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Development of a Decision-Support tool for TxDOT Delivery Methods Selection

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Development of a Decision-Support tool for TxDOT Delivery Methods Selection

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

May 2015

Dedication

A mamá y a papá;

a mis hermanos y hermanas, los mejores que me podrían haber tocado;

a Juana, la más hermosa medida del paso del tiempo;

a mis amigas, que supieron acortar la distancia maravillosamente;

and to all the wonderful people I met in Austin during the last two years,
that made me feel at home.

Acknowledgements

In the first place, I would like to thank Dr. Bill O’Brien for his time, guidance and support during this research project. I would also like to thank Dr. O’Connor and Dr. Leite for their advice and encouragement, and to all CEPM faculty for sharing their knowledge with me through classes and informal chats. I would like to especially thank Nabeel Khwaja and all TxDOT collaborators, for sharing their time and experience with me. This work wouldn’t have been possible without you.

I would also like to extend my gratitude to BEC.AR and the University of Texas at Austin: without your scholarship programs this experience abroad and research project wouldn’t have been possible for me.

Last, but not least, I would like to say thanks to all those who encouraged me in this studying abroad adventure, giving me endless confidence and support, both when making this decision and during my two amazing years at UT Austin.

Abstract

Development of a Decision-Support tool for TxDOT Delivery Methods Selection

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The University of Texas at Austin, 2015

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Alternative delivery methods for transportation infrastructure projects, besides the traditional Design-Bid-Build (DBB) approach, have been implemented by private and public sectors since the last decades. The Texas Department of Transportation (TxDOT) is not the exception, and the fact that TxDOT has available alternatives for delivering its projects lead to the need of a formal decision process. This work presents the existent approaches made by different owner entities to formalize the delivery method decision. This research provides with decision procedures, criteria and principles to develop a quantitative decision-support tool; thus serving any entity seeking for a formalized and documentable Delivery Method decision procedure.

A complete decision process was developed specifically for TxDOT, based on the literature review findings, but also on the agency's needs, experience and legal authority. This work intends to help the agency's staff make an informed choice between their available delivery methods: Design-Bid-Build and Design-Build. The decision method was formalized in the way of a Multiple Criteria Decision Making (MCDM) process, and

organized as a MS Excel decision-support tool. The process incorporates knowledge –in the shape of performance scores– from TxDOT experts as well as from other organizations that work closely with the agency. This input allows for the creation of a tool fully customized for TxDOT goals and projects' characteristics. The decision-support tool developed incorporates quantitative measures, but is transparent and flexible. It constitutes a rigorous, repeatable and documentable decision process, evaluating characteristics and goals of each project to determine each delivery method's suitability degree.

Overall, the present works provides with guidelines for the development of a decision-support tool regarding the delivery methods decisions for any entity needing to formalize the process. It also specifically contributes to TxDOT, producing a formalized decision process that may be taken as an example for any other entity willing to modify and quantify their current Delivery Method selection procedure.

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Chapter 1: Introduction

Alternative Delivery Methods (DM) are those that go beyond the traditional Design-Bid-Build (DBB) approach, giving the owner different options for contracting capital projects. State agencies have usually been a step behind in the implementation of these methods, mainly due to regulatory barriers. However, methods like Design-Build (DB) or Construction Manager at Risk (CMAR) are nowadays becoming common practices for many public entities.

The Construction Industry Institute (CII) describes in its Project Delivery Contract Strategy (PDCS) publication (CII, 2003) the DBB method as a serial sequence of design and construction phases, in which procurement begins with construction. The owner contracts separately with the designer and the constructor. On the other hand, DB responds to an overlapped sequence of design and construction phases where procurement begins during design, and the owner only contracts with a Design-Build team. Ghavamifar and Touran (2008) describe CMAR as a “delivery method in which a contractor comes on board early during the project design phase”, even though the owner contracts the design separately. The Construction Manager (CM) provides constructability reviews and cost estimates during the design phase (Khalil, 2002). During construction, the CM is in charge of contract packaging and contractor’s coordination, being responsible for the cost and schedule as a General Contractor (GC). The sequence of each of the described DM can be seen in Figure 1. Both DB and CMAR can overlap the design and construction phases, and its main difference resides in the contractual relationships between the parties and the owner.

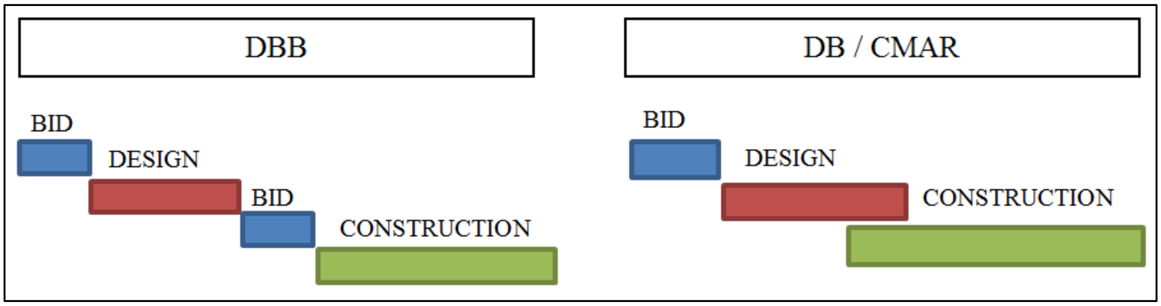


Figure 1. Time sequence of different delivery methods

According to the Design Build Institute of America (DBIA), in 2013 38% of the non-residential construction bids used DB methodology (Duggan and Patel, 2013), and DB market share rises in the subsector of projects above $10 million, reaching 52%. The use of DB methodology increased 30% since 2005. CMAR is used in almost 5% of the projects, and the traditional method accounts for the remaining 57%. Among the areas that most utilize DB are military facilities and commercial developments. Governmental, retail, medical and educational constructions show a high DB usage rate too (above 35%). These trends motivated numerous studies regarding the selection between different delivery methods, the criteria to use, and the relative benefits of each alternative.

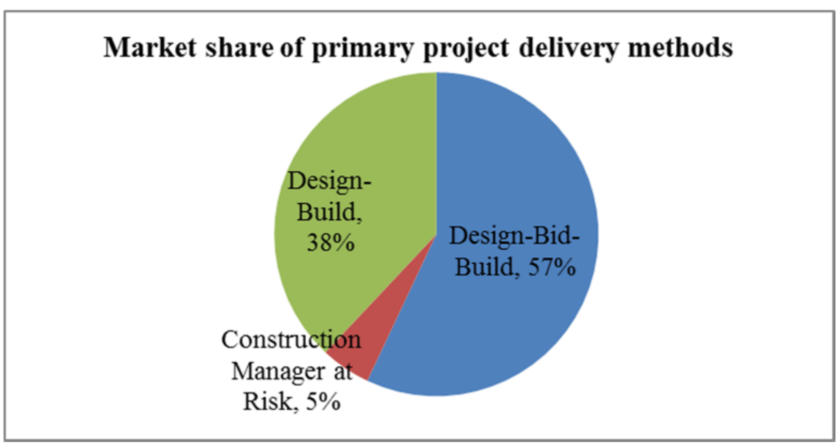


Figure 2. Market share of the primary project delivery methods (DBIA, 2013)

RESEARCH MOTIVATION

In September 2011 TxDOT received legislative authority to utilize DB as a project delivery method for its transportation projects (Texas Transportation Code; Chapter 223; Subchapter F). Prior to this legislative change, TxDOT was limited to using the traditional DBB approach for delivering all its funded construction projects. According to the Transportation Code, TxDOT "may enter into a design-build contract for a highway project with a construction cost estimate of $50 million or more to the department"; and "The department may not enter into more than three contracts under this section [Design-Build] in each fiscal year" (this limitation expiring on August 2015). Regarding CMAR delivery method, TxDOT does not have authority to apply it as stated in the exemptions of the Government Code, Title 10, Subtitle F, Chapter 2269: "Contracting and delivery procedures for construction projects". However, it is expected that this delivery method will become available soon; therefore the decision process designed is easily adaptable to this new alternative.

DB differs considerably from the traditional delivery method and provides TxDOT with a readily available alternative with different benefits, associated costs, and risks. The availability of both DBB and DB provides a choice to the TxDOT decision-makers. In order to recommend one method over the other, TxDOT needs a transparent and documentable decision-support process that is able to incorporate major characteristics of each method and at the same time is applicable to all their individual projects. At this stage CMAR will not be included, since the method is not currently available.

National Implications

Besides Texas, many other U.S. states are going through a similar situation: the need to select a convenient delivery method for each project, documenting and justifying the decision taken. According to the FHWA Division office Survey in 2012, only eight states have no authority to use DB, and three states have partial authority. All the rest enjoy full authority to deliver projects as DB. As for CMAR, by 2012 thirteen states had full authority and seven had partial authority. The fact that each state has different authority and needs illustrates the necessity for customized tools, each one reflecting general concerns about public capital projects, but also accounting for specific agency's situations.

This work is intended to serve as a starting point for any U.S. state needing to develop an objective tool to document the process of selecting a delivery method. General knowledge was extracted from literature and from the analysis of the currently available decision procedures. Data collection included the most common objectives that owners, especially transportation agencies, seek for when considering alternative delivery methods. It also enumerated project characteristics that have an impact on that decision. Once analyzed the existing practices, the procedure followed to customize the tool for the specific TxDOT's needs and objectives is explained. These same guidelines could be followed by any state seeking for a customized decision process.

RESEARCH OBJECTIVE

The objective of this research is the development of a decision-support tool to compare the currently available delivery methods and help detecting the most appropriate one for each TxDOT's capital project. The product was specifically designed and validated for its use in TxDOT projects, incorporating the agency's most common objectives and project characteristics. For each project, the decision-support tool assesses its characteristics and associated risks, as well as the project and agency's goals. Based on this input, it compares the applicable project delivery methods and provides a recommendation. The tool offers an objective, transparent and documentable decision process to justify the choice. It is MS Excel based, to make it easy to use and relatively simple to modify or upgrade according to TxDOT needs. Changes in the agency's situation or extraordinary project characteristics must be reflected at all times to ensure that the tool fully meets the agency's goals.

Research Team

This research effort was led by UT-Austin Construction Engineering and Project Management (CEPM) program, together with the Center for Transportation Research (CTR). It was externally supported by TxDOT Dallas District, which served as liaison with various pertinent Divisions and Offices of TxDOT to provide oversight and support during the development phase. The research team included all parties that usually participate in TxDOT's delivering of highway capital projects. The support and participation of TxDOT experienced personnel goes in line with the objective of creating a tool fully adapted to the agency's needs, most common objectives, and project characteristics. Expertise external to the agency was also included: contractors and consultants participated in the process. To reach the intended level of customization, the research team worked jointly with TxDOT personnel, with the objective of gathering first-hand input about the agency's needs, and as a contact point with the private sector.

RESEARCH SCOPE

Gordon (1994) defines the construction contracting method as having four parts:

1. **Scope –** portion of work to contract;

2. **Organization –** business entity that will have a contract with the owner (engineer, contractor, construction manager);
3. **Contract –** agreement that rules the relationship of the owner and the organization; and
4. **Award –** method used to select the contractor.

The developed decision tool is focused on the organization portion of the contracting method: selecting the type of entity (design build team, contractor, or CM) that the owner will contract with. This work is based on the assumption that the scope portion of the contract is fairly defined before the different delivery methods are evaluated. Scope changes are one of the main reasons for cost overrun in highway construction projects, independently of the delivery method used (Creedy et al., 2010). Also, changing the project scope would imply changing several of its characteristics. Since the delivery method selection is heavily dependent on the project characteristics, scope should be fairly defined before the use of the decision tool.

Once the scope is fixed and the business entity type is selected, different contracting strategies can help fulfill owner's objectives. The decision among them was left out of the scope of the tool, to be studied in a different research stage. Finally, the contract award procedure needs to fulfill the Texas Statute's guidelines and will not be discussed in this work. The overall sequence of the decision procedure, in the shape of a decision-tool flowchart, can be seen in Figure 3.

Alternatives to consider

Aligned with the current TxDOT legislative authority, the tool takes into account two possible delivery methods at this stage: the traditional DBB method, and the DB methodology. However, the flexible nature of the tool allows the easy incorporation of any other method as it becomes available, being CMAR the most probable candidate to be incorporated in the near future. As it can be seen in the tool flowchart (Figure 3), the process does not take into consideration Public Private Partnerships (PPPs) or any other kind of delivery method used for not fully funded projects.

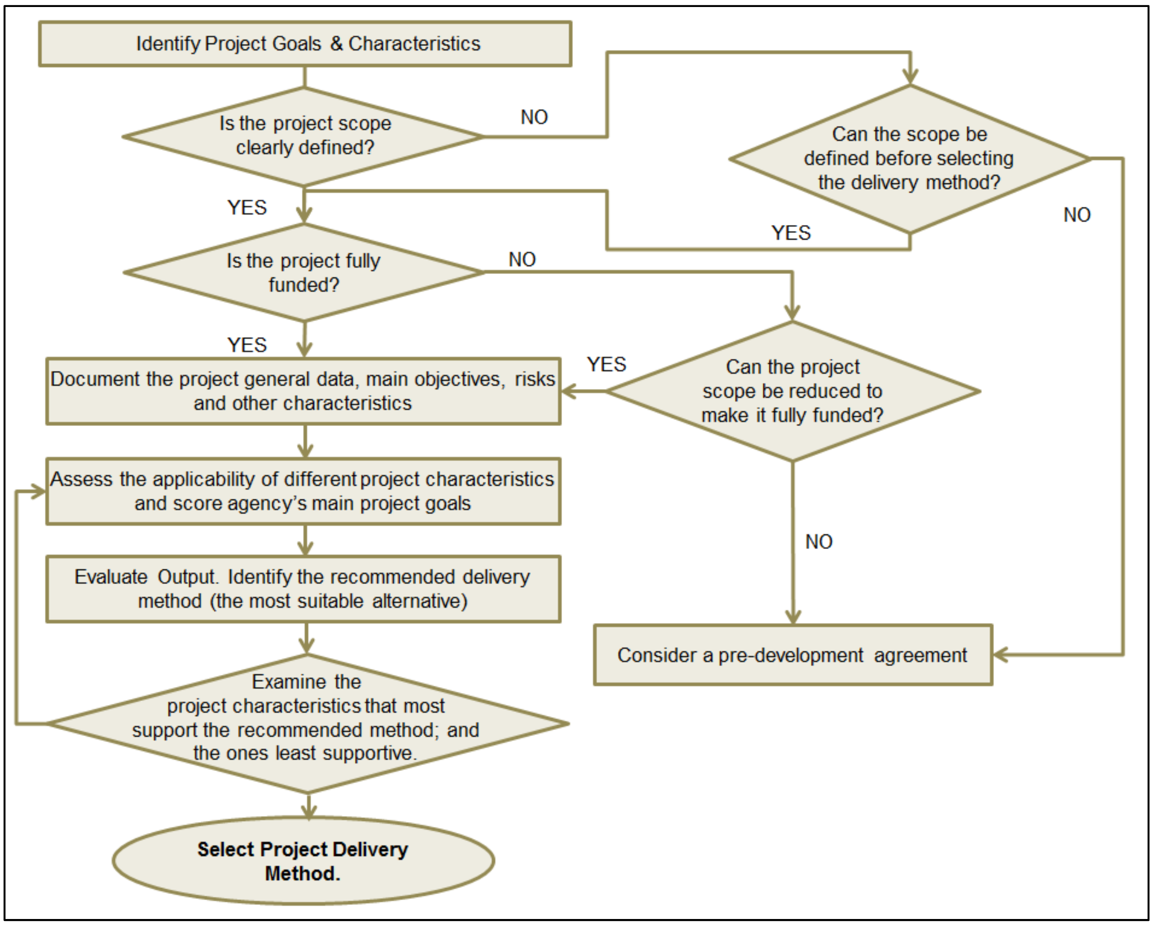


Figure 3. Decision process flowchart

Anticipated research results

Overall, the research effort resulted in:

- An objective decision tool, applicable to a broad range of projects, which helps TxDOT decide among the available delivery methods and formally document the decision, for each individual project. The tool fulfills TxDOT's main concerns taking into account a broad range of criteria, including -but not limited to- cost, schedule, quality, risk, etc.

- A guide on the factors of greatest concern regarding delivery method selections, and how each of those factors is better fulfilled by the different delivery methods.
- A precedent for other DOT or any public agency willing to develop a similar tool.

STRUCTURE OF THE THESIS

This thesis is organized in seven chapters reflecting the evolution of the research efforts. The first chapter introduces the research topic and scope, as well as the objectives, motivation and research team. The second chapter presents the literature review, including existent delivery method decision-support tools, factors that drive the decision and an analysis regarding the relative efficiency of project delivery methods. Chapter 3 will introduce the research methodology and conceptual background of the decision making process chosen.

Chapters 4 to 6 present the results and the development of the TxDOT decision tool. Chapter 4 reports the final decision matrix and performance scores that will be the basis for comparing the different alternatives. Chapter 5 describes the tool itself, its sections, logic and user interface. Chapter 6 goes through the case-studies based validation process. Finally, Chapter 7 presents the conclusions and recommendations, including benefits and challenges of implementing the tool.

Chapter 2: Literature Review

This literature review covered three major areas regarding Delivery Methods selection, each one in a different subsection, as follows:

1. Existing selection methodologies: examination and comparison of the existing methodologies that owners apply to make a decision regarding the different delivery methods that they have available. Shortcomings and most outstanding points.
2. Decision Criteria: Main factors that drive owner's decision regarding the most suitable delivery method for each capital project.
3. Comparative performance of Delivery Methods: compilation and analysis some of the studies about comparative performance of different Delivery Methods, especially DBB and DB.

By reviewing the mentioned areas, we identified features not applicable for TxDOT current situation or needs, as well as practices well suited for the agency. From the information obtained, it was possible to draw a path from where to move forward to fulfill the TxDOT's needs.

EXISTING DELIVERY METHOD DECISION-SUPPORT METHODOLOGIES

Different Departments of Transportation (DOTs), research institutes, and federal organizations developed in the last decade tools to help owners select the most suitable delivery method for each individual capital project. Each of them presented their own methodology, varying from very precise quantitative tools such as the Construction Industry Institute Project Delivery Contract Strategy (CII PDCS), to simple qualitative guidelines listing decision factors with the aim of structuring a discussion, such as the Colorado DOT and other DOTs.

Quantitative approaches ask the decision maker to detect the factors that are more likely to affect the project success, weight objectives, and set priorities. Based on that input data, a score is developed for each Delivery Method. On the other hand, many U.S. DOTs such as Colorado DOT, Minnesota DOT, Virginia DOT, and NY DOT, along with some organizations like NTTA and AASHTO, developed more subjective processes where the user qualitatively estimates in what extent each delivery method would help achieve the project's objectives. These processes are simpler and encourage discussion and clash of ideas. However, no guarantee can be given on consistency or accuracy of the selection: each decision is subjective and highly dependent on the decision-making team members.

The Transportation Research Board (TRB) managed to group these two positions and developed a framework for a tiered decision making process (Touran et al., 2009). A first qualitative assessment is made –Tier1–, and the analysis further deepens if the optimal result is not clear after the first screening. All types of approaches are described in detail in the next sections, and their advantages, disadvantages, and capabilities are compared.

General framework

The TRB through its Transit Cooperative Research Program (TCRP) published in 2009 a "Guidebook for the Evaluation of Project Delivery Methods", with the objective of assisting agencies "in selecting the most appropriate project delivery method for their projects and in documenting this decision" (Touran et al.,2009). The approach consists of three different phases (Tier 1, 2, and 3) that are used subsequently depending on how easily the project delivery method can be defined.

Tier 1 is a qualitative approach to DM selection, where the decision team decides on the most appropriate approach for achieving each of the project's main objectives. A scale varying from the "Most appropriate DM" to the "Least appropriate DM", including a "Not applicable DM" option is used. No numerical assessments are made. A matrix summarizes the results for all the objectives or factors considered, and a final decision is made analyzing the overall picture. If the delivery method is clearly defined after Tier 1, there is no need to use the next phases.

Tier 2 takes place when the first stage did not yield the optimum delivery method. It consists of a "Weighted matrix delivery decision approach". The decision makers should select a maximum of 7 main factors out of the 24 provided. Then, the relative weights of the factors have to be determined, according to its importance in the project. Also, scores relating the delivery method alternatives with each factor have to be settled by the decision team in a 1-10 scale, creating thus a decision matrix. These scores reflect the extent of alignment of the delivery method with each decision criterion. Tier 2 approach provides a more objective solution and a deeper analysis, in exchange of a more time-consuming process.

Tier 3 consists on an "Optimal risk-based approach", which should be performed taking into consideration only the two most suitable delivery methods (according to the results obtained in Tier 1 and 2). This phase is based on risk-based cost estimating methods. A first qualitative step consists on the development of a risk-allocation matrix. A second step quantitatively predicts the effects of the each delivery method in the cost and schedule of the project. This level implies expensive risk analysis methods and decision makers with high-level skills, but it is intended to accurately predict the level of project success.

Overall, the TCRP document presents a variety of approaches that serve as a framework to classify the studied methodologies and place TxDOT needs. In the following sections, existing Tier 1 (qualitative) and Tier 2 (quantitative) methodologies are described. Following, the features of each method, including its advantages and disadvantages, is summarized.

Qualitative methodologies

Some agencies choose to limit their delivery method decision process to a TRB Tier 1 approach, developing guidelines or structured discussions that do not rely on scores' matrixes or analytical calculations. Some of these entities are Colorado DOT, AASHTO, North Texas Tollway Authority (NTTA); and Virginia, Florida, Minnesota, New York and Washington DOTs. Their approaches are presented in the next sections.

Colorado DOT methodology

Colorado Department of Transportation (CDOT) published its formal approach for highway project delivery selection in 2012. They select the most convenient project delivery method among the three approaches that are currently possible for CDOT: DBB, DB and Construction Manager/General Contractor (CM/GC). The selection is based on 4 or 5 primary evaluation factors selected among the 8 available. The decision team then completes the *Project Delivery Selection Matrix (PDSM) Summary*, discussing opportunities and obstacles of each delivery method related to the selected factors, as in the Tier 1 TRB approach. A list of opportunities and obstacles is given, to guide de discussion. Following, the team performs a brief pass/fail analysis of the secondary factors left out in the previous step, and an initial risk to ensure that risks can be properly allocated and managed by the potential delivery method. An example of *PDSM Summary* can be seen in Figure 4, where the selected method for the US 6 Bridge over Garrison Street Replacement was Design-Build, mainly due to schedule constraints.

PROJECT DELIVERY METHOD OPPORTUNITY/OBSTACLE SUMMARY			
	DBB	DB	CM/GC
Primary Evaluation Factors			
1. Delivery Schedule	–	++	+
2. Project Complexity & Innovation	+	++	+
3. Level of Design	+	+	+
4. Cost	–	+	+
5. Perform Initial Risk Assessment	–	+	+
Secondary Evaluation Factors			
6. Staff Experience/Availability (Owner)		✓	
7.Level of Oversight and Control		✓	
8. Competition and Contractor Experience		✓	

++	Most appropriate delivery method
+	Appropriate delivery method
–	Least appropriate delivery method
X	Fatal Flaw (discontinue evaluation of this method)

Figure 4. CDOT PDSM Summary. US 6 Bridge over Garrison St. 03/04/2014.

This selection process has been applied in 14 projects until March 2014, including bridges (new structures and replacements), tunnel projects, tolled lanes, widening projects, and reconstruction projects. DBB was selected for only one project, where the design was advanced. DB was chosen for six projects, mainly when schedule was one of the primary goals or constraints of the project. CM/GC was preferred in the remaining seven projects, where complexity and innovation were main characteristics of the work to perform.

Among the advantages of CDOT's method, it should be highlighted its simplicity. It promotes a structured discussion giving the decision-makers a guideline of the topics to consider. Also, it is concise and states that it can be completed in no more than a 4-hour workshop. The three delivery methods included are suitable for the CDOT current situation; and the eight factors considered are representative of the usual concerns of most agencies delivering highway projects.

However, these factors are sometimes too broad to assess the real needs of specific projects, and there's no established relative weight among them. Additionally, the eight factors mix characteristics of the project to evaluate with owner's needs and project goals. Overall, the final decision is subjective and dependent of the decision-making group, and thus difficult to justify outside that team.

AASHTO methodology

The AASHTO guide for DB Procurement was published in 2008. It is intended to assist agencies in the DB procurement process, and was designed for small to medium projects ($10-$100 million). It does not propose a clear methodology to decide whether to deliver certain project as Design-Build, but highlights the benefits of that delivery method and exemplifies when it should and shouldn't be used. The methodology states that the maximum advantages of use DB arise in innovative projects where a DB team may have superior qualifications than the agency and is likely to offer new technical solutions or management approaches. Besides, AASHTO guide justifies the use of the DB based on other benefits: shorter overall project duration, earlier cost and schedule certainty (leading to less schedule and cost growth), generation of a project above minimum quality standards (at opposed to a lowest cost bid that strictly follows minimum requirements), and improved constructability.

On the other hand, the document explains that a project is not a good DB candidate when it involves third party issues such as permits and environmental concerns, uncertainty in the funds available, or when the project's scope or its location does not generate adequate competition. As for the level of design, the authors found that a higher level of agency satisfaction correlates with less of 30% of completion of preliminary design. The more advanced the design, the lesser the potential benefits of DB, such as contractor input to improve constructability, cost-effectiveness, or claims avoidance due to a single point of responsibility in the design-construction process. Overall, the document succeeds in listing the main benefits and weak points of the DB methodology, and describing the projects that may be good candidates for this methodology. However, it is not the purpose of the publication to provide a formal methodology to select a delivery method. Overall, the guide may help teams justify the decision taken regarding the use of DBB or DB once the delivery method is already chosen.

NTTA Manual

North Texas Tollway Authority (NTTA), in its Project Delivery Method Implementation Manual (2008), describes the ideal delivery method as the one able to deliver the project at the least life cycle cost, the earlier possible time, and with high quality. To select a method with such characteristics, the agency suggests starting with a list of the project goals, and then looking into the proposed factors that could impact the delivery method decision. The manual links each of the proposed factors with the delivery method (among DBB, DB and CMAR) that best helps to accomplish it. However, the procedure falls short in combining these items, to adapt it to a multi-criteria decision process that usually involves trade-offs between multiple of these issues. The manual also fails to consider the impact of intrinsic characteristics of each project, by generalizing the choice of the "best-fit" delivery method for each issue. In a project with the design in an advanced stage, it is not clear that DB would lead to the shortest possible schedule; or in a project where the scope is or can be well defined, it is not obvious that a DBB approach would be beneficial.

Other DOTs approaches

Many of the U.S. DOTs published Design-Build manuals that include guidelines to identify potential DB candidates. Virginia DOT published its Design-Build Procurement Manual in 2011. In this publication, the agency names "potential design-build projects", such as emergency and repair projects, those where it is necessary to maximize the use of available funding, or projects directly impacting public safety, supporting public development, or using innovative design and construction techniques. Florida DOT takes a similar approach by listing the types of projects for which a DB contract should be considered and those that are not good DB candidates. However, these lists contradict for some type of projects. For example, emergency repairs are good DB candidates for VDOT, but not for FDOT. It is understandable that repairs may need an accelerated schedule, and DB can provide this to the project. However, the numerous unknowns that usually characterize repairs can lead to difficulties to define project scope, and may results on over costs if the risk of uncertainties is completely shifted to the contractor.

Minnesota DOT, in its Design-Build Manual (2011), includes a section on "When to use Design-Build". It states that projects are good match for DB delivery method when acceleration is required, when there are opportunities to transfer the risk to the contractor, or where innovation is needed. It encourages the decision makers to base the choice of the delivery method on the goals and risks of the project, and to check previous MnDOT projects delivered as DB. Washington State DOT takes a similar approach in their Guidebook for DB Highway Project Development (2004), where the decision makers need to characterize project goals, potential benefits, and risks, and then determine if DB would be an appropriate delivery method. New York State DOT Design-Build Procedures Manual (2005) provides a list of factors that should be considered, and requires that the decision makers develop a decision paper for each DB candidate project, justifying the recommendation to use this delivery method. As seen, these publications serve the purpose of identifying decision factors that matter for public transportation agencies, but they do not give a structured methodology leading to a recommended delivery method.

Overall, none of these DOTs have a systematic and objective approach for deciding when to use DB strategy. The criteria are frequently broad and the decision is subjective. The teams are usually asked to justify the decision taken, instead of following a decision process. For example, in the New York State DOT (NYSDOT) Design-Build Procedures Manual (2005) it is stated that the Department will develop a decision paper for each DB candidate project, justifying the recommendation to use this delivery method. This kind of selection is often based on a list of typical projects that may be candidates for a DB. What is more, the lists are never all-inclusive and often present just examples of good DB candidates. Although some project characteristics are considered, they are not always combined with the agency current situation, needs or goals.

Quantitative methodologies

Quantitative methodologies for recommending a project's delivery method involve mathematical calculations that guide decision-making teams to make the best possible choice. In this section four quantitative approaches will be presented: University of Colorado's Web-based selector (1997); several publications applying the Analytical Hierarchy Process (AHP); the Construction Industry Institute PDCS tool; and Georgia DOT's method. All these approaches can be classified as Tier 2 in the TRB framework. They usually involve selection and weighting of the decision criteria as input data, being the weighting based on previous projects, as in Chen et al. (2010), or on expert's judgment (CII PDCS, 2003). The output consists of a score for each of the available alternatives, so they can be compared and the most convenient option can be detected. The quantitative methodologies detected usually share the decision factors with the qualitative ones already presented, but take the decision process one step further, making it less dependent on the decision maker. These processes create a more objective and repeatable process, instead of a guided discussion.

Colorado Web-Based Selector

In 1997 the University of Colorado developed a Web-Based selector to detect projects that are likely to succeed if delivered as Design-Build. The model is based on data obtained from retrospective surveys about completed DB projects (case studies). All surveys were distributed on the public sector, 85% of them belonging to building projects. Using the answers obtained, several regression models were tested to find the relationship between different project's measures and the likelihood of project success. Five models were finally developed, relating five measures with project success: Overall satisfaction, Administrative burden, Conformance to expectations, Schedule variance and Budget variance. Twenty-six project characteristics were found to be predictors of a project success, using one or more of the developed models. This tool consists of three input sections about the project characteristics, the ranking of the success criteria, and additional project information. The output compares average scores of the original case studies and the particular project score. These steps can be seen in Figure 5.

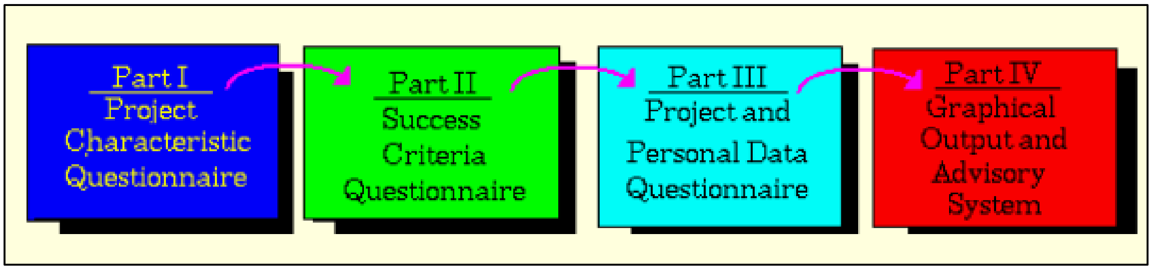


Figure 5. Design-Build Selector (DBS) process (University of Colorado, 2007)

The DB Selector presents an interesting research process, involving case studies instead of expert's input and considering a broad range of factors, although most of them related to public building projects. The tool also separates the project characteristics from the possible outcomes (success criteria). However, this last group does not represent the owner's main goals, but are the indicators that have been found to have the greater correlation with project success. Additionally, Colorado Web-Based Selector does not provide with a clear threshold to select DB as a delivery method and it does not compare it with any other method. For other entities to apply a similar method, a large database of DB projects needs to be available.

Analytical Hierarchy Process

Khalil (2002), Mahdi and Alreshaid (2005) and Mafakheni et al. (2007) presented delivery method selection procedures based on the Analytical Hierarchy Process (AHP). This multi-criteria decision making procedure consist on assigning relative weights to the decision factors using pair-wise comparisons. The factors are organized hierarchically: for example, Khalil defined as first level criteria "project needs", "owner's needs" and "owner preferences". Into each of those broad categories more detailed factors are included (see *Factors that drive the delivery method selection*). Once the criteria are selected, a pair-wise comparison is performed at each level. The relative importance of the elements of one level is determined comparing its ability to achieve the objective of the level immediate above. Those preference ratios are then used to calculate a score for each project delivery alternative. AHP methodology has the advantage of allowing the introduction of quantitative (such as price) and qualitative (like constructability) objectives at the same level. Also, great organization of criteria and sub-criteria is presented. However, numerous pair-wise comparisons need to be performed to make each decision, turning the method into a complex and time-costly procedure.

CII's Project Delivery Contract Strategy (PDCS)

The Construction Industry Institute (CII) published its Project Delivery Contract Strategy (PDCS) - Owner Tool in 2003. This methodology is based on Simple Multi-Attribute Rating Technique using Swings (SMARTS) decision making process (Anderson & Oyetunji, 2003; Oyetunji & Anderson, 2006). It was mainly developed for private industrial and building projects. It takes into account twenty decision factors and twelve different project delivery methods, reflecting the broad range of possibilities of private projects.

The first step in the tool development was to define the factors relevant to the decision to be made: thirty factors were identified and prioritized according to expert's input. Twenty of those were finally incorporated in the tool (Anderson & Oyetunji, 2003). The same procedure was followed to list the possible outcomes of the decision, and finally twelve delivery methods were included. A scores matrix linking decision factors and alternatives was developed including the aggregate knowledge of 32 project managers, grading each outcome (project delivery method) in relation to its ability to achieve each attribute, in a 0-100 point scale (i.e. answering “In what extent does the Traditional delivery method contribute towards ensuring the shortest schedule?”). A portion of the score’s matrix can be seen further on in this literature review (Table 6). This score’s matrix is built-in the model and is fixed across the different uses/projects.

The decision maker(s), to determine the most convenient delivery method for certain project, select the most important 4 to 6 factors from the list of 20 available, according to the project’s needs and objectives. The most important factor is assigned 100 points, and the following are ranked and scored according to their relative importance to the top criterion. Combining the scores that the decision-makers set as inputs and the experts-based scores matrix, an index is calculated for each of the twelve delivery methods. The tool ranks them and suggest reviewing the top three alternatives for suitability, although the alternative with the higher index would be the most convenient to contract the project. The suitability review should include compatibility with the level of design completion, level of owner’s control effort and business risk associated. In a following step, compensation approaches (or contract strategies) associated within the chosen delivery method can be revised too, to select the most appropriate. The selection may be influenced by corporative culture, statutory limitations, or level of familiarity with some approaches. The flowchart of the tool stating these steps can be seen in Figure 6.

The CII PDCS technique is considered objective and require significantly less user effort than the AHP process, given that the expert’s scores matrix is given. The subjectivity is reduced to the relative scores of the factors, which is appropriate to reflect the different priorities and owner’s objectives for each project. The process has been formalized as a MS Excel Spreadsheet, which makes it easily understandable and flexible to changes incorporation. However, the accuracy of the final decision relies in the development of the scores matrix, which entails expert's input. These scores should be revised and adjusted for different owners, situations and type of projects.

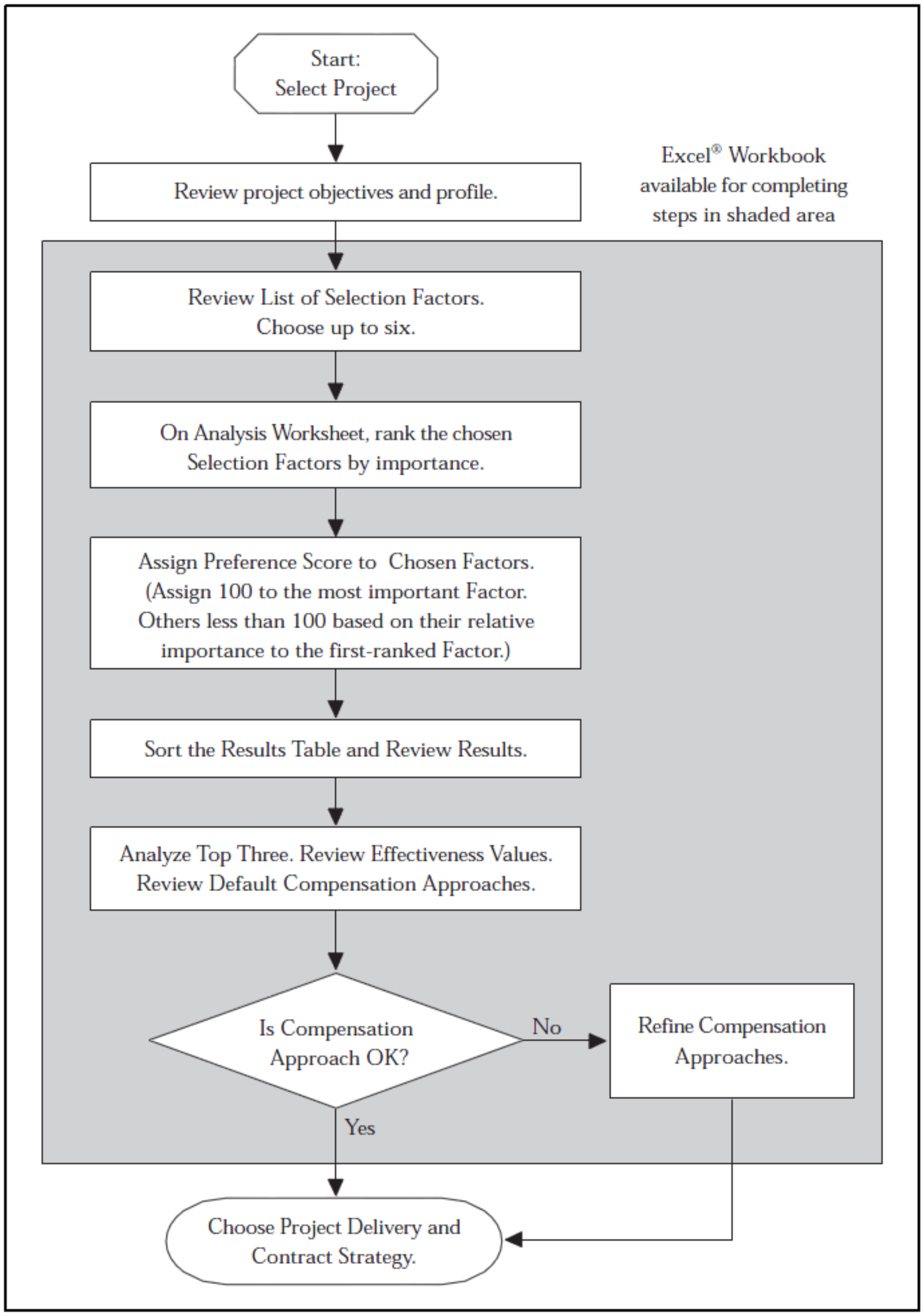


Figure 6. CII PDCS process flowchart

Georgia DOT tool

Georgia DOT developed in 2012 a JAVA applet tool with the purpose of assessing the appropriateness of a project to be delivered as Design-Build. The tool doesn't compare several delivery methods, but scores the project in a 0-100 scale according to its suitability for Design-Build. The first step for the decision-maker(s) is to define the agency's strategic objectives and the project characteristics and goals. Then, a series of questions evaluate deal-breaker issues, with the objective of discarding DB if one or more of the requirements are not met. In order to be a DB candidate, the project has to meet:

- Legal & Statutory Requirements
- Agency Resources and Experience
- Project Funding
- Leadership Support (such as public endorsement)
- Design Build Marketplace Conditions (availability of qualified teams)

If the project meets these five characteristics, a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is performed in seven fixed areas: Schedule, Cost, Quality, Level of Design, Innovation, Staff Experience and Marketplace conditions. The applet guides the user through all seven areas. Strengths and weaknesses are scored on a 1-10 scale with strengths receiving a positive score and weaknesses a negative score. Opportunities and threats are scored on a 1-5 scale with opportunities receiving a positive score and threats receiving a negative score. Figure 7 shows a screenshot of the tool where the user has to select the strengths of the project regarding 'Quality', and rank in a 1-10 scale the effect of those strengths in the project. This process has to be repeated 28 times, considering the 7 areas and the 4 issues (strengths, weaknesses, opportunities and challenges). To finalize the process, the user has to allocate a total of 100 points among the seven areas, to reflect the main objectives of the project and the agency.

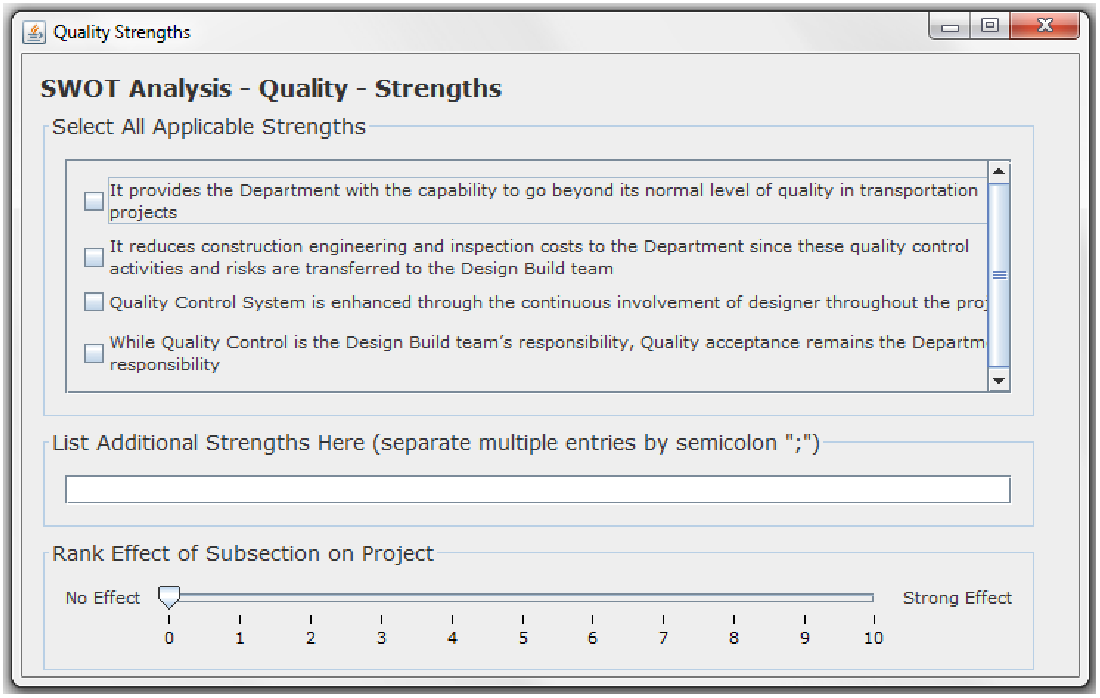


Figure 7. Screenshot of GDOT Java Applet Tool. Area: Quality. Issue: Strengths

Overall, the novelty of the method is the introduction of the deal-breaker issues, to detect barriers to the implementation of the delivery method up-front, and save the decision-makers' time. On the other hand, the tool is hard to adapt to different project's needs or agency's objectives, since the seven areas of evaluation are fixed. Its rigid structure is also reflected in the fact that it is a JAVA Applet, which difficult the introduction of changes and the audit or review of the logic. Additionally, the life-span of the tool may be short if GDOT is considering the incorporation of other delivery methods besides DB. Finally, the tool is time demanding and complex, given that users have to introduce 35 scores to receive the outcome.

Summary and Conclusion on existing methodologies

The presented tools and guidelines are a general panorama of where the different agencies and DOTs stand in the development of delivery methods selection methodologies. Some procedures guide the user through the development of scores or qualitative discussions; while others help teams justify a decision when it is already taken, such as the AASHTO Guide or the NTTA Manual. All the methodologies accurately recognize the factors that drive the decision, although only some approaches link those factors with the project's objectives. Some methodologies, like CDOT, take into consideration the most common goals but fail to differentiate the projects in a detailed fashion, according to their characteristics.

Methods vary regarding simplicity and time needed for the decision process. CDOT offers a guided discussion that can be completed in no more than a 4-hour workshop. For using the GDOT tool, on the other hand, users have to introduce 32 scores and need a deep understanding of the functioning of the applet. This difference in flexibility and qualitative/quantitative measures comes together with the objectivity provided by each method and its ability to propose and document a decision independently of the decision making team. CII and GDOT's approaches are more objective methods, as they involve quantitative measures. On the other hand, CDOT's structured discussion may be subjective and dependable on the decision team.

All the methodologies were reviewed with members of TxDOT. The team found that none of these tools presents an objective and transparent process that is also suitable for public highway projects. This situation reveals the need to develop a customized model suitable for infrastructure transportation public projects, including each entity's goals, most common project characteristics, and legislative authority.

This customization procedure is the one followed to meet TxDOT needs. The first step towards the TxDOT model is to gather all the factors that the different literature and decision methodologies detected as criteria that drive the delivery method decision. Following, these criteria needs to be selected according to the agency's needs and most common project characteristics.

FACTORS THAT DRIVE THE DELIVERY METHOD SELECTION

In this section, the decision criteria used by different methodologies will be compiled, with the purpose of condense them into a single catalog to be used as the starting point for the development of TxDOT's –or any other – decision tool. Literature and decision-support methodologies from where to extract the major factors, criteria, o issues that most influence the delivery method decision at the project level are abundant. The number of factors varies among methodologies from simple approaches selecting 4 or 5 criteria –such as in 2012 Colorado DOT (CDOT) approach–, to more complex analysis involving more than 30 criteria (Mahdi and Alreshaid, 2005). Some of the studies order the different factors hierarchically (TRB Tiered approach, 2009; Khalil, 2002; Mahdi and Alreshaid, 2005; Gordon, 1994) while others simply list them at the same level (Colorado DOT, 2012; Georgia DOT, 2012; CII PDSM, 2003). This factors' review is organized in two sections: factors extracted from existing decision methodologies, and factors from academic literature.

Factors from existing methodologies

The TRB Tiered approach, base all its 3 phases on 24 factors, grouped in 5 categories or "issues": Project-level, Agency-level, Public policy/regulatory, Lifecycle, and Other. These factors have been selected based on nine case studies analyzed with on-site interviews. Of those case studies, 5 were delivered as DB contracts, and the same number were rail/light rail related projects.

Colorado DOT methodology incorporates the eight factors that can be seen in Table 1, and request the user to choose 4 or 5 for a first assessment. However, the remaining factors are evaluated too, at least in a pass/fail basis, to ensure that they don't clash with the delivery method selected. It should be highlighted that the user does not assign relative weights to these factors (besides selecting the 4 or 5 more important ones), and the tool considers that all of them are equally important when summarizing the benefits in a matrix for the team to select a delivery method.

Table 1. Colorado DOT PDSM's factors

1. Delivery Schedule	2. Perform Initial Risk Assessment
3. Project Complexity & Innovation	4. Staff Experience/Availability (Owner)
5. Level of Design	6. Level of Oversight and Control
7. Cost	8. Competition and Contractor Experience

CII approach lists 20 factors, among which the user should chose up to 6 to include in the decision process. These factors can be seen in Table 2. Besides selecting some factors, the user has to rank them and assign a "preference score", in a 1-100 scale. This score is used afterwards to weight the influence of each factor when calculating the rating of each alternative.

Georgia DOT assesses the Strengths, Weaknesses, Opportunities and Threats of the project in seven areas: Project delivery schedule, Innovation, Level of design, Project delivery cost, Quality, Staff experience, and Marketplace conditions, competition and design build team experience. The users have to address all seven factors and then assign them priorities.

Table 2. CII PDCS Selection Factors

<table>
<tr><td>COST FACTORS</td><td>OTHER FACTORS</td></tr>
<tr><td>- Control cost growth
- Ensure lowest cost
- Delay or minimize expenditure rate
- Facilitate early cost estimates
- Reduce risks or transfer risk to contractor (s)</td><td rowspan="3">- Ease change incorporation
- Capitalize on expected low levels of changes
- Protect confidentiality
- Capitalize on familiar project conditions
- Maximize Owner's controlling role
- Minimize Owner's controlling role
- Maximize Owner's involvement
- Minimize Owner's involvement
- Capitalize on well-defined scope
- Efficiently utilize poorly defined scope
- Minimize number of contracted parties
- Efficiently coordinate project complexity or innovation</td></tr>
<tr><td>SCHEDULE FACTORS</td></tr>
<tr><td>- Control time growth
- Ensure shortest schedule
- Promote early procurement</td></tr>
</table>

The North Texas Tollway Association (NTTA) doesn't recommend a certain decision process, but lists several factors that should be taken into account: Quality, Schedule, Cost, Risk assessment, Owner's preferences, Ability to define scope, Project complexity and Stakeholder issues. However, the way these factors should be integrated to make a multi-criteria decision is not part of their guidelines. The same applies for NYSDOT, where the decision makers need to justify the selection considering certain factors, but not formal procedure is given. NYSDOT's criteria includes: time, clarity of scope, flexibility, innovation and creativity, status of design, approval requirements, cost, environmental issues and potential proposal costs and stipends.

Khalil (2002), Mahdi and Alreshaid (2005), and Mafakheni (2007) use AHP as the decision methodology. To reflect the hierarchy of the process, they list major categories that further divide into additional criteria. In the first study, the major areas and sub-criteria are: (1) project characteristics; (2) owner's needs, and (3) owner's preferences. All subcategories can be seen in Figure 8. Mahdi and Alreshaid (2005) use seven main criteria and 34 sub-criteria, which can be seen in Table 3. Finally, Mafakheni (2007) concluded that the major factors that drive the Delivery Method selection are cost, schedule, quality, complexity, scope change, experience, value engineering, financial guarantee, risk management, uniqueness, external approvals, project size, and culture.

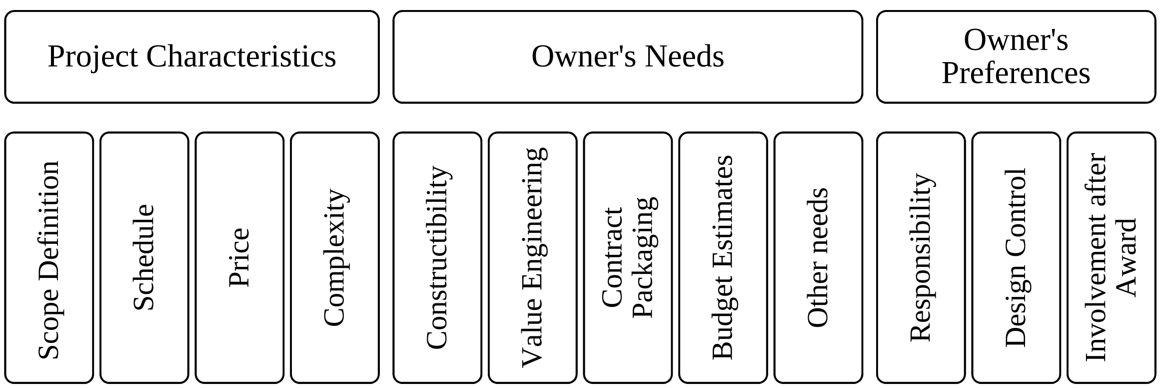


Figure 8. Hierarchy design for the project delivery selection model (adapted from Khalil, 2002)

Table 3. Factors considered in DM selection (adapted from Mahdi and Alreshaid, 2005)

OWNER CHARACTERISTICS	PROJECT CHARACTERISTICS	DESIGN CHARACTERISTICS
- Owner understanding the project scope - Owner control over design - Owner benefits from cost saving - Owner involvement in project details - Applicability of the delivery options	- Precise cost estimate before contract signing - Time reduction - Tight project milestone or deadlines - Cost saving - Project fixed budget - Precise definition of project scope - Project size and complexity	- Potential for design changes during construction - Design quality available in house - Flexibility to redesign after construction cost commitment - Effectiveness and constructability of the design
REGULATORY	CONTRACTOR CHARACTERISTICS	RISK
- Allowance for competitive bidding - Desired contractual relationship - Regulatory and statutory requirements - Complexity of decision making - Reduction in administrative staff - Enough experience to carry out the delivery option - Funding cycle	- Availability of experience for carrying out the delivery option - Familiarity and establishment - Contractor input in design - Experience needed for a particular delivery option - Construction quality - Coordination and communication - Clarity of defined roles	- Risk management improvements - Risk allocation CLAIMS AND DISPUTES - Claims and disputes between design and builder/single point of responsibility - Conflict of interest

Additional factors present in literature

Songer and Molenaar (1996) performed a survey among owners to detect the primary causes of DB selection. They found that public and private sectors do not differ in the factors considered to choose a Design-Build approach instead of the traditional method. The most important criteria mentioned by owners were schedule reduction, cost establishment and reduction, innovation, and schedule establishment. In most of the cases, public and private attitudes towards the factors to consider were similar. The same authors, in 1997, center their study in the use of DB in the public sector, performing surveys and interviews to agency's representatives. They concluded that the most important success criteria for an owner is staying in budget, conform to user's expectations and stay on schedule. As for the project characteristics, the most appropriate ones for DB projects are a well-defined and understood scope, adequate owner's staffing and construction sophistication, and an stablished budget (Songer & Molenaar, 1997).

Touran et al. (2011) researched the specific reasons in transit projects for the selection of an alternative delivery method, relaying on case studies. Their findings are summarized in Table 4. Regarding risk involved in selecting a DB delivery method, Tran and Molenaar (2013) collected data from highway projects' professionals all across the U.S. They found that the primary reason for DB selection is the time saving. The research studied 39 risk factors and reduced them to the seven ones that have the greatest influence on DB selection: scope risk, third-party and complexity risk, construction risk, utility and ROW risk, level of design and contract risk, management risk and regulation and railroad risk.

Table 4. Pertinent issues in PDM selection in transit (adapted from Touran et al., 2011)

Project-level Issues	**Agency-level issues**	**Public policy/ regulatory issues**	**Life Cycle issues**
- Project size/complexity - Cost - Schedule - Risk Management - Risk allocation - LEED Certification	- Agency experience - Staffing required - Staff capability - Agency goals and objectives - Agency control of project - Third party agreement	- Competition - Disadvantage business enterprise impacts - Labor unions - Fed/state/local laws - FTA/EPA regulations - Stakeholder/ community input	- Life cycle costs - Maintainability - Sustainable Design/ construction goals **Other issues** - Construction Claims - Adversarial relationships

Gordon (1994) and Ghavamifar and Touran (2009) present two innovative approaches. The first study list the criteria in decreasing importance, and states that the delivery method selection should be made by eliminating alternatives that can’t fulfill the needs assessed in the list. This filter should be applied in the order that the factors were presented: project, owner, and market drivers, as can be seen in Figure 9.

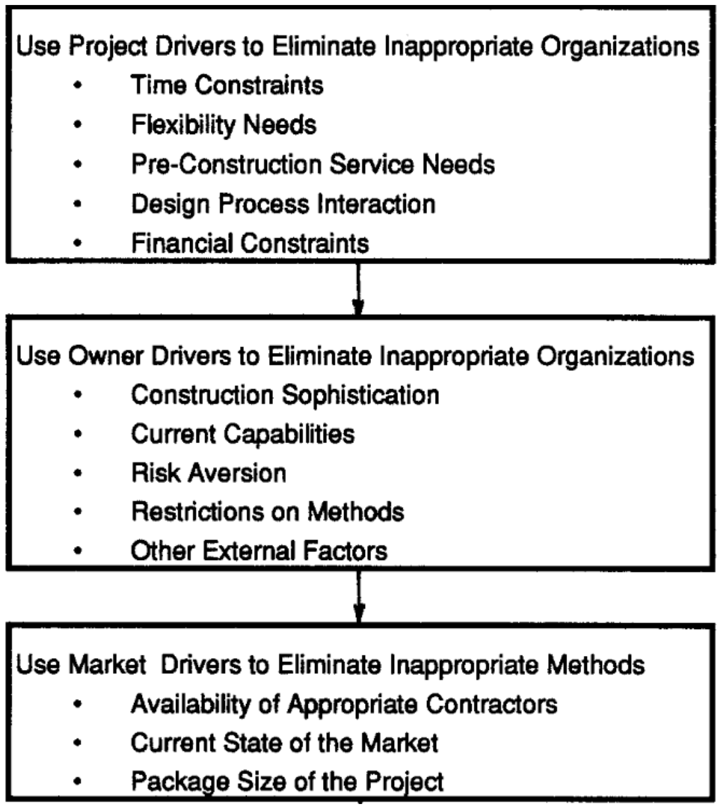


Figure 9. Factors or “Drivers” assessed in Gordon’s methodology

In the second innovative approach, Ghavamifar and Touran (2009) focus their research in the *project control* vs *risk transfer* tradeoff that owners face when selecting a delivery method. Through the traditional delivery method, the owner retains more control over the project, but also holds the major risks. At the other end, the DB methodology allows the owner to shift the risk to the contractor, in exchange for bidding the project on the base of a defined scope and a preliminary design, instead of a complete set of plans and specifications. Figure 10 represents the trade-off levels for the three most used delivery methods.

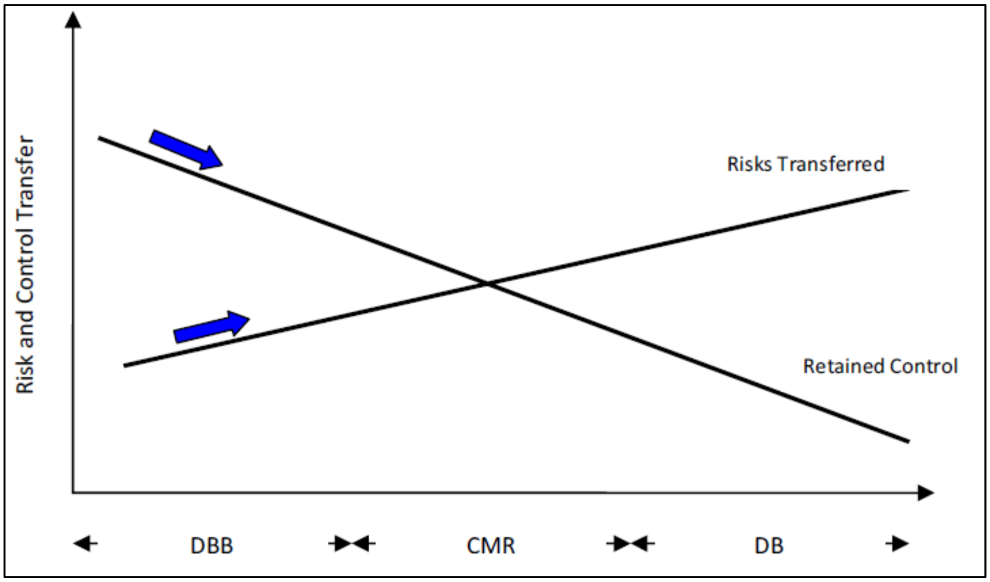


Figure 10. Risk and control transfer in different DM (Ghavamifar and Touran)

Koppinen & Lahdenpera (2007) specifically centered in road projects. In their study, they state that the delivery method decision should be based on the economic efficiency of each alternative. They made an extensive literature review, as well as surveys, to detect the criteria used to select the project delivery method. They came with 19 factors and additional sub-criteria, being cost, schedule, quality, and project team the most repeated characteristics across the studies.

Creedy et al. (2010) center their studies on the risk factors that lead to cost overrun, specifically to highway construction process. They found that the five principal cost overrun factors, in order of relevance, are: design and scope change; site conditions; deficient documentation, owner project management costs, and services relocation.

Decision factors summary

Different types of decision procedures and literature provided with a broad list of factors affecting the delivery method decision. The majority of the sources studied combine three types of factors in their decision criteria:

- Project goals, such as meeting schedule and cost targets;
- Owner characteristics, like Staff Experience/Availability; and
- Project characteristics, such as need for design-contractor integration, ROW acquisition or level of scope definition.

Some variation exists in the factors considered by each method, although many are repeated. The variation has its reasons in the fact that the diverse methodologies target different kind of projects and owners. Although Songer and Molenaar (1996) found that public and private sectors do not highly differ in the factors considered to choose DB, differences have been seen in the lists provided by different studies. For example, the factors included in CDOT or GDOT methodologies are a more consolidated list that those presented in academic papers, since most probably a broader list was filtered and revised to match, in each case, the agency's needs and more common objectives.

As a result of the extensive literature review, a list of 34 factors was extracted and classified into 6 categories: Cost, Schedule, Changes, Project Characteristics, Agency Needs, and Risk factors. The full list of factors can be seen in Table 5. This list serves as a starting point for the selection of the most applicable decision criteria, which will finally be a different list for each entity. A selection of factors, starting from this consolidated list, was finally incorporated in TxDOT's decision-support tool.

Table 5. Factors extracted from Literature Review

COST			
1	Lower total project cost	4	Unfavorable marketplace conditions
2	Expenditure rate/Agency financial capacity	5	Influence of procurement cost
3	Maintenance costs		
SCHEDULE			
6	Criticality of schedule	7	Schedule acceleration
CHANGES			
8	Project flexibility	10	Low level of design
9	Clarity of scope	11	Advanced level of design
AGENCY			
12	Agency involvement and control	15	Agency inexperience
13	Development of institutional knowledge	16	Agency high workload
14	Agency experience	17	Agency low workload
PROJECT CHARACTERISTICS			
18	Innovation	23	Coordination challenge
19	Best value	24	Project size
20	Flexibility in quality control	25	Prescriptive specifications
21	Familiar project conditions	26	Contract award process
22	Traffic delays		
RISK ELEMENTS			
27	Likelihood of cost growth	31	Uncertain site conditions
28	Likelihood of schedule growth	32	Third party agreements
29	Likelihood of disputes and claims	33	Acquisition of ROW
30	Public opinion	34	Unidentified Utilities

RELATIVE EFFICIENCY OF ALTERNATIVE DELIVERY METHODS

With the objective of developing a structured, objective and quantitative decision-support tool, validated numerical measures of the performance of each delivery alternative are needed (Oyetunji & Anderson, 2006). The present TxDOT legislative situation leads this study to focus on three delivery methods: DBB, DB and CMAR. In this section, the literature comparing these three delivery methods is presented. Even though the decision on the preferred methodology should be made at the project level, some authors intended to find correlations between certain delivery method and specific project outcomes, regardless of the projects' characteristics. Besides these performance scores, the methodologies used to obtain the quantitative data was be reviewed as well.

Several studies have been conducted to compare the traditional DBB methodology with the second most used delivery method in non-residential construction projects: Design-Build (Duggan & Patel, 2013). Most of the studies highlight the advantages of the DB methodology, and conclude that DB is a more convenient approach in the majority of the cases (Hale et al., 2009; Shrestha et al., 2011; Warne, 2005; Konchar & Sanvido, 1998). However, the results obtained are not always statistically valid or take into consideration a specific type of projects, which limits its general applicability. Studies are not so abundant regarding CMAR methodology. Only 13 US States had full authority to use CMAR methodology by 2012 (FHWA Division Office Survey 2012). The regulations in most of the U.S. DOTs do not allow using this methodology in public projects yet, so sample public projects to use as experimental evidence are not easy to find.

Important differences can be found among various types of construction projects. Effectiveness of a method in building construction does not mean that the method is the most suitable for highway projects. The same differences apply for public and private owners, and even between different public agencies. However difficult to make generalizations, some studies attempt to study patterns.

Findings

Some studies obtained quantitative measures of the relative performance of different delivery methods. CII's PDCS (2003) developed its "relative effectiveness values" matrix based on the experimented judgment of project managers (Oyetunji & Anderson, 2006). To minimize errors regarding each specialist's limited experience, thirty-two project manager's expertise was collected individually in a first stage. This activity prepared the specialists and served as a starting point for discussions on future workshops. The team opted for behavioral aggregation (Oyetunji & Anderson, 2006), so the knowledge was ratified through six "decision workshops" were consensus has been reached. The final values were obtained with a 10 points margin of error, which was considered acceptable. A sector of the "relative effectiveness values" matrix, which is part of CII's PDCS tool, can be seen in Table 6. CII found that the traditional DBB method and the "Fast-Track" one were the best ones for "delaying or minimizing expenditure rate". As for ensuring the shortest schedule, DB, Turnkey and Fast track methodologies were given the maximum score.

Hale et al. (2009) and Konchar and Sanvido (1998) studied US Navy's building and other 300 building projects across the US, respectively. They both found that DB was more convenient than DBB methodology both in cost and schedule.

Table 6. Sector of CII PDCS score matrix

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
		Control cost growth	Ensure lowest cost	Delay or minimize expenditure rate	Facilitate early cost estimates	Reduce or transfer risks to contractor(s)	Control time growth	Ensure shortest schedule	Promote early procurement
PDCS 1	Traditional D-B-B	80	90	100	0	80	20	0	0
PDCS 2	Traditional with early procurement	50	100	70	20	50	50	50	90
PDCS 3	Traditional with PM	80	70	90	10	60	20	10	0
PDCS 4	Traditional with CM	80	70	90	10	60	20	0	0
PDCS 5	Traditional with early procurement and CM	50	60	60	20	20	50	40	90
PDCS 6	CM @ Risk	60	40	40	70	70	70	80	100
PDCS 7	Design-Build (or EPC)	90	80	10	90	90	90	100	100
PDCS 8	Multiple Design-Build	70	80	30	80	80	80	90	100
PDCS 9	Parallel Primes	0	0	50	20	10	0	90	80
PDCS 10	Traditional with Staged Development	0	0	60	0	0	0	60	50
PDCS 11	Turnkey	100	80	0	100	100	100	100	100
PDCS 12	Fast Track	40	40	100	60	0	80	100	100

Other authors' effort to prove the benefits of a certain delivery method failed to find statistically valid conclusions, but demonstrate tendencies that are worth to mention, especially those referred to public highway projects. Warne (2005) studied 21 highway projects delivered using the DB methodology. The study highly advises the use of DB, but the quantitative information supporting the recommendation is considered subjective: the methodology of gathering the data consisted on asking how much time/budget the project would have been taken if delivered with other method. Shrestha et al. (2011) compared DBB and DB delivery methods for highway projects above $50M. They found that the projects delivered under DB methodology have better performance than DBB projects in terms project schedule, with faster delivery speed and construction speed per lane. However, no difference was found in change orders' quantity or cost, neither in cost related factors.

On the other side, Ibbs et al. (2003) challenged the general preference for DB that the other studies were based on. According to the analysis of 67 CII projects delivered using DBB and DB methodologies, the advantages of DB were clear regarding time savings. However, no relationship was found between the delivery method and the cost savings and work productivity. The authors conclude that the DM chosen is not a main factor for project success. Instead, the final performance of a project highly depends on the performance and experience of the owner and contractor, the communication among them, and the clarity of the specifications and scope of work.

Conclusions

Overall, efforts regarding the relative advantages of alternative delivery methods have been focused mainly on Design-Build, as the most powerful alternative to the traditional method. Statistically valid data obtained was primarily based on military and industrial construction. Public highway projects studied yielded weak statistical evidence of the relative performance of the delivery methods. It can be concluded that performance scores should be collected in specific relation with the entity delivering the projects, their staff and experience. Also, those scores should be related to the type of project being constructed. Too many factors affect each delivery method performance for general conclusions to be made. Each project performance will depend on the combination of all present issues, and are not always in direct relationship with the delivery method procedure. Overall, Delivery Methods performance needs to be specifically assessed by entity and project type.

In conclusion, new data should be collected specifically related to the TxDOT projects, in order to build a quantitative tool reflective of TxDOT expertise. The tool to be developed cannot depend in studies involving all type of public and private projects; it needs to capture TxDOT team’s wisdom, as there is in-house experience on DB projects available. Agency's experience and procedures will be highly determinative of the level of achievement of the objectives with each delivery method.

LITERATURE REVIEW GENERAL FINDINGS

The research done shows that the decision tools preferred by different owners vary in a wide range: from objective and detailed decision matrixes such as CII's PDCS (involving 20 factors and 12 delivery methods), to simple guidelines listing the factors and projects type that should be considered when selecting a delivery method. The reviewed methodologies imply different ranges of effort, time invested, and quality of the outcome, and all of them are meeting the developers' needs. However, the variety encountered is not equally broad in relation to the factors considered in the delivery method decision process. All of the tools include Cost and Schedule among its mains factors, and most of them put emphasis in Innovation and Risk factors.

Some general conclusions have been made regarding the relative efficiency of different delivery methods for achieving project goals. However, each method's real ability to predict a project's success should be evaluated by the agency involved in the decision process. Previous experiences in each organization can lead to worthy conclusions that would be missed if seeing the big picture or the mix of experiences of various owners.

Challenges

Overall, the literature review done shows the decision tools currently available for owner's use. As seen, those tools are usually (and should be) owner customized, representing a particular organization's main objectives, needs, and common characteristics of its projects. For this reason, the methodologies presented and the factors more commonly considered can only be used as a starting point from which to develop a decision tool that suits each owner's needs and priorities. Differences with other entities can be huge: for example, TxDOT maintains a considerable staff of designers and engineers, while other DOTs mostly outsource their design tasks. Other differences, such as market conditions, experience, main actors and stakeholders, and type and size of projects should be taken into consideration too.

Therefore, the challenges are: (a) to create a methodology that allows to take advantage from the existing tools' features and criteria and to customize them to fit individual owners' and projects' needs; and (b) to apply that methodology in the creation of a customized TxDOT decision-support tool, valid for their specific highway projects. Other agencies aiming to develop a decision process should take a similar approach, adapting these findings to their specific situation.

Chapter 3: Research methodology

With the objective of developing a decision-support tool to detect the most suitable Delivery Method for each TxDOT project, a research process was developed. This process was based in the information obtained in the literature review, regarding the different criteria used and selection methodologies available. The Literature Review uncovered many of the existing delivery method decision-support tools, some developed for the private sector (such as CII PDSM), while others made by public agencies (like CDOT). However, none of these efforts adapt to TxDOT current practices, needs or legislative authority. The literature review also uncovered the multiple factors that affect the Delivery Method decision. The design of TxDOT's decision-support tool needs to incorporate these conflicting criteria and to represent the complete spectrum of TxDOT projects' characteristics and objectives. The research process designed to cover these needs is represented in Figure 11.

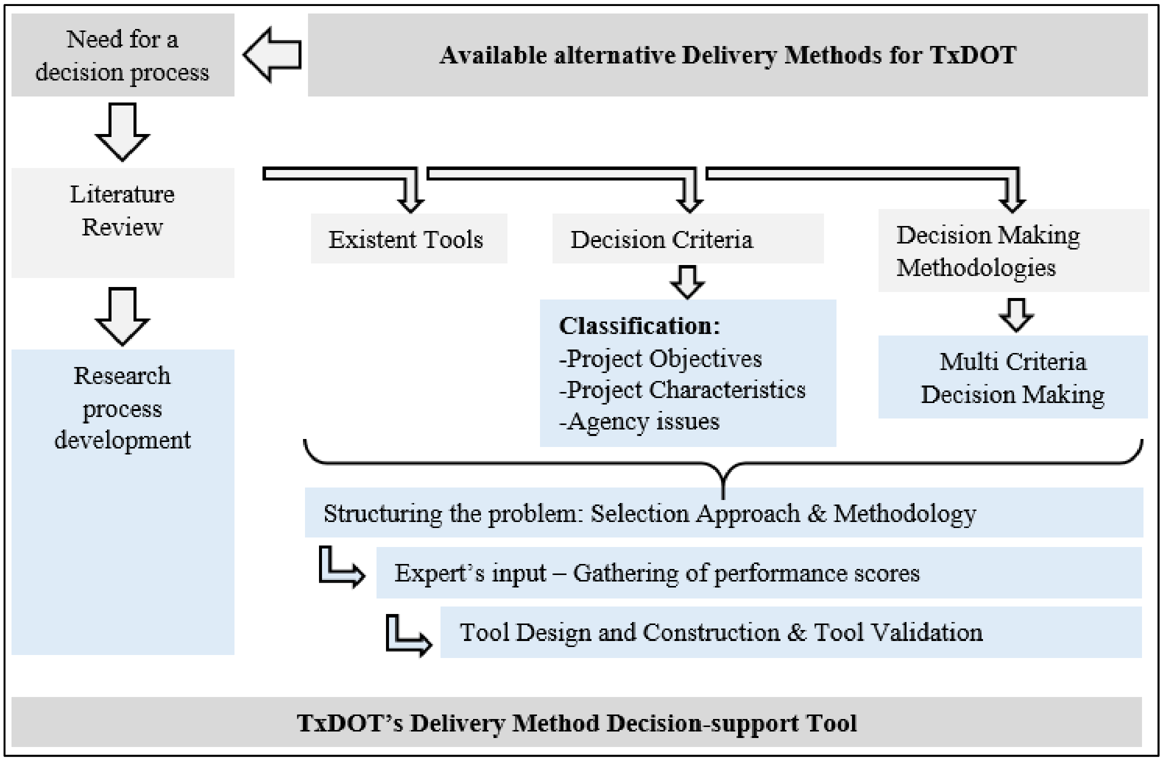


Figure 11. Research Methodology flowchart

RESEARCH DEVELOPMENT PROCESS

The research process for the development of this decision support tool is divided into 7 phases. The steps followed and the methodology for each one can be seen in Table 7. In the following sections, details of each of the phases will be presented.

Table 7. Research Process

	PHASE	METHODOLOGY / OUTPUT
1	Statutory Review	Obtain decision alternatives: Delivery methods available. *(See Chapter 1: Introduction)*
2	Literature Review	Obtain preliminary decision criteria.
3	Final Decision Criteria	Project characteristics and objectives selected together with TxDOT personnel.
4	Project Delivery Method Selection Approach	Decision Making Methodology: Application of a Multi Criteria Decision Making procedure to TxDOT problem
5	Scores Matrix Development	Scoring of Alternatives: How each Delivery Method contributes to the achievement of the objectives, for different project characteristics. Scores are specifically adjusted for TxDOT experience.
6	Tool Building	Development of MS Excel Spreadsheet tool for implementation.
7	Tool Validation	Case-studies based calibration to ensure tool's validity.
8	Research Deliverables	- Thesis Report - MS Excel Tool - User Guide

STATUTORY REVIEW

A TxDOT statutory review was performed on the first place, with the objective of detecting the agency's present limitations and the delivery alternatives to include in the tool. This review uncovered that limitations regarding cost or quantity of DB projects were soon to be out of effect, and the method should be included in the tool at its full potential. However, CMAR was not a delivery method available to the agency yet. Finding details can be seen in Chapter 1.

LITERATURE REVIEW

The literature review covered three types of studies: (1) those describing the existing decision processes, (2) those determining the most common criteria used; and (3) research regarding the relative efficiency of different delivery methods. The first type was intended to uncover tools or processes adequate for decision-making affecting public projects with diverse characteristics. These methods may help develop or inspire the type of procedure needed for TxDOT or any other public agency seeking for decision-making aid. The second type served as the starting point for selecting the decision criteria specifically affecting construction delivery methods. These factors can be further refined to specifically target public projects, transportation jobs, and finally reach those applicable to for TxDOT's projects. Finally, relative efficiency of different delivery alternatives was investigated to obtain quantitative measures of their performance.

Keywords used for the search included: Multi Criteria Decision Making, Design-Bid-Build / Design-Build, Delivery Methods selection criteria, Delivery Methods comparison, Highway projects Delivery Methods, etc. Details on the results obtained were presented in Chapter 2: Literature Review.

FINAL DECISION CRITERIA

The final decision criteria have its origins in the 34 factors identified during the literature review (See Table 5 in Chapter 2: Literature Review). Following Olson's (1995) recommendation, since the decision alternatives were defined a priori due to legislative regulations, the research team used a bottom-up approach to organize the criteria list. This method consists of identifying those factors that affect each of the alternatives, making them good or bad choices. This way, only the real differentiators were taken into account: criteria that help distinguish between the alternatives. Finally, a list of fully applicable criteria for TxDOT highway projects was generated.

Two different types of criteria were identified: Project's characteristics and project's objectives. Therefore, the factors extracted from the literature review were classified accordingly. The different project characteristics and their degree of applicability are capable of describing a broad range of TxDOT infrastructure projects. Once the project scope is defined, its characteristics are fixed too. On the other hand, project objectives reflect the agency's goals and priorities for this particular project. This is not intrinsic to the project and may vary for different agency's situations. The grouping guidelines can be seen in Figure 12.

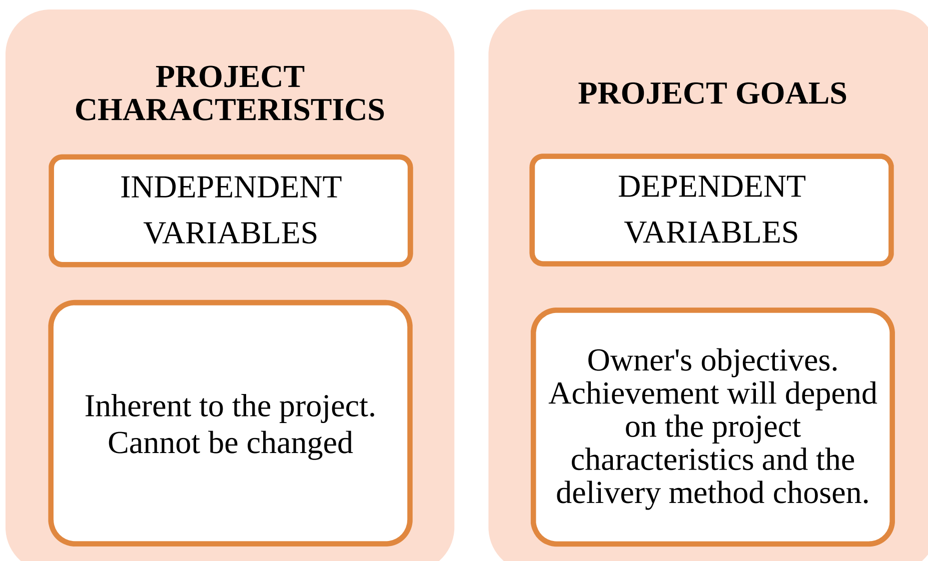


Figure 12. Classification of decision criteria: independent and dependent variables

The selection and classification of criteria incorporated the collective wisdom of the TxDOT team, to ensure the fulfillment of the agency's needs. This activity was performed in periodic meetings with the project team composed of representatives of UT, CTR, and TxDOT. The procedure alternated face to face meetings and conference calls. Also, partial individual reviews were performed by the different members of the team and then discussed as a group. TxDOT personnel's input was fundamental in this process to ensure that the selected criteria would meet the agency's needs and most common project characteristics. The tool is intended to be used at the project level, so it would not incorporate institutional goals that should be evaluated on the side. The research group determined that the delivery method for an individual project should not be based in long-term institutional goals, but should consider more measurable and project-level objectives. Finally, four main objectives and twelve project characteristics were selected to be incorporated to the tool. Details regarding the selection procedure and the final criteria will be presented in Chapter 4: Results.

PROJECT DELIVERY METHOD SELECTION APPROACH

The ultimate goal of the delivery method selection is to achieve project success through the accomplishment of the project's proposed goals. However, the performance of a project is highly dependent on its own characteristics, besides being influenced by the selected delivery method. The aim of the created decision-support tool is to model this complex relationship and to recommend the delivery method that most benefits the desired project objectives, knowing the applicable project characteristics. The relationship among these variables is represented in Figure 13. Two levels of criteria exists (project's objectives and project's characteristics), so the decision process needs to incorporate these conflicting criteria.

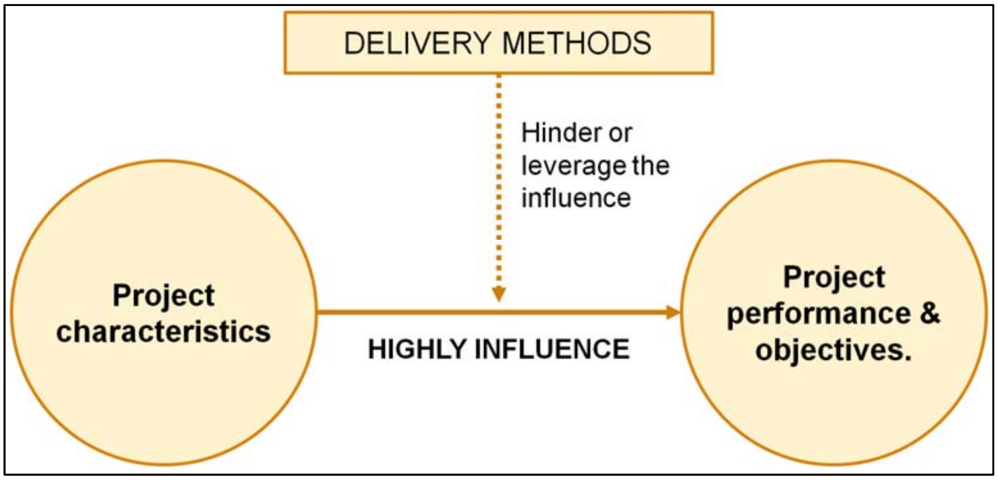


Figure 13. Factors that influence project performance

The criteria selected needs to be integrated into a single decision procedure that allows for the incorporation the complete spectrum of TxDOT projects' characteristics and objectives. A Multiple Criteria Decision Making (MCDM) process allows for this integration. Following, MCDM basic concepts will be presented, including its suitability as a methodology for creating a transparent and objective tool, adjusted to TxDOT needs, practices, and opportunities.

Multiple Criteria Decision Making

Tradeoffs between different objectives are inherent to all the complex decisions and across many disciplines. For this reason, decision support processes including conflicting measurable and non-measurable objectives have been widely studied. Each desired objective, and its relative importance compared to the remaining goals, represents a decision point for the user. These conflicts or tradeoffs can be solved in an objective and quantitative way under a MCDM framework using value functions. These functions, also called utility functions, calculate the value that each alternative *i* bring to the table in the following shape: $Value_i = \sum_{k=1}^{K} w_k * v_{ik}$, where K is the number of criterions, w_k is the relative weight of criterion k, and v_{ik} is the value that alternative i has on criterion k (Olson, 1995). Each of the alternatives considered will have for a particular project a different utility function value, which allows an objective and quantitative comparison that helps decision makers select among the available options.

This utility theory approach is adjusted to TxDOT needs since it is "an attempt to rigorously apply objective measurement to decision making" (Olson, 1995). If alternatives are compared in a rational unbiased manner, including their performance on concrete, measurable attributes, rigorous and more complete decisions are likely to result. The use of this methodology for the TxDOT customized decision-support tool allows the calculation of a quantitative score for each alternative, leading to an objective comparison of delivery methods and to a documented procedure. According to Olson (1995), the analysis of a multi-criteria problem requires multiple steps, including identifying and organizing objectives –what wants to be accomplished–, and then measuring how well each available alternative perform in order to fulfill the goals. This process, called problem structuring, will be explained in the following section.

Structure of the problem

The developed tool can be classified as a multiple attribute decision process, since it helps select among a limited number of pre-selected alternatives (Delivery Methods, in this case), each characterized by different attributes (Zanakis et al., 1998; Yoon & Hwang, 1995; Olson, 1995). To structure such a decision-support tool, two sets of scores are needed in relation to the selected criteria: *inter* and *intra* attribute comparisons (Zanakis et al., 1998). Inter-attribute are those comparisons made in between decision-factors, stating which one is more important to the decision maker or more applicable to the problem. Those scores were represented as w_k in the utility function, symbolizing the relative weights of different criteria.

On the other hand, intra-attribute comparisons score each decision criterion against a possible outcome or alternative (v_{ik}, in the utility function), grading how well the alternative i suits (helps achieve, overcome, etc.) the criterion k. These intra-attribute scores are translated into quantitative measures of the suitability of each delivery method for different project characteristics. The decision criteria incorporated in this process have to be independent, since the combined effect of all attributes should not double-count any characteristic.

Those intra-attribute scores, also called performance scores, were obtained in a collaborative effort with TxDOT officials to reflect the performance obtained using the agency's current practices. These scores characterize the relationship between the available options and the criteria and are built-in the model. Conversely, inter-attribute weighting is done by the decision makers each time the tool is used, since they reflect the most applicable project characteristics and desired objectives for a particular project. Inter-attribute weighting is the input for the developed tool. Finally, the tool's output consists of an aggregated score for each DM (the Value Function outcome), and a recommendation to adopt the alternative with the higher score. Details on each of the tool elements and how they were measured are explained in the following sections.

SCORES MATRIX DEVELOPMENT

The objective of the scores' matrices is to measure the combined effect of each delivery method and the different project characteristics on the desired project outcomes. These scores are what we called intra-attribute comparisons (v_{ik}, in the utility function), grading how the alternative *i* (DBB or DB) relates to the criterion *k* (each objective or characteristic). These scores are the basis for the final recommendation, since combined with the user inputs (project characteristics and goals relative weights) yield to a score for each DM. The scores matrixes (one for each delivery alternative) were specially adjusted for TxDOT. Scores were collected through two workshops involving agency's experts, each followed by phone interviews.

The experts were selected from diverse TxDOT divisions, as well as from contractors and consulting companies that usually work with the agency. This way, we can ensure that the scores represent the agency's most common practices, but also different experiences. The selection of the participants was based on their experience in both delivery methods available: all reflective practitioners with relevant experience were invited to participate. Regarding TxDOT participants, it was ensured that they come from different divisions and districts, representing all stages of projects. As for external experts, highly experienced people that usually work together with TxDOT were called to participate, including consultants, contractors and FHWA. The aggregated expertise of different specialists ensures a tool that is highly representative of the different TxDOT experiences. Details on the participants and workshops performed will be provided in the following sections.

Workshop #1

A first Workshop was conducted in April 2014 and consisted of two parts: firstly, the project's objectives and scope were presented, and afterwards the participants performed an individual scoring assignment. The activity, which included first-line TxDOT personnel, was focused on quantifying the relative benefits of each delivery method for different projects' characteristics and objectives. Since the scores gathered needed to be adjusted to the agency's experience and past project's performance, only experienced TxDOT personnel participated. The selected collaborators were in an ideal position to give quantitative output, since all of them had a long career inside TxDOT or in a company attached to the agency, different degrees of Design-Build experience, and a deep knowledge of the challenges faced nowadays by the agency.

Workshop #1 had nine participants, including district engineers representing North, East and South Texas areas, and division directors involving construction and strategic projects divisions. There were representatives of the four most populated Texas cities: Houston, Dallas/Fort Worth, San Antonio and Austin. The group comprised more than 250 years of experience inside TxDOT environment, which means more than 25 years of TxDOT experience for each respondent, on average.

The individual activity proposed consisted of scoring the 12 selected project characteristics across 4 project goals, for each of the two delivery methods.

Figure 14 shows an example of the activity worksheet used for the DBB scores. With the objective of refining the list of project characteristics, the list was open to suggestions, and during the activity one new characteristic was added: project complexity. Finally, all nine participants completed the activity shown in Figure 14.

Design-Bid-Build (DBB) Delivery Method

Measurement Scale:		
	++	Strongly positive
	+	Positive
	0	Negligible
	-	Negative
	- -	Strongly negative

☒ Please check the box if your response depends on other project characteristics or needs further discussion

	How will each of the **following project characteristics**, along with a **Design-Bid-Build delivery method**, contribute to each of the **project goals**?	PROJECT GOALS				Comments
	PROJECT CHARACTERISTICS	Lower capital cost	Higher Cost Predictability	Higher Schedule Predictability	Lower Capital Maintenance Cost	
1	Project has **well known site conditions** that won't cause significant field changes.					
2	The project might benefit from the introduction of **innovative methodologies** early in the planning/design phase.					
3	The **project design** (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.					
4	The project would benefit from **designer-contractor integration** that would reduce coordination challenges					
5	Prescriptive project requirements in methods, materials and/or procedures **limit contractor innovation** via alternates.					
6	The project's small size and budget make the procurement/bidding process uneconomical. Agency **procurement costs** would be an unacceptably high percentage of project costs.					
7	**Early completion** adds significantly extra value for key project stakeholders.					
8	The agency is better equipped to manage **third party issues**					
9	The project would benefit from **shifting the risk of third party issues** to the contractor					
10	**Completion date of ROW acquisition** is highly uncertain.					
11	**Utility relocations** have not been completely identified and may result in changes in the cost and/or the design of the project.					
12	The location, size and/or type of work has the effect of **limiting marketplace competition**.					

Figure 14. Workshop #1 Activity for DBB Delivery Method

The scoring was done following the scale shown in Table 8, reflecting the combined effect of the delivery method and the project characteristic on the desired goal. A 5 points Likert-type scale was used to rate each situation. This scale was chosen because it gives the experts the chance to accurately reflect all possibilities. If a certain project characteristic or delivery method is not considered to affect the project outcome, it allows the selection of a neutral effect on goal. For the cases where an effect is detected, there are two levels of impact from where to choose, to detect those characteristics/ Delivery Methods with a stronger impact on projects' goals. A 3-points scale would not allow for different levels of outcomes, and a 4-points scale would not include a neutral option. A 5-points scale added the needed accuracy without being over-complex.

Table 8. Workshop rating scale

Workshop scoring	Effect on Goal
++	Strong positive effect on goal
+	Positive effect on goal
O	Negligible
-	Negative effect on goal
- -	Strong negative effect on goal

Follow-on interviews

Phone interviews were performed with some of the participants of the first workshop. The main objective of these interviews was to better understand the impact of selected project characteristics on project outcomes. Understanding different perspectives allowed for the improvement of the characteristics' definitions and therefore the resulting selection tool. It was the purpose of the team to be sure to incorporate all available expertise into the list of project characteristics, agency's objectives, and numerical indicators.

During the phone interviews, the participants were specially asked to explain the characteristic *project complexity*, added during the first workshop. It has been found that the different descriptions obtained in the interviews responded to characteristics already incorporated in the original list. Respondents mentioned that complex projects are those with a non-standard type of design and construction, needing numerous permits and great number of parties involved. These descriptions overlap with many of the already incorporated characteristics, such as innovative methodologies, design-contractor integration and third party issues management. However, during the interviews it was uncovered that the permits issue was not fully covered, so this characteristic was added to the final list.

Additional changes were made to the characteristic's list. A modification originated in the first workshop and confirmed during the interviews was related to the ambiguity in the *marketplace competition* factor. It was pointed by experienced personnel that the competition generated by a project is not a differentiating factor. If the competition is limited, the goals are not likely to be met, regardless of the chosen delivery method. It was also found that marketplace competition is not an independent variable, since competition depends on project size and cost, innovation needed, level of difficulty, and location. Finally, the characteristics' wording was polished and definition of some terms added, to ensure the list was clear and that all users would interpret it in a consistent way.

Workshop #2

After evaluating the results obtained in Workshop#1 and in the performed interviews, the list of project characteristics was refined. A new Workshop was performed during February 2015 to obtain the scores for the polished list, as well as to enlarge the participation of TxDOT personnel and to incorporate external expertise. The new experts that participated in Workshop #2 increased the sample to 24 valid scores. From those, 16 were TxDOT members, 5 were American Council of Engineering Companies (ACEC) members, 2 were members of the Associated General Contractors of America (AGC), and the remaining participant was representing the Federal Highway Administration (FHWA). Proportions are shown in Figure 15. TxDOT participants represented the Fort Worth district, and the following divisions: Maintenance, Comprehensive Development Agreement (CDA) program, Engineering Operations for Metropolitan Districts and Engineering Operations for Rural/Urban Districts.

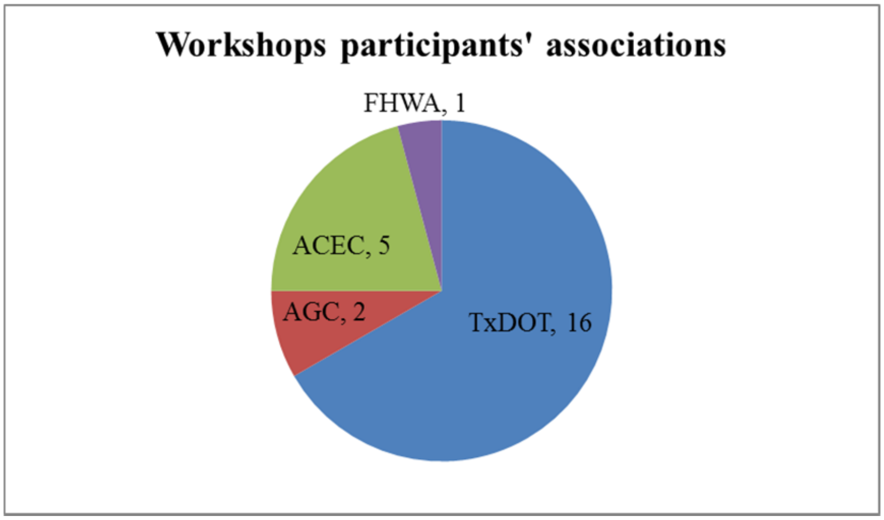


Figure 15. Participants for Workshop #2.

The average experience of the participants was 28.6 years in the transportation industry. All of them had experience in alternative delivery methods, and participants reunited experience in all phases of the project, including planning, procurement, design, construction and general management.

The second workshop had a similar structure to the first one: a presentation including a project overview followed by an individual activity to obtain the influence of different project characteristic and delivery methods on the project objectives. As in Workshop #1, the activity was designed dividing both delivery alternatives. The participants first scored the characteristics and objectives for the Design-Bid-Build alternative. Afterwards, they were provided with the Design-Build scores sheets, and completed the second part of the activity. This sequence was chosen to avoid a simple comparison and force the participants to site themselves in a specific delivery method scenario. A sample of the activity sheet is shown in Figure 16.

If the delivery method is to be Design-Bid-Build,

and using the following measurement scale:

++	**Strong positive effect on goal**
+	**Positive effect on goal**
0	**Negligible**
-	**Negative effect on goal**
- -	**Strong negative effect on goal**

Design-Bid-Build Scores Sheet

GIVEN the following project Characteristic:

1	The project has **well-known site conditions** that won't cause significant field changes.		
	How will this characteristic contribute to achieve …	**SCORE ↓**	Comments?
GOALS	**Lower capital cost**		
	Higher Cost Predictability		
	Higher Schedule Predictability		
	Lower Capital Maintenance Cost		

Figure 16. Workshop #2 Activity (DBB / Characteristic # 1).

Follow-on interviews

A second set of follow-on phone interviews was performed after the Workshop #2. These interviews had two objectives: gather missing background data about some of the participants, and confirm answers that were out of the expected range. Only the participants that were necessary to fulfill these objectives were contacted. The interviews were performed during March 2015. A total of 10 participants were contacted, and some scores were modified – mainly due to misunderstanding of the task – and other ratified. Including this modifications, the final scores' matrix was developed.

Aggregation of the scores obtained

The 24 valid scores obtained from different experts during the workshops were translated into quantitative measures following the scale presented in Table 9. These scores needed to be condensed into a single decision matrix representing all opinions and experiences. In a multi-expert decision making procedure there are two ways to aggregate the knowledge: (1) individual or mathematical aggregation, and (2) group based approaches, also named consensus or judgment aggregation (Tsiporkova & Boeva, 2006; Goodwin & Wright, 1991). Both methods have advantages and disadvantages, and there is no one more suitable for all conditions. Consensus allows for exchange of ideas and open discussion, getting the experts to negotiate on the final scores. However, if different hierarchy levels exist on the room, the decision may be biased towards the more powerful members (Tsiporkova & Boeva, 2006). This was the approach utilized to develop the CII PDCS tool, where Project Managers agreed on the final scores after several workshops.

Table 9. Workshop scores' scale

Workshop scoring	Effect on Goal	Corresponding score on matrix
++	Strong positive effect on goal	2
+	Positive effect on goal	1
O	Negligible	0
-	Negative effect on goal	-1
- -	Strong negative effect on goal	-2

Individual methods or mathematical aggregation take the individual scores and process them, for example using averages. According to Tsiporkova & Boeva (2006), "the individual-based decision models enable more adequate treatment of the individual expertise and preferences of the different participants in the decision process". This method is beneficial when experts from different organizations, backgrounds and experiences are participating: consensus is unlikely achievable but everybody's opinion needs to be reflected in the decision model. Since this is the case of the experts involved, and time constraints for the project and overloaded expert's calendars make consensus an impractical choice, mathematical aggregation was adopted for the TxDOT model.

Simple averages for the scores provided by the 24 participants formed the scores' matrixes. Other alternatives were evaluated, such as weighted averages or grouping of the participants according to their TxDOT division, their organization (TxDOT/External), and other criteria. But finally, with the experts considered a representative sample of TxDOT interests and experiences, and since they were carefully selected by the agency, it was determined that simple averages would accurately represent all experiences. Two matrixes, one for each delivery method, were arranged as in Figure 17. The matrix accommodates one score in each cell (v_{ik}, in the utility function), each one relating the impact of certain characteristic in one of the four selected goals, for a given Delivery Method.

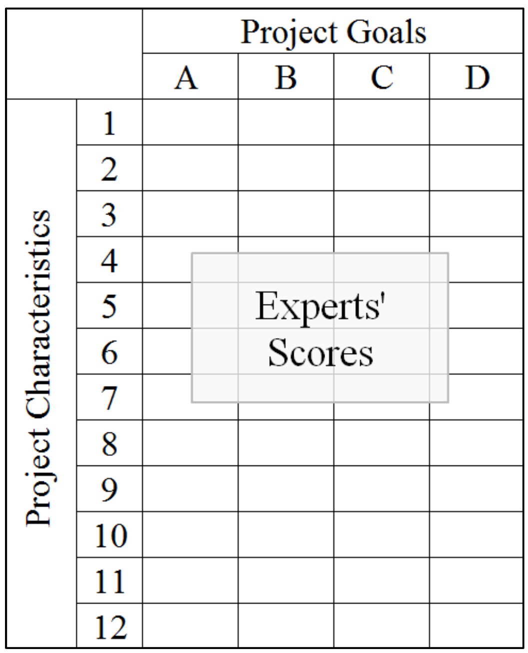


Figure 17. Sores' Matrix sample

TOOL BUILDING

The decision-support tool built, which gives a recommendation on the most suitable delivery method, needs two main inputs: project's characteristics and goals. Each one represents on the value function the relative weight of the different decision criteria. Figure 18 shows the decision process that was created. In step 1, the decision-makers need to assess the inter-attributes weights related to project characteristics, indicating the extent of applicability of each one in the project. Step 2 is also about inter-attributes weights, but regarding the objectives that want to be achieved and their relative importance. Finally, Step 3 presents the output and invites the decision-makers to analyze the recommended alternative. The decision support tool guides the user through these steps in a user-friendly and simple interface built as an MS Excel Spreadsheet. The tool allows decision makers to concentrate on the characteristics and objectives of the project to evaluate, without having to worry about the performance scores already built-in. Details on the tool sections and functioning can be found in Chapter 5.

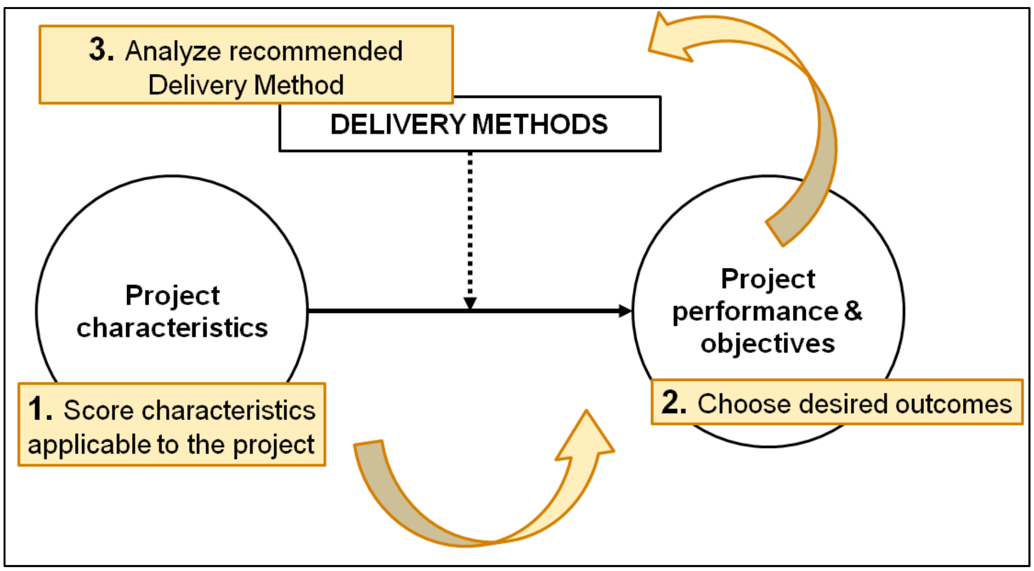


Figure 18. Decision Tool process

TOOL VALIDATION

Validation background

The value functions developed need to go through a validation process to assure that the decision-support tool produces recommendations that are aligned with the common sense and expectation of experts. Olewnik and Lewis (2005) introduced two types of validation processes: empirical and relativist validation. This study is based on collected data based in experts' knowledge and project performance information such as risks, rewards, and objectives; therefore an empirical validation cannot be performed (Olewnik and Lewis, 2005), as there is no experimental set of data involved. Instead, a "relativist validation" needs to be done, based on a qualitative analysis of a semiformal and communicative process. Here, the validation process "is seen as a gradual process of building confidence in the usefulness of the new knowledge" (Pedersen et al., 2000).

Olewnik and Lewis (2005) affirm that a decision support tool is valid if it contains three elements: (1) It is logical –the results obtained are aligned with the intuition or common sense; (2) it uses reliable information –which can be achieved through experts' input; and (3) it does not bias the decision maker –their preferences and goals should not be set. Points two and three are incorporated in the decision-tool structure, since the intra-attribute comparison is based on expert's input (see *Scores Matrix Development* section); and the decision-makers' and agency's priorities and objectives can be set each time the tool is used. Therefore, validation was centered in the first item: ensure that the results obtained are aligned with the intuition and common sense of decision makers. This can be determined using case studies (Olewnik and Lewis, 2005), and soliciting the input of TxDOT personnel. Details on the case studies used and validation results can be seen in Chapter 6.

Validation procedure

The validation of the TxDOT decision-support tool was performed to ensure it gives, for all TxDOT projects, logical results aligned with experts' expectations. Validation was case-study based, and considered a full range of possibilities: extreme cases where the application of certain delivery method was evident to experts; and projects that could have been successfully delivered using any method. Case studies allow the comparison of the human decision making process and the decision-support tool recommendation, assuring that the latter accurately reflects TxDOT experience.

For each project, two validation sessions were done, involving the research team and a TxDOT expert. In the first one, input information to run the tool for a specific project was provided to the research team. The same experts providing the information were also asked what they considered to be the most suitable delivery method to fulfill each of the four objectives and the general most convenient delivery method. They provided specific reasons for their decision in terms of the project characteristics most affecting the outcome. In a second session, after running the tool with the data provided, TxDOT's expert answers or 'predictions' were compared with the tool recommendation and the results were discussed. In each case, the most and least supportive characteristics of the chosen delivery method were analyzed jointly with TxDOT personnel to check the accuracy of the model.

A total of eight projects were tested, with budgets varying between $7.1 Million to $1200 Million. Project characteristics varied from rehabilitations that were bid with a complete set of plans prepared; to highly innovative projects that were procured using schematic design. Projects belong to Collin County, Dallas County and the Houston area were tested. Details of each of the projects and the validation results can be seen in Chapter 6.

RESEARCH DELIVERABLES

The main deliverable for this research effort is a MS Excel based Decision-Support tool. This tool is accompanied with a user manual explaining the basic functioning and maintenance procedures, in case the scores matrixes need to be modified. Additional experience will certainly be gained by the Agency and will need to be reflected in the scores. Modifications may also be needed in the future to include upcoming delivery alternatives, such as Construction Manager at Risk. Details about how the MS Excel tool was constructed are given in Chapter 5.

Chapter 4: Scores Matrix Results

In this chapter, the scores obtained from TxDOT first-line personnel will be presented, characterizing the contribution of each delivery method and project characteristic towards the achievement of the project's objectives. This collected data is the basis for the development of the decision tool. To collect the data, on a first stage team the research team went through the factors obtained in literature and other decision tools to differentiate objectives and project characteristics, and filter the list according to TxDOT needs. Once the decision criteria were selected, a series of workshops and interviews were conducted to measure the impact of each delivery method and project characteristic on the project goals. The methodology of data collection was in-depth described in Chapter 3.

FACTORS: CHARACTERISTICS & OBJECTIVES

The literature review yield 34 factors, as shown in Table 5. The original list was polished in order to customize it for TxDOT project's characteristics and needs. Individual progressive reviews and meetings with the project team produced 4 main objectives (Table 10) and 12 project characteristics (Table 13).

Project & Agency Objectives

The four main objectives selected to be incorporated in the decision-support tool for being relevant for delivery method selection can be seen in Table 10. From the original 34-factors list, five were detected to be project's objectives. From those, two were grouped for referring to the schedule: "Likelihood of schedule growth" and "Criticality of schedule", condensed into the adopted goal "Higher schedule predictability". The remaining three goals were taken from the original list.

Table 10. Project & Agency Objectives

Lower **capital cost**	The contractual cost of the project must be the lowest reasonable; the budget available is tight.
Higher **cost predictability**	The project must be completed within the budget. The agency wants to avoid cost growth.
Higher **schedule predictability**	The project must be completed within the target schedule. The agency wants to avoid schedule growth.
Lower capital **maintenance costs**	The agency is concerned about minimizing the maintenance costs during the life cycle of the project.

The factors left aside in the Project & Agency Objectives category include *Quality*, *Safety* and *Meet target duration*. Together with the TxDOT collaborators, it was decided that certain target project duration could be met with any Delivery Method and the proper incentives and contractual clauses, so the goal was not considered a differentiating factor. As for Quality and Safety, those are always considered as top priority objectives and should be completely fulfilled regardless of the chosen DM. In sum, the absence of these goals in the tool structure does not mean that they are unimportant goals for TxDOT, but reflects that those objectives do not help identify the most suitable delivery method for each capital project.

Project Characteristics

The project characteristics selected are based on the literature review and on the input from TxDOT personnel during Workshop #1 and the follow-on interviews. During the development of the final project characteristics list, it have been left aside scope definition factors, characteristics that don't apply or are infrequent to TxDOT projects, those that were significantly overlapped (duplicated criteria), and non-differentiating factors (those that do not help to recommend a certain delivery method). Project characteristics left aside and the specific reasons can be seen in Table 11.

Table 11. Factors Discarded

Factor Discarded	Main Reason
Expenditure rate / Agency financial capacity	Not a common issue for TxDOT
Marketplace Competition	
Project Flexibility to changes	Included in flowchart: scope needs to be defined before the use of the tool
Clarity of Scope	
Best Value	Innovation is the major driver for using best value
Flexibility in quality control	Not a differentiator between delivery methods
Development of institutional knowledge	Not a project level issue
Agency high/low workload	
Contract award process	Not a differentiator between delivery methods: TxDOT has knowledgeable staff for either contracting process
Public Opinion	Specific public concerns can be discussed during a risk workshop

Scope definition factors left aside require some additional explanation. Initially, two factors aiming to detect the level of scope definition of the project were included. However, the team has later decided that to complete the delivery method selection process projects have to be fully defined in terms of scope. Scope changes have been found to one of the main reasons for cost overrun in highway construction projects, independently of the delivery method used (Creedy et al., 2010). In a different study, well-defined scope was ranked first among the factors for successful public-sector DB projects (Songer & Molenaar, 1997). For these reasons, the decision tool is intended to be used after the project's scope is defined, and the funding available. The scope definition issue was then included in the tool flowchart (Figure 3), and left aside from the project characteristics' list.

Once discarded the non-applicable factors, 19 characteristics were left. Those were grouped into the selected 12 project characteristics. The grouping guidelines can be seen in Table 12. The final selected factors were then worded and defined by the research team, after receiving feedback from various TxDOT divisions. The final list and definitions can be seen in Table 13.

Table 12. Origin of Project Characteristics

#	Selected Characteristic	Original Factor
1	Well known site conditions	Familiar Project Conditions
		Uncertain site conditions
2	Innovative methodologies	Innovation
		Agency Experience/Inexperience
3	Project design stage	Low/Advanced level of design
4	Designer-Contractor integration	Coordination challenges
		Likelihood of disputes and claims
5	Limit in contractor innovation	Prescriptive specifications
		Agency involvement and control
6	Incremental agency efforts and expenses	Project size
		Influence of procurement cost
7	Early completion	Traffic delays
		Need for schedule acceleration
8	Agency to manage third party issues	Agency experience/inexperience
		Third Party Agreements
9	Shifting the risk of third party issues	Innovation
10	Uncertain ROW acquisition	Acquisition of ROW
11	Utility relocations	Unidentified utilities
12	Permits	Complexity: Added by participants in Workshop#1 & broken down into more objective criteria in follow up interviews (need for innovation, # of parties involved, and permits).

Table 13. Project Characteristics & Definitions

1	Project has **well known site conditions** that won't cause significant field changes.
2	The project will benefit from the introduction of **innovative methodologies** early in the planning/design phase.
	Innovative methodologies could include innovative practices regarding planning, design, construction methods or sequences, traffic handling techniques, etc.
3	The **project design** (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.
4	The project requires the benefit of designer-contractor integration to reduce **coordination challenges**.
	Coordination challenges include, but are not limited to, constructability issues, claims or rework due to design flaws, delays or extra costs due to lack of communication channels between the designer and the contractor, etc.
5	Prescriptive project requirements for methods, materials and/or procedures **limit contractor innovation** in terms of alternatives.
6	For this project, alternate delivery methods shall create **incremental agency efforts and expenses** that are expected to be greater than the savings in capital expenses.
	Incremental agency efforts and expenses include time spent preparing contracting documents and reviewing DB teams' qualifications statements, proposals, stipends to unsuccessful proposers, independent legal and financial experts, QA effort, etc.
7	**Early completion** will add significant **extra value** for key project stakeholders.
	Extra value refers to diminished traffic bottlenecks, faster travel time, and improved safety.
8	The agency is **better equipped** than the contractor to manage **third party issues**.
	Better equipped means having greater experience, and thus likely to perform better than the contractor in terms of time and budget needed to solve those issues. Third party issues refer to issues that are neither under the control of TxDOT nor under the developer's control.
9	The project is likely to benefit from **shifting the risk of third party issues** to the contractor.
10	**Completion date of ROW acquisition** is highly uncertain.
11	**Utility relocations** have not been completely identified and are likely to result in important changes in the design, cost, and/or schedule of the project.
12	The project includes **permits** requiring coordination and regulatory approval during the design and/or construction phases of the project.
	Permits may include multiple step approvals, several review cycles, and/or mandatory processes that can delay or affect the sequence of work.

FINAL SCORING MATRIX

Based on the activities performed with TxDOT personnel, two scores matrix have been developed, one for each delivery method alternative. As explained in Chapter 3: Research Methodology, the scores given by each TxDOT specialist were translated into quantitative measures. These scores are considered a reflection of each expert's experience, so its average is representative of the overall past performance of DBB and DB projects under different circumstances. Therefore, a simple average of the 24 scores obtained filled each of the cells of the scores matrix. Each numerical value measures how the project characteristic contributes to achieve the objective, if the project is delivered with the corresponding delivery method. Matrixes for DBB and DB can be seen in Table 14 and Table 15 respectively.

The scores were collected in individual activities during Workshop 1 and 2, and confirmed during the follow-on interviews. During those phone conversations, 10 participants were contacted, changing a total of 16 characteristic's scores. Some scores were rectified immediately, others were confirmed, and in two cases the participants said not to believe that a project characteristic can ever be true. In those cases, their scores for that specific characteristic were dropped, for not being aligned with the task guidelines: "How a certain objective would be affected **if X characteristic is present**". Other participants confused a (-) sign, corresponding to a negative impact, with a decrease in the capital cost (that would be a positive impact on the goal). After detecting and correcting these misunderstandings, the final scores matrix were calculated and incorporated into the MS Excel decision-support tool.

Table 14. Design-Bid-Build Scores Matrix

	Design-Bid-Build (DBB) Delivery Method	PROJECT GOALS			
		Lower capital cost	Higher Cost Predictability	Higher Schedule Predictability	Lower Capital Maintenance Cost
	PROJECT CHARACTERISTICS	SCORES' MATRIX			
1	The project has well-known site conditions that won't cause significant field changes.	1.29	1.42	1.13	0.13
2	The project will benefit from the introduction of innovative methodologies early in the planning/design phase.	0.38	0.17	0.13	0.13
3	The project design (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.	0.96	1.00	0.79	0.04
4	The project requires the benefit of designer-contractor integration to reduce coordination challenges.	-0.50	-0.25	-0.29	-0.13
5	Prescriptive project requirements for methods, materials, and/or procedures limit contractor innovation in terms of alternatives.	0.04	0.79	0.50	0.08
6	For this project, alternate delivery methods shall create incremental agency efforts and expenses that are expected to be greater than the savings in capital expenses.	0.73	0.59	0.27	0.00
7	Early completion will add significant extra value for key project stakeholders.	-0.59	-0.55	-0.27	-0.09
8	The agency is better equipped than the contractor to manage third party issues	1.09	0.77	0.82	0.09
9	The project is likely to benefit from shifting the risk of third party issues to the contractor	-0.50	-0.71	-0.71	-0.08
10	Completion date of ROW acquisition is highly uncertain.	-1.00	-1.21	-1.38	-0.04
11	Utility relocations have not been completely identified and are likely to result in important changes in the design, cost, and/or schedule of the project.	-1.42	-1.50	-1.71	-0.17
12	The project includes permits requiring coordination and regulatory approval during the design and/or construction phases of the project.	-0.72	-0.89	-0.78	0.00

Table 15. Design-Build Scores Matrix

Design-Build (DB) Delivery Method		PROJECT GOALS			
PROJECT CHARACTERISTICS		Lower capital cost	Higher Cost Predictability	Higher Schedule Predictability	Lower Capital Maintenance Cost
		SCORES' MATRIX			
1	The project has well-known site conditions that won't cause significant field changes.	1.17	1.13	1.00	0.25
2	The project will benefit from the introduction of innovative methodologies early in the planning/design phase.	1.67	1.08	1.13	0.88
3	The project design (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.	-1.13	-0.43	0.09	-0.04
4	The project requires the benefit of designer-contractor integration to reduce coordination challenges.	1.42	1.25	1.21	0.54
5	Prescriptive project requirements for methods, materials, and/or procedures limit contractor innovation in terms of alternatives.	-1.05	-0.61	-0.57	-0.35
6	For this project, alternate delivery methods shall create incremental agency efforts and expenses that are expected to be greater than the savings in capital expenses.	-0.82	-0.64	-0.09	-0.09
7	Early completion will add significant extra value for key project stakeholders.	0.36	0.55	1.27	0.18
8	The agency is better equipped than the contractor to manage third party issues	-0.91	-0.82	-0.82	-0.18
9	The project is likely to benefit from shifting the risk of third party issues to the contractor	0.83	1.21	0.92	0.21
10	Completion date of ROW acquisition is highly uncertain.	-0.13	0.00	0.21	-0.04
11	Utility relocations have not been completely identified and are likely to result in important changes in the design, cost, and/or schedule of the project.	0.08	0.08	0.25	0.04
12	The project includes permits requiring coordination and regulatory approval during the design and/or construction phases of the project.	-0.11	-0.17	-0.11	0.06

ANALYSIS

Aggregated scores

The results obtained and presented in Table 14 and Table 15 are plotted in Figure 19 and Figure 20 for an easier and scaled comparison of results obtained for each characteristic and delivery method. Some criteria have a positive impact in the project's objectives for both delivery alternatives, such as #1 "Well Known Project Conditions" and #2 "Benefit from the introduction of innovative methodologies", although DB highly exceeding DBB in all four goals in the second one. Other factors are beneficial under only one of the delivery methods being considered, such as #4 "Designer contractor integration" advocating for DB, or #6 "Incremental agency efforts and expenses" leading towards DBB.

The scores' matrices, as they came out from the workshops and follow-on interviews, have a higher total score for DB than for DBB. This may be interpreted as a built-in bias in the tool. However, these results are due to characteristics especially selected to detect DB projects, for it being the only alternative delivery method available to TxDOT at the present moment. Validation demonstrated that, if the characteristics are assessed correctly, the tool gives accurate results for the full range of projects. Details of validation results are given in Chapter 6.

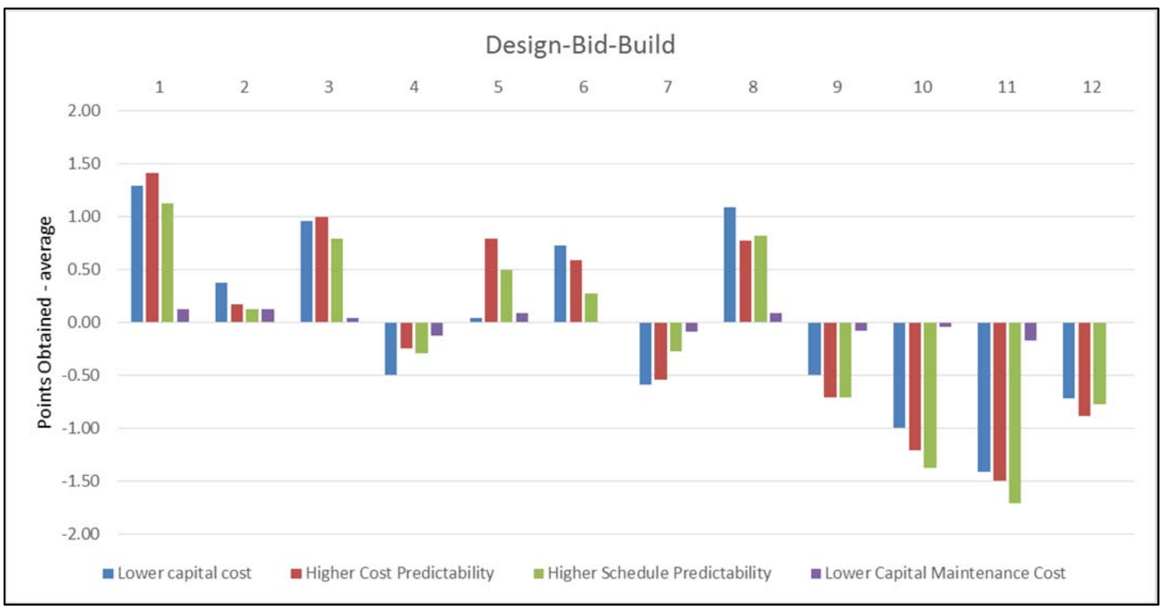


Figure 19. Results obtained per characteristic and goal - DBB

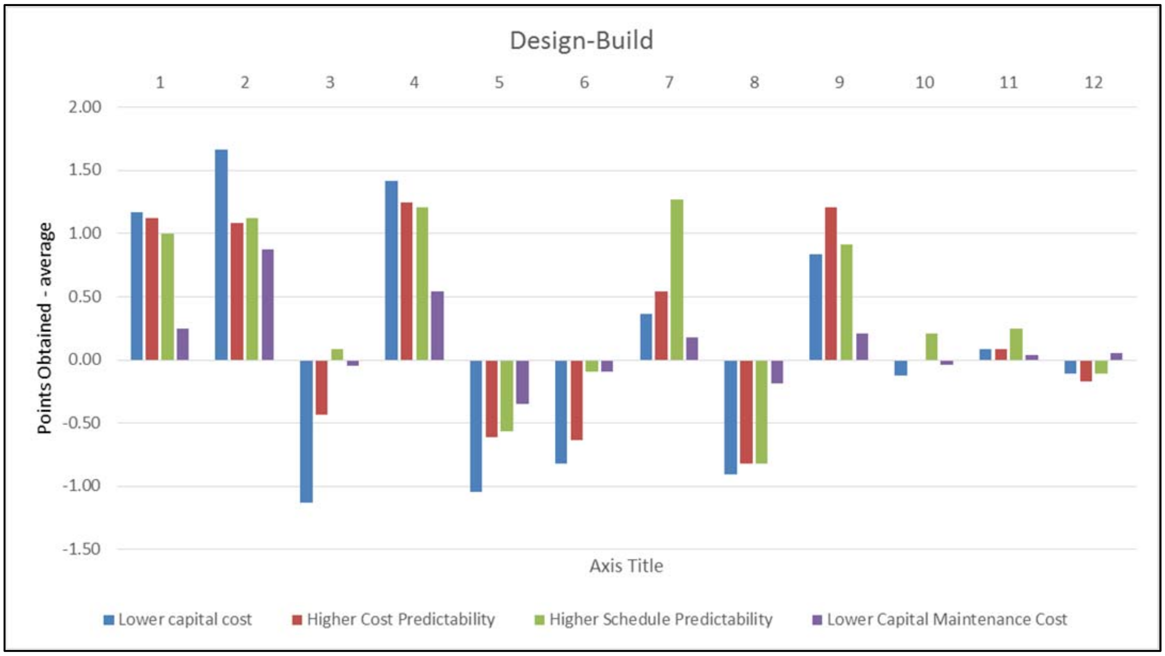


Figure 20. Results obtained per characteristic and goal - DB

Figure 21 shows a ranking of the characteristics according to the difference in the scores each one obtained for the two delivery methods. These graphs' horizontal axis represents the DB score minus the DBB score, mapping how much of a differentiator each factor is. A characteristic that is represented as +2 in the graph obtained for the given objective two more points in DB than in DBB. Characteristics with negatives results scored higher for the DBB delivery method than for DB, plotted at the bottom of the list. From the graphs can be concluded that characteristics #1 and #12 (close to zero) are not great differentiators. Aversely, Characteristics #8 and #9 are good differentiators, in favor of DBB and DB respectively.

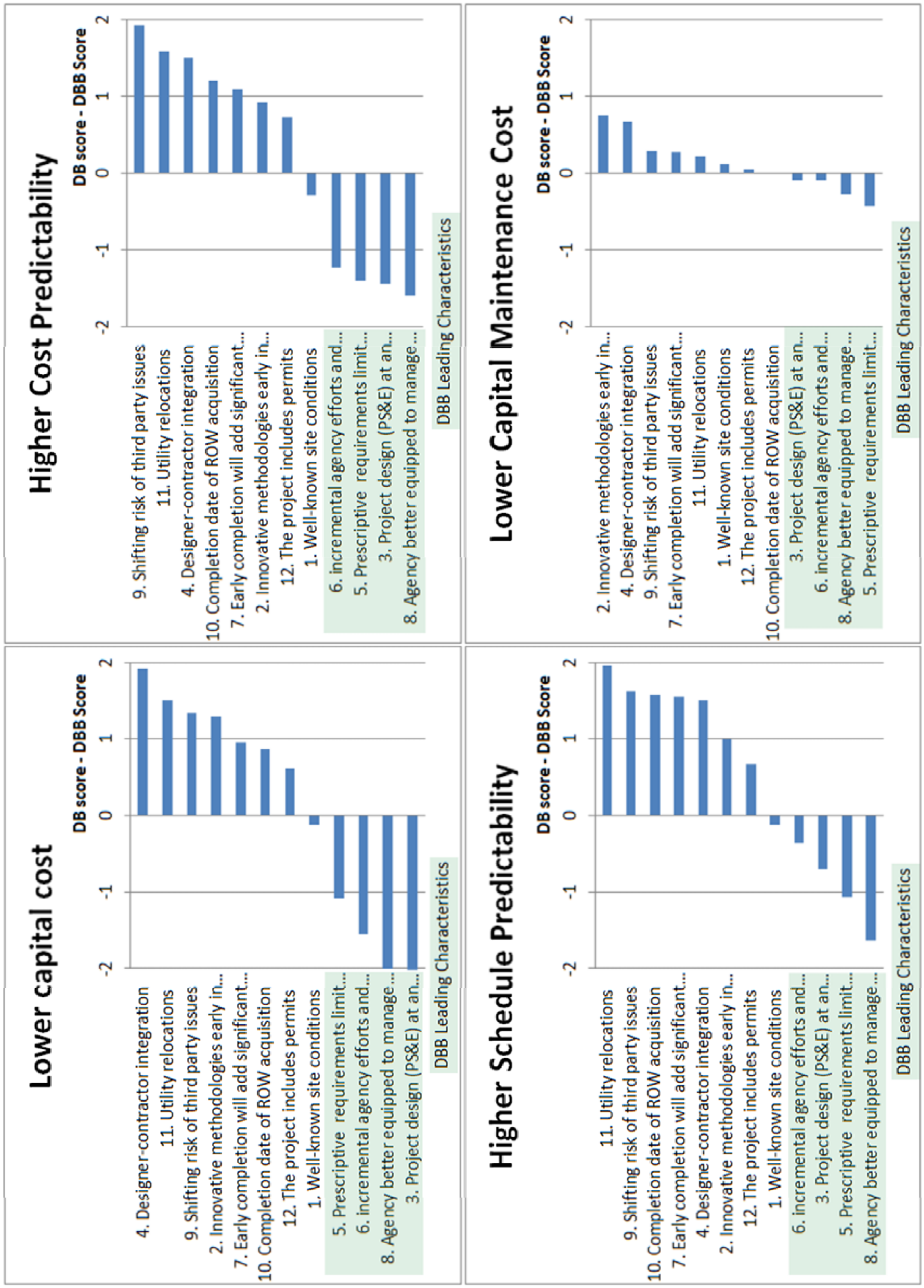


Figure 21. Characteristics most influencing the decision

It can be also concluded from the graphs that "Lower Capital Maintenance Cost" is the objective that act less as a differentiator, since the characteristics' scores where closer to be negligible for the achievement of this objective, so the represented scores are closer to zero. This may be due to the timeframe needed to measure the effect of different project characteristics and delivery methods on highway projects' maintenance: designs are made to last more than a decade, so the effects needs to be measured in the long term, being this information less handy for the experts.

Subgroups analysis

The 24 experts participating in the workshops can be classified into two groups: TxDOT personnel (16 participants) and External Expertise (8 participants). Taking into account this differentiation, a first analysis consisted on comparing the scores obtained for each group for the different project characteristics, grouping the four objectives. Since for a given project characteristic the scores on each objective were similar or in the same direction (same sign), grouping objectives for this analysis was considered valid. The results are shown in Table 16, where each cell represents the average of experts' scores for each group. The highlighted cells indicate differences higher than 70% in the scores provided by each group. This is the case of 7 out of the 24 scores (30%).

Table 16. Subgroups analysis results

		DBB			DB		
	PROJECT CHARACTERISTICS	TxDOT	External	Difference	TxDOT	External	Difference
1	Project has **well known site conditions** that won't cause significant field changes.	4.29	3.14	-27%	3.59	3.43	-4%
2	The project will benefit from the introduction of **innovative methodologies** early in the planning/design phase.	1.29	-0.43	**-133%**	4.82	4.57	-5%
3	The **project design** (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.	3.18	1.86	-42%	-1.88	-0.50	**-73%**
4	The project would benefit from **designer-contractor integration** that would reduce coordination challenges	-1.12	-1.29	15%	4.59	4.00	-13%
5	Prescriptive project requirements in methods, materials and/or procedures **limit contractor innovation** via alternates.	2.06	-0.14	**-107%**	-2.76	-2.00	-28%
6	The project's small size and budget make the procurement/bidding process uneconomical. Agency **procurement costs** would be an unacceptably high percentage of project costs.	1.80	1.14	-37%	-1.88	-0.80	-58%
7	**Early completion** adds significantly extra value for key project stakeholders.	-1.38	-1.83	33%	2.75	1.33	-52%
8	The agency is better equipped to manage **third party issues**	2.76	2.80	1%	-3.29	-0.80	**-76%**
9	The project would benefit from **shifting the risk of third party issues** to the contractor	-2.29	-1.29	-44%	3.47	2.43	-30%
10	**Completion date of ROW acquisition** is highly uncertain.	-3.53	-3.86	9%	0.06	0.00	**-100%**
11	**Utility relocations** have not been completely identified and may result in changes in the cost and/or the design of the project.	-4.54	-5.43	20%	0.65	0.00	**-100%**
12	The project includes **permits** requiring coordination and regulatory approval during the design and/or construction phases	-3.27	-1.00	-69%	0.36	-1.43	**-493%**

Since the differences obtained in this groups' analysis are considered worth of attention, the dependence of the answers on the expert' groups was further analyzed through chi-square test for independence. This test will confirm whether the experts' group is associated with the score, for different sub sets of characteristics and goals.

The two nominal variables to consider are:

- Group: t=TxDOT expert;
  e= External expert
- Answer: Positive answer (++,+)
  Neutral answer (0)
  Negative answer (-,--)

The test hypotheses are:

- H_0: Experts' group and answers are independent
- Ha: Experts' group and answers are not independent (knowing one variable can help predict the other).

The significance level to be used is: 0.05. So, if the obtained p is greater than 0.05 we will accept the null hypothesis.

The tests were run for each of the 12 characteristics and 2 delivery methods: a total of 24 tests were done. Each test combines the answers from all four objectives, for two main reasons: (1) the responses tend to be of the same sign for all four objectives for a certain characteristic, as can be seen in Figure 19 for DBB and in Figure 20 for DB; and (2) it was necessary to enlarge the data points to comply with chi-square basic assumptions regarding sample size and expected counts. The tests were run using the IBM SPSS software. Positive test results can be seen on Table 17.

Table 17. Chi-square tests results

DM & Char. #	Characteristic	p value
DBB #1	The project has well-known site conditions that won't cause significant field changes.	0.023
DBB #2	The project might benefit from the introduction of innovative methodologies early in the planning/design phase.	0.027
DB #8	The agency is better equipped to manage third party issues	0.017

Out of the 24 total tests ran, only 3 resulted in values of $p<0.05$, meaning the acceptance of the alternative hypothesis –the answer is not independent of the experts' group. As seen in Table 17, there are only a few cases where TxDOT personnel and external experts differ in their opinion, and that statement cannot be generalized to a delivery method or a certain set of characteristics. These results reflect the diversity incorporated into the tool by including external expertise, but confirms that in only 12% of the cases the opinion of TxDOT personnel and external experts statistically differ. The scores related to these characteristics were incorporated in the tool in the same way it was done for all others, since all come from the same 24 experts sources. The validation of the decision-support tool, based on already delivered and upcoming projects, confirmed that these scores accurately represent the decision-makers mindset.

Chapter 5: TxDOT Project Delivery Selection Tool

Once obtained the expert's data needed, the decision-support tool was designed. In this chapter, that decision process especially designed for TxDOT use will be described. The decision tool was built in MS Excel and consists of five sections, as shown in Figure 22. The first section welcomes the user and presents the tool. It is followed by three input sections, where project general information, characteristics and goals are collected, respectively. Finally, the last section presents the output, including the relative scores for the analyzed delivery methods, and the characteristics that most and least support each alternative.

Figure 22. Tool Sections

The tool, to fulfill TxDOT requirements, needs to:

- Be transparent and modifiable
- Be rigorous and repeatable
- Be quantitative and independent of the decision maker (s)
- Be customized for TxDOT most common project characteristics, needs and objectives

For these reasons, the tool was developed in MS Excel, its logic is easily auditable and its bases can be modified as the agency's needs change. The tool is founded on the scores' matrixes obtained in the workshops, to ensure it would represent the agency's main concerns. As discussed in Chapter 3: Research Methodology, the project characteristics and objectives included were broadly discussed and polished in a team work effort including TxDOT first-line personnel.

Following, each of the tool sections will be presented and described.

WELCOME SECTION

The “Welcome” portion presents basic information for the user, such as the purpose of the tool and the delivery methods to compare. It invites the user to name the project that is going to be evaluated, and save the MS Excel tool as a new file. It also presents the general flowchart of the tool, for the user to get familiarized with the process that is about to start.

PROJECT INFORMATION SECTION

The “Project Information” sheet invites the user to fill in project basic information, as shown in Figure 23. Also, it leaves room for the project's main risks and challenges, since listing them would be helpful for the analysis that follows in the Project Characteristics section.

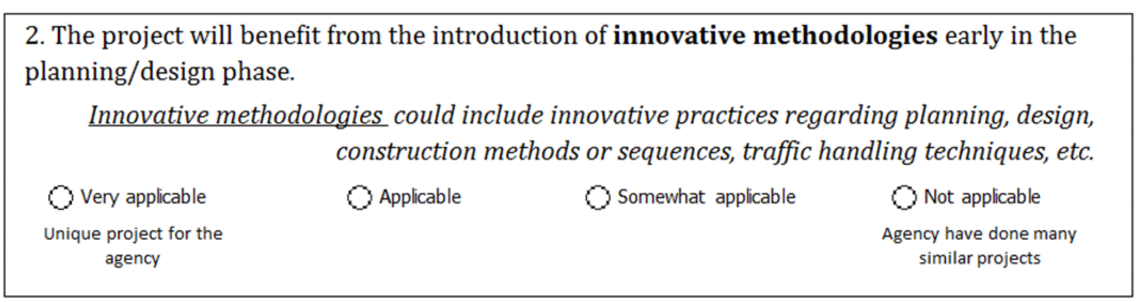
Name:	
Location:	
Brief Description:	
Budget:	
Source of funding:	
Required completion date:	
Main Stakeholders:	

Figure 23. Project General Data

As the flowchart indicates, the “Project Information” sheet includes two deal breaker questions: “Is the project scope clearly defined?” and “Is the project fully funded?”. Those questions are intended to identify those projects that are outside of the ideal scope of the decision-support tool. In a third sub-section, the user is asked to characterize the evaluating team, listing the number and names of the participants, and the date of evaluation. This information allows keeping track of projects that may have been evaluated many times, in different stages.

PROJECT CHARACTERISTICS SECTION

This section lists all 12 selected project characteristics, and asks the user to assess how applicable each one is according to the project being evaluated. The applicability is measured in a 4-points scale common to all project characteristics: Very applicable, Applicable, Somewhat applicable, and Not applicable. However, each characteristic has an auxiliary gradation to guide the user to the most representative answer. An example of the way each project characteristics is scored can be seen in Figure 24. The four options (from Very applicable to Not applicable) are translated by the tool in a 0 to 3 score, to serve as input for the final scores calculation. All 12 project characteristics have to be measured before continuing to the next step.


2. The project will benefit from the introduction of **innovative methodologies** early in the planning/design phase.

Innovative methodologies could include innovative practices regarding planning, design, construction methods or sequences, traffic handling techniques, etc.

○ Very applicable — Unique project for the agency
○ Applicable
○ Somewhat applicable
○ Not applicable — Agency have done many similar projects

Figure 24. Project Characteristic #2

GOALS SECTION

In this third input section, the user is asked to distribute a total of 100% between the four selected goals, reflecting its relative importance for one particular project. Any distribution is possible: all 100% points can be allocated in a single objective, or the distribution can be 25% for each. An interactive graph shows the selected weights.

FINAL OUTPUT SECTION

The final output is represented in the tool as a combination of bar charts and heat maps, as shown in Figure 25. First, a statement giving a decision recommendation is presented, based on the difference in the scores obtained by each delivery method (see Table 18). This difference, in absolute value, is then plotted in a zone-divided bar chart. Following, for a detailed plot of the results obtained for the two alternatives is presented separately for each of the 4 objectives, and the total score of each delivery method is given, to allow the direct comparison of alternatives.

Table 18. Recommendation given (based on Scores' difference)

Difference in Scores	**Recommendation**
0-0.15	No Delivery Method can be recommended. Tier 3 analysis is needed to select a Delivery Method.
0.15-0.30	Weak Delivery Method recommendation is given. Tier 3 analysis is recommended.
>0.30	A Delivery Method is recommended.

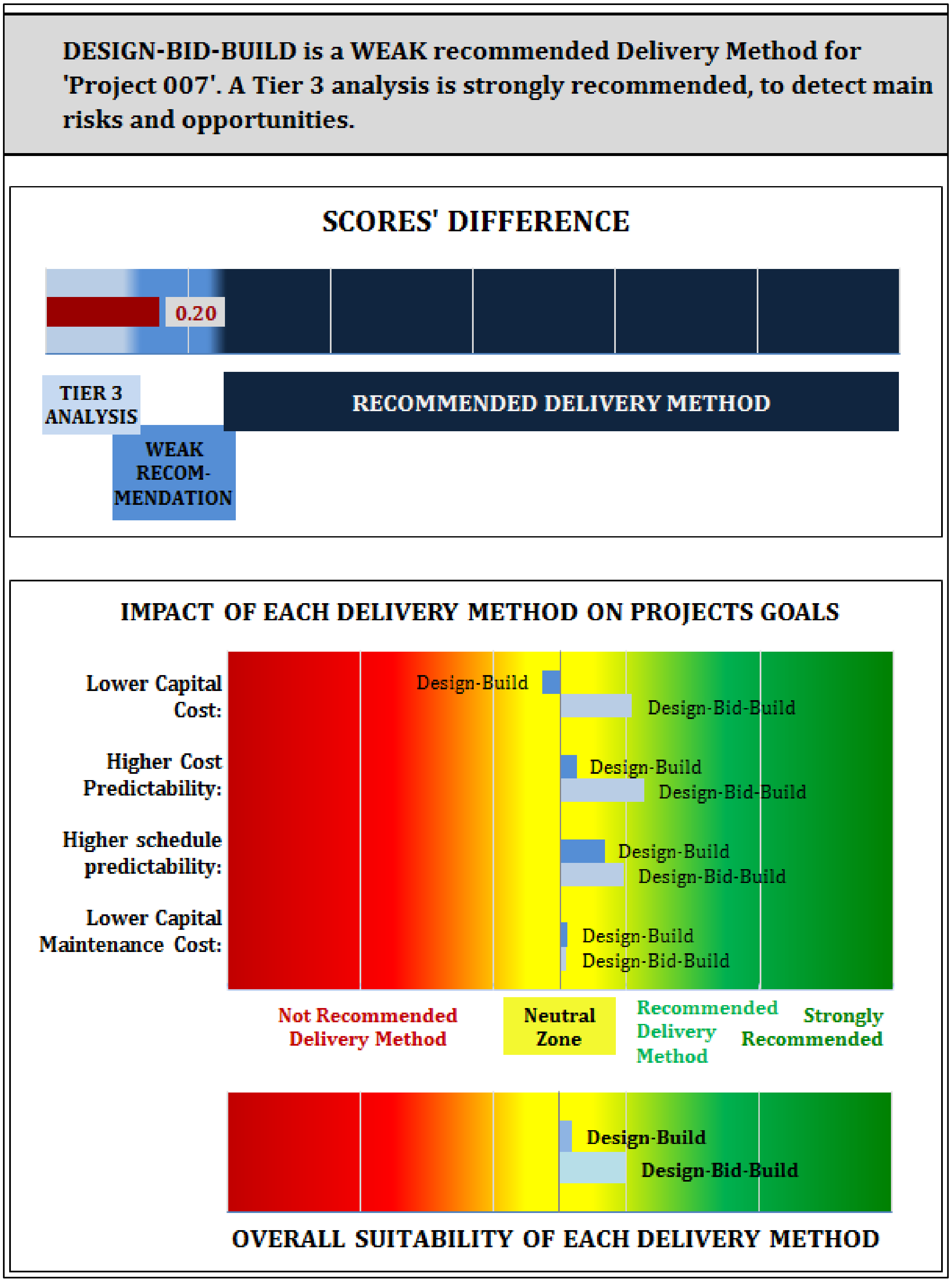


Figure 25. Tool output

The Output section also presents the most and least supportive characteristics for each delivery method. This feature helps the decision makers understand the reasons of the recommended method, and drives the focus to those characteristics that could signify a project risk for not supporting the most suitable alternative.

Logic behind the tool

In this section, the calculations to obtain the output scores will be explained step by step. These two scores, one for each delivery alternative, are based on two main sets of data:

a. The characterization of the project, including the project characteristics' scores and the objectives' weights (Sections 3 and 4), that are introduced by the decision maker each time the tool is used, and for each project.

b. The delivery methods scores matrix, built-in the model and based on the aggregated knowledge of 24 experts, including TxDOT first line personnel and external firms' experienced staff. These scores, presented in *Chapter 4: Results*, represent the joint likelihood of project characteristics and delivery methods to meet project's goals.

Once identified the data involved, the calculations, repeated for each delivery method alternative, are as follows (see Figure 26):

1. The applicability of each characteristic that was introduced in Section 3 is ranked in a 0 to 3 scale –column [A]-, as follows: Not applicable (0), Somewhat Applicable (1), Applicable (2), and Very applicable (3). This ranking is multiplied by the scores' in the matrix –columns [B] to [E]-, for each one of the objectives.

2. The score obtained for each characteristic is added vertically, to obtain a total score per goal.
3. The score obtained is then scaled to fit the (+2) to (-2) scale in which the scores matrix was developed (Table 3). A strong positive effect on a certain goal corresponds to a score of +2, while a strong negative effect corresponds to a score of -2. Therefore, the obtained goal's score represents how the delivery method affects the fulfillment of that objective, for the project being analyzed.
4. For a certain delivery method, the scores corresponding to the four different objectives are combined together in a weighted average. The weights used are the percentages allocated by the decision maker(s) in the "Project Goals" section of the tool. This way, a unique score is obtained for each delivery method.

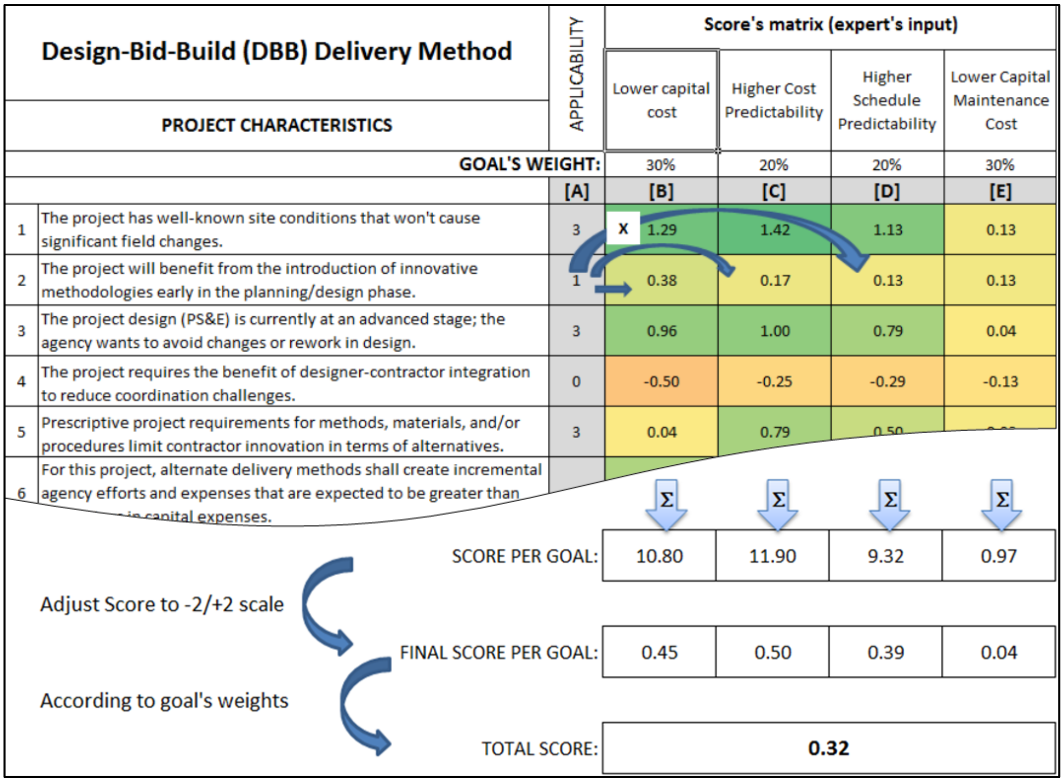


Figure 26. Calculations behind the tool

Chapter 6: Tool Validation Results

INTRODUCTION

For being this research project funded on expert's opinion and no in experimental data, the basis for the validation of the decision-support tool are case studies. As the decision-support tool is especially designed for TxDOT, agency's past and upcoming projects were run through the model. A total of eight projects were used to test the tool. The sample was varied in budget, location, main objectives and project characteristics. The objective of this process was to compare experts' thoughts and the tool's recommendation about the most suitable delivery method. Also, the experts were asked for the project's characteristics that are most important in the decision. This way, the tool functioning can be compared with the human decision-making process, to ensure the tool accurately represents the agency's expertise.

Each of the projects tested will be presented in the following subsections. For every case study, the general information is given, followed by a comparison of the delivery method recommended by the tool and the experts' thoughts.

CASE STUDIES TESTED

A total of eight case studies were tested. The projects varied in budget from $7.1 Million to $1.2 Billion. Regarding characteristics, they varied from highly complex projects, such as Southern Gateway, to low-innovation projects like 75 Rehabilitation. All project characteristics were covered, as can be seen in the Validation Summary further on. Projects tested, their location and budget can be seen in Table 19. Also, in Table 20 the main challenges of each project are shown.

Table 19. Validation Case Studies

	Project	**Area**	**Budget**
1	Southern Gateway	Dallas	$ 400 M
2	75 Rehabilitation	Collin County, TX	$ 7.1 M
3	Woodall Rodgers Deck Park	Dallas	$ 48.4 M
4	LBJ East	Dallas	$ 1200 M
5	Midtown Express (SH183)	Dallas	$ 1000 M
6	SH-360	Fort Worth	$ 300 M
7	I-69	Houston	$ 136 M
8	SH-146	Houston / Seabrook	$ 189 M

Table 20. Validation projects' main challenges

		PROJECTS							
		LBJ	Midtown Express	SH-360	Southern Gateway	75 Rehabilitation	Rodgers Deck Park	I-69	S-146
RISK & CHALLENGES	Traffic Issues				X	X			
	Cost Control				X				
	Schedule Control				X	X		X	
	Quality				X	X			
	Technical difficulties			X			X		
	Coordination	X	X						
	Large Size	X	X						
	Rail Road Corridor			X				X	X
	Utilities								X

Case Study #1: Southern Gateway

The Southern Gateway project consists of the widening of 19 miles of I-35E, including main lanes and managed lanes. It also includes the reconstruction of 11 miles of U.S. 67. Table 21 shows the general information of the project.

Table 21. Southern Gateway general Info

Location:	Dallas County
Brief Description:	Reconstruction of Interstate 35e/ US 67. Add capacity including manage lanes
Budget:	$400M
Special Characteristics, Risks and/or challenges:	• Stakeholder support
	• Traffic management
	• Cost & schedule control
	• Quality

The most important goals for the Southern Gateway project are "Lower Capital Cost" (40%) and "Higher Schedule Predictability" (30%). Some of its more applicable characteristics are:

- The project will benefit from the introduction of innovative methodologies early in the planning/design phase.
- The project requires the benefit of designer-contractor integration to reduce coordination challenges
- Early completion will add significant extra value for key project stakeholders.
- Completion date of ROW acquisition is highly uncertain.

The developed decision-support tool, when tested for the Southern Gateway project, recommended Design-Build as the most suitable delivery method for the project. Result obtained can be seen in Figure 27. According to the interviewed experts, the

Southern Gateway project should be delivered as Design-Build for three main reasons: (1) innovation is needed; (2) the project has a tight schedule (and would benefit from early completion); and (3) because it is a large project and thus cost savings from Alternative Technical Concepts (ATC) are expected. The outcome obtained matches the experts' opinion, and the most supportive characteristics listed in the tool were confirmed to be the main reasons for DB alternative to be selected.

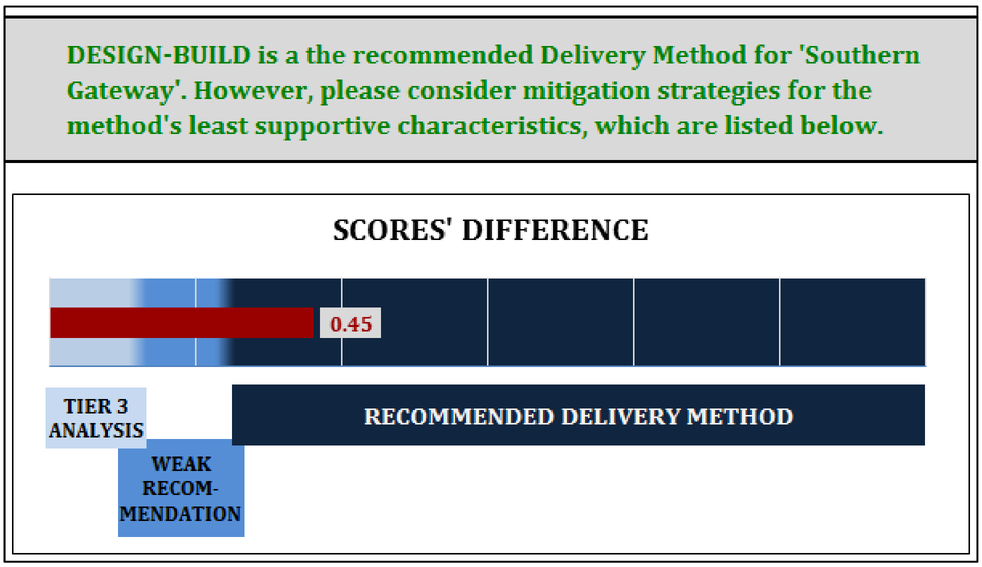


Figure 27. Tool Output for Southern Gateway.

Case Study #2: U.S. 75 Rehabilitation

The second case study consists of the rehabilitation of U.S. 75 in Collin County, TX. Table 22 shows the general information of this project.

Table 22. U.S. 75 Rehabilitation general Info

Location:	Collin County, TX
Brief Description:	Rehabilitation of an existing highway facility - Full depth repair and overlay.
Budget:	$7.1 M
Special Characteristics, Risks and/or challenges:	• Maintenance of traffic
	• Impacts to commuters, time impact
	• Quality of work
	• Schedule

The most important goals for the .S. 75 Rehabilitation project are "Lower Capital Cost" (30%) and "Lower Capital Maintenance Cost" (30%). Some of its more applicable characteristics are:

- The project has well-known site conditions that won't cause significant field changes.
- The project design (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.
- Prescriptive project requirements for methods, materials, and/or procedures limit contractor innovation in terms of alternatives.
- For this project, alternate delivery methods shall create incremental agency efforts and expenses that are expected to be greater than the savings in capital expenses.

The decision-support tool outcome for U.S. 75 Rehabilitation highly recommended DBB, obtaining a difference in alternatives' scores of 0.39. The characteristics listed by the tool as most supportive of this decision were also mentioned by experts as the primary cause for the delivery method selection. Those characteristics are very well known site conditions –for being it a rehabilitation–, and PS&E at a very advanced stage. As seen, the decision-support tool accurately reproduces the expert's decision making rationale.

Case Study #3: Woodall Rodgers Deck Park

The Woodall Rodgers Deck Park is a 5 acres deck park that connects Downtown, Uptown and the Art district in Dallas, Texas. The park was constructed above the Woodall Rodgers Freeway (366), so the project included tunnel construction work. Table 23 shows the general information of this project.

Table 23. Woodall Rodgers Deck Park general information

Location:	Dallas, TX
Brief Description:	Downtown Dallas park, linking Downtown, Uptown and the Art District.
Budget:	$ 48.4 M
Special Characteristics, Risks and/or challenges:	• Tunnel construction with fireproofing
	• Insulation and other safety features
	• Waterproofing the roof deck

The most important goals for the Woodall Rodgers Deck Park are "Higher Cost Predictability" (35%) and "Lower Capital Cost" (25%). Some of its more applicable characteristics are:

- The project has well-known site conditions that won't cause significant field changes.
- The project will benefit from the introduction of innovative methodologies early in the planning/design phase.
- The project design (PS&E) is currently at an advanced stage; the agency wants to avoid changes or rework in design.

For Rodgers Deck Park, both delivery alternatives got similar scores in the tool's output, with a difference of only 0.02 points. According to the interviewed experts, the Rodgers Deck Park project combines different characteristics that make the delivery method decision a difficult one. On the one side, the need for the agency interacting with third parties, the small scale of the project and the plans substantially completed before procurement lead to DBB as the most suitable delivery method. On the other side, early completion and some utility issues may be on favor of DB. What is more, the recommendation changed as the decision-makers slightly modified some of the characteristics. For example, the users were discussing if characteristic #9 (Shift the risk of third party issues) and characteristic #11 (Utilities relocation) should be 'Not Applicable' or 'Somewhat Applicable'. Those slightly changes in the characteristics applicability reversed the tool's recommendation.

Regarding the different agency's objectives, the experts agreed that a DBB delivery method would probably reduce the overall cost of the project, but a DB contract would help accelerate the project schedule. As can be seen in Figure 28, the tool output reproduced the expert's thoughts regarding the different objectives. From this analysis and the results, it can be concluded that the tool accurately represents the decision-makers mindset, and in this particular case it does not give a clear recommendation. For a project like Rodgers Deck Park, a Tier 3 risk analysis is needed to fundament a decision.

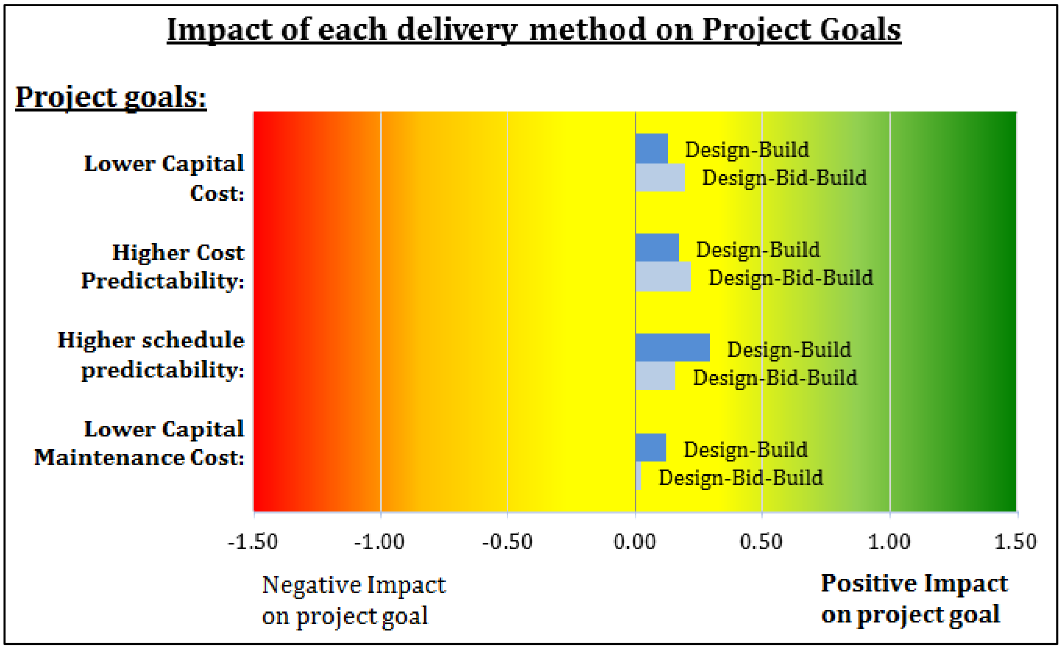


Figure 28. Rodgers Deck Park: Impact of each delivery method on Project Goals.

Case Study #4: LBJ East

The LBJ East project includes managed lanes and reconstruction of Interstate Highway I-635 (LBJ), from I-35E to SH 75. The project will also complete a continuous frontage road system. Table 24 shows the general information about the project.

Table 24. LBJ East general Info

Location:	Dallas, TX
Brief Description:	11 miles reconstruction project from SUS 75 to IH 30 which will add managed lanes and continuous frontage roads, and also add general purpose lanes capacity.
Budget:	$1.2B
Special Characteristics, Risks and/or challenges:	• Large size project (length and cost) • Complex coordination between all stakeholders

The four proposed goals are equally important (25% each) for LBJ East Project. Some of its more applicable characteristics are:

- The project will benefit from the introduction of innovative methodologies early in the planning/design phase.
- The project requires the benefit of designer-contractor integration to reduce coordination challenges
- Early completion will add significant extra value for key project stakeholders.
- The project is likely to benefit from shifting the risk of third party issues to the contractor.
- Utility relocations have not been completely identified and are likely to result in important changes in the design, cost, and/or schedule of the project.

The developed decision-support tool, when tested for the LBJ project, highly recommended Design-Build as the most suitable delivery method for the project, obtaining a difference of 0.48 with DBB. The outcome obtained matches the experts' opinion, due to the size and complexity of the project, the risks entailed and the benefits that could be extracted from innovative methodologies and ATC.

Case Study #5: Midtown Express (SH 183 Managed Lanes)

The Midtown Express project has a similar scope that LBJ Express, including managed lanes and reconstruction of a highway. Table 25 shows the general information about the project.

Table 25. Midtown Express general Info

Location:	Dallas, TX
Brief Description:	Reconstruction and widening of existing general purpose lanes and the addition of managed lanes along portions of SH 183, Loop 12, and SH 114.
Budget:	$1.0 B
Special Characteristics, Risks and/or challenges:	• Large size project (length and cost)
	• Complex coordination between all stakeholders

The four proposed goals are equally important (25% each) for Midtown Express Project. Some of its more applicable characteristics are:

- The project will benefit from the introduction of innovative methodologies early in the planning/design phase.
- The project requires the benefit of designer-contractor integration to reduce coordination challenges
- Early completion will add significant extra value for key project stakeholders.

The developed decision-support tool, when tested for the Midtown Express project, highly recommended Design-Build as the most suitable delivery method for the project, with a difference of 0.34 points with DBB. The results obtained are not as strong as in the LBJ case study (difference of 0.48), because there are not utility issues in Midtown Express, diminishing its risks. However, the outcome obtained still matches the experts' opinion, due to the size and complexity of the project, the risks entailed and the benefits that could be extracted from innovative methodologies.

Case Study #6: SH 360

The SH 360 project consists of 9.2 miles of improvements to SH 360 including two toll lanes in each direction from approximately E. Sublett Road/Camp Wisdom Road to East Broad Street; and one toll lane in each direction with periodic passing lanes from East Broad Street to US 287. Table 26 shows the general information about the project.

Table 26. SH 360 general Info

Location:	Fort Worth
Brief Description:	New construction of a 4 lane toll road from Camp wisdom to Broad St. and a 2 lane toll road from Broad St. to US 287
Budget:	$300 M
Special Characteristics, Risks and/or challenges:	• UPRR crossing underpass
	• 3 overhead electric crossings
	• 72" and 90" water utility crossings

The most important goals for the project are "Lower Capital Cost" (30%), "Higher Cost Predictability" (30%) and "Higher Schedule Predictability" (30%). Some of its more applicable characteristics are:

- The project has well-known site conditions that won't cause significant field changes.
- The agency is better equipped than the contractor to manage third party issues.
- Utility relocations have not been completely identified and are likely to result in important changes in the design, cost, and/or schedule of the project.

The tool output shows, for SH 360, that the difference in scores is low (0.13 points), and both delivery methods' score is on the "neutral zone", meaning that no method is recommended (Figure 29). For this project, characteristics leading to each delivery alternative conflict and ultimately both methods obtain similar and low scores. Experts agreed that this project groups characteristics leading to both delivery methods, and an extensive Tier 3 risk analysis would be needed.

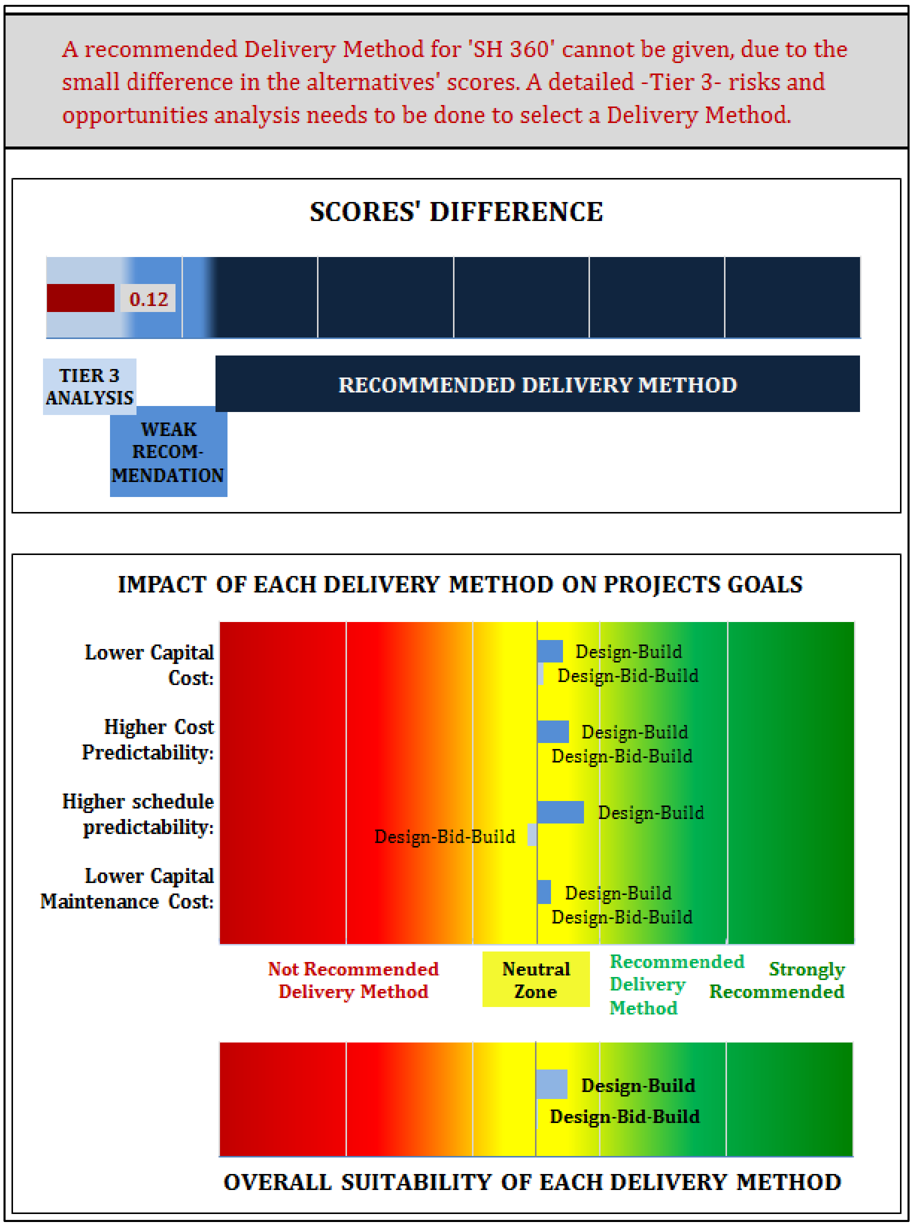


Figure 29. SH 360 Tool Output

Case Study #7: I-69

I-69 Project consists on the widening and construction of frontage roads in the mentioned interstate, belonging to the Houston area. Table 27 shows the general information about the project.

Table 27. I-69 general Info

Location:	Houston
Brief Description:	Widening freeway & adding frontage roads
Budget:	$136 M
Special Characteristics, Risks and/or challenges:	• Tight schedule
	• Railroad involved
	• Less 50% design done. In house design.

The most important goals for the project are "Lower Capital Cost" (30%), "Higher Cost Predictability" (30%) and "Lower Capital Maintenance Cost" (30%). Some of its more applicable characteristics are:

- The project has well-known site conditions that won't cause significant field changes.
- Prescriptive project requirements for methods, materials, and/or procedures limit contractor innovation in terms of alternatives.
- Completion date of ROW acquisition is highly uncertain

The tool output shows for I-69 that the difference in scores is low (0.10 points), and both delivery methods' score is on the "neutral zone", meaning that no method is recommended. However, DBB gets positive score (0.08), while DB obtains a slightly negative score (-0.02). The tool's outcome met expert's expectations. They were expecting a slight recommendation towards DBB, although in the neutral zone. Also, as the tool does not include agency-level issues such as in-house availability of design resources, so a detailed analysis would strengthen the DBB recommendation.

According to the experts, ROW was a pending issue at the time of letting, but the project allowed for 18 month of construction before ROW could potentially impact the schedule, making this issue a not critical one. Utilities relocation was pending on ROW acquisition, but around of 50% of the work could be performed –on the median– before utilities were relocated, since that was needed for frontage road construction. Same approach was taking with the railroad permits: it was possible to build around the issue until the permit was cleared. This illustrates the need of a Tier 3 detailed analysis in all cases, since a deeper understanding on the impact of each project characteristic on the cost and schedule can help identify the best decision.

Case Study #8: SH-146

ISH-146 Project consists on the widening, construction of frontage roads and express lanes in the Seabrook area in Houston. Table 28 shows the general information about the project.

Table 28. SH-146 general Info

Location:	Houston / Seabrook
Brief Description:	Widening (+2 lanes/direction) , Express lanes, Frontage roads
Budget:	$189 M (no ROW included)
Special Characteristics, Risks and/or challenges:	• Purchasing Rail Road inactive corridor • Utilities relocation, specially gas lines

The most important goals for the project are “Lower Capital Cost” (30%), “Higher Cost Predictability” (30%) and “Lower Capital Maintenance Cost” (30%). Some of its more applicable characteristics are:

- The project will benefit from the introduction of innovative methodologies early in the planning/design phase.
- The project requires the benefit of designer-contractor integration to reduce coordination challenges.
- Completion date of ROW acquisition is highly uncertain (and utility relocation is pending on ROW acquisition).

The tool output shows, for SH-146, a positive score for DB (0.24) and a negative one for DBB (-0.26). The difference between these scores (0.50) signifies a clear DB recommendation. The tool's outcome initially surprised the experts, because the design is being performed in-house. However, they reported big unknowns regarding Utilities, ROW and Permits, which may mean big scope changes. After realizing the numerous unknowns and how innovation can help solve them, the team jointly agreed that at this stage DB is the most suitable delivery method. As the scope of the project becomes better defined, the project characteristics and uncertainties may change, so the tool should be utilized once more before delivering SH-146.

VALIDATION SUMMARY

The purpose of this validation process was to run different types of projects through the model and compare the decision-makers' thoughts and conclusions with the recommendations given by the tool. The eight projects tested covered more than 85% of the possibilities regarding project characteristics, as can be seen in Figure 30. This was considered a broad enough range of projects for the validation purposes. Regarding the outputs obtained, in 4 out of the 8 projects tested DB was the recommended delivery method. DBB was recommended in one case. In the remaining three cases a recommendation could not be given, due to the small relative difference of the scores obtained by each alternative. Table 29 summarizes the results obtained.

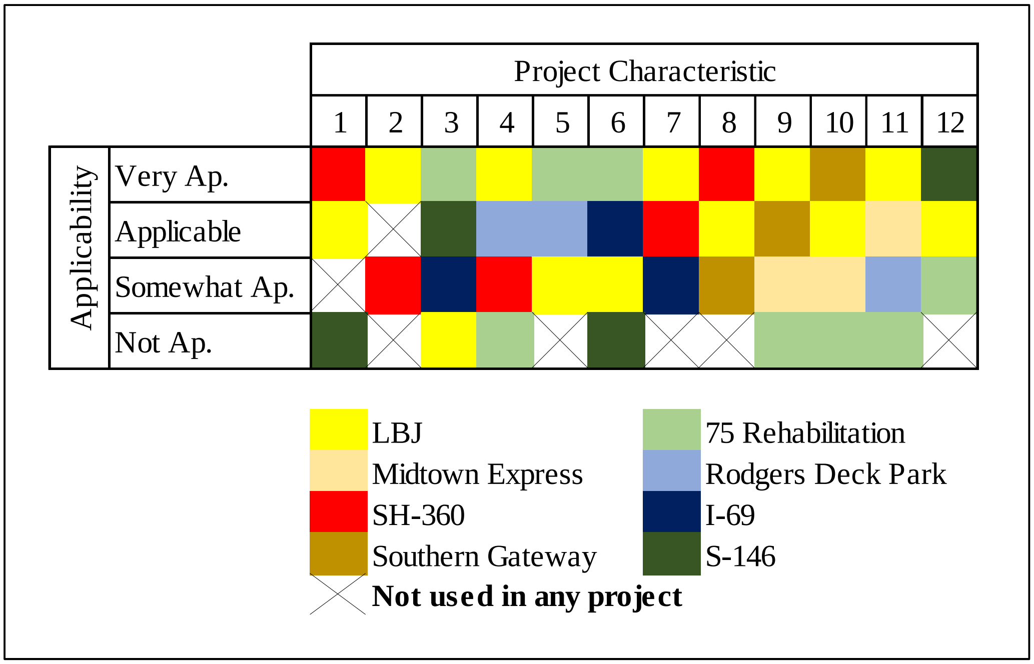


Figure 30. Validation Characteristics' Range

Table 29. Validation Projects' Output

	Project	Score Obtained			Tool Recom - mendation:	Expert's Agreement
		DBB	DB	Dif.		
1	75 Rehabilitation	**0.32**	**-0.07**	**0.39**	DBB	YES
2	Southern Gateway	**-0.18**	**0.34**	**-0.52**	DB	YES
3	Woodall Rodgers Deck Park	0.16	0.18	-0.02	Tier 3 analysis	YES
4	LBJ East	-0.16	**0.32**	**-0.48**	DB	YES
5	Midtown Express (SH183)	-0.07	**0.27**	**-0.34**	DB	YES
6	SH 360	0	0.13	-0.13	Tier 3 analysis	YES
7	I-69	0.08	-0.02	0.10	Tier 3 analysis	YES – DBB would be selected due to Agency's issues
8	SH-146	-0.26	**0.24**	-0.5	DB	YES – but scope is not defined yet

Overall, a total of 8 projects were analyzed, covering all output possibilities and more than 85% of the project characteristics options. In all cases, the tool not only produced the decision recommendation that experts thought was more suitable, but also precisely listed the project characteristics that most and least support each alternative. After analyzing these 8 projects, it can be said that the tool accurately reproduces the mental decision process of TxDOT experts. It can be confirmed that the decision-support tool created is a valid formal and objective procedure to select a delivery method for a particular TxDOT capital project. However, validation should be a continuous process, as new projects are assessed using this decision-support tool.

Chapter 7: Conclusions and Recommendations

CONCLUSIONS

Alternative delivery methods have been rapidly growing among private and public owners. Due to regulatory constraints, not all U.S. Departments of Transportation are allowed to contract projects using delivery methods other than the traditional Design-Bid-Build. This thesis went into the details of existing delivery method selection procedures and factors affecting the decision. The decision criteria extracted from literature included the most common owner objectives, projects' characteristics and entity's issues that guide the delivery method selection. Based on these findings, the research team developed a multi-criteria decision procedure. Starting from the factors' list, any public agency in need for a formal and repeatable decision process will be able to select the most applicable criteria and incorporate it into a MCDM model. This methodology allows any transportation infrastructure owner to develop a formal and objective methodology to select the most suitable delivery method for its public projects.

This work also customized the decision procedure tool to assist TxDOT personnel in the delivery method selection at the project level. The MS Excel-based decision-support tool include, as alternatives, DBB and DB methodologies. The tool created formalized and objectivized an already existent –but subjective– decision process. It was developed with the input of first-line TxDOT personnel to ensure it would reflect the agency's experiences and preferences. Twelve characteristics and four project objectives were detected as main decision criteria for the agency's delivery method selection. These factors are considered to define a broad range of projects, making the tool helpful in diverse situations. However, the input information needs to be clear and defined when the tool is used: we highly recommended running the tool only after the project's scope is defined. If the input data is provisory or not accurate, so will be the recommendations. By formalizing the decision and giving quantitative measures of each alternative, we provide TxDOT with a documented and repeatable process that goes beyond the subjectivity of each individual.

We recognized that TxDOT legislative authority, projects' characteristics and objectives may change in the future, that is why the tool was developed in a MS Excel interface, which makes it easily auditable and modifiable. One of the main challenges is to keep the tool updated as and when necessary, according to the agency's situation, needs or legislative authority changes.

RECOMMENDATIONS

The present research effort could be extended in several ways. First, it is possible to further develop the validation process. Even though the tool was tested with a full range of projects, covering all selected characteristics and goals, some additional studies could be done with an experimental set of data of already delivered projects. Also, to demonstrate that the tool is independent of the decision-maker, different experts could be asked to use it for the same projects, and a comparison of the results obtained should be done. Validation should also be a continuous process, keeping track of the fulfillment of each objective and the suitability of the delivery method for the projects where the decision-support tool is used. This way, it would be possible to compare and verify experts' input scores (scores matrixes) with the actual project performance; and make modifications and calibration as needed.

Also, the developed tool can be taken a step further by adding a detailed Tier 3 procedure when the delivery method is not clearly defined after the analysis. Such analysis should follow the TRB TCRP (2009) approach, guiding a detailed risk assessment. Contract strategies would be another useful add-in to the tool, guiding the decision makers to the selection of contract clauses that help mitigate the project's risks, for any selected delivery methods. CII PDCS (2003) includes this feature and can be a good starting point and example towards that end.

CONTRIBUTIONS

The present work serves as a starting point for any transportation-related owner that, having more than one delivery alternative, need to develop a decision-support tool suited for their goals. The comprehensive literature review on existing methods and decision criteria provides a baseline from where to select the criteria that guides the delivery methods decision. The Agency-level issues, project's objectives and project's characteristics provided describe a broad range of situations. From that foundation, owners can select among the existent processes and factors those that better suit their needs. The separation between objectives and project characteristics can accommodate needs of entities that may be delivering similar projects, but each willing to achieve different goals. Also, the project-level tool centers on the scope of the project and leaves aside, for an optional subsequent analysis, those factors that depend on the agency's characteristics and temporary situations, such as level of expertise or workload. Overall, the research process presented may be reproduced by other agencies to obtain results customized to their own experience, agency and project's characteristics, and most common goals.

Finally, a transparent and objective tool for TxDOT Delivery Method selection was created, meant for the use of the agency, but also intended to guide any other owner. This tool presents unique characteristics and a transparent development approach that makes it available for other owners, and places it a step further the existent methodologies.

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