. Selecting an appropriate project delivery system is one of the most important strategic decisions towards a successful project. The decision is made during the initial phase of every project. Decision made corresponding to delivery system selection affects all phases of project execution as well as the efficiency of project execution. Consequently, selecting the most appropriate project delivery system is of great importance for a successful project.

Project delivery systems in trenchless projects has been the subject of studies by Kramer and Meinhart (2004) and Guy (2007). Kramer and Meinhart (2004) analyzed the number of trenchless projects delivered using different systems. The summary of the case studies is presented in Table 1.

Table 1-Case studies regarding alternative delivery systems utilized in trenchless technology projects (Kramer and Meinhart, 2004)

Project	Owner	Trenchless Method	Delivery Method
Lake Austin& FM 2222 Crossing	City of Austin, Texas	Horizontal Directional Drilling (HDD)	Design-Bid-Build (DBB)
H&RP Intake/Outfall	Pentagon Renovation Program	Micro-Tunneling	Design-Build
Potomac Yard Offsite Sanitary Trunk Sewer	Crescent Resources LLC	Micro-Tunneling	Modified Design-Build
Cooper River 115 KV Submarine Cable Project	South Carolina Electric & Gas Company	Horizontal Directional Drilling (HDD)	Engineering-Procurement-Construction-Management (EPCM)

Kramer and Meinhart (2004) concluded that selected project delivery system was successful to meet the project requirements and owner needs: none of the studied projects experienced time or cost overruns. In addition to schedule and cost requirements, selected delivery systems also met other requirements such as constructability considerations, construction start before design completion, etc. This consistent tailoring the project delivery system to project needs and owners' requirements made each of the above-mentioned projects a success.

In another study, Guy (2007) introduced Design-Build as a "perfect solution" for trenchless renewal projects. "Pairing trenchless solutions with Design-Build delivery system produces a powerful synergy that is virtually unequalled in construction" (Guy, 2007). Design-Build delivery system has intrinsic distinctiveness compared to other delivery methods, including (Guy,2007):

- Reduced design time (fast-tracking)
- Reduced owner risks (transferring risks to single source of responsibility)
- Accounting for constructability considerations
- Fewer disputes between project parties

Considering advantages of both trenchless technology and Design-Build delivery system, Guy (2007) points out to the following benefits as a result of delivering trenchless project using Design-Build method:

- Lower initial and lifecycle costs for the owner
- Reduced probability of increases in construction costs and schedules caused by weather and environmental issues
- Solving owner’s “trust” concerns (i.e., by having a single source of responsibility)
- Long-lived sustainable pipeline solutions
- The opportunity of even more protracted project schedules (i.e., by starting construction before design completion).

In this paper, the appropriateness of different project delivery systems for trenchless projects are evaluated. The question that this paper tries to answer is whether the most appropriate project delivery systems differ in various trenchless methods , i.e., words, do the characteristics of trenchless projects affect the project delivery system selection process. To answer this question, PDS are examined through a structured decision-making process called Fuzzy Delivery System Selection Model (FDSSM). Decision attributes such as the ease of change incorporation, the ability to efficiently coordinate project complexity or innovation, and the level of design completion before construction, are used as the criteria for evaluating different project delivery systems. The process of incorporating the impacts of: (a) the characteristics of trenchless projects and (b) owners' needs in the FDSSM is performed by collecting data using questionnaires deployed to professionals involved in the trenchless industry in order to determine the importance of delivery systems selection attributes for different trenchless methods, and then analyzing this data. The sensitivity of PDS rankings with respect to trenchless methods is considered in order to evaluate whether similar project delivery systems are equally effective in different trenchless methods The effectiveness of PDS with respect to attributes is defined as follows: a project delivery system is most effective with respect to an attribute (e.g., ability to control growth in costs) if there is no project delivery system that is more effective than that PDS. The following section of the paper briefly discusses the FDSSM methodology. Afterwards, data collected are presented. Subsequently, the results of the analysis are presented followed by result discussion. The paper is concluded with a summary and conclusion.

2. Methodology

Different methods and techniques for selecting appropriate delivery system have been proposed to help project owners to select the most appropriate project delivery system for their projects. Table 2 summarizes numbers of these methods and techniques.

Table 2- Proposed Methods for Delivery System Selection

Researcher (Year)	Proposed Method	Methodology	Application and Features
Gordon (1994)	Process of Elimination	Subjective multistage imination processel	Subjective decision making No rating (multistage screening) Lacks quantitative analysis Does not consider uncertainty
Alhazmi & McCaffer (2000)	Parker's judging alternative technique	Value engineering method	Alternatives assessment method Ratings by crisp numbers Does not consider uncertainty
Cheung et al. (2001)	Objective-Subjective method with the application of Analytical Hierarch Process (AHP)	Multicriteria decision making method	Quantitative decision making Hierarchical analysis Effectiveness and weight ratings by crisp numbers The alternative with the highest utility is ranked first Does not consider uncertainty
Oyetunji & Anderson (2006)	Simple Multi-Attribute Rating Technique with Swing rates (SMARTS) method	ng Multiattribute rati technique	Quantitative decision making Effectiveness and weight ratings by crisp numbers The alternative with the highest utility is ranked first Does not consider uncertainty

The proposed methods listed in Table 2 improve the selection process since they are based on sound analytical theory. These methods are multi-criteria decision making techniques. However, none of the proposed methods consider the inherent uncertainty in the delivery system selection. Uncertainty arises when the effectiveness of different alternatives effectiveness and the contributions of factors such as controlling cost and schedule growth , risk transferring, facilitating early procurement, etc. to project selection have to be determined. In methods listed in Table 2, the effectiveness values and weights are determined by 'crisp numbers'. Yet, the effectiveness of a delivery system with respect to an attribute as well as the attributes weights in a project cannot determined with certainty In 'crisp' methods, the risk attitude of the decision maker is not taken into consideration in decision making process. To address these challenges, Mostafavi and Karamouz (2010) proposed a fuzzy-based delivery system selection model called Fuzzy Delivery System Selection Model (FDSSM) that accounts for uncertainties inherent in the project delivery system selection process. The model utilizes fuzzy numbers in determining effectiveness values and weights and subsequent alternative utilities to account for the uncertainty. Instead of ranking the delivery alternatives based on crisp utility values, the model ranks delivery systems based on their utility membership functions. Fuzzy membership functions (numbers) corresponding to the utility of each alternative are ranked through Technique for Order Preference by Similarity to Ideal Solution (fuzzy TOPSIS) approach. Fuzzy TOPSIS is an effective method for ranking fuzzy utility membership functions based on the criteria considered by Yuan (1991): "fuzzy preference representation, rationality of fuzzy ordering, distinguishibility between numbers, and robustness by small changes in the membership function of fuzzy numbers." In this method, the distance of each alternative utility membership function to the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) is evaluated. Then, the alternative which is simultaneously closer to FPIS and farther from FNIS is selected as the best alternative. The FDSSM is applied in this paper to assess project delivery systems in trenchless projects.

Like any decision making method, FDSSM includes decision alternatives and decision attributes. 12 project delivery alternative and 20 selection factors form the FDSSM framework. Table 3 and Table 4 list the 12 delivery systems and 20 selection factors considered in FDSSM.

Table 3-Alternative project delivery systems considered in FDSSM model (Oyetunji & Anderson, 2006)

Alternative Project Delivery systems	
Traditional D-B-B	Design-build (or EPC)
D-B-B with early procurement	Multiple design-build
D-B-B with project manager	Parallel primes
D-B-B With construction manager	D-B-B with staged development
D-B-B with early procurement and construction manager	Turnkey
Construction manager-at-risk	Fast track

Table 4-Selection factors considered in the FDSSM model (Oyetunji & Anderson, 2006)

Selection Factor statement	
Control cost growth	Protect confidentiality
Ensure lowest cost	Capitalize on familiar project condition
Delay or minimize expenditure rate	Maximize owner's controlling role
Facilitate early cost estimate	Minimize owner's controlling role
Reduce risk or transfer risk to contractor(s)	Maximize owner's involvement
Control time growth	Minimize owner's involvement
Ensure shortest schedule	Capitalize on well defined scope
Promote early procurement	Efficiently use poorly defined scope
Ease change incorporation	Minimize number of contracted parties
Capitalize on expected low levels of changes	Efficiently coordinate project complexity or innovation

In this model, the fuzzy utility number of each alternative is derived from the Eq.1:

$$\tilde{U}_i = \sum_{J=1}^{m} \tilde{w}_j . \tilde{r}_{ij} \quad [1]$$

Where $\widetilde{w}_j$ and $\widetilde{r}_{ij}$ are approximated fuzzy triangular numbers corresponding to the weights (importance) of attributes and effectiveness of each alternative with respect to each attribute, respectively. Then, the derived utility fuzzy numbers are ranked using fuzzy TOPSIS method. In this method, the distance of each fuzzy number corresponding to each alternative to the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) is evaluated. Then, the alternative which is simultaneously closer to FPIS and farther from FNIS is selected as the best alternative. The ranking of delivery alternatives in this study is performed using fuzzy TOPSIS method.

The effectiveness values of the delivery alternatives with respect to the selection factors does not change for every project (Oyetunji and Anderson, 2006). Therefore, to determine appropriate project delivery system for a specific project, the importance of the selection factors in that specific project should be determined. To assess the applicability of different project delivery systems in trenchless projects, the importance of selection factors for different trenchless projects can be determined by collecting data through questionnaires from professionals involved in the trenchless industry.

3. Data Collection and Analysis

A survey was conducted to capture the importance of selection factors in different trenchless projects. The questionnaire were sent to a list of trenchless contractors, construction managers, and owners. A group consists of Four project managers, two engineers, and two experts in trenchless projects completed the questionnaire. Each of the respondents considered one type of trenchless project: three respondents considered Micro-tunneling, four considered HDD, and one considered Pipe-jacking. The respondents were either project managers or project engineers. While considering each of the trenchless methods, the respondents determined the importance of selection factors based on the characteristics of the trenchless method. Table 5 summarizes the importance weights determined by the respondents. Importance weights reflect the characteristics of the considered project and the owners' needs based on respondents experience and knowledge. Since the owners' needs are different in different projects, some importance weights inconsistencies are typically expected. However, in general, the set of the importance weights that captures general project characteristics and owners' requirements are consistently determined by the respondents. Figure 1 illustrates the output screen of the program. The importance weights were entered in the FDSSM model to select the three best delivery systems for each trenchless method. The output screen in Figure 1 corresponds to selection factors weights determined by respondent 4 considering Micro-tunneling projects

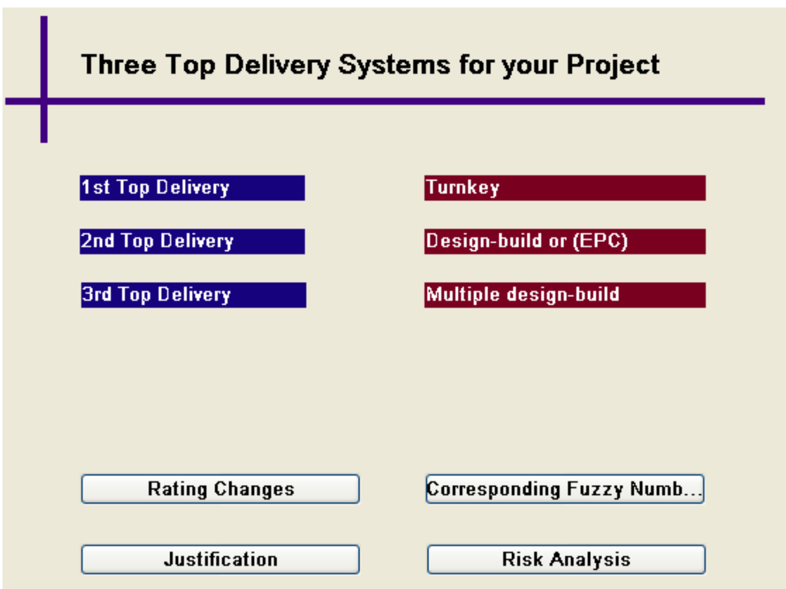

Figure 1-Output screen of FDSSM model

Table 5-Summary of selection factors weights in considered trenchless projects

Respondent ID (Trenchless project considered) / Selection Factor	**1 (Micro-tunneling)**	**2 (HDD)**	**3 (HDD)**	**4 (Micro-tunneling)**	**5 (Pipe-jacking)**	**6 (HDD)**	**7 (Micro-Tunneling)**	**8 (HDD)**
Control cost growth	MH	MH	VH	MH	MH	MH	M	MH
Ensure lowest cost	M	VH	M	M	M	MH	MH	M
Delay or minimize expenditure rate	M	M	M	L	L	MH	MH	MH
Facilitate early cost estimate	M	MH	VH	MH	M	M	ML	VH
Reduce risk or transfer risk to contractor(s)	VH	VH	MH	MH	M	MH	H	VH
Control time growth	MH	MH	MH	VH	VH	M	M	MH
Ensure shortest schedule	MH	MH	ML	ML	ML	ML	ML	M
Promote early procurement	VH	M	MH	MH	MH	M	VH	MH
Ease change incorporation	VH	MH	MH	ML	ML	M	ML	VH
Capitalize on expected low levels of changes	MH	M	ML	MH	MH	ML	M	MH
Protect confidentiality	L	L	ML	L	L	L	L	M
Capitalize on familiar project condition	MH	MH	VH	MH	MH	M	M	M
Maximize owner’s controlling role	M	ML	MH	M	M	MH	MH	ML
Minimize owner’s controlling role	ML	VH	ML	L	L	ML	L	VH
Maximize owner’s involvement	ML	L	ML	L	L	ML	ML	M
Minimize owner’s involvement	MH	VH	ML	VH	VH	MH	MH	MH
Capitalize on well defined scope	M	MH	MH	VH	VH	VH	VH	VH
Efficiently use poorly defined scope	M	ML	M	L	L	L	L	MH
Minimize number of contracted parties	VH	MH	MH	VH	VH	VH	VH	MH
Efficiently coordinate project complexity or innovation	VH	M	VH	VH	VH	VH	VH	VH

*Note: VH: Very High, H:High, MH: Moderately High, M:Neither High Nor Low (Medium), ML: Moderately Low, L:Low, VL: Very Low

Table 6 lists the model outcomes for each of the respondents. The model outcomes are based on the importance weights assigned by each respondents to the selection factors. For instance, Respondent 1 considered the importance of the factors in micro-tunneling projects. Based on the input, the model has derived turnkey, design-build, and CM at risk to be the most appropriate delivery systems. As shown in Table 6, three respondents considered micro-tunneling projects, four considered HDD, and one considered pipe jacking. The model outcomes consistently rank turnkey and design-build as the most appropriate delivery alternative for the trenchless methods considered.

Table 6- Alternate delivery systems for trenchless methods

Respondent ID	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
Trenchless Method	Micro-Tunneling	HDD	HDD	Micro-Tunneling	Pipe Jacking	HDD	Micro-Tunneling	HDD
Appropriate Delivery System Ranking	Turnkey	Turnkey	Turnkey	Turnkey	Turnkey	Turnkey	Turnkey	Turnkey
	Design-Build	Design-Build	CM at Risk	Design-Build	Design-Build	Design-Build	Design-Build	Design-Build
	CM at Risk	Multiple Design-Build	Design-Build	Multiple Design-Build	Multiple Design-Build	Multiple Design-Build	Multiple Design-Build	Multiple Design-Build

4. Discussion of Results

Based on the model outcomes (Table 5), turnkey and design-build system would be the best alternative delivery system for micro-tunneling, HDD, and pipe jacking trenchless projects that is consistent with what Guy (2007) concluded. Since the selection factors accounting for both owners' requirements and project characteristics for delivery system selection, delivery system rankings might be dominated by the importance of the factors related to owner's requirements and not to different project characteristics. To identify dominant factors, factors considered to be "highly important" by all of the respondents were identified. These factors include: reducing or transferring risks to contractors, controlling time growth, promoting early procurement, ease change incorporation, capitalizing on well-defined scope project, and efficiently coordinate project complexity and innovation. Among these factors, all except "ease change incorporation", "promoting early procurement ", and "efficiently coordinate project complexity and innovation" account for owner's requirements. "Easing the incorporation of change becomes important where there are expected changes in the project which is the case when underground investigations are not accurately performed and the used trenchless method lacks required accuracy. "Promoting early procurement" is important in all pipeline projects, and , efficiently coordinating project complexity and innovation is crucial when , the selected trenchless method is not capable of overcoming project complexities and allowing for innovation. Hence, project complexities, required accuracy, etc. should be considered while the trenchless method is selected.

Appropriate project delivery system differs in projects due to different owner's requirements. Since the project delivery system is selected before the selection of the trenchless method, an appropriate project delivery system would enhance the chance of the most appropriate trenchless method be selected. For instance, constructability considerations made possible through design-build system, enhances design considerations in selecting an appropriate trenchless method. This was the case in H&RP Intake/Outfall project in 2001 and during Pentagon Renovation Program. Design-Build system was selected for this project. Early involvement of the design-build team resulted in innovative changes to the conceptual design of the project. In the conceptual design it was determined that the project was to be constructed using segmental liner plate tunneling through a complex soft geology below the water table. However, design-build team proposed micro-tunneling method with raised elevation that reduced the risks associated with dewatering. The Design-build system allowed innovative approaches to be considered by the design-build team that finally led to reduced schedule, costs, and risks (Kramer and Meinhart, 2004). Nevertheless, if owners' requirements lead to selection of an alternative delivery method other than design-build, still the project can be a success using an appropriate trenchless method as Kramer and Meinhart (2004) cited case studies of successful projects performed through different project delivery systems and different trenchless methods (Table 1).

5. Summary and Conclusion

In this paper, appropriateness of project delivery alternatives for different trenchless projects were evaluated using FDSSM model which facilitates a quantitative evaluation of appropriateness of project delivery systems for trenchless projects. The appropriateness is evaluated based on the effectiveness of delivery systems to meet project requirements and owners' needs. For this purpose, a group of trenchless experts were asked to determine the importance of the selection factors which reflect the project characteristics and owner's needs. An appropriate delivery method is the one which effectively meets important selection factors. FDSSM model derives the fuzzy utility membership functions of the delivery alternatives based on the determined importance weights and hence ranks the alternatives through fuzzy TOPSIS approach.

The model output shed light on the appropriateness of turnkey and design-build delivery alternative for Micro-tunneling and HDD trenchless projects. Further assessment of the collected data revealed that the ranking of delivery systems in the model was dominated by the importance of factors related to owners' requirements and not the factors related to project characteristics. Therefore, the characteristics of the trenchless projects play a less significant role in the selection process than the factors related to the owners' requirements .

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