Cost-Duration-Based Lump Sum Project Selection Framework Using Stochastic Methods for Design-Bid-Build Resurfacing Projects

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
May 4, 2019

Keywords: Cost-Based Decision-Making, Design-Bid-Build, Lump Sum Contracting, Multi-Attribute Utility Theory, Unit Price Contracting

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ABSTRACT

The appropriate selection of procurement tools and contracting strategies is a key factor in the successful completion of construction projects and has become an important and growing area of study for both researchers and practitioners. However, most recent and concurrent research efforts undertaken in this area are focused on the implementation of alternative project delivery methods, with little attention paid to continue improving the traditional design-bid-build (DBB) contracting approach. It is a fact that the construction industry has seen a rapid increase in the use of alternative contracting methods during the last couple of decades, but it is also a fact that DBB contracting is still the most used project delivery method in the US. Thus, any efforts towards the improvement of this contracting approach would be expected to have a significant positive impact on the construction industry. This study has been aimed to contribute to the improvement of this traditional project delivery method on a specific relevant area that has great influence on the ability of public owners to successfully complete construction project; the effective selection of payment provisions in DBB contracts.

This study has been conducted for the Florida Department of Transportation (FDOT) and is specifically focused on assisting this agency in the identification of DBB resurfacing projects that would offer better value-for-money if executed with lump sum (LS) payment provisions instead of using the traditional unit price (UP) compensation approach. To achieve this research objective, the author has developed a data-driven decision-making framework designed to anticipate and compare the expected cost and schedule performance of a given DBB resurfacing

project under each compensation approach. The proposed decision-making framework was developed using non-linear regression techniques, Monte Carlo Simulation, and data from 86 resurfacing projects completed by FDOT between January 2015 and March 2017: 63 UP and 23 LS projects.

The proposed LS project selection framework is actually the result of integrating two sub-frameworks: one to evaluate LS candidate projects based on their expected cost performance and one to evaluate the same projects from a schedule performance perspective. These frameworks produce stochastic construction cost and duration estimates in the form nomograms. Each of the two nomograms, the cost-based and duration-based nomograms, require two inputs: number of lane miles and desired confidence level set by decision-makers. These two inputs produce four outputs per nomogram: probability of having higher construction costs/duration if UP is used instead of LS; expected project cost/duration (deterministic estimate) if LS provisions are used; the worst case scenario if LS provisions are used; and the best case scenario if LS provisions are used. The worst and best case scenarios are defined in the form of cost and time savings and losses based on the desired confidence level.

Finally, the study describes a Multi-Attribute Utility Theory (MAUT) model that combines the outputs from the cost- and schedule-based nomograms into an integral LS project selection framework with the ability to make trade-offs among four cost and schedule performance objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty. The MAUT model facilitates the identification of the compensation approach with the highest overall level of satisfaction of these performance objectives, which would be the approach that offers the best value-for-money for FDOT's resurfacing projects.

DEDICATION

I dedicate my dissertation work to my family and friends. A special feeling of gratitude to my loving mother, Nagwa Dongola whose words of encouragement and push for tenacity ring in my ears. My brothers Tarig and Ahmed have never left my side and are very special. Finally I dedicate this dissertation to the soul of my father whose picture had never got out of my mind.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Dr. Jorge Rueda for the useful comments, remarks and the hand by hand engagement through the learning process of this dissertation. Furthermore I would like to thank Drs. LaMondia, Zech, and Azhar for the guidance they provided during my period at Auburn.

Finally, I would like express my deepest appreciation to my friends and my loving wife for the moral support they provided me throughout the entire process.

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LIST OF ABBREVIATIONS

DBB	Design-Bid-Build
UP	Unit Price
LS	Lump Sum
MAUT	Multi-Atribute Utility Theory
FDOT	Florida Department of Transportaion
DOT	Department of Transportaion
CO	Change Order
SAUF	Single Attribute Utility Function
EV	Extreme Value Distribution
N	Normal Distribution
SD	Standard Deviation

CHAPTER 1 INTRODUCTION

1.1 Background

Public owners in the transportation construction industry have been increasingly using alternative project delivery methods (e.g. design-build; construction manager/general contractor or construction manager at risk; partnership) to maintain, repair, and expand the transportation infrastructure in the US. The implementation of these methods is part of the efforts made by federal and state department of transportations (DOTs) to cope with the tight deadlines and even tighter budgets of today's construction industry. Alternative project delivery methods have proven their effectiveness in improving project performance in terms of quality, cost, and project duration *(1)*. However, DOTs recognize that alternative procurement strategies are not always the most suitable approach. In fact, most transportation construction and maintenance projects are currently being procured through traditional design-bid-build (DBB) contracting (*2*). For instance, between January 2015 and March 2017, the Florida Department of Transportation (FDOT) –one of the leading DOTs in the use of alternative contracting methods *(3)*– awarded more than 71% of all its projects using a traditional DBB approach. Therefore, any efforts towards the improvement and optimization of DBB practices, as the research efforts described in this study, are expected to have a considerable impact on DOTs' construction and maintenance programs and to contribute to the appropriate use of taxpayer's money.

In DBB contracting, design is fully accomplished by the DOT, using either in-house or consultant designers, before advertising and awarding a separate construction contract *(1)*. As occurs with any other project delivery method, DBB contracts can be tailored, to some extent, to match specific project needs. It is done through the combination of procurement procedures intended to address different administrative and management aspects of the project *(4)*. In the case of procedures to compensate general contractors, a construction contract on a DBB project could provide for compensation based on the actual amount of work performed (unit price), on a lump sum proposed by the contractor, or on the actual costs incurred by the contractor plus a fee to allow for a profit (cost reimbursable or cost-plus). It would depend on the specifics of the project and/or the preferences of the agency. Contractual obligations and exposure to risk vary depending on the selected compensation provision, meaning that contractors must develop a different pricing strategy for each compensation approach. It also means that when selecting a compensation approach, a DOT should consider the cost implications associated with each alternative. However, there is a lack of mechanism to factor construction cost estimates into the selection of procurement strategies –a widespread problem across all project delivery methods and contracting approaches *(1, 4, 5)*. "because no adequate and systematic method exists to evaluate how project delivery methods and contracting approaches have impacted costs, it is difficult to validate the financial impacts of their use"*(4)*.

This study describes the development of a cost-duration-based decision-making tool intended to assist FDOT with the selection of contractor compensation provisions in DBB resurfacing projects. More specifically, the proposed tool facilitates the comparison of stochastic cost and project duration estimates associated with the use of the two main compensation approaches used by FDOT in DBB construction and maintenance projects: unit price (UP) and lump sum (LS).

Current methods for the selection of suitable projects for LS contracting are mainly based on expert judgment. Almost any group of projects that involves simple and well defined tasks is a good candidate for LS contracting. The lack of mechanisms to formally determine whether to use LS or UP contracting make it difficult for DOTs to assess the schedule and cost implications of using a LS approach. Thus, in some cases DOTs may be overvaluing the benefits offered by Lump Sum contracting by paying unreasonably high construction prices than those that would be obtained using traditional UP procedures.

1.2 Proposed Lump Sum Project Selection Framework

Previous research has revealed that LS provision in DBB contracts are more beneficial in well-defined projects, where significant changes to requirements are unlikely making it easier for contractors to price the work described in the solicitation documents. Conversely, LS might be less appropriate where speed is important, or where the nature of the work is not well defined. In that case, a UP approach would be more suitable. LS contracts usually require greater efforts from owners for the preparation of solicitation documents and from contractors for the preparation of bid packages. These extra efforts are required in an attempt to account for all possible changes that might happen during the life of the project (*6*). This approach led some of the public agencies to use UP more than LS.

Taking into consideration the fact that actual construction costs and project duration (either under LS or UP contracts) cannot be predicted beyond a reasonable doubt, the proposed LS project selection framework includes stochastic sub-frameworks to quantify cost estimating and schedule uncertainty on a per project basis. These are the cost-base and location-based LS project selection sub-frameworks shown in Figure 1.1. Quantitative cost and duration assessments are performed using three main inputs: 1) project scale; 2) historical data to identify cost/duration escalation trends and quantify uncertainty; and 3) the risk tolerance of the decision-makers. The proposed methodology is developed using non-linear regression, Monte Carlo simulation, and other statistical testing techniques, as well as data from resurfacing projects completed by FDOT between January 2015 and March 2017.

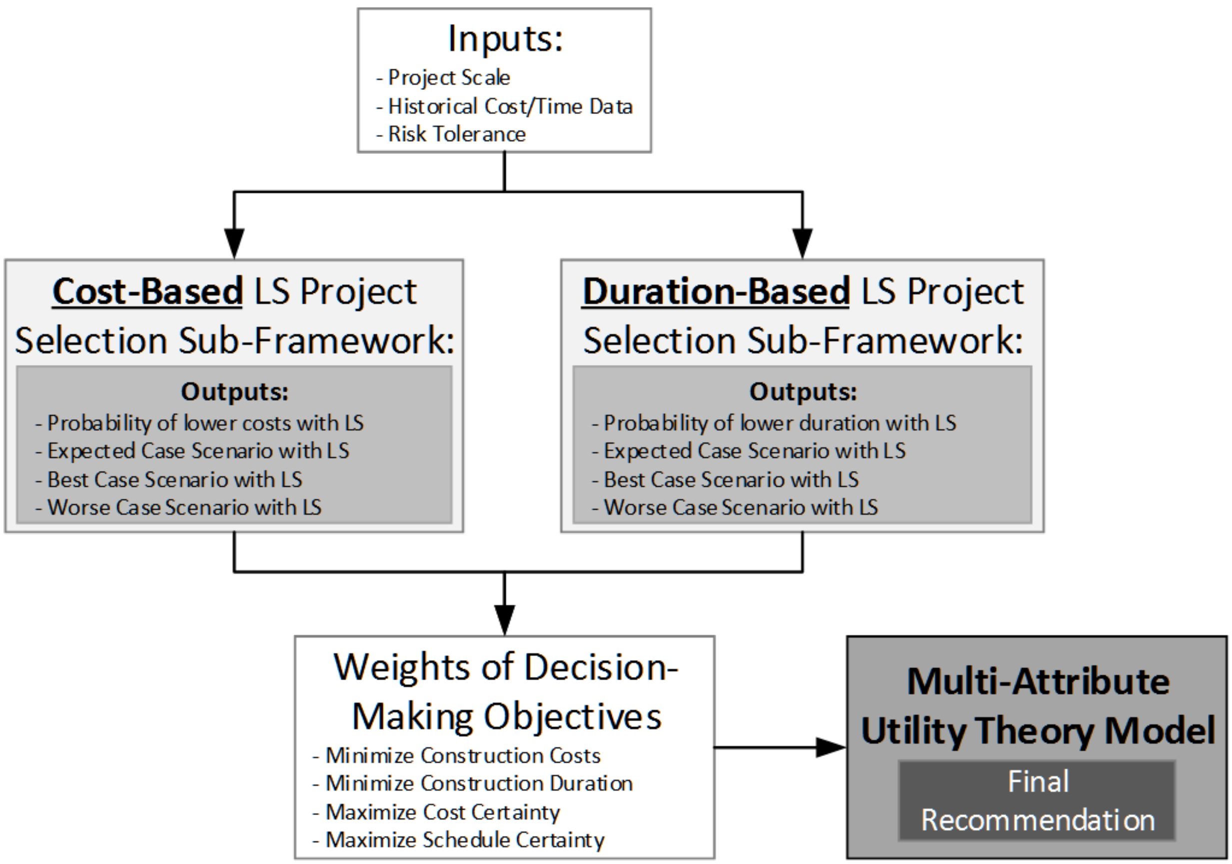

Figure 1.1 Overall Lump Sum Project Selection Framework

The cost- and duration-based LS project selection sub-frameworks shown in Figure 1.1 produce stochastic construction cost and duration estimates allowing for an approximation of the probability of having a lower cost and a shorter schedule if LS provisions are used, as well as cost and duration estimates under three different case scenarios: expected; best; and worst case scenarios. The best and worst case scenarios are defined by the risk tolerance of decision-makers, which corresponds to the desired confidence level.

While in some projects the selection of the compensation approach may be aimed to minimize project costs, other projects may require a shorter duration, even if that is reflected in higher construction costs. Likewise, there are cases where lower project costs and shorter durations are not as important as cost and schedule certainty (*7, 8*). Thus, it is necessary to integrate both the cost-based and duration-based LS project selection sub-framework in order to make effective decisions on the selection compensation approaches for DBB projects. In this study, these two sub-frameworks are integrated through a Multi-Attribute Utility Theory (MAUT) model.

MAUT models are commonly used to facilitate trade-offs among multiple objectives, such as the four decision objectives under consideration in this study : 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty. The proposed MAUT model takes the outputs from the cost and duration sub-frameworks and processes them to yield a recommendation on the most suitable compensation approach based on weights assigned to the four decision objectives and in an attempt to maximize value-for-money in DOT's investments.

This dissertation provides enough information for the development of spreadsheets for the implementation of the proposed LS project selection framework. Additionally, the mathematical functions involved in each sub-framework are comprised into nomograms to facilitate the use of the tool by different types of decision-makers and in different environments. Even though the proposed tool is only applicable to resurfacing projects awarded by FDOT, the methodology presented in this study could be replicated for other agencies and types of projects as well as include other compensation approaches.

1.3 Research Objectives

The research efforts described in this dissertation were intended to *develop a methodology to objectively identify DBB projects that would offer better value-for-money if executed with LS compensation provisions*. Recognizing anticipated construction costs and project duration as the major decision drivers, the author strategically designed and followed a research plan to achieve the primary research objective through the following three sub-objectives:

- Develop a stochastic *cost-based* LS project selection sub-framework for DBB projects.
- Develop a stochastic *duration-based* project selection sub-framework for DBB projects
- Develop a MAUT model to combine the previously developed cost- and duration-based LS project selection sub-frameworks, allowing for trade-offs among four decision-making objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty.

The objectives and sub-objectives outlined above were achieved following the research plan presented in Chapter 3 Methodology, which can be summarized in the following seven tasks:

1. Conduct an extensive literature review on LS guidelines and practices.
2. Collect, clean, and explore FDOT historical bid data from all projects awarded between January 2015 and March 2017.

3. Identify a suitable type of construction work to effectively demonstrate the application of the proposed decision-making tool.
4. Develop a stochastic *cost-based* LS project selection sub-framework for DBB projects by developing deterministic and stochastic cost estimating models based on the historical bid data.
5. Develop a stochastic *duration-based* LS project selection sub-framework for DBB projects by developing deterministic and stochastic schedule estimating models based on the historical bid data.
6. Develop a MAUT model that integrates the cost and duration sub-frameworks developed in the previous steps facilitating trade-offs among four decision objectives, which, if satisfactorily achieved, would serve to demonstrate value-for-money in FDOT's investments.
7. Analyze the results from the MAUT model and formulate conclusions and recommendations.

1.4 Organization of the Dissertation

To provide a comprehensive description of the research performed, this dissertation was divided into eight chapters and they were organized as follows:

- Chapter 1:Introduction
- Chapter 2: Literature Review
- Chapter 3: Research Methodology
- Chapter 4: Cost-Based Lump Sum Project Selection Sub-Framework for DBB Resurfacing Projects

- Chapter 5: Duration-Based Lump Sum Project Selection Sub-Framework for DBB Resurfacing Projects
- Chapter 6: Cost-Duration-Based Lump Sum Project Selection Framework: A Multi-Attribute Utility Theory Model
- Chapter 7: Conclusions and Recommendations

Chapter 1: Introduction, provides a brief description of the motivation behind the dissertation. This chapter explains the facts and issues that motivated this study and defines the problem statement that frames the research efforts behind this dissertation.

Chapter 2: Literature Review, furnishes the reader with the background information and relevant terminology necessary to understand the content of the subsequent chapters. This chapter presents and analyzes information obtained through a comprehensive literature review on topics related to this study. This chapter provides the reader with a better understanding of the principles of DBB contracting, summarizes the state-of-the-practice of LS contracting among DOTs, and defines some key terms used throughout this dissertation

Chapter 3: Research Methodology, gives and overall description of the methodology and research plan designed and implemented for the development of this dissertation. This chapter illustrates all research tasks in a chronological order, starting with the literature review and finishing with the MAUT cost-duration-based LS project selection framework. More detailed information about the methodology and research tools used in this dissertation is presented in their respective chapters.

Chapter 4: Cost-Based Lump Sum Project Selection Sub-Framework for DBB Resurfacing Projects, describes the development of a preliminary cost-based decision-making tool intended to assist FDOT with the selection of suitable DBB resurfacing projects for LS contracting. The tool was developed using non-linear regression techniques, Monte Carlo Simulation, and data from 86 resurfacing projects completed by FDOT.

Chapter 5: Duration-Based Lump Sum Project Selection Sub-Framework for DBB Resurfacing Projects, uses the same 86 historical resurfacing projects used in Chapter 4, but this time to develop a preliminary duration-based decision-making tool intended to assist FDOT with the selection of suitable DBB resurfacing projects for LS contracting.

Chapter 6: Cost-Duration-Based Lump Sum Project Selection Framework: A Multi-Attribute Utility Theory Model, describes the development of a decision-making model that integrates the two sub-frameworks presented in Chapters 4 and 5. Besides integrating the sub-frameworks, this model identifies suitable DBB projects for LS compensation provisions by making trade-offs among four decision objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty.

Chapter 7: Conclusions and Recommendations, provides a brief overview of the findings and main contributions of this dissertation. It discusses the results presented in Chapters (4 to 6) and its potential implications on the construction industry. Likewise, this chapter discusses some recommendations for future research based on the findings presented throughout this dissertation.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents and analyzes information obtained through a comprehensive literature review on topics related to this study. This chapter provides the reader with a better understanding of the principles of DBB contracting, summarizes the state-of-the-practice of LS contracting among DOTs, and defines some key terms used throughout this dissertation.

2.2 Background

Regardless of the increasing implementation of alternative contracting methods by DOTs, traditional DBB contracting is still the most common mechanism used to procure construction services. The main characteristic in DBB contracting is that all project phases are performed in series. It means that design must be fully accomplished before proceeding with the advertisement and award of a separate construction contract (*1*). Given that design and construction activities are contracted separately, there is no contractual relationship between the designer and the contractor as shown in Figure 2.1.

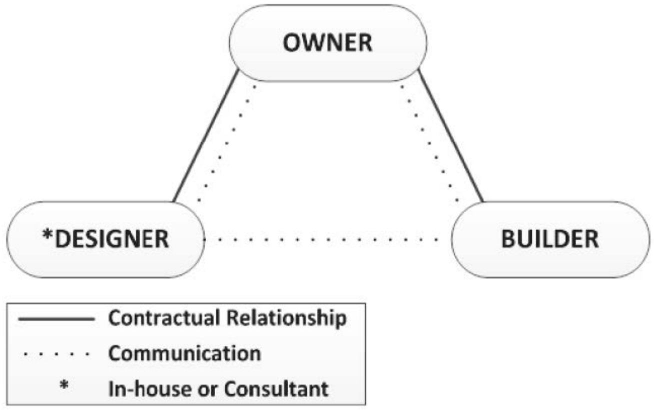

Figure 2.1 Design-Bid-Build Contracting

Even though DBB contracts are usually awarded to the low-bid responsive contractor, they can also be awarded on a best-value or negotiated basis in order to mitigate risks related to the selection of a contractor who has submitted a low price proposal inconsistent with the construction documents (*1, 9*). Likewise, UP compensation provisions are commonly used in DBB contracts; however, some DOTs in states like Florida, California, and Colorado, have found value in the use of LS provisions in this traditional procurement approach. It should be noted that the study referred to in this dissertation is focused on DBB-LS contracts awarded on a low-bid basis.

"Payment provisions are a contracting strategy that addresses how the [DOT] will pay a constructor for the work performed in accordance with the contract. Roadway projects commonly use only two different payment methods: unit price or lump sum" (*10*). There are other less-frequently used compensation approaches in the transportation construction industry, as well as a number of supplementary provisions to support or customize the generic form of UP and LS contracting. Table 2.1 list all common, less common, and supplementary payment provisions identified by Molenaar et al. (2014) in a previous study on transportation contracting methods.

Table 2.1 Payment Provisions used by DOTs (*10*)

Common Payment Provisions	Less Common Payment Provisions	Supplementary Payment Provisions
• Unit Price • Lump Sum	• Cost Reimbursable • Guaranteed Maximum Price • Contract Force Account	• Price Adjustment Clause • Shared Risk Pool • Payment by Plan • Incentives/Disincentives • No Excuse Incentives • Interim/Milestones Completion Dates • Material and Workmanship Warranty • Performance Warranty • Lane Rental • Active Management Payment Mechanism

Besides dictating the procedures to compensate contractors for the work performed, payment provisions also define the bidding approach to be used in construction and maintenance contracts. In UP contracts, bidders are required to submit unit prices for all pay items and bid quantities listed in the solicitation documents, and the contract is usually awarded on a low-bid basis. The selected contractor is then compensated through partial payments based on actual quantities of work measured by the owner (or its representative) and the unit prices submitted by the contractor (*11*). On the other hand, in LS contracts, contractors prepare and submit a lump sum bid based on plans and specifications advertised by the owner in the solicitation documents (*12*). A LS bid is a fixed amount of money in exchange of which the contractor agrees to perform all work described in the contract documents. This amount includes all material, labor, equipment, overhead, and profit (*13, 14*). As in UP contracts, DBB-LS contracts are commonly awarded to the lowest bidder, but in this case, the selected contractor is compensated based on the LS bid and a payout schedule agreed upon by the owner and the contractor (*11*, *15*, *16*).

In UP contracts, the work to be performed by the contractor is broken down in multiple work/pay items and the contractor agrees to be paid a fixed cost per unit of work for each item

(*10*), such as per-cubic-yard of excavation or linear foot of guardrail. Payments to the contractor are based on actual quantities of work performed by the contractor and measured by the owner for each pay item multiplied by their respective unit prices. The unit-cost for each item commonly includes all labor, materials, project overhead, company overhead, and profit. Sometimes overhead items are paid separately (*6*).

2.3 Lump Sum Provisions - Advantages and Disadvantages

Table 2.2 summarizes the advantages and disadvantages identified by the literature review conducted for this study. Most authors and DOTs agree that one of the main benefits that motivates the use of LS contracts is the reduction of contract administration costs and construction inspection efforts related to quantity verification and measurement (*11*, *13*, *15*, *16*, *17*, *18*). It allows field inspectors to pay more attention to ensure that the final product meets minimum quality and performance standards (*11*, *15*).

Table 2.2 Lump Sum Advantages and Disadvantages

Advantages	Disadvantages
• Reduce contract administration costs and efforts related to quantity verification and measurement • Simplify the payment process • Allow inspectors to focus on the achievement of minimum quality and performance standards • Incentivize contractors to implement better cost control measures • Provide greater flexibility to contractors for the selection of construction means and methods	• Greater difficulty in pricing and negotiation of change orders and extra work • Greater difficulty in the identification of extra work and changes in the scope of work • Higher contingencies may be included in price proposals • Require higher design quality to avoid change orders and potential disputes/claims

During the last 15 years DOTs increased their construction projects funding by more than 40% but the number of inspectors either remained the same or declined (*19*). This shortage could be attributed to one of the following reasons (*20*):

- The lack of sufficient training for the new hires in the inspection industry;
- Retirement of experienced inspectors and no one can fill their spots; or
- Departure of experienced inspectors to private companies due to uncompetitive pay in the government (*20*).

Mainly two activities have been affected by the shortages as reported by a recent U.S. DOT study, which are construction inspection and materials testing (*21*). Researchers proposed many solutions to overcome the problem. A study conducted by The University of Texas at Austin and sponsored by Texas Department of Transportation (TxDOT) to reduce the construction inspection workload recommended the implementation of Lump Sum contract to help the inspectors focus more in the quality of the work performed by contractors rather than measuring the quantities completed (*22*). As an additional benefit, Kaplanogu and Arditi (2009) suggested that LS offers the owner the best protection because in LS the project is only executed when the work is clearly defined and understood by all parties (*23*).

Benefits offered by LS contracts are the result of moving procurement practices towards a more “all-inclusive” approach; however, it also seems to be the cause of their main disadvantage: the greater difficulty in managing and negotiating extra work and change orders. The absence of unit prices for specific materials or activities makes it difficult for both DOTs and contractors to price change orders and extra work as well as to identify legitimate deviations from the original scope of work contained in the LS bid *(13, 18)*. This situation may force contractors to increase contingencies in their price proposals to compensate for the greater risk. DOTs have made efforts to overcome the disadvantages identified in the use of LS provisions by limited the use of these provisions to “simple” projects, as described in the following section.

2.4 Departments of Transportation’s Lump Sum Practices

The literature review on LS practices across the country revealed that at least five state DOTs have developed and implemented formal guidelines to govern the use of LS in DBB contracting. As shown in Figure 2.2, these DOTs are Alaska, California, Colorado, Florida and Michigan. The literature review also showed that DOTs in Montana and Washington State have developed guidelines for a narrower use of LS provisions, where their application is limited to the compensation of traffic control activities performed by contractors. Likewise, the author found that Texas DOT is currently in the process of developing its own LS contracting guidebook.

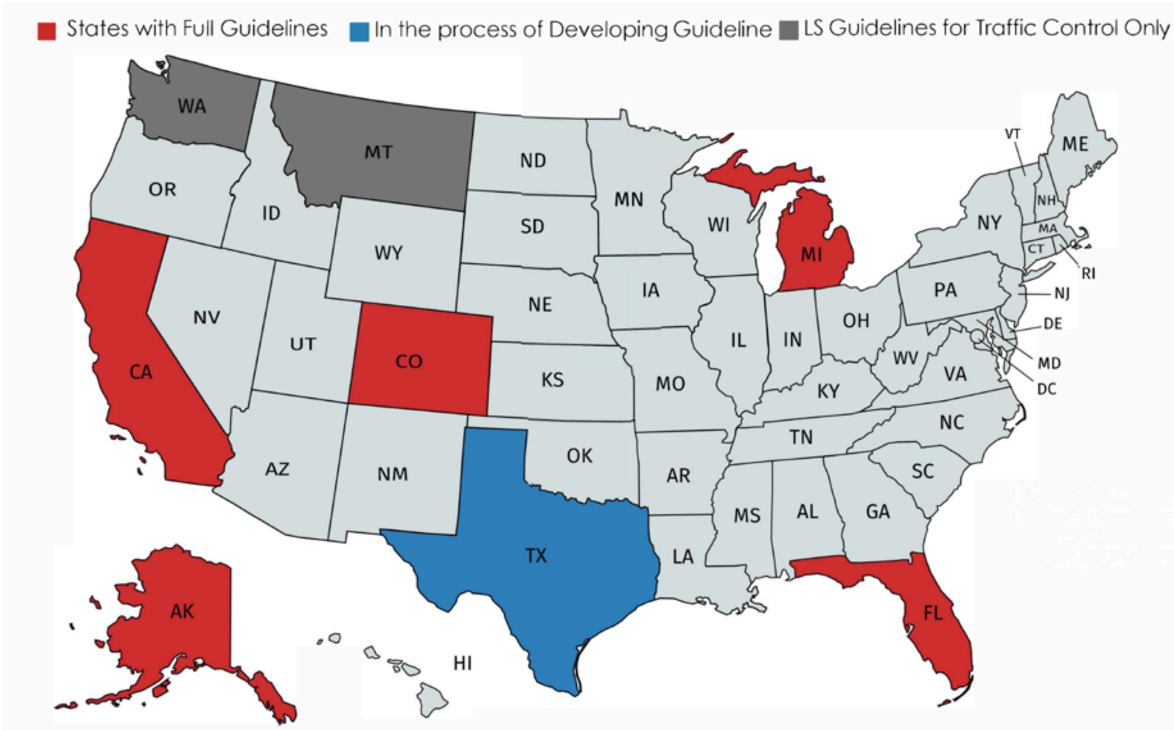

Figure 2.2 States that Utilize Lump Sum Guidelines

2.5 Current Lump Sum Project Selection Practices

All sets of guidelines reviewed by the author present similar descriptions of the DBB-LS contracting process. Contractors are required to prepare and submit a LS bid comprising all the work described in the bid documents (plans, specifications, drawings, etc.) provided by the agency. It was also found that LS users agree that these provisions should be mainly used in simple with well-defined scope of work for all parties (Design and Construction), low risk of unforeseen conditions (i.e., minimal underground utility issues, low likelihood of quantity variations), and low possibility for changes in scope during design and construction (*15, 16, 17, 24, 25*). Alaska added another conditions to the selection process which is “Projects with limited opportunity for contractors to provide less than the required quantities, such as asphalt thickness, steepened slopes, and culvert lengths" (*15*). The review of contracting guidelines showed the use of similar LS project selection criteria across DOTs. Examples of these criteria include projects with:

- A well-defined scope of work for all parties *(15, 16);*
- Low risk of unforeseen conditions *(15, 16);*
- Low possibility for scope changes during all project phases *(15, 16)*; and
- Low possibility for contractors to provide less than the required quantities of work *(15)*.

As an additional strategy to facilitate the decision-making process on whether or not to use LS provisions instead of a UP approach, DOTs have included in their LS guidelines examples of specific types of projects that may be suitable for LS. Table 2.3 presents the most and least suitable types of transportation projects listed in LS guidebooks.

Table 2.3 Most and Least Suitable Types of Projects for LS Contracting (*15, 16, 17*)

Most Suitable	Least Suitable
• Bridge painting • Bridge projects (with limited earthwork or pile driving) • Fencing or guardrail installation • Intersection improvements • Landscaping • Lighting • Simple milling and resurfacing projects • Minor road widening (with limited earthwork) • Sidewalks • Signing • Signalization • Simple transportation enhancement projects • Traffic Markings	• Urban construction reconstruction • Rehabilitation of movable bridges • Projects with subsoil earthwork • Concrete pavement rehabilitation projects • Major bridge rehabilitation/repair projects

It should be noted that the LS project selection criteria described above consist of subjective parameters to be evaluated by project managers or construction engineers on a per project basis. Ultimately, the decision of whether or not to use a LS approach depends on the experience and professional judgement of the decision-makers. The most suitable types of projects listed in Table 2.3 are intended to be used as a reference for decision-makers rather than as an absolute rule. Not all projects for these types of work are good candidates for LS. They still need to be evaluated in the light of the agency's selection criteria. Lump sum guidelines for the states of Alaska, California, Colorado, Florida and Michigan can be found in Appendix B of this study.

2.6 Florida Department of Transportation (FDOT) – Lump Sum Contracting

As the other LS users, FDOT is only using this compensation approach on simple DBB projects. FDOT defines "Simple" in terms of the nature of the work activity, not by its cost. These simple projects should have a well-defined scope for all parties of design and construction, low risk of unseen conditions, and low possibility for change. Examples for these projects would be Bridge Painting, Bridge Projects Guiderails, Fencing, Landscaping, Resurfacing (without complex overbuild requirements) and sidewalks. While other projects such as urban construction/reconstruction, and major bridge rehabilitation where many unknown quantities exist the use of unit price is more favorable by FDOT.

Under FDOT's current alternative contracting program, LS contracting is classified as an innovative approach different from DBB (*13*). However, for the purposes of this study, LS is considered as a contract provision that can be used in DBB contracts as a substitute to the usual UP bidding/compensation approach. This assumption is made based on the fact that LS contracts awarded by FDOT do not alter the traditional DBB contractual relationships between owners, designers, and contractors (*18*). The design and construction phases are still performed in sequence and by different entities. LS provisions are also used by FDOT in design-build contracts; however, this study is only focused on DBB-LS contracts, which are usually labeled by FDOT as "lump sum contracts" (*16*)

FDOT has made clear that "Lump Sum contracts are not fixed price"(*18*). It means that LS bids submitted by contractors are susceptible to changes due to changes in the scope of work, extra work, or unforeseen conditions. FDOT's LS contract documents include predetermined unit prices for key work items to facilitate the pricing of change orders and extra work (*18*).

2.7 Cost and Duration Escalation due to Change Orders

It is almost certain that no construction project is free of change during the course of the design or construction (*26*). These changes could be generated in the form of change orders (COs) either requested by the owner or generated in the field (*27*). The owner's generated COs are modifications to the scope of work, design, or other aspects of the project, requested by the owner as a unilateral decision. Field generated COs are changes made to overcome problems or conflicts that are detected in the field during construction and are commonly issued after a careful discussion of the problem between the owner and the contractor (*27*). These changes can negatively affect project performance in many ways, resulting in significant cost and schedule growth (*28*). Table 2.4 shows the classification of COs found in FDOT's data. FDOT uses ten different terms to label each of its COs. Table 2.4 also shows the type of impact associated with each type of CO: cost impact, schedule impact, or both. Researchers have suggested that the selection of contracting provision (including compensation approaches) has a direct effect on the magnitude and frequency of COs, as well as on their impacts on original construction budgets and schedules, which further supports the need for this study.

Table 2.4 FDOT's Types of Change Orders and their Impacts

Description	Impact	
	Schedule	Cost
Contingency Supplemental Agreement	No	Yes
Time Extension Agreement	Yes	No
Holiday Duration Extension	Yes	No
Modifying Pay Item Participation	No	No
Supplemental Agreement	Yes	Yes
Movement of Items Within Contract	No	No
Work Order for Specification Change Only	No	No
Unilateral Supplemental Agreement	Yes	Yes
Weather Days' Duration Granted	Yes	No
Contingency Work Order Duration Adjustment	Yes	No

Previous research was mainly focused on the comparison between delivery methods, such as DBB and DB (*29*), rather than on different DBB contract structures. Although researchers and practitioners have not reached agreement on this matter, one study found a higher frequency of COs on DBB than those on DB projects (*30*), increasing the overall project cost and schedule uncertainty. Another study found that the typical LS nature of DB allows this contracting method to outperform DBB in terms of budget and schedule control (*29*). Likewise, a case study conducted in Oman concluded that the main causes of COs impacting construction budgets and schedules are associated with owner's generated COs and with differing site conditions (*31*).

2.8 Multi-Attribute Utility Theory

Multi-attribute utility theory (MAUT) is a decision-making approach that facilitates the evaluation of multiple alternatives on multiple weighted objectives using utility values, which allow "apples to apples" trade-offs between decision objectives (*32*). The output of a MAUT model consists of an overall utility value for each alternative. The higher the overall utility value, the better the overall level of satisfaction of the decision objectives. Thus, the recommended alternative would be the one with the highest overall utility value. The alternatives evaluated by the MAUT model presented in this study correspond to the two compensation approaches under consideration (UP and LS). Likewise, the overall utility values in the output are assumed to represent the value-for-money offered by each alternative.

The existing literature seems to lack examples of MAUT techniques used for the selection of contracting provisions. However, a number of multi-objective decision-making models have been proposed in the construction industry for project prioritization and resource allocation purposes. In 2007, Tsamboulas used a MAUT framework to prioritize multinational transportation infrastructure projects across 21 countries members of the Trans European Motorway and Railway networks (*33*). Before Tsamboulas' study, Gercek et al. used Analytic Hierarchy Process (AHP), another multi-objective decision-making approach, to evaluate and rank rail transit network projects in Istanbul, Turkey (*34*). Likewise, Gaytan and Garcia developed an evolutionary-framework to evaluate a list of transportation candidate projects based on multiple objectives (*35*).

Gaytan and Garcia also discuss some of the disadvantages of applying benefit-cost approaches for the assessment of multiple alternatives. Besides the challenges associated with the consideration of multiple decision objectives, decision-makers in benefit-cost analyses face “considerable difficulties in measuring all relevant impacts [of the projects under consideration] in monetary terms” (*35*). This is also the reason that led the author of this dissertation to use a multi-objective decision analysis technique like MAUT instead of a benefit-cost analysis.

The alternatives evaluated by the MAUT model presented in this study correspond to the two compensation approaches under consideration (UP and LS). Likewise, the overall utility values in the output are assumed to represent the value-for-money offered by each alternative. The concept of value-for-money is explained in detail in the following section.

2.9 Value for Money

The literature review revealed a number of different definitions for “value-for-money,” many of them adjusted to specific industries, but this term generally used to describe the commitment and assurance to achieve the best results possible from the money spent (*36*). Value-for-money is associated with the concept of “value thinking,” which was introduced by Lawrence Miles in the 1940s. Miles was a purchase engineer with General Electric Company (GEC). During that period, the manufacturing industry in the United States (US) was running at maximum capacity, which resulted in shortages of some industrial raw materials. GEC wished to expand its production, and Miles was assigned the task of purchasing the materials to permit the expansion. Often he was unable to obtain the specific material or component specified by the designer. Thus, he reasoned, “if I cannot obtain the specified item then I must obtain an alternative which performs the same function.”

When Miles found alternatives to the specified item, they were then tested and approved by the product designer. Miles found there were multitudes of substitutions for providing equal or better performance at a lower cost than the items specified. From Mile's new innovative method, he proposed a system that he called "value analysis." Since Miles initial epiphany, his proposed methodology has become an innovative rational requirement to maximize the benefits achieved through decision-making processes involving multiple alternatives (*37*).

The concept of "value-for-money" that has evolved out of Miles' idea is a little more complex. In some cases, it integrates economy, efficiency, effectiveness, and equity factors (*38*). These factors are usually referred to as the four "E's," and are defined below and illustrated in Figure 2.3.

- **Economy:** Procuring the inputs by minimizing the cost without compromising quality.
- **Efficiency:** Determine the proficiency of the inputs being converted into outputs within the specified quality.
- **Effectiveness:** The amount of outcomes achieved in relation to the total cost of the inputs.
- **Equity:** Value for money should be equitable by ensuring that benefits are distributed fairly (*38*).

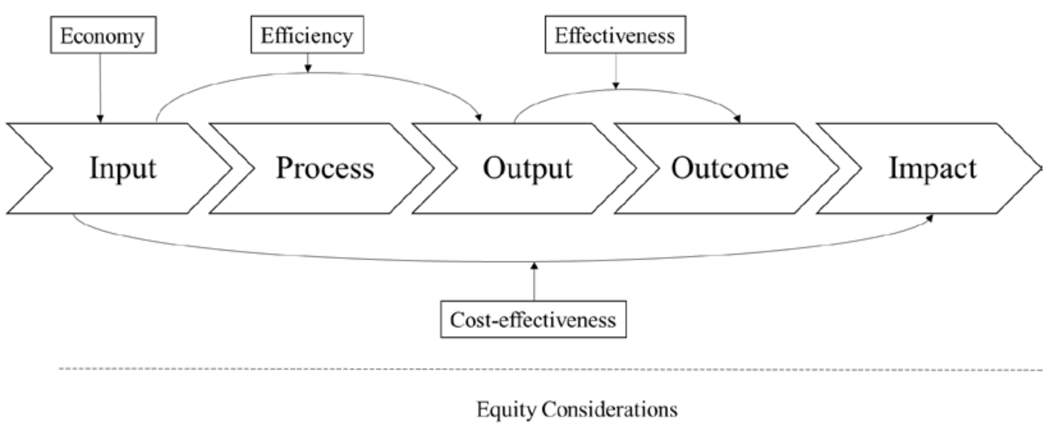

Figure 2.3 4Es Framework (*39*)

The Department for International Development (DFID) in the UK uses three of the four "E's" mentioned above in its value-for-money assessments: economy, efficiency, and effectiveness. However, the addition of the fourth dimension to this process, equity, was proposed by the Independent Commission for Aid Impact (ICAI) (*38*). Value-for-money analysis has been used in a number of different contexts. For example, in some application, including the one presented in this dissertation, this concept is assumed to be a synonym for cost-effectiveness/cost-utility (*40*), which in the construction industry is usually evaluated in terms of cost, time, and quality (*41, 42*). Given that the two alternatives to be evaluated by the methodology proposed in this dissertation are only intended to modify the compensation approach and the distribution of risk between owners and contractors in DBB projects, they are not assumed to significantly influence quality nor the construction means and methods used to convert construction inputs (i.e. materials, equipment, and labor) into the desired output (a finished project). Thus, this study is mainly focused on economy and effectiveness factors. More specifically, the proposed methodology produces a recommendation based on four decision objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty.

2.9.1 Value-for-Money Assessment Approaches

This section presents a classification of value-for-money approaches. Although they involve different assessment procedures and requirements, any of them can be used regardless of the number of E's" considered in the value-for-money analysis. Based on this classification system, there are three types of value-for-money assessment methods (*40*): 1) non-monetary; 2) monetary; and 3) relative cost and benefits methods.

1. Non-Monetary Methods

Non-monetary methods are used to evaluate the effectiveness of the alternatives in non-monetary terms. Cost-effectiveness and cost-utility analysis are the two types of non-monetary methods described in the existent literature.

a. **Cost Effectiveness Analysis (CEA)** is a type of economic analysis that compares the relative costs and outcomes of different courses of action. Cost-effectiveness analysis is distinct from cost–benefit analysis, which assigns a monetary value to the measure of effect. Cost-effectiveness analysis is widely used in the health services field as ratios rather than monetary values, where health effects are inappropriate to monetize. (*43, 44*).
b. **Cost-Utility Analysis (CU)** is like cost-effectiveness analysis. The main difference between the two methods is that CU estimates benefits in terms of utility values (*40*). MAUT is an example of CU analysis, and is the approach used in this study.

2. Monetary Methods

Monetary methods rely on the analysis of whether or not the outcomes outweigh the costs of the investment or course of action under consideration. To compare benefits and costs it is necessary to define both of them in the same monetary units. It means that efforts are required to monetize expected benefits, which is usually a challenging process. **Cost Benefit Analysis (CBA)** is the most common monetary method (*45*).

3. Relative Cost and Benefits Methods

Relative cost and benefit models use relative/indirect measures to assess cost-effectiveness. This method indirectly compares the cost to the benefits of the project being analyzed. **Rank Correlation of Cost vs Impact (RCCI)** and **Basic Efficiency Resource Analysis (BERA)** are the main relative cost and benefit methods used in value-for-money assessments. RCCI allows for the relative measurement of value-for-money by correlating the costs and benefits across a portfolio of initiatives. BERA examines relative value by plotting programs on a four-quadrant graph based on costs and impacts (*46*).

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents an overall description of the research plan to be followed to accomplish the research objectives outlined in Chapter 1. This chapter illustrates all research tasks in a chronological order, starting with the literature review and finishing with the MAUT cost-duration-based LS project selection framework.

3.2 Research Methodology

The research methodology for the proposed study is illustrated in Figure 3.1. After defining and stating the problem, the study begins with a comprehensive literature review aimed to collect information about the current practices in DBB and LS and contracting. This information has been analyzed and used to better understand the research problem and to design an effective research plan to achieve the research objectives. Subsequently, the author has proceeded to collect and clean FDOT historical data from previous projects. FDOT's online project database provides information about all projects awarded by the agency for the last two and half years from the date the data was first accessed. Available information in these databases includes data for all types of work and contracting methods used by FDOT. Data extracted and cleaned by the author corresponds only to DBB-LS and DBB-UP projects awarded by FDOT between January 2015 and January 2017.

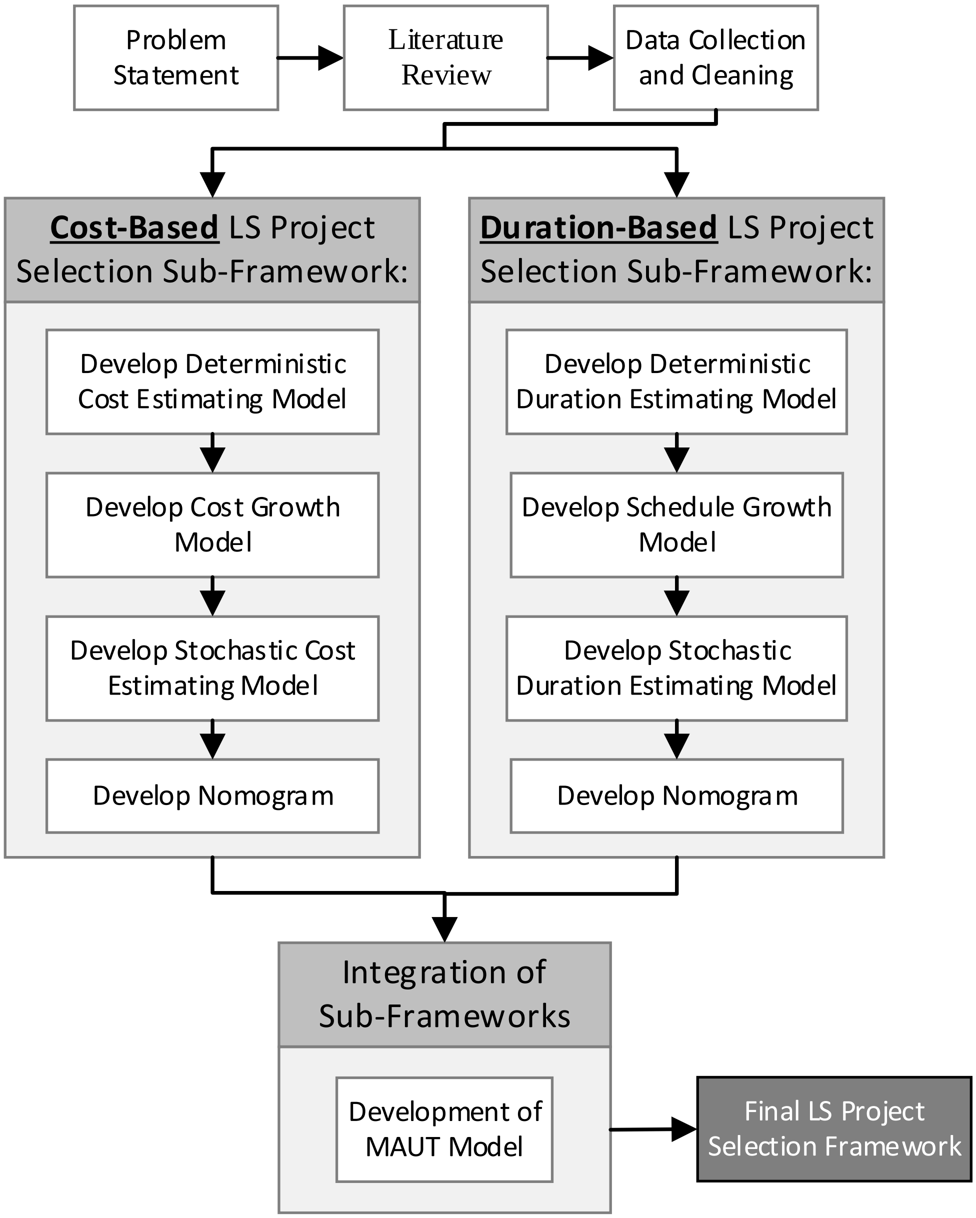

Figure 3.1 Proposed Research Methodology

Having collected all relevant available data, the author proceeded to develop the cost and duration assessment sub-frameworks. These two sub-frameworks are developed through similar processes, with the main difference being the type of measurement used in the stochastic estimates and nomograms. One produces a stochastic cost output in dollars, while the other produces a stochastic project duration estimate in work days. The steps followed to develop the cost sub-framework are presented in detail in Chapter 4. The same steps were followed to develop the duration sub-framework are presented in detail in Chapter 5.

After the development of the construction cost and duration assessment sub-frameworks, they were integrated into an overall cost-duration-based LS project selection framework using MAUT techniques that allow for trade-offs among the four decision objectives considered when identifying suitable DBB projects for LS payment provisions: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty. The following sections briefly describe two major research instruments used, in this study: Monte Carlo simulation and MAUT. Other research tasks and tools used in this study are presented in later chapters.

3.3 Monte Carlo Simulation

Monte Carlo simulation, or probability simulation, is a mathematical method used to calculate possible outcomes by generating multiple sets of random values (iterations) for specific variables. Random values for the input variables are generated based on previously defined probability distributions. Monte Carlo simulation techniques are widely used in research to validate analytical processes and solve large, complex systems where analytical approximations are not easy to obtain otherwise (*47*).

In this study, Monte Carlo simulation techniques are used to compare stochastic UP and LS estimates within both the cost and duration sub-frameworks. The role of this research instrument in this study is illustrated in Figure 3.2. In the cost sub-framework, the proposed methodology includes the development of a deterministic cost estimating model and a cost growth model for each payment approach (UP and LS). These two pairs of models are used to develop two stochastic cost estimates for a given candidate project: one stochastic cost estimate if UP provisions are used, and one if LS provisions are used instead.

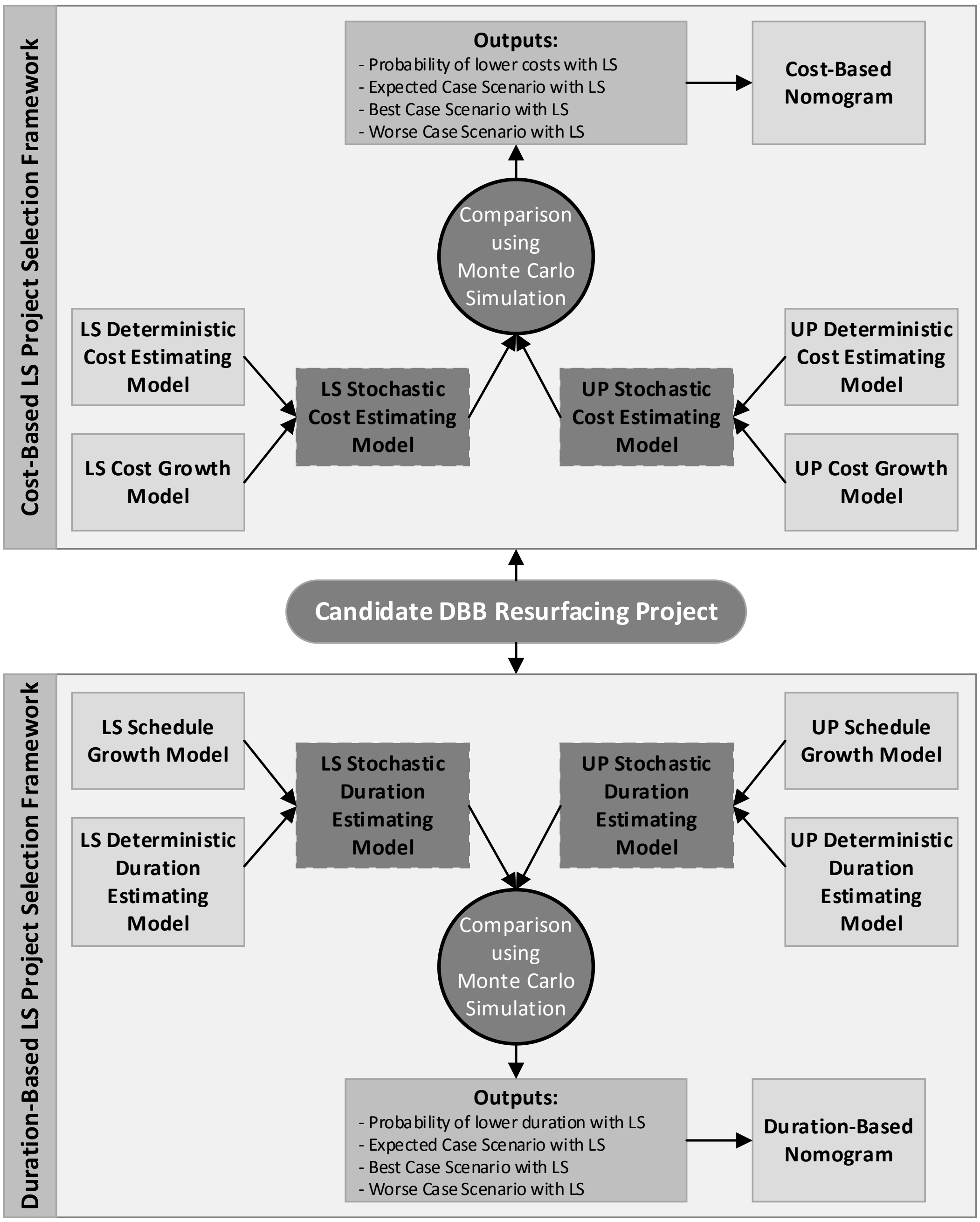

Figure 3.2 Mote-Carlo Simulation Process

A Monte Carlo simulation process was then performed to compare both stochastic estimates to calculate the probability of having lower costs if LS provisions are used. Likewise, the difference in dollars measured for each iteration, is used to measure the cost saving, or extra costs, associated with the use of LS provisions under each of the three scenarios considered in this study. Finally, the outputs from the simulation process are used to create cost-based nomograms. A similar process was then followed to develop the duration assessment sub-framework, but to compare stochastic duration estimates. More information on the use of Monte Carlo simulation techniques is presented in Chapters 4 and 5.

3.4 Multi-Attribute Utility Theory

As previously discussed, MAUT techniques are used in this study to maximize value-for-money in the selection of DBB compensation approaches by making trade-offs among four decision objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty. MAUT uses utility values to help decision-makers identify the best or most suitable option among multiple alternatives taking into consideration multiple objectives and the decision-maker's preferences (*32*). Trade-offs among decision objectives are made based on weights previously determined by decision-makers for all objectives (*48*). Besides its ability to facilitate trade-offs among conflicting objectives, MAUT was also selected for its simplicity. MAUT models are easily understood by practitioners and different types of stakeholders.

The use of utility values to determine the level of achievement of decision objectives allows MAUT models to aggregate different types of measures or units such as dollars, workdays, percentages, ratios, etc. The functions used to translate each measure into a utility value are usually referred to as single attribute utility functions (SAUFs). SAUFs convert measures into normalized utility values between zero and one; zero representing unfavorable values and one representing favorable values in the model.

Practitioners and stakeholders are drawn to MAUT models because of their simplicity. They provides a straightforward approach to aid decision-makers to evaluate trade-offs among multiple items according to weights predetermined by them for all items (*48*). Figure 3.3 is the generic representation of the process to develop and implement the MAUT model for this study. The steps of this process are described in the following sections.

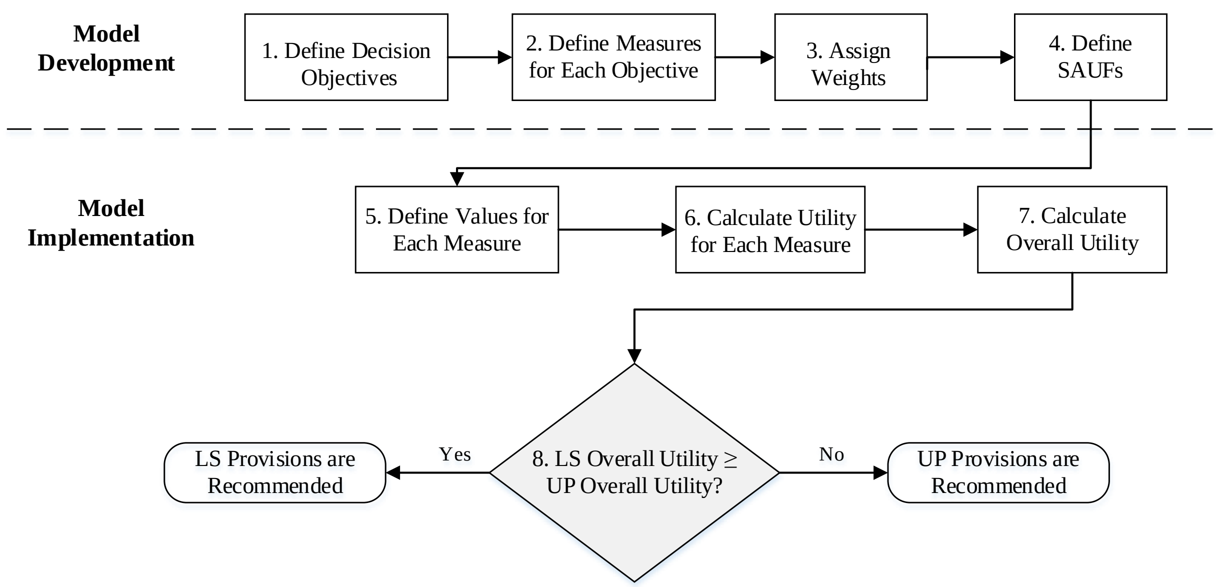

Figure 3.3 MAUT Model Development and Implementation

3.4.1 MAUT Model Development

Figure 3.4 illustrates the MAUT model obtained after finishing the four steps in the Model Development Phase shown in Figure 3.3.

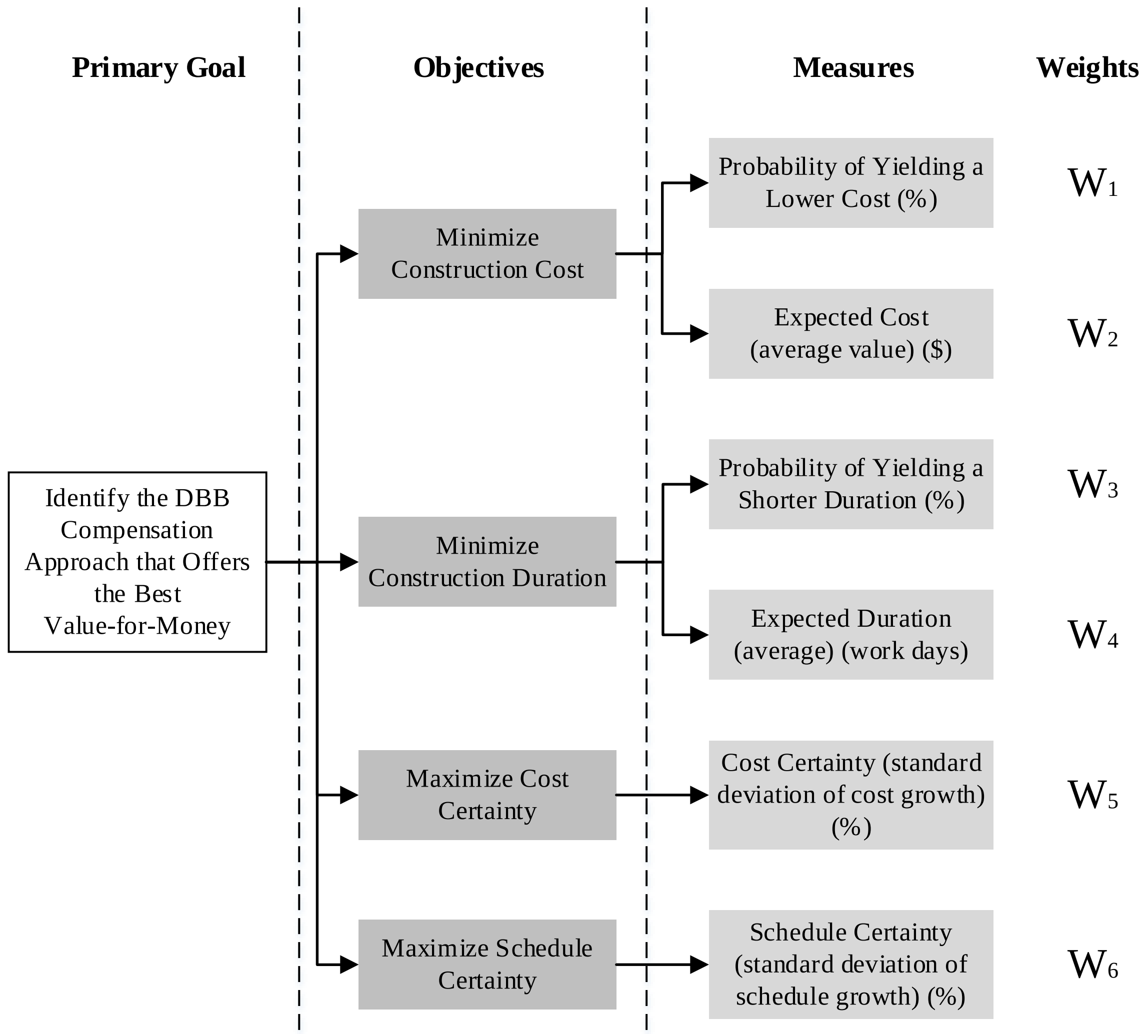

Figure 3.4 MAUT Model – Hypothetical Project

As part of the proposed methodology, this study recommends the determination of the measured weights on a per project basis (Step 3), since those are expected to change according to project-specific requirements. On the other hand, Steps 1, 2, and 4 can be revised on an as needed basis, or in case the agency decides to incorporate additional/different decision objectives or measures. To identify the DBB compensation approach (LS or UP) that would offer the best value-for-money, this dissertation recommends the use of four decision objectives:

1. Minimize Construction Cost
2. Minimize Construction Duration
3. Maximize Cost Certainty
4. Maximize Schedule Certainty

Each of the first two decision objectives is assessed for each compensation approach with two measures provided by the cost and duration assessment sub-frameworks: probability of yielding a lower cost and shorter duration, and the expected construction cost and duration. Expected values for cost and duration correspond to the average values of their respective stochastic estimates. The measures for the cost and schedule certainty objectives correspond to the standard deviations of the cost and schedule growth models, respectively. These growth models are presented in Chapters 4 and 5 and are intended to represent the level of uncertainty in these two project performance indicators. More specifically, cost and schedule growth refer to the difference between expected (at contract award) and actual (at project completion) values for these two parameters.

There are a number of weighting approaches used in multi-objective decision analyses. For instance, Zardari et al. describes 27 different weighting approaches classified into three groups: subjective, objective, and combined (subjective and objective) (*49*). This dissertation guides readers in the use of the swing weighting method, whose implementation in MAUT models is recommended by Chelst and Canbolat (*48*) to maintain the user-friendliness of this multi-objective decision approach. The swing weighting method is classified by Zardari et al. as a subjective approach, and its application can be summarized in three steps: 1) rank all measures from the most important to the least important; 2) assign 100 points to the highest ranked measure and assign points to the other measures using the highest ranked measure as a reference; and 3) calculate the total number of points for all alternatives and use this total value to determine the relative weight for each measure. Steps 1 and 2 depend on the experience and judgement of decision makers, while step three is a simple mathematical calculation.

The following is an example of a swing weighing process for a given project. This is an example of a project in which the schedule constraints are more important that the budget considerations. It should be noted that the weights calculated in this example are not intended to be a fixed set of weights recommended by the author. Since decision-makers' priorities may change according to the context and specifics of each project, this weighting process should be followed on a per project basis.

1. Rank of measures from the most important (1) to the least important (6) (see Table 3.1).

Table 3.1Swing Weighting Method – Ranking of Measures (Example)

Measure	Rank
Probability of Yielding a Lower Cost	4
Expected Cost	5
Probability of Yielding a Shorter Duration	1
Expected Duration	2
Cost Certainty	6
Schedule Certainty	3

2. Assign 100 points to highest ranked measure and use it as a reference to assign points to the other measures (see Table 3.2). For each of the other measures, decision-makers

should answer this question: If the highest ranked measure has 100 points, how many points should be assigned to this measure based on its relative importance to this decision? It should be noted that two or more measures could be assigned the same number of points if they are consider equally important.

Table 3.2 Swing Weighting Method – Relative Importance Points (Example)

Measure	Rank	Points
Probability of Yielding a Lower Cost	4	75
Expected Cost	5	70
Probability of Yielding a Shorter Duration	1	100
Expected Duration	2	90
Cost Certainty	6	50
Schedule Certainty	3	85

3. Calculate total number of points and use it to calculate relative weights for all measures (see Table 3.3). Example; the relative weight for the first measure is equal to its number of points divided by the total number of points (75 / 470 x 100% = 16%). It should be noted that the sum of all measure weights is equal to 100% ($\sum W_i = 100\%$).

Table 3.3 Swing Weighting Method – Relative Weights (Example)

Measure	Rank	Points	Weight (W_i)
Probability of Yielding a Lower Cost	4	75	16%
Expected Cost	5	70	15%
Probability of Yielding a Shorter Duration	1	100	21%
Expected Duration	2	90	19%
Cost Certainty	6	50	11%
Schedule Certainty	3	85	18%
	Total	**470**	

The fourth and last step in the development of the MAUT model (Phase 1 in Figure 3.3) corresponds to the formulation of the SAUFs required to convert what into normalized utility values between zero and one; with zero representing the least desired value and one corresponding to the value that would have the greatest contribution towards the achievement of value-for-money. Each measure has its own SAUF and all of them will be shown and discussed in detail in Chapter 5.

3.4.2 MAUT Model Implementation

The first step in the implementation of the MAUT model (step 5 in Figure 3.3) consists of determination of the values for all six measures for each alternative (LS and UP) in their actual units (i.e. percentage, dollars, and work days). These values are then be transformed in the next step (step 6 in Figure 3.3) into utility values using their corresponding SAUFs. Having all measures defined in the same units allows for their integration in the form of a weighted sum to calculate an overall utility value for each DBB compensation approach (step 7 in Figure 3.3). Equation 3.1 shows the calculation of the overall utility value.

$$\boldsymbol{Overall\ Utility = \sum_{i}^{n} U_i \times W_i} \qquad \textbf{(3.1)}$$

Where: $U_i = Utility\ value\ for\ measure\ i$

$W_i = Weight\ assigned\ to\ measure\ i$

$n = number\ of\ measures$

In the final MAUT implementation step (step 8 in Figure 3.3), the model provides a recommendation on whether to use LS or UP compensation provisions for the DBB project under consideration. This recommendation is made by comparing the overall utility values of both alternatives. The alternative with the greater overall utility value is recommended. In case of having the same overall utility value for both alternatives, which is an unlikely scenario, a LS approach would be recommended since it would be expected to offer more benefits to the agency according to the discussion of LS advantages and disadvantages presented in Chapter 2.

CHAPTER 4 COST-BASED LS PROJECT SELECTION SUB-FRAMEWORK FOR DBB RESURFACING PROJECTS

4.1 Introduction

This chapter describes the development of the cost-based LS project selection sub-framework for DBB resurfacing projects. The tool was developed using non-linear regression techniques, Monte Carlo Simulation, and data from 86 resurfacing projects completed by FDOT between January 2015 and March 2017; 63 UP and 23 LS projects. The tool is presented in the form of a nomogram, comprising the mathematical functions involved in the cost comparison of UP and LS into a two-dimensional chart that facilitates the use of the tool by different types of decision-makers and in different environments. The nomogram allows for a quick approximation of the probability of having a lower cost under each compensation approach and the potential savings or extra costs of using a LS provision under three different scenarios: expected, best, and worst case scenarios. The use of nomogram requires two inputs from the resurfacing project under consideration: 1) project scale in terms of lane miles and 2) risk tolerance. The nomogram also facilitates the assessment of LS cost implications under different confidence levels, allowing FDOT to make decisions under different levels of risk.

4.2 Development of Cost-Based LS Project Selection Sub-Framework

Figure 4.1 is an abstract of this study's research methodology with regard to the development of the cost-based LS project selection sub-framework. After the initial literature review to gain a better understanding of DOTs' DBB contracting practices and contractor compensation procedures, the author proceeded to gather the available relevant data and information, including historical bid data from all projects awarded by FDOT between January 2015 and March 2017. Bid data was collected from bid tabulations published by FDOT (*50*).

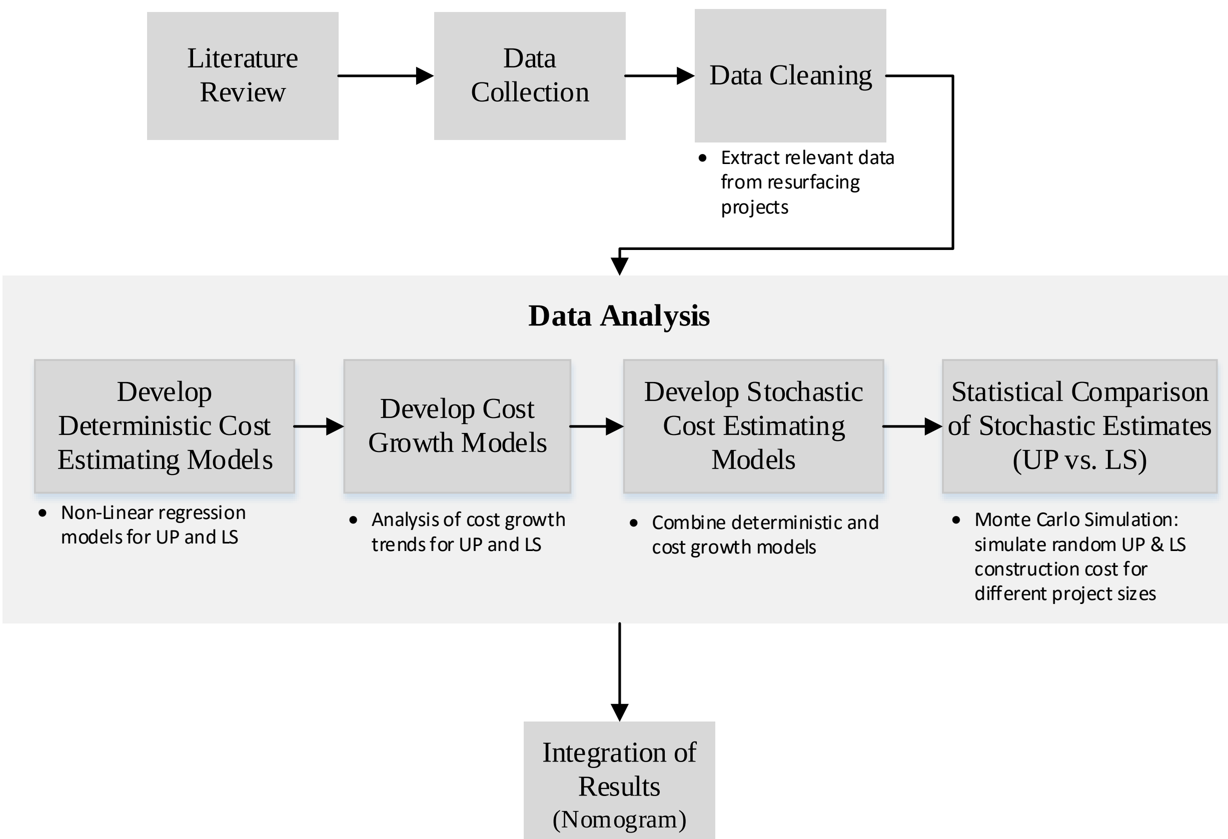

Figure 4.1 Research Methodology: Cost-Based Sub-Framework

It is important to remember that the cost-based sub-framework presented in this chapter, as well as the duration-based sub-framework in Chapter 5 and the over framework in Chapter 6, are only applicable to resurfacing DBB projects. Resurfacing is generally defined as a work to add asphalt layers to an existing pavement to extend the service life of the road (*51*). Data from 338 resurfacing projects was initially extracted from the available datasets. This data was carefully inspected and further reduced based on the needs of the study. The following criteria were used for the final selection of projects:

- Only projects with scopes of work exclusively focused on resurfacing activities (projects including other types of work besides resurfacing were discarded).
- Only completed projects (projects in which final payments have been made to contractors in order to have access to actual construction costs)
- Only projects with a uniform road cross-section along the project to facilitate the calculation of construction costs per lane mile.

Google Earth was used to review the road cross-section of all 338 projects and to verify the number of lane miles per project. A total of 86 resurfacing projects (63 UP and 23 LS projects) met the criteria listed above and were used to develop the LS project selection model. The relevant data for these 86 resurfacing projects corresponds to the "historical cost data" input listed in Figure 1.1. All sets of data used in the analysis can be found in Appendix A. It should be noted that the criteria to select suitable projects for this study was used only for modeling purposes. The proposed tool is applicable to all resurfacing projects for which the total number of lane miles has been determined.

Data analysis on the selected 86 resurfacing projects was further divided into four parts (see Figure 4.1). In the first part, the author used non-linear regression techniques to develop deterministic cost estimating models based on the total number of lane miles for both UP and LS contracts. This is how the “project scale” input is included into the proposed methodology. The second part of the data analysis consisted in modeling the expected cost growth for each compensation approach based on the quantitative analysis of cost estimating uncertainty. Deterministic cost estimating models and cost growth models were then combined to produce two stochastic cost estimating models; one for UP and other for LS projects. A stochastic approach was used in this study to account for the unavoidable cost estimating uncertainty faced by estimators and project managers in the construction industry.

The stochastic cost estimating models were then used to determine the probability of UP costs exceeding LS costs for different project sizes (size measured in lane miles) using Monte Carlo simulation techniques. Finally, simulation results were used to develop a nomogram that comprises the entire methodology into a two-dimensional chart. The development and use of the nomogram is explained in more detail throughout the chapter. The data collected for UP and LS projects are shown in Figure 4.2 and Figure 4.3, respectively.

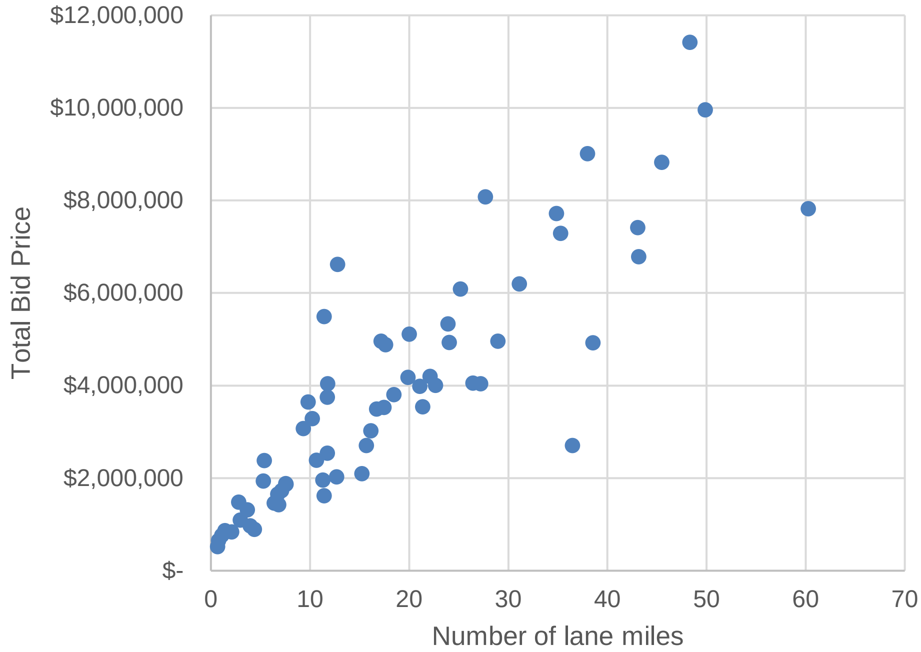

Figure 4.2 UP Projects - Cost Data

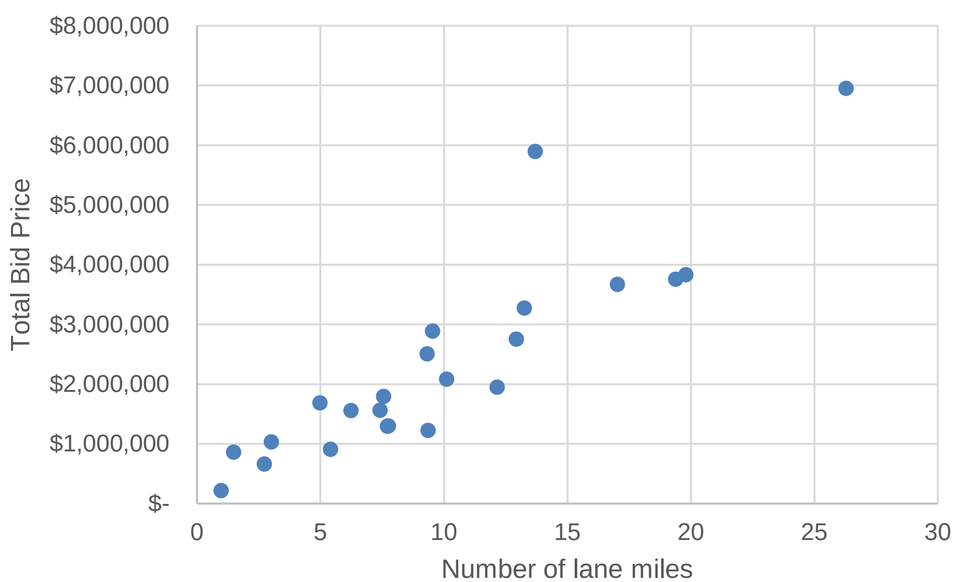

Figure 4.3 LS Projects - Cost Data

4.3 Data Analysis and Results

This section presents the results for each of the four parts of the data analysis illustrated in Figure 4.1.

4.3.1 Deterministic Construction Cost Estimates

Deterministic cost estimating models for UP and LS were developed using historical bid data and non-linear regression techniques to correlate actual total bid prices per lane mile submitted by successful contractors with the total number of lane miles to be resurfaced. The total number of miles in resurfacing projects are usually known early during the planning phase. Therefore, these deterministic models actually provide early estimates for UP and LS projects based on the total number of lane miles. The use of early construction cost estimates is a key factor in the proposed methodology since "the decision to use the Lump Sum Contracting Technique on a project should be made during the scope development process, rather than during or after the design process" (*16*).

Figure 4.4 and Figure 4.5 present the deterministic construction cost estimating models for UP and LS contracts, respectively. The regression equation that best fits each dataset is shown in the top-right corner of each figure. Both curves show an inverse relationship between total lane miles and cost per lane mile, which was expected by author. Larger amounts of work in construction projects are usually paid at lower rates per unit of work *(52)*. The deterministic model for UP projects (Figure 4.4) shows a stronger correlation between total bid price per lane mile and total number of lane miles than that in the LS model. It could be explained by the fact the UP model was developed with a considerably higher number of data points. Sixty-three UP projects are shown in Figure 4.4, while the model for LS project was built with 23 projects. This study assumes that the non-linear regression model shown in Figure 4.5 is a good approximation of the model that would be obtained with a larger sample of projects.

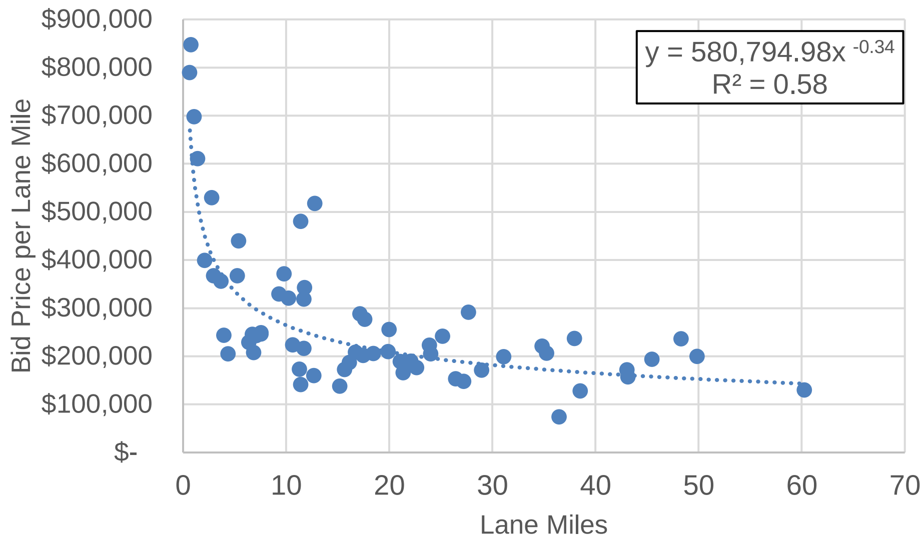

Figure 4.4 UP Deterministic Cost Estimating Model

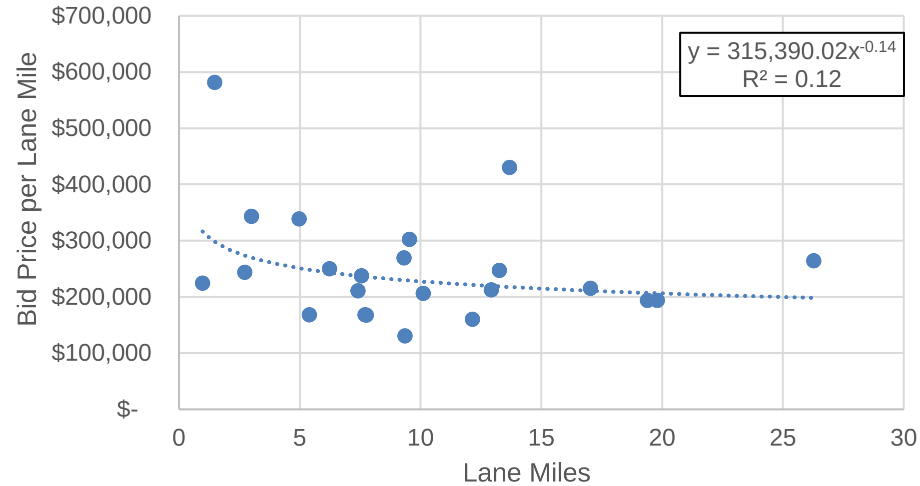

Figure 4.5 LS Deterministic Cost Estimating Model

An interesting observation was made when both the UP and the LS deterministic cost estimating models were plotted in the same chart. Figure 4.6 shows that, on average, resurfacing projects of less than approximately 21 lane miles are expected to have a lower cost per mile if LS provisions are used. The comparison of this breakpoint against the data from LS projects used in this study revealed that only one of the 23 LS resurfacing projects was more than 21 lane miles. It could be seen as an indicator of the potential cost-effectiveness of FDOT's current subjective LS project selection procedures, which are based on selecting "simple" projects for LS according to three criteria: well-defined scope, low risk of unforeseen conditions, and low possibility of scope change (*16*). This is an important observation; however, it should be noted that these models were built with total bid prices and do not reflect actual costs paid by FDOT (*53*). Likewise, these are deterministic models, which are average representations of the cost behavior of UP and LS projects. It does not mean that all resurfacing projects of less than 21 lane miles will have lower costs for FDOT. Deterministic cost models ignore the risk inherent in construction cost estimating and do not provide decision-makers with the ability to consider multiple case scenarios. The proposed methodology is intended to be an improved version of the deterministic analysis presented in this section through the modeling of cost growth and the stochastic comparison of UP and LS costs.

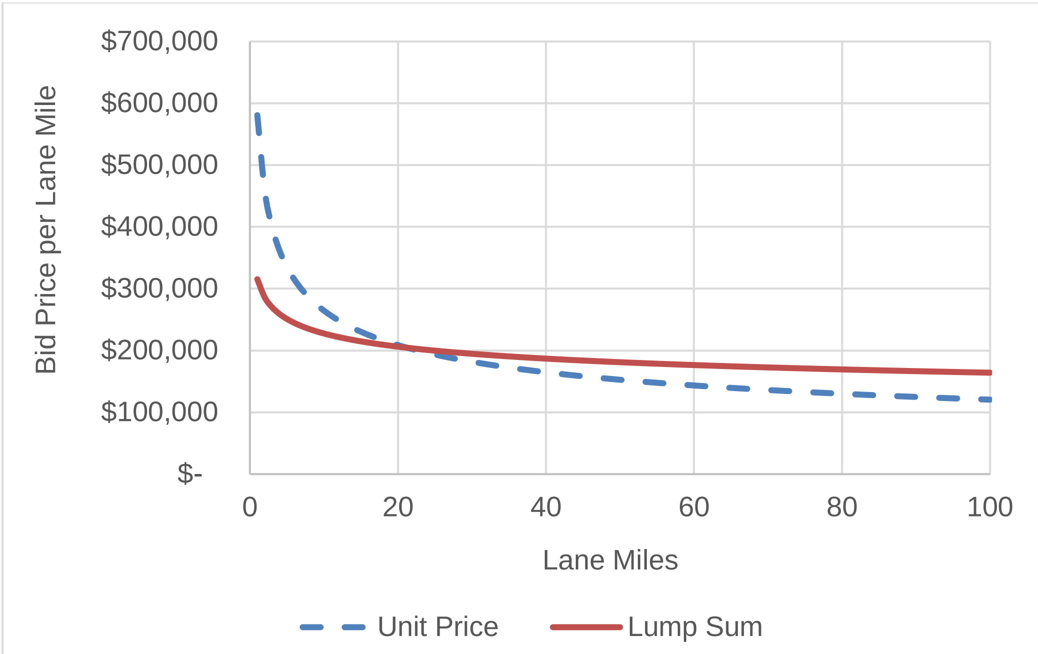

Figure 4.6 UP and LS Deterministic Cost Estimating Models

4.3.2 Cost Growth Modeling

Cost growth in this study is defined as the percentage variation of the original contract cost (total bid price from selected contractor) from the total actual cost at project completion, including change orders and cost adjustments (Cost Growth = [Actual Cost – Original Cost]/Original Cost). The process to model cost growth for UP and LS projects consists of two steps: 1) the calculation of cost growth for each UP and LS project; and 2) the use of statistical inference methods to determine the type probability distribution that best fits the cost growth values for UP and LS. Table 4.1 and Table 4.2 show the cost growth values for all UP and LS projects, respectively, which correspond to the first part of the process.

Table 4.1 UP Projects – Cost Growth

No	Miles	Original Cost	Actual Cost	Cost Growth	No	Miles	Original Cost	Actual Cost	Cost Growth
1	0.66	$ 521,217.55	$ 506,672.13	-3%	33	16.14	$ 3,021,171.51	$ 2,921,086.34	-3%
2	0.77	$ 648,208.71	$ 638,066.90	-2%	34	16.73	$ 3,493,487.41	$ 3,547,935.65	2%
3	1.09	$ 759,549.53	$ 735,190.97	-3%	35	17.17	$ 4,955,711.06	$ 4,790,431.51	-3%
4	1.41	$ 862,770.36	$ 791,326.63	-8%	36	17.47	$ 3,529,617.70	$ 3,475,221.87	-2%
5	2.10	$ 841,046.90	$ 781,435.70	-7%	37	17.63	$ 4,883,159.85	$ 4,581,603.56	-6%
6	2.80	$ 1,483,128.17	$ 1,430,102.15	-4%	38	18.46	$ 3,802,688.89	$ 3,479,142.77	-9%
7	2.98	$ 1,095,029.24	$ 997,606.57	-9%	39	19.88	$ 4,178,282.93	$ 4,017,351.92	-4%
8	3.69	$ 1,312,213.59	$ 1,254,212.88	-4%	40	20.00	$ 5,112,998.18	$ 5,183,132.95	1%
9	3.96	$ 966,283.04	$ 953,705.99	-1%	41	21.07	$ 3,983,485.70	$ 3,695,175.48	-7%
10	5.38	$ 896,919.51	$ 777,645.27	-13%	42	21.35	$ 3,543,343.50	$ 3,802,307.75	7%
11	5.28	$ 1,940,620.07	$ 1,856,551.56	-4%	43	22.09	$ 4,199,999.48	$ 3,826,661.87	-9%
12	5.40	$ 2,376,742.36	$ 2,384,891.78	0%	44	22.65	$ 4,007,551.55	$ 3,641,742.32	-9%
13	6.38	$ 1,463,327.52	$ 1,424,598.85	-3%	45	23.91	$ 5,333,715.73	$ 5,049,335.18	-5%
14	6.74	$ 1,656,116.65	$ 1,659,137.45	0%	46	25.04	$ 4,933,423.90	$ 4,649,829.70	-6%
15	6.85	$ 1,424,722.42	$ 1,391,631.60	-2%	47	25.16	$ 6,085,725.81	$ 5,952,142.50	-2%
16	7.12	$ 1,728,947.87	$ 1,633,505.84	-6%	48	26.44	$ 4,054,389.57	$ 3,749,496.73	-8%
17	7.56	$ 1,885,541.29	$ 1,821,043.74	-3%	49	27.22	$ 4,037,986.70	$ 3,846,478.33	-5%
18	7.58	$ 1,865,345.96	$ 1,622,085.47	-13%	50	27.70	$ 8,076,272.17	$ 7,667,982.38	-5%
19	9.31	$ 3,069,378.46	$ 2,906,325.38	-5%	51	28.96	$ 4,962,037.99	$ 4,756,358.08	-4%
20	9.82	$ 3,648,201.75	$ 3,514,981.59	-4%	52	31.10	$ 6,196,552.04	$ 5,669,933.59	-8%
21	10.23	$ 3,284,461.01	$ 3,131,127.75	-5%	53	35.84	$ 7,717,553.92	$ 7,576,665.71	-2%
22	10.65	$ 2,386,059.87	$ 2,290,475.30	-4%	54	35.28	$ 7,289,392.69	$ 7,140,235.06	-2%
23	11.30	$ 1,961,731.16	$ 1,958,165.54	0%	55	36.48	$ 2,702,300.94	$ 2,445,065.27	-10%
24	11.42	$ 5,490,800.16	$ 5,404,113.44	-2%	56	37.98	$ 9,008,955.84	$ 8,863,555.68	-2%
25	11.43	$ 1,619,320.78	$ 1,566,710.74	-3%	57	38.53	$ 4,926,846.56	$ 4,585,418.50	-7%
26	11.73	$ 2,539,890.92	$ 2,497,433.75	-2%	58	43.07	$ 7,416,925.38	$ 7,441,691.97	0%
27	11.74	$ 3,745,728.33	$ 3,415,842.50	-9%	59	43.15	$ 6,785,910.43	$ 7,183,335.97	6%
28	11.78	$ 4,039,522.34	$ 4,226,492.10	5%	60	45.48	$ 8,823,739.00	$ 7,800,286.81	-12%
29	12.70	$ 2,030,029.00	$ 2,045,055.57	1%	61	48.32	$ 11,419,266.79	$ 9,884,931.68	-13%
30	12.79	$ 6,621,886.77	$ 6,552,075.16	-1%	62	49.88	$ 9,957,902.43	$ 9,419,098.68	-5%
31	15.22	$ 2,097,226.82	$ 1,978,887.02	-6%	63	60.26	$ 7,824,412.70	$ 7,721,970.60	-1%
32	15.67	$ 2,706,520.06	$ 2,796,761.63	3%	-	-	-	-	-

Table 4.2 LS Projects - Cost Growth

Number	Miles	Awarded amount	Final Project Cost	Cost Growth
1	0.98	$ 219,505.00	$ 213,917.00	-3%
2	1.48	$ 862,415.80	$ 823,651.81	-4%
3	2.73	$ 664,503.82	$ 636,000.00	-4%
4	3.01	$ 1,033,200.00	$ 920,105.14	-11%
5	5.98	$ 1,688,000.00	$ 1,606,582.22	-5%
6	5.41	$ 910,000.00	$ 883,226.89	-3%
7	6.23	$ 1,558,478.00	$ 1,525,500.59	-2%
8	7.41	$ 1,563,213.43	$ 1,512,750.97	-3%
9	7.56	$ 1,795,728.27	$ 1,760,006.21	-2%
10	7.71	$ 1,296,000.00	$ 1,222,129.81	-6%
11	7.75	$ 1,298,500.00	$ 1,319,720.21	2%
12	9.32	$ 2,509,778.30	$ 2,358,043.58	-6%
13	9.36	$ 1,223,500.00	$ 1,216,825.17	-1%
14	9.54	$ 2,888,000.00	$ 2,634,048.09	-9%
15	10.11	$ 2,084,540.00	$ 2,051,990.95	-2%
16	12.15	$ 1,947,842.63	$ 1,891,898.60	-3%
17	12.94	$ 2,754,000.00	$ 2,686,703.58	-2%
18	13.26	$ 3,276,000.00	$ 3,298,885.66	1%
19	13.69	$ 5,895,900.00	$ 5,727,577.20	-3%
20	17.03	$ 3,670,000.00	$ 3,621,208.52	-1%
21	19.39	$ 3,757,548.78	$ 3,684,887.35	-2%
22	19.80	$ 3,832,891.28	$ 3,786,450.72	-1%
23	26.28	$ 6,951,000.00	$ 6,782,907.00	-2%

In the second part of the process to model cost growth, the author used the chi-square goodness of fit statistical test to infer the most suitable probability distribution for each set of cost growth values. This statistical test was conducted using a statistical software package called @Risk, which facilitates the calculation of goodness of fit for several probability distributions. Using this statistical test, it was found that cost growth values for UP projects follow a normal distribution with mean (μ) -3.9% and standard deviation (σ) 5.3%. This normal distribution with the frequency of cost growth values is illustrated in Figure 4.7.

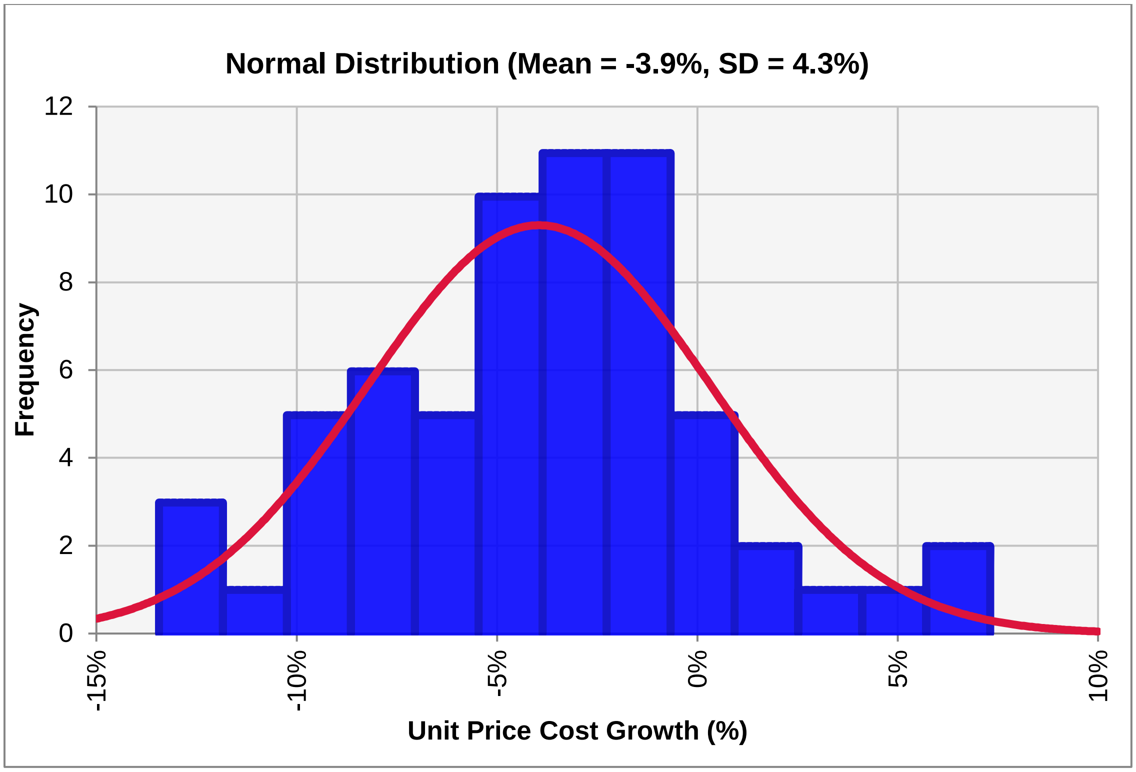

Figure 4.7 UP Cost Growth Probability Distribution

On the other hand, the distribution of cost growth for LS projects seems to match with an extreme value minimum distribution (Gumbel distribution) with alpha (location parameter; γ) and beta (scale parameter; β) values equal to -1.9% and 0.02 (mean = -3.2%; standard deviation = 2.8%), respectively. This probability distribution deals with data that has an extreme deviation from the mean (*54*). Extreme value distributions are commonly used in hydrology to estimate unusually large natural events such as 100 year flood peaks (*55*). The extreme value minimum distribution and distribution of growth values for LS projects is illustrated in Figure 4.8.

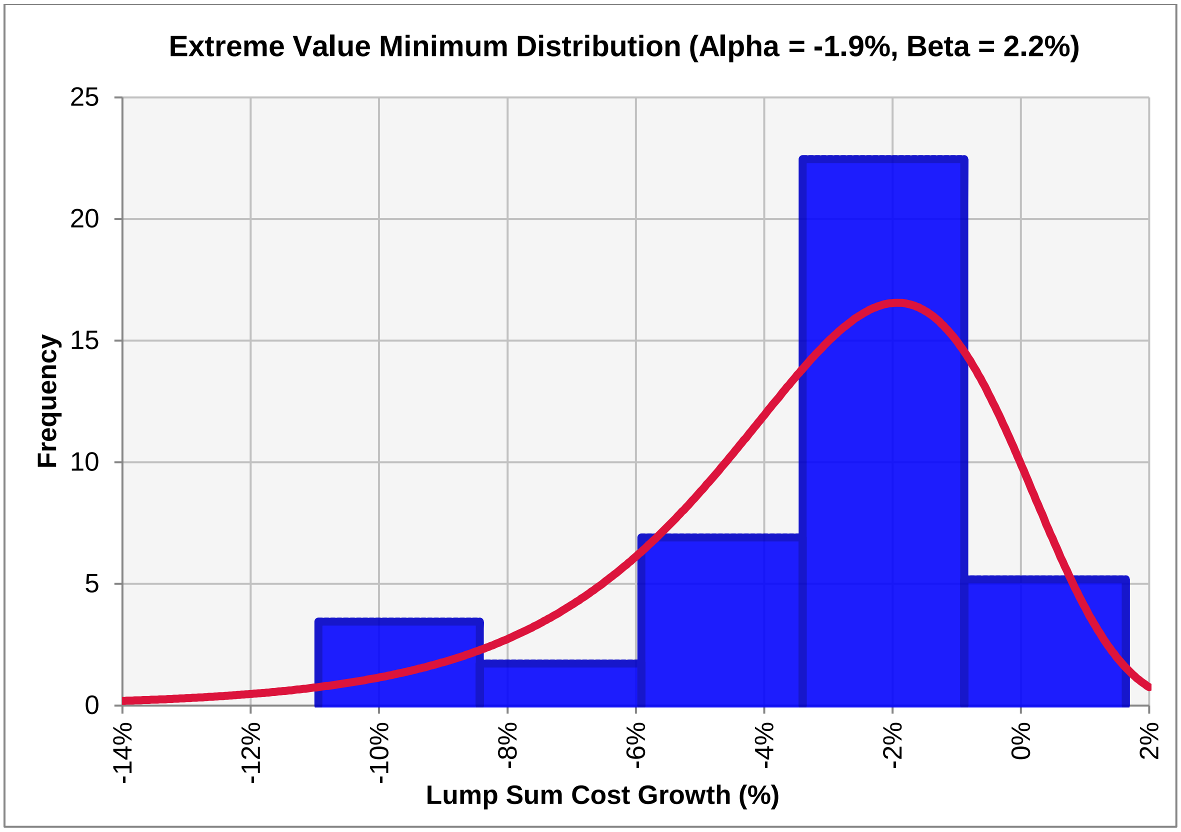

Figure 4.8 LS Cost Growth Probability Distribution

Figure 4.9 helps to visualize the difference between the cost growth distributions for both types of projects by plotting them on the same graph. A comparison between these two graphs shows similar negative mean values; -3.9% and -3.2%, indicating that actual final costs in both types of projects tend to be lower that original contract values. However, standard deviation values show that values in cost growth distribution for UP are more spread out than in the distribution for LS projects (standard deviation for UP = 5.3%; LS = 2.8%). That means LS projects have higher cost certainty, which is an important aspect in the comparison of stochastic values presented in the following sections.

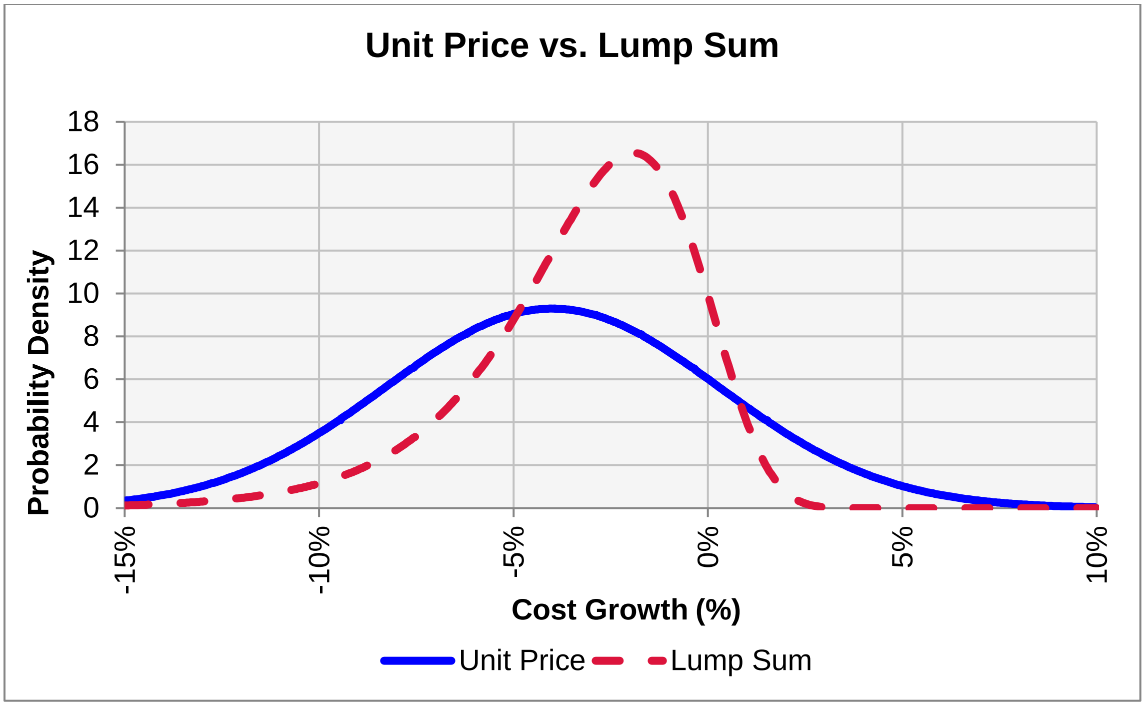

Figure 4.9 Cost Growth Comparison: Unit Price vs Lump Sum

4.3.3 Stochastic Construction Cost Estimating Models – Development and Comparison

Stochastic cost estimates are produced by combining the deterministic and cost growth models. The combination of these models for UP and LS resurfacing projects was performed using Equations 4.1 and 4.2, respectively. What these equations are doing is to first estimate the deterministic cost for a given number of lane miles, and then assessing possible fluctuations in this value based on observed cost growth trends (cost growth model).

$$\boldsymbol{SE_{(UP,x)} = DE_{UP,x} \times \left(1 + N(-0.039; 0.043)\right)} \qquad \textbf{(4.1)}$$

Where:

$x = Lane\ miles$

$SE_{(UP,X)} = Stochastic\ cost\ estimate\ for\ a\ UP\ project\ of\ x\ lane\ miles$

$DE_{(UP,X)} = Deterministic\ cost\ estimate\ for\ a\ UP\ project\ of\ x\ lane\ miles$

$N(-0.039; 0.043) = UP\ Cost\ Growth\ Model \rightarrow Normal\ Dist.\ (mean = -3.9\%; SD = 5.3\%)$

$$\boldsymbol{SE_{(LS,x)} = DE_{LS,x} \times \left(1 + EV(-0.019; 0.02)\right)} \qquad \textbf{(4.2)}$$

Where:

$x = Lane\ miles$

$SE_{(LS,X)} = Stochastic\ cost\ estimate\ for\ a\ LS\ project\ of\ x\ lane\ miles$

$DE_{(LS,X)} = Deterministic\ cost\ estimate\ for\ a\ LS\ project\ of\ x\ lane\ miles$

$EV(-0.019; 0.02) = LS\ Cost\ Growth\ Model \rightarrow ExtremeValueDist.\ (alpha = -1.9\%; beta = 0.02)$

Stochastic cost estimating models for UP and LS (Equations 4.1 and 4.2) were compared for different project sizes (number of lane miles) to determine the probability of UP costs being greater than LS costs as a function of the number of lane miles (ranged from 1 to 50 miles). The stochastic comparison was performed using a statistical software package (@Risk) and Monte Carlo techniques to simulate 10,000 pairs of random values for Equations 1 and 2 for each type of project and for each project size. In other words, 10,000 pairs of values (one UP and one LS value) were randomly generated and recorded for a resurfacing project of 1 lane mile; and then it was repeated 49 more times for different numbers of lane miles. The number of times UP costs exceeded LS costs was calculated and used to determine the probability of having greater costs if UP is used for each project size (number of durations UP exceeded LS/10,000 * 100%). Figure 4.10 shows these probabilities for resurfacing project ranging from 1 to 50 lane miles.

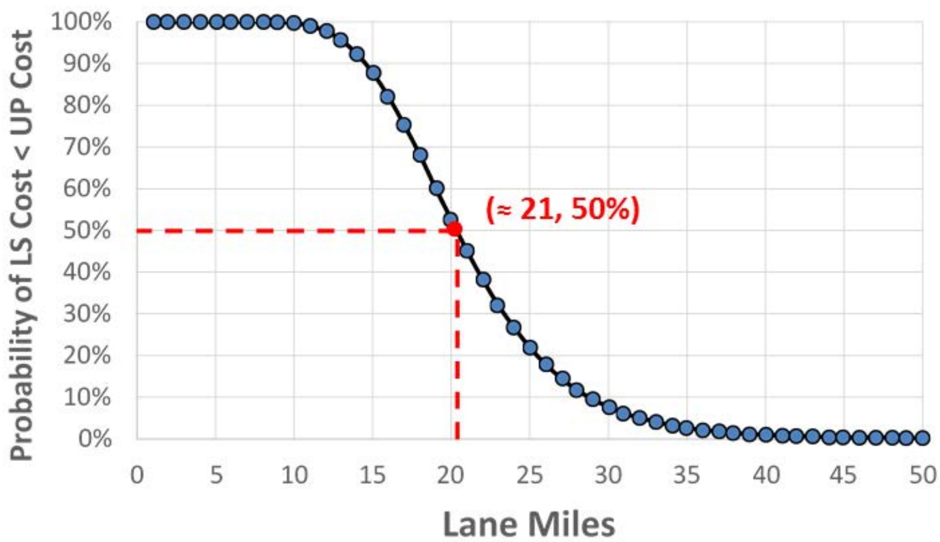

Figure 4.10 Probability of Having Lower Costs with LS

Interestingly, the stochastic model also shows that an LS approach tends to be more cost-efficient for resurfacing projects of less than approximately 21 lane miles. As shown in Figure 4.10, the probability of UP costs exceeding LS costs is greater than 50% for resurfacing projects of less than 21 lane miles, which is the same break point obtained with the deterministic model. However, this graph also shows that for projects ranging between 10 and 35 lane miles there is still a chance of making the wrong decision. For resurfacing projects of less than 10 lane miles, LS is clearly the best option; contrary to project of more than 35 miles where UP is the best alternative.

It is important to know the probability of making the wrong decision, but, it is more important to know the consequences of making the wrong decision, which is not shown in Figure 4.10, and in some cases could be significant. Such information was collected during the simulation and provided to decision-makers through the nomogram described in the next section.

4.4 Integration of Results – Development of Cost-Based Nomogram

The nomogram presented in Figure 4.11 integrates the entire methodology proposed in this chapter into a single two-dimensional graph that facilitates decision-making under different confidence levels. The nomogram uses two inputs: number of lane miles and desired confidence level set by decision-makers. These two inputs produce four outputs: probability of having higher construction costs if UP is used instead of LS; expected case scenario if LS provisions are used (calculated with average values from deterministic models); the worst case scenario if LS provisions are used; and the best case scenario if LS provisions are used. The confidence level depends on the risk profile of the decision-makers (*48*), and presents the “risk tolerance” input listed in Figure 1. The higher the confidence level, the larger the range between the worst and best case scenarios, and the higher the confidence of decision-makers that the actual savings/costs of using LS on a given project will lay within this range.

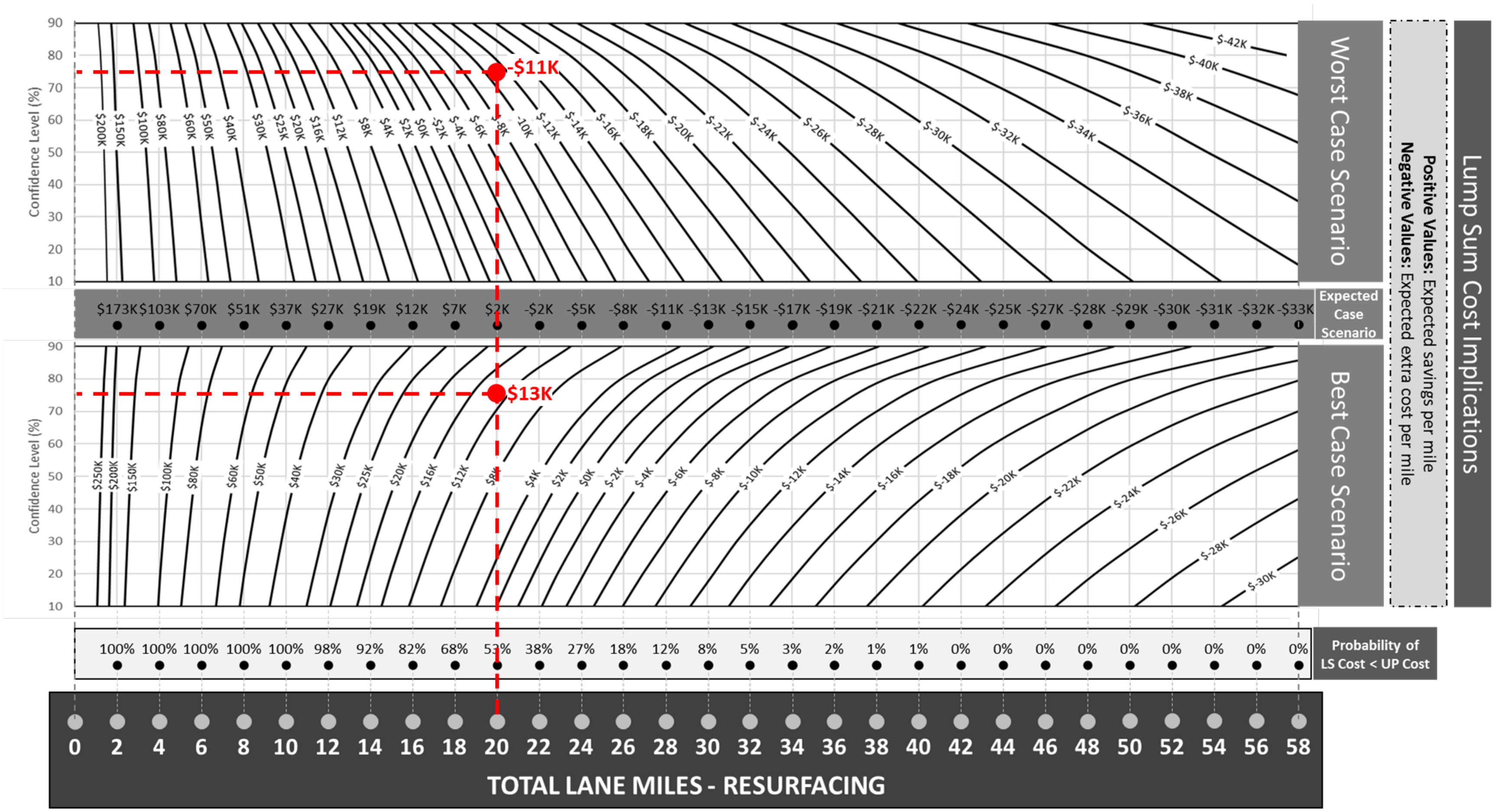

Figure 4.11 LS Project Selection - Cost-Based Nomogram

If, for example, FDOT decides to use this cost-based nomogram and a 75% confidence level to decide whether or not to use a LS approach on a given project, that agency would be 75% sure that the actual cost implications of using LS provisions is between paying $11,000 of additional costs and $13,000 of potential savings (see Figure 4.11), with average expected savings of around $2,000. The estimation of the different case scenarios in dollars will make it easier to integrate the nomogram with FDOT's decision-making practices. If we add to the example in this paragraph that FDOT has estimated that the use of LS would represent an increase of $10,000 in design costs due to the higher design quality required in LS of contracts, this additional cost could be integrated with the nomogram because they use the same units –dollars. In that case, using LS would be less attractive with potential saving of $3,000, in the best case scenario, or extra costs that could add up to $21,000.

4.5 Summary

This chapter summarizes the research efforts made to develop a stochastic cost-based decision-making tool to identify suitable DBB resurfacing projects for LS provisions. The proposed methodology compares UP and LS stochastic estimates for candidate projects and provides decision-makers with the probability of UP costs exceeding LS costs, as well as an estimate of the cost implication of using LS. The development and implementation of the cost-based decision-making tool was illustrated using bid data from 86 resurfacing projects completed by FDOT between 2015 and 2017 (63 UP and 23 LS). A number of techniques were used to process this data into cost-growth, deterministic, and stochastic cost estimating models for UP and LS. The primary contribution of this chapter is a cost-based nomogram that provides decision-makers with three valuable outputs: probability of having higher construction costs if UP instead of LS; the expected-case scenario if LS provisions are used; the worst case scenario if LS provisions are used; and the best-case scenario if LS provisions are used.

CHAPTER 5 DURATION-BASED LS PROJECT SELECTION SUB-FRAMEWORK FOR DBB RESURFACING PROJECTS

5.1 Introduction

This chapter describes the development of the duration-based LS project selection sub-framework by replicating the same process presented in Chapter 4, but this time to assess the schedule implications of using LS provisions in resurfacing projects awarded by FDOT. Thus, it discusses the development of a deterministic project duration model, a schedule growth model, and a stochastic duration model for both UP and LS DBB projects. In this chapter, the author also used non-linear regression and Monte Carlo simulation to compare the stochastic schedules for both compensation alternatives. The duration-based LS project selection sub-framework was developed using non-linear regression with the same data used in Chapter 4 (data from 86 resurfacing projects completed by FDOT between January 2015 and March 2017; 63 UP and 23 LS projects).

As with the cost sub-framework, the duration-based LS project selection tool was also comprised into a nomogram to facilitate its implementation by FDOT's decision-makers. Thus, the users of this tool (as well as the cost-based tool in Chapter 4) are not required to have advanced statistical or quantitative analysis skills. The duration-based nomogram's outputs are: an approximation of the probability of having a lower project duration if LS provisions are used and the potential time savings or additional work days required to complete the project under two different case scenarios: expected, best, and worst case scenarios. The duration-base nomogram requires the same two inputs as the cost-based nomogram: 1) project scale in terms and 2) risk tolerance (desired confidence level set by decision-makers).

5.2 Development of Duration-Based LS Project Selection Sub-Framework

As mentioned above, the duration-based LS project selection sub-framework was developed through the same data collection and processing tasks followed to develop the cost-based sub-framework. The specific part of the overall research methodology that corresponds to the duration sub-framework in shown in Figure 5.1. Part of the literature review efforts were focused on better understanding this schedule implication of using LS payment provisions, which allowed for an effective design of the methodology presented in this chapter.

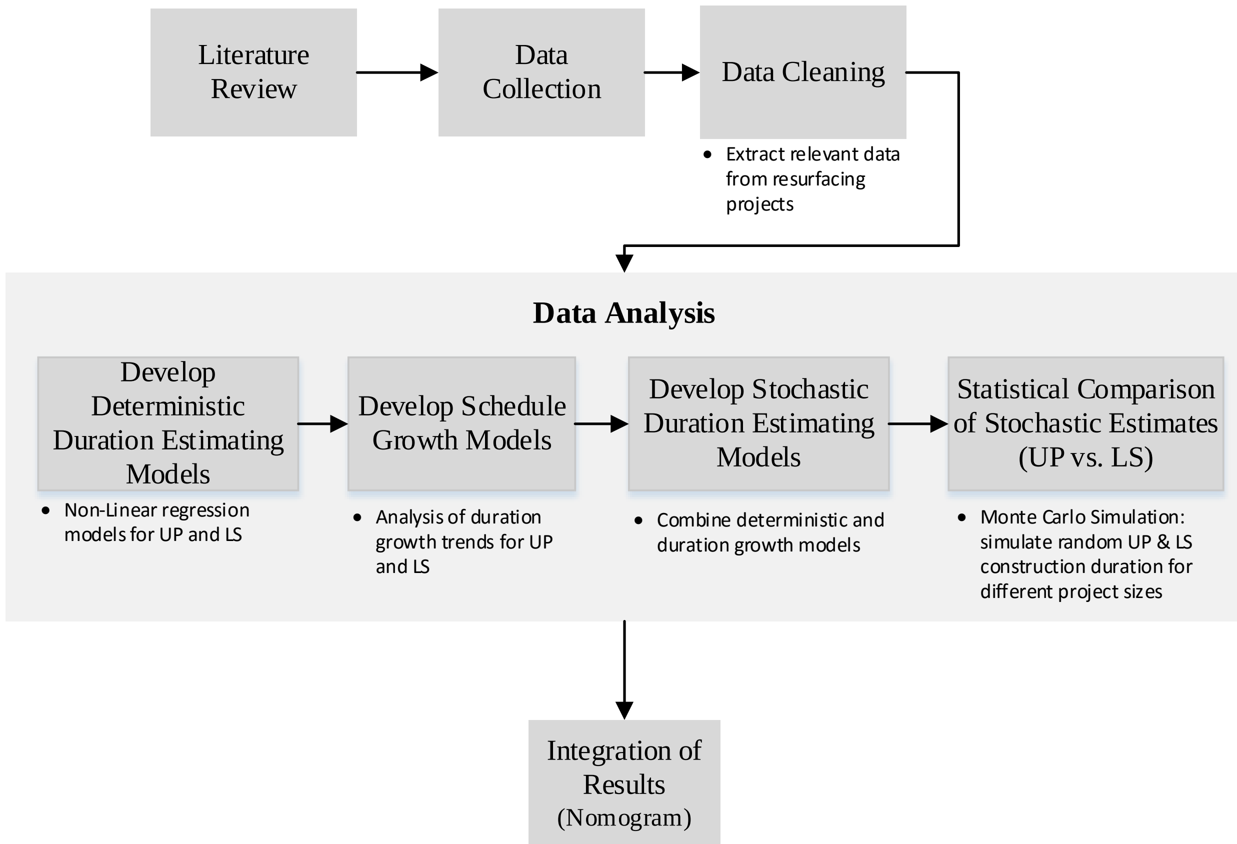

Figure 5.1 Research Methodology: Duration-Based Sub-Framework

Data collection and cleaning efforts partially overlapped with those from Chapter 4. The same projects used to develop the cost-based tool were included in the analysis of this chapter. The criteria followed for the final selection of projects were as follows:

- Only projects with scopes of work exclusively focused on resurfacing activities (projects including other types of work besides resurfacing were discarded).
- Only completed projects (projects in which final payments have been made to contractors in order to have access to actual construction durations)
- Only projects with uniform road cross-section along the project to facilitate the calculation of construction durations per lane mile.

All sets of data used in the analysis can be found in Appendix A of this study. The data points for both UP and LS projects are shown in Figure 5.2 and Figure 5.3, respectively.

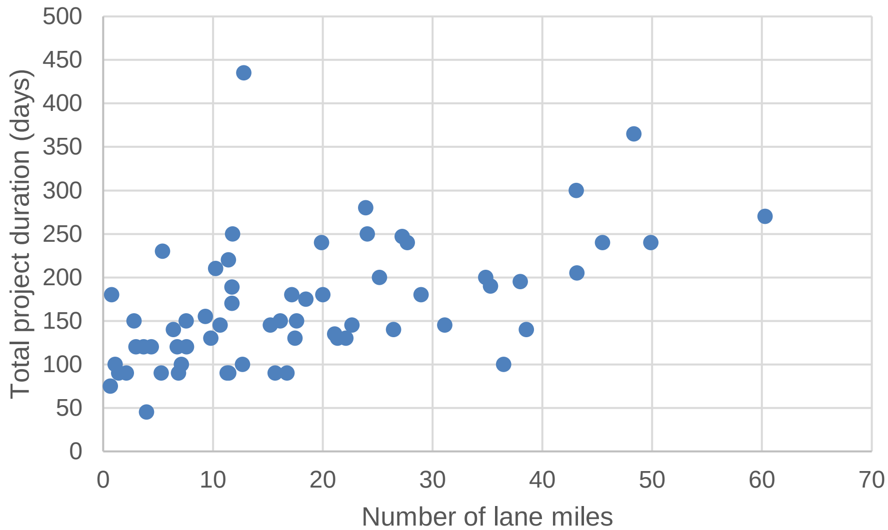

Figure 5.2 UP Projects - Duration Data

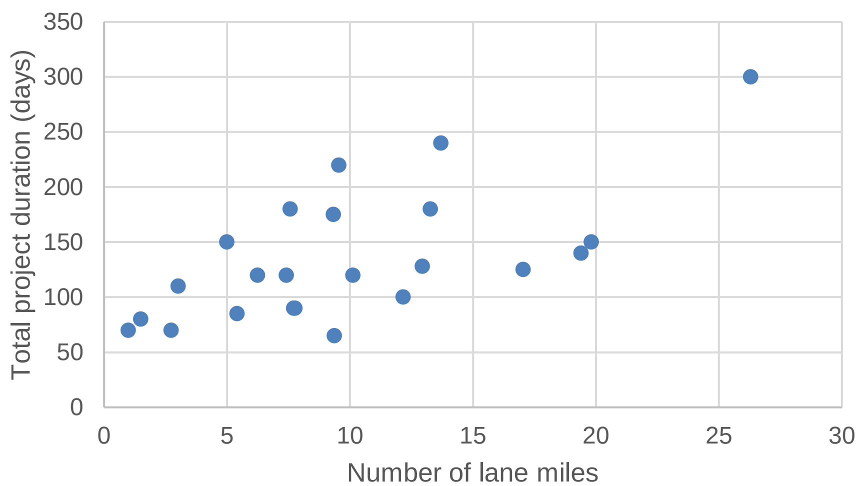

Figure 5.3 LS Projects - Duration Data

5.3 Data Analysis

This section presents the results for each of the four parts of the data analysis illustrated in Figure 5.1: 1) the development of deterministic duration estimating models based on the number of resurfacing lane miles, 2) the creation of the schedule growth model, 3) the integration of the deterministic and schedule growth model to produce a stochastic duration model, and 4) the Monte Carlo simulation to compare the stochastic schedules of UP and LS DBB resurfacing projects.

5.3.1 Deterministic Construction Duration Estimates

Non-linear regression techniques allowed for the creation of UP and LS deterministic duration estimating models, which are mathematical functions that correlate observed duration estimates made by FDOT at contract award with the number of resurfacing lane miles in UP and LS projects.

The deterministic construction duration estimating models for UP and LS contracts are illustrated in Figure 5.4 and 5.5, respectively. The regression equation that best fit each dataset is shown in the top-right corner of each figure. These models show the same behavior as the deterministic cost models, both curves present an inverse relationship between total resurfacing lane miles and duration per lane mile.

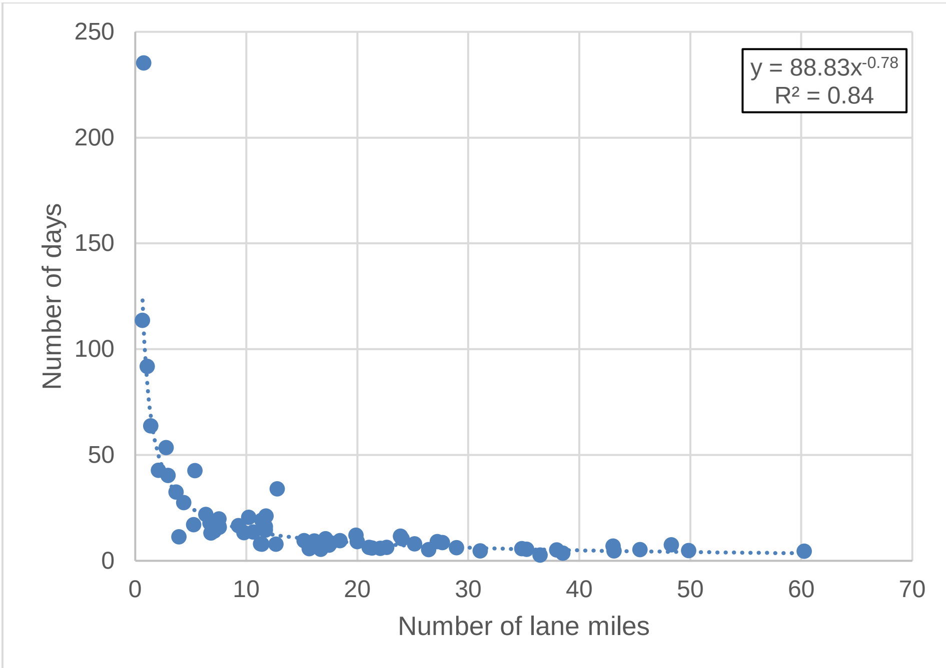

Figure 5.4 UP Deterministic Duration Estimating Model

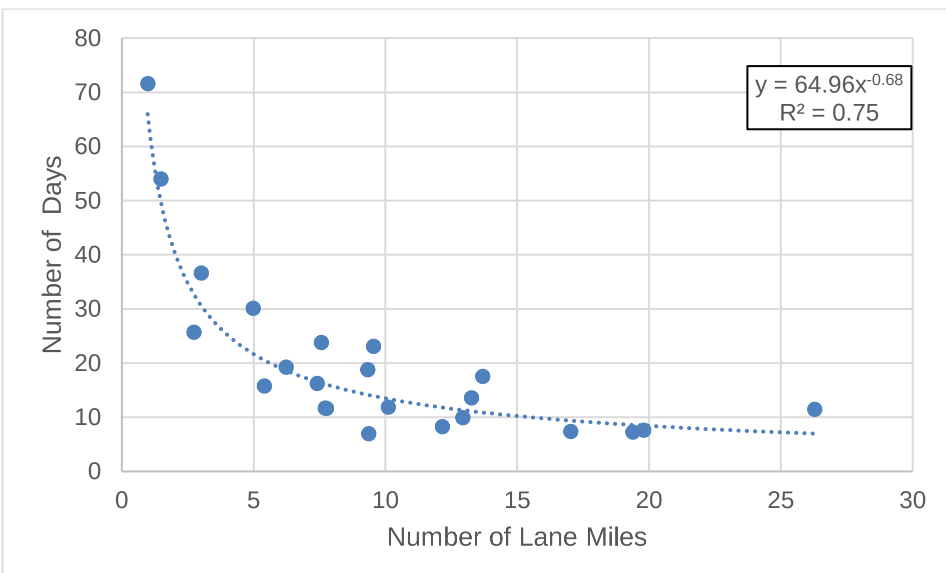

Figure 5.5 LS Deterministic Duration Estimating Model

Although the relationship between number of lane miles and project duration is not clearly shown in Figures 5.2 and 5.3, the strong correlation between these two parameters is better illustrated in Figures 5.4 and 5.5, when project duration is presented on a per lane mile basis. The models have an R^2 of 0.84 and 0.75 for UP and LS, respectively. This means that about 84% and 75% of the project duration variability in UP and LS projects, respectively, can be explained by the number of lane miles to be resurfaced.

Both deterministic models are visually compared in Figure 5.6. To the untrained eye, and based only in Figure 5.6, it looks like the selection of compensation procedures does not affect the schedule performance of resurfacing DBB projects. However, it should be noted that Figure 5.6 is only illustrating deterministic expected values (average values), ignoring the unavoidable uncertainty associated with the prediction of construction periods. In this case, the difference in the schedule implications of the payment approaches under consideration is mainly attributed to schedule growth trends, as will be explained in the next section.

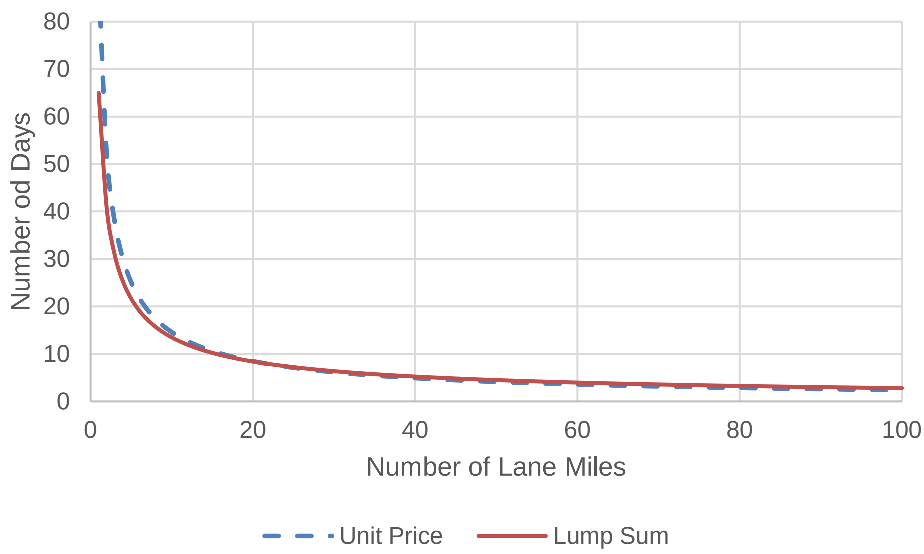

Figure 5.6 UP and LS Deterministic Duration Estimating Models

5.3.2 Schedule Growth Modeling

Schedule growth in this study is defined as the percentage difference between the original contract duration (expected project duration estimated by FDOT at contract award) and the actual duration recorded at project completion, including change orders and duration adjustments (Schedule Growth = [Actual Duration – Original Duration]/Original Duration). As with the cost growth model, the process to model schedule growth for UP and LS projects consists of two steps: 1) the calculation of schedule growth for each UP and LS project; and 2) the use of statistical inference methods to determine the type probability distribution that best fits the schedule growth values for UP and LS. Table 5.1 and Table 5.2 show the schedule growth values for all UP and LS projects, respectively, which corresponds to the first part of the process.

Table 5.1 UP Projects – Schedule Growth

No	Miles	Original Duration (work days)	Actual Duration (workdays)	Schedule Growth	No	Miles	Original Duration (work days)	Actual Duration (workdays)	Schedule Growth
1	0.66	75	95	26.7%	33	16.14	150	175	16.7%
2	0.77	180	206	16.4%	34	16.73	90	159	76.7%
3	1.09	100	97	-3.0%	35	17.17	180	223	23.9%
4	1.41	90	132	46.7%	36	17.47	130	160	23.1%
5	2.10	90	93	3.3%	37	17.63	150	268	78.7%
6	2.80	150	179	19.3%	38	18.46	175	308	76.0%
7	2.98	120	156	30.0%	39	19.88	240	195	-18.8%
8	3.69	120	131	9.2%	40	20.00	180	229	27.2%
9	3.96	45	43	-6.4%	41	21.07	135	159	17.8%
10	6.38	120	199	66.8%	42	21.35	130	152	16.9%
11	6.28	90	114	26.7%	43	22.09	130	178	36.9%
12	6.40	230	326	41.7%	44	22.65	145	151	6.1%
13	6.38	140	221	57.9%	45	23.91	280	314	12.1%
14	6.74	120	127	6.8%	46	26.04	250	288	16.2%
15	6.85	90	86	-6.4%	47	26.16	200	234	17.0%
16	7.12	100	162	62.0%	48	26.44	140	150	7.1%
17	7.56	150	189	26.0%	49	27.22	247	408	66.2%
18	7.58	120	144	20.0%	50	27.70	240	567	136.3%
19	9.31	155	210	36.5%	51	28.96	180	207	16.0%
20	9.82	130	198	52.3%	52	31.10	145	216	49.0%
21	10.23	210	255	21.4%	53	36.84	200	237	18.5%
22	10.65	145	179	23.4%	54	36.28	190	227	19.5%
23	11.30	90	110	22.2%	55	36.48	100	210	110.0%
24	11.42	220	246	11.8%	56	37.98	195	318	63.1%
25	11.43	90	225	150.0%	57	38.53	140	278	98.6%
26	11.73	170	206	21.2%	58	43.07	300	388	29.3%
27	11.74	189	212	12.2%	59	43.15	205	244	19.0%
28	11.78	250	386	56.4%	60	46.48	240	318	32.5%
29	12.70	100	128	28.0%	61	48.32	365	530	46.2%
30	12.79	435	375	-13.8%	62	49.88	240	504	110.0%
31	16.22	145	197	36.9%	63	60.26	270	447	66.6%
32	16.67	90	111	23.3%	-	-	-	-	-

Table 5.2 LS Projects – Schedule Growth

Number	Miles	Original Duration (days)	Actual Duration (days)	Schedule Growth
1	0.98	70	97	38.6%
2	1.48	80	95	18.8%
3	2.73	70	83	18.6%
4	3.01	110	134	21.8%
5	6.98	150	187	26.7%
6	6.41	85	74	-12.9%
7	6.23	120	162	36.0%
8	7.41	120	128	6.7%
9	7.56	180	247	37.2%
10	7.71	90	88	-2.2%
11	7.75	90	129	43.3%
12	9.32	175	201	16.9%
13	9.36	65	72	10.8%
14	9.54	220	212	-3.6%
15	10.11	120	127	6.8%
16	12.15	100	108	8.0%
17	12.94	128	173	36.2%
18	13.26	180	250	38.9%
19	13.69	240	295	22.9%
20	17.03	125	237	89.6%
21	19.39	140	181	29.3%
22	19.80	150	302	101.3%
23	26.28	300	303	1.0%

The chi-square goodness of fit statistical test and @Risk were used again in this chapter to identify the most suitable probability distribution for each set of schedule growth values (one set for UP and one for LS projects). This statistical test revealed that schedule growth trends for both UP and LS are better represented by extreme value distribution. The same type of distribution was used in the LS cost growth model. Values of γ and β were 20.926% and 0.2397 for UP, and 13.94% and 0.191 for LS. As mentioned in the previous chapter, this probability distribution deals with data that has an extreme deviation from the mean (*54*), meaning that these are asymmetric distributions. The extreme value distributions with the frequencies of schedule growth values for UP and LS projects are illustrated in Figure 5.7 and Figure 5.8, respectively.

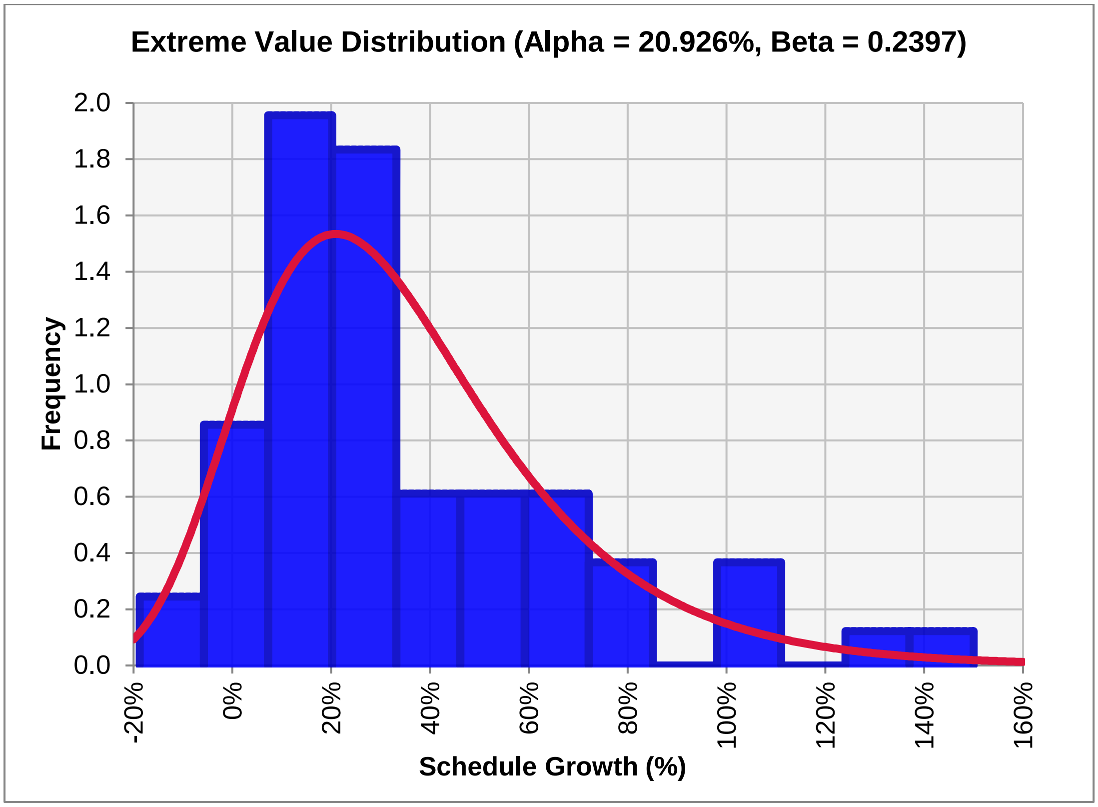

Figure 5.7 UP Schedule Growth Probability Distribution

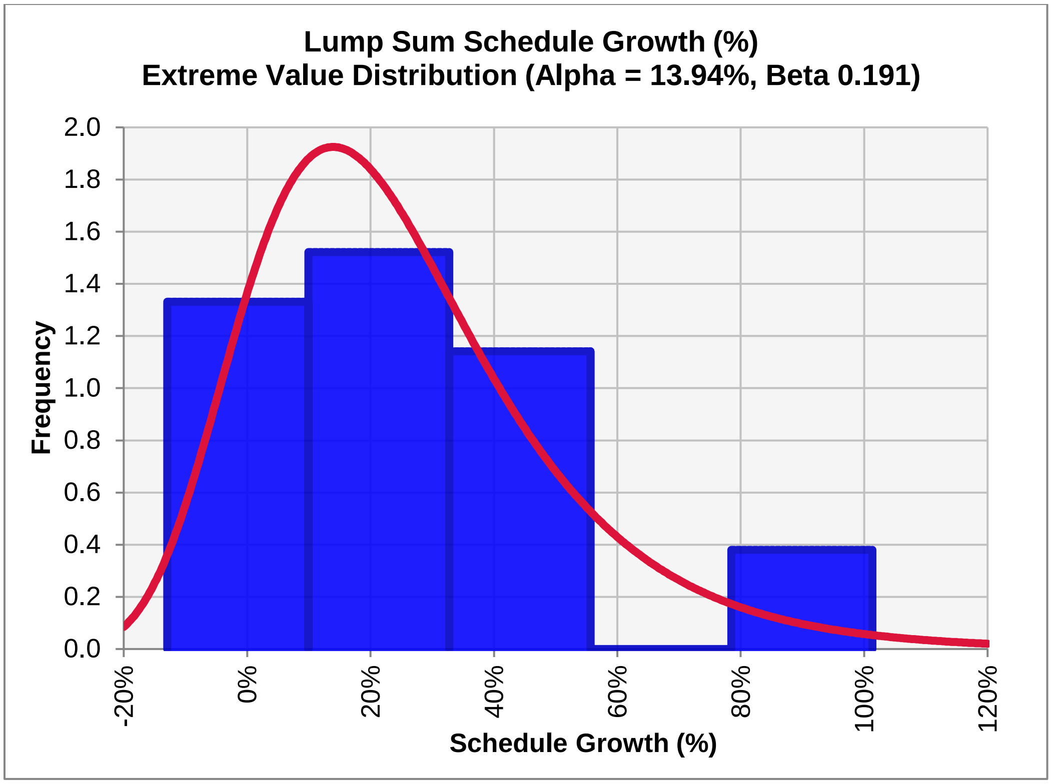

Figure 5.8 LS Schedule Growth Probability Distribution

When compared with the deterministic models illustrated in Figure 5.4, Figure 5.5 shows that the schedule implications of using LS instead of traditional UP provisions are mainly associated with uncertainty of schedule growth trends. Both models present positive mean values (UP = 34.76%; LS = 24.97%), indicating that actual final project durations in both types of projects tend to be longer than originally estimated by FDOT.

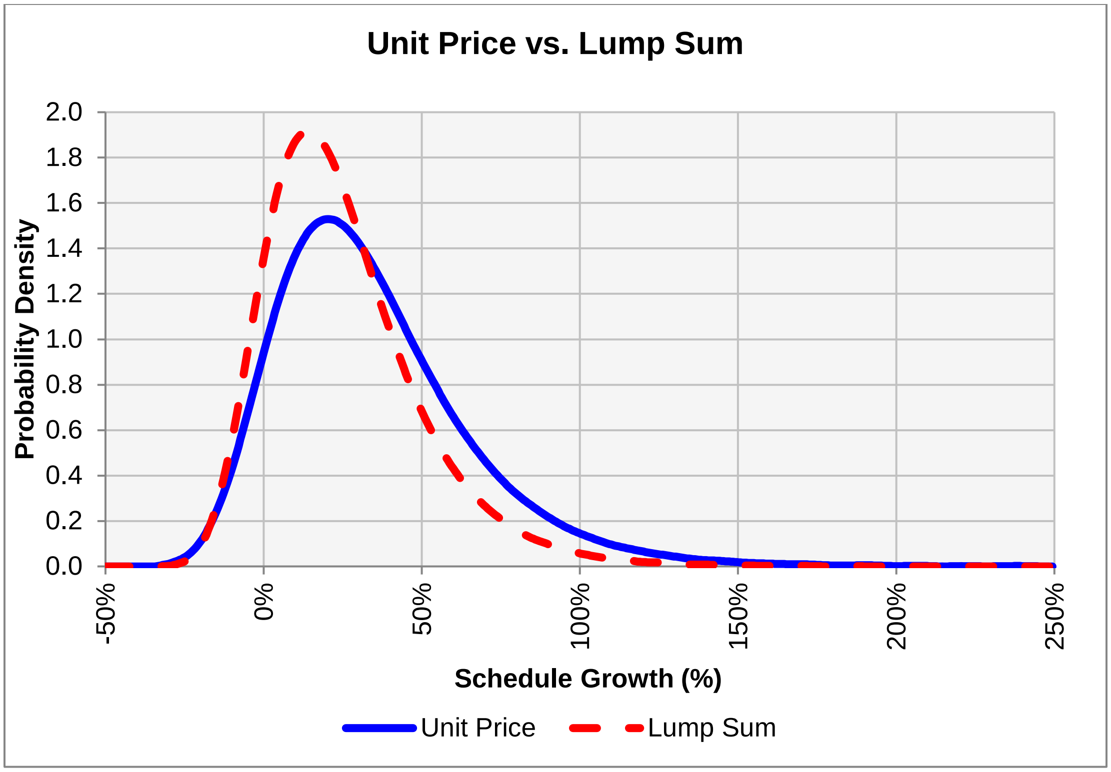

Figure 5.9 Schedule Growth Comparison: Unit Price vs Lump Sum

5.3.3 Stochastic Construction Duration Estimating Models – Development and Comparison

As with the cost sub-framework in Chapter 4, stochastic duration estimates are produced by combining the deterministic and schedule growth models, as shown in Equations 5.1 and 5.2. These equations first estimate the deterministic duration for a given number of lane miles, then assess possible fluctuations in this value according to the schedule growth models.

$$\boldsymbol{SE_{(UP,x)} = DE_{UP,x} \times \left(1 + EV(0.209; 0.23974)\right)} \qquad \textbf{(5.1)}$$

Where:

$x = Lane\ miles$

$SE_{(UP,X)} = Stochastic\ duration\ estimate\ for\ a\ UP\ project\ of\ x\ lane\ miles$

$DE_{(UP,X)} = Deterministic\ duration\ estimate\ for\ a\ UP\ project\ of\ x\ lane\ miles$

$EV(0.209; 0.239) = LS\ Cost\ Growth\ Model \rightarrow ExtremeValueDist.(alpha = 20.9\%; beta = 0.239)$

$$\boldsymbol{SE_{(LS,x)} = DE_{LS,x} \times \left(1 + EV(0.139; 0.191)\right)} \qquad \textbf{(5.2)}$$

Where:

$x = Lane\ miles$

$SE_{(LS,X)} = Stochastic\ cost\ estimate\ for\ a\ LS\ project\ of\ x\ lane\ miles$

$DE_{(LS,X)} = Deterministic\ cost\ estimate\ for\ a\ LS\ project\ of\ x\ lane\ miles$

$EV(0.139; 0.191) = LS\ Cost\ Growth\ Model \rightarrow ExtremeValueDist.(alpha = 13.9\%; beta = 0.191)$

Stochastic duration estimating models for UP and LS (Equations 5.1 and 5.2) were compared for different project sizes (number of lane miles) to determine the probability of UP durations greater than LS durations as a function of the number of lane miles (ranged from 1 to 50 miles). The stochastic comparison was performed via Monte Carlo simulation with the help of @Risk. A total of 10,000 pairs of random values for Equations 5.1 and 5.2 were generated for each project size. These pairs of values (one UP and one LS value) were then compared, estimating for each considered project size the probability of having a lower project duration if LS provisions are used ([number of times LS simulated durations were lower than UP simulated durations]/10,000 * 100%). Figure 5.10 shows these probabilities for resurfacing project ranging from 1 to 50 lane miles.

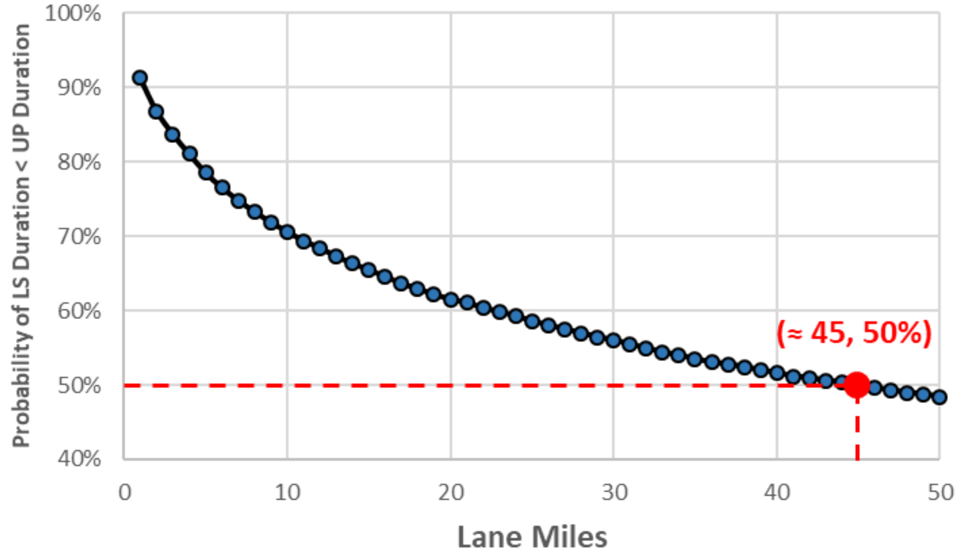

Figure 5.10 Probability UP will be less than LS

As shown in Figure 5.10, the probability of UP durations exceeding LS durations is greater than 50% for resurfacing projects of less than 45 lane miles. However, this does not mean that after 45 miles it always better to use UP approach since the probability is not 0%. It was also noted that, the graph is only showing up to 50 miles for illustration purposes. The probability was checked at 50,000 miles and it was 0.7% which means that, there is a still a chance that LS can have a lower estimate that UP.

It is important to know the probability of making the wrong decision, but it is more important to know the consequences of making the wrong decision, which is not shown in Figure 5.10, and in some cases could be significant. Such information was collected during the simulation and provided to decision-makers through the nomogram described in the next section.

5.4 Integration of Results – Development of Duration-Based Nomogram

The last step in the development of the duration sub-framework corresponds to the development of the duration-based nomogram, similar to the one developed in Chapter 4 for the cost factor, but this time assessing the implication of using the LS provision in terms of work days. The nomogram uses the same two inputs (number of lane miles and desired confidence level set by decision-makers) to produce four outputs: probability of having a longer project duration if UP is used instead of LS; expected case scenario is LS provisions are used (calculated with average values from deterministic models); the worst case scenario if LS provisions are used; and the best case scenario if LS provisions are used. The expected case scenario in the nomogram shows once again the low LS schedule implications at a deterministic level, which contrasts with the wide ranges that separate the best and worst case scenarios at the difference confidence levels.

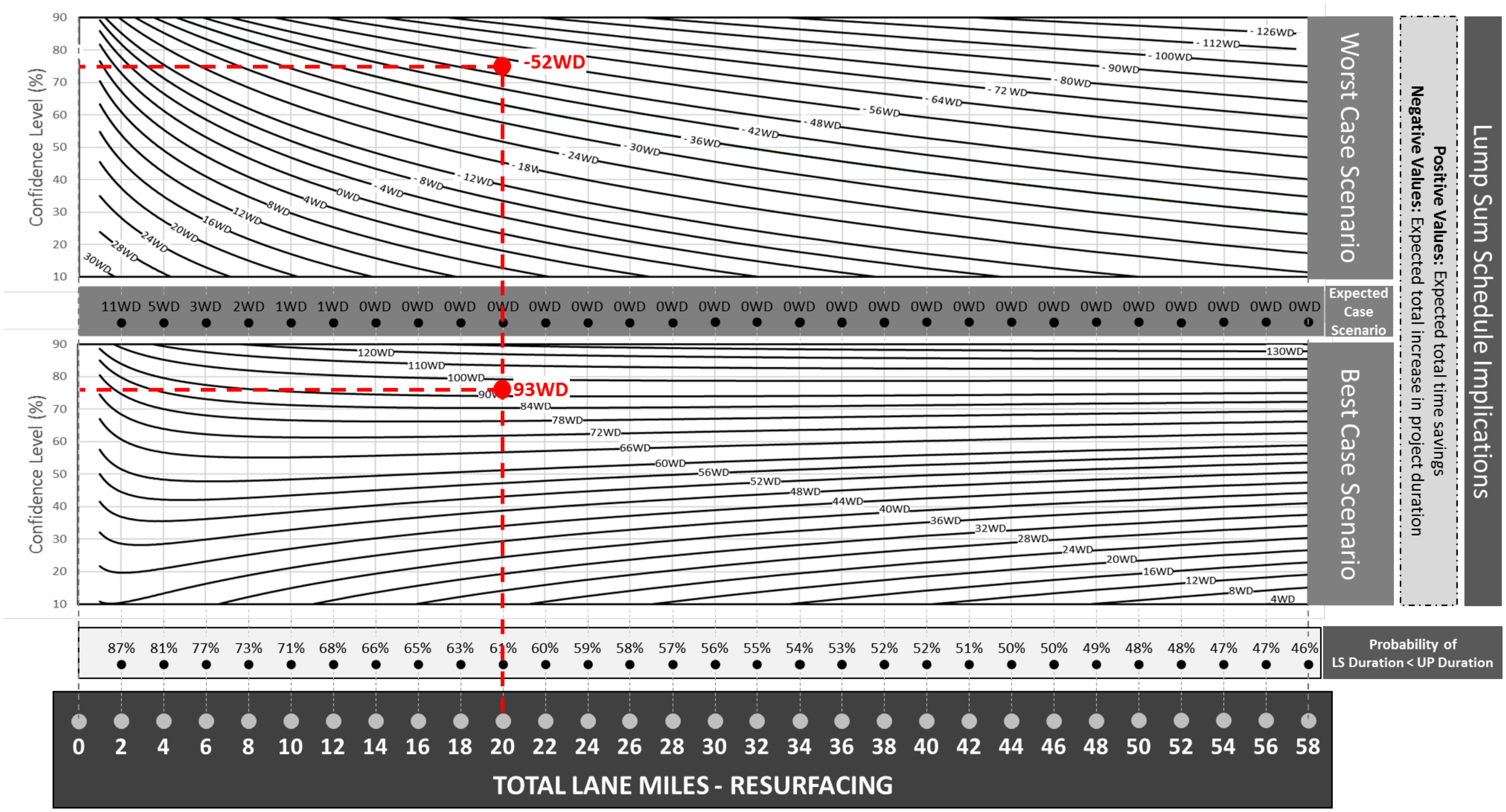

Figure 5.11 LS Project Selection - Duration-Based Nomogram

If FDOT decides to apply this nomogram to the same 20-lane-mile resurfacing project used as an example in Chapter 4, and again with a 75% confidence level, FDOT would be 75% sure that the potential schedule impact of using LS provisions would range from early project completion by 93 work days (WDs) and a late completion by 52 WDs (see Figure 5.11). The main difference between cost- and duration-based nomograms is that the former assesses cost implications on a per-lane-mile basis, while the nomogram in Figure 5.11 is approximates the total schedule impact at project completion.

5.5 Summary

This chapter presented the step-by-step process followed to develop the duration-based LS project selection sub-framework, which corresponds to the same methodology that led to the development of the cost sub-framework in Chapter 4. The development of the duration-based tool involved the creation of deterministic project duration, schedule growth, and a stochastic duration models for both UP and LS DBB projects. The UP and LS stochastic models were then compared using Monte Carlo simulation techniques to better understand the level of schedule uncertainty that should be considered when selecting a compensation approach for a DBB resurfacing projects. Finally, all the research efforts presented in this chapter were comprised into a duration-based nomogram, which provides decision-makers with four important elements to be considered during the selection of the payment approach: the probability of having a longer project duration if UP is used instead of LS; expected case scenario if LS provisions are used (calculated with average values from deterministic models); the worst case scenario if LS provisions are used; and the best case scenario if LS provisions are used. Having developed the cost and duration sub-frameworks, the next step is to integrate them into an overall decision-making framework, which is accomplished using multi-objective decision analysis techniques, as explained the following chapter.

CHAPTER 6 COST-DURATION-BASED LUMP SUM PROJECT SELECTION FRAMWORK: A MAUT MODEL

6.1 Introduction

This chapter presents the final decision-making framework proposed to assist FDOT with the selection of contractor compensation provisions in resurfacing DBB projects. This framework consists of a MAUT model that integrates the cost and duration sub-frameworks developed in Chapters 4 and 5, respectively. The Model will facilitate trade-offs among four decision objectives, which, if satisfactorily achieved, would serve to demonstrate value-for-money in FDOT's resurfacing investments. The following are the four decision objectives considered in the MAUT model:

1. Minimize Construction Cost
2. Minimize Construction Duration
3. Maximize Cost Certainty
4. Maximize Schedule Certainty

6.2 Methodology

Figure 6.1 reviews the process followed to develop the MAUT model. This figure and each of its steps were previously introduced in Chapter 3. This chapter revisits each of the four MAUT model development steps providing more detailed information on the proposed model. Likewise, the MAUT model implementation phase is illustrated in a step-by-step manner until producing a recommendation on a hypothetical resurfacing project whether to use UP or LS provision.

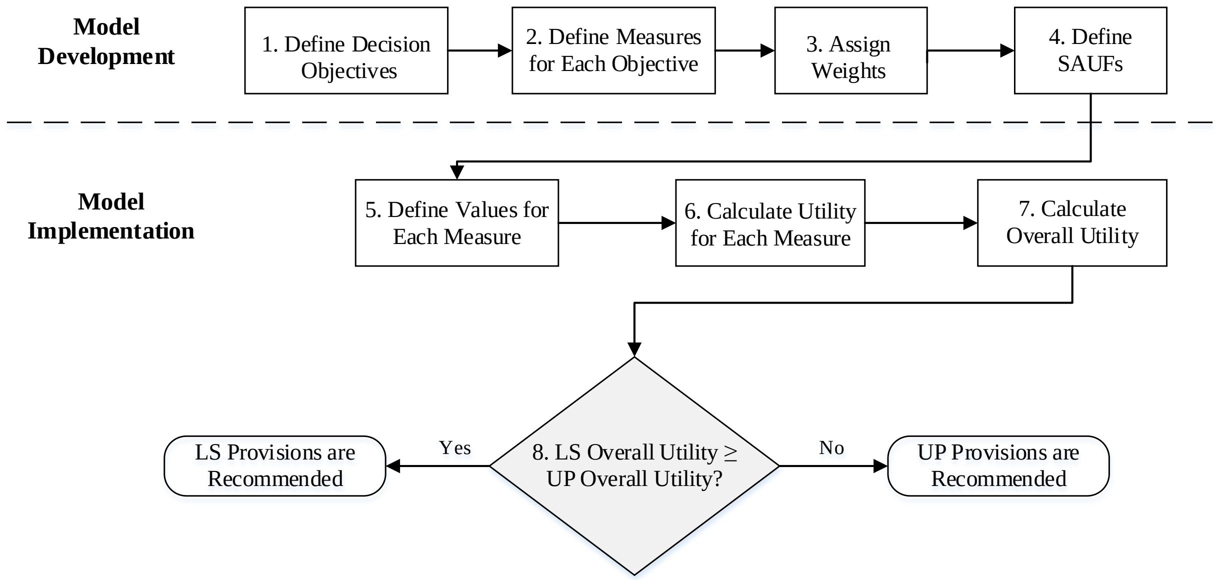

Figure 6.1 MAUT Model Development and Implementation

6.2.1 Define Decision Objectives

Following are brief descriptions of the four decision objectives that have been mentioned previously in this dissertation:

- Minimize construction costs: This objective refers to the maximization of cost savings, which is an increasingly important decision driver for DOTs given shrinking annual budgets to maintain a deteriorating transportation infrastructure. This unavoidable situation has DOTs constantly looking for strategies to optimize utilization of limited available resources in an attempt to do more with less. That is precisely what this decision objective is intended for.

- Minimize construction duration: Long transportation construction projects have several types of impacts on stakeholders at all levels (e.g. economic, social, environmental, political, etc.). Impacts range from traffic congestion and economic losses for road users and existent local businesses to visual pollution and discomfort of surrounding communities. Virtually all negative impacts are proportional to the duration of construction projects, and in some cases they even escalate exponentially overtime. Thus, any efforts to keep transportation project as short as practically possible should translate into benefits to all stakeholders.
- Maximize cost and schedule certainty: These are actually two separate objectives in the proposed MAUT model; however, they both were included taking into consideration the needs and proprieties of a specific type of decision-maker. Under some circumstances, the agency's program management may prefer the certainty of a guaranteed price and completion date more than potential cost and schedule savings. Certainty is usually preferred over savings in situations where budget and schedule control is essential to achieve organizational goals.

6.2.2 Define Measures

Figure 6.2 shows the six measures proposed in this study to evaluate the level of achievement of the above decision objectives. Each of these measures is briefly described below.

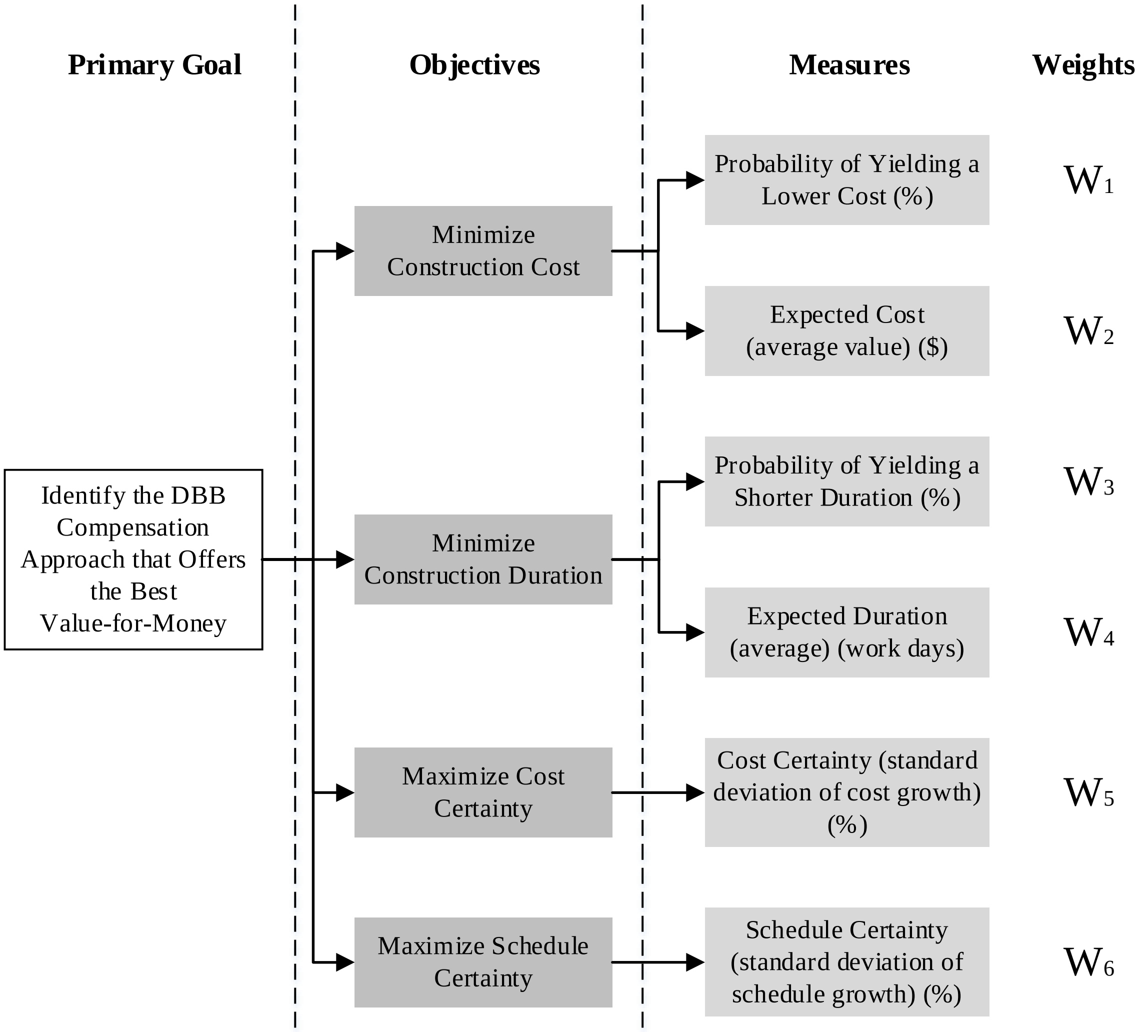

Figure 6.2 MAUT Model – Hypothetical Project

- **Minimize Construction Costs**
  - Probability of yielding a lower cost (%): This measure is provided by the cost-based nomogram and was estimated through simulation. The nomogram only provides the value for this measure for the LS alternative in a direct manner (see "Probability of LS Cost < UP Cost" in Figure 4.11). However, the LS and UP probabilities under this

measure are complementary, meaning that these are only two alternatives and are mutually exclusive. Thus, if the MAUT model is to be applied on a 20-lane-mile resurfacing project, the value under this measure for the LS alternative would be 53% (see cost-based nomogram in Figure 4.11), while the value for UP would be 47% (1 – 0.53 = 0.47).

- Expected cost ($): Knowing that a LS-DBB approach is more likely to generate greater cost savings is a valuable piece of information for decision-makers. However, not knowing the potential magnitude of those savings could prevent FDOT from making needed trade-offs with other project objectives. For example, if in a 30-lane-mile resurfacing project the agency is willing to incur additional costs associated with the use of LS provision in order to get other non-monetary benefits, it would be first important to quantify the potential cost of that decision. That is the main purpose of this measure. Values for this measure are calculated using the UP and LS deterministic cost estimating model developed in Chapter 4 (Figures 4.4 and 4.5). These values correspond to average observed costs per lane mile.

- **Minimize Construction Duration**
  - Probability of yielding a shorter duration (%): This measure is the equivalent of the first measure described above under the minimize construction cost objective, but in this case intended to maximize time savings. These values were also generated via Monte Carlo simulation. Given that these are also mutually exclusive probabilities, the values under this measure for both alternatives are determined as described above for the "probability of yielding a lower cost" measure but using the duration-based nomogram presented in the previous chapter (see Figure 5.11).

- Expected Duration (work days): This is also a "duration-based version" of the second measure described above for the minimized construction cost objective. It is intended to fulfill a similar purpose and its values are calculated in a similar manner. The main difference is that, in this case, the expected duration values correspond to average observed project durations for UP and LS resurfacing projects awarded and completed by FDOT. These expected duration values are calculated with the deterministic duration estimating model developed in Chapter 5 (Figures 5.4 and 5.5).

- **Maximize Cost and Schedule Certainty**
  - Cost and Schedule Certainty: These two measures refer to the level of certainty by which a project will be completed within a given cost budget and schedule. These measures become key decision drivers when budget and schedule control are a priority. Although the cost- and duration-nomograms provide a measure of uncertainty in the form of best and worst case scenarios, the MAUT model uses as an uncertainty input the standard deviation of the cost and schedule growth models developed in Chapters 4 and 5. These standard deviations are simpler inputs and their magnitudes are directly associated with the confidence intervals that define the best and worst case scenarios in both nomograms.

6.2.3 Assign Weights

The weight assigned to each measure indicates its importance relative to the decision at hand. Weights must be assessed on a per project basis based on the specific requirements of each project. The methodology chapter in this dissertation (Chapter 3) presented a detailed description of the recommended weighing methodology recommended by the author: the swing weighting approach.

6.2.4 Define SAUFs and Values for Each Measurement

As explained previously in this dissertation, SAUFs play a key role in MAUT models. SAUFs are mathematical functions that translate all measured values into the same utility units. SAUFs allow the aggregation of all measures to quantify the overall level of satisfaction of objectives in the form an overall utility value. As discussed in the initial paragraph for this section, single attribute utility functions are used to aggregate multiple provisions in order to compare them.

SAUFs convert measures into normalized utility values between zero and one; with zero and one being least and most preferred values, respectively, for each measure. Given that the preferred conditions may change from project to project, SAUFs should be reassessed before each use of the MAUT model and according to the specifics of each project. The revision of a SAUF is usually performed concurrently with the first MAUT implementation step: "define values for each measure". The concurrent execution of these two tasks provides decision-makers the possibility of using current measure values from the decision at hand to define the most and least preferred scenarios required to create the SAUFs.

6.3 Hypothetical Example

The rest of this section illustrates the process to develop SAUFs for a hypothetical 24-lane-mile resurfacing project for which FDOT is attempting to find the most suitable compensation approach. In order to better understand the implications of this decision, it is necessary to situate this project in both the cost-based and schedule-based nomograms, which at the same time would assign values to some of the measures. Figures 6.3 and 6.4 show the cost-based and duration-based nomogram values for this example assuming a confidence level of 60%. According to the cost-based nomogram, at a deterministic level, FDOT should expect losses of about $5,000 per lane mile if LS provisions are used. However, from a probabilistic perspective, there is a 27% cost saving with a LS approach. With a 60% confidence level, FDOT could save as much as $2,000 per lane mile, but could also lose $14,000 per lane mile. On the other hand, the duration-based nomogram shows results in favor a LS approach, with a 59% probability of getting a shorter project duration with LS payment provisions. Although deterministic construction duration estimates show no difference in project duration, the stochastic analysis shows that, in the best case scenario (with a 60% confidence level) FDOT could finished this project almost 70 work days earlier than expected if LS provisions are used. The worst case scenario under these conditions corresponds to a potential delay in project completion of 38 work days, approximately. The measured values are now available and summarized in Table 6.1.

Table 6.1 Values for MAUT Measures

Objective	Measure	LS	UP
Minimize Construction Costs	Probability of yielding a lower cost	27%	73%
	Expected Cost	$202K/LM	$197K/LM
Minimize Construction Duration	Probability of yielding a shorter duration	59%	41%
	Expected Duration	168 WD	168 WD
Maximize Cost Certainty	Cost Certainty	2.6%	4.3%
Maximize Schedule Certainty	Schedule Certainty	24.5%	30.7%

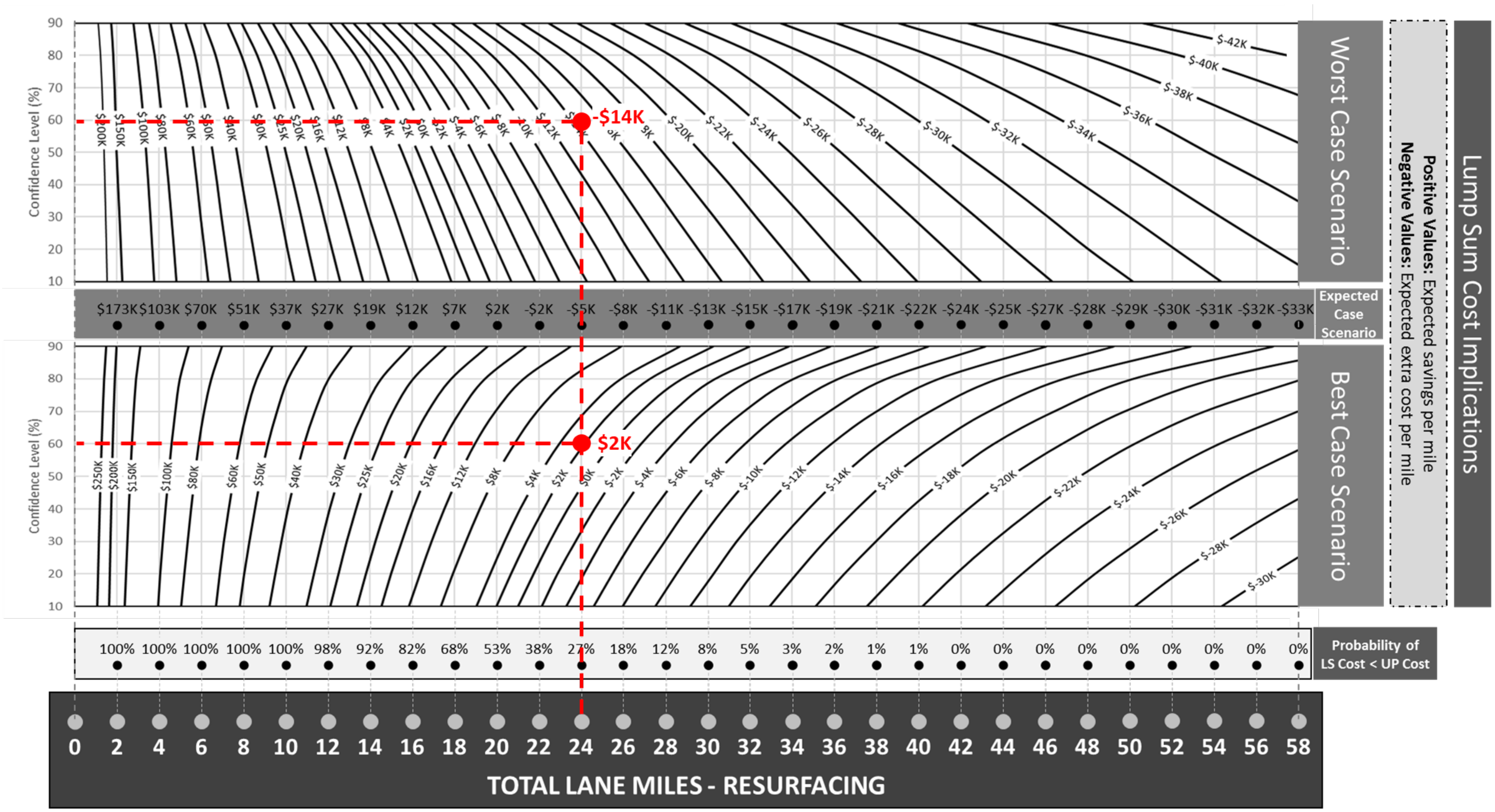

Figure 6.3 Cost-Based Nomogram – Example (24-lane-mile project)

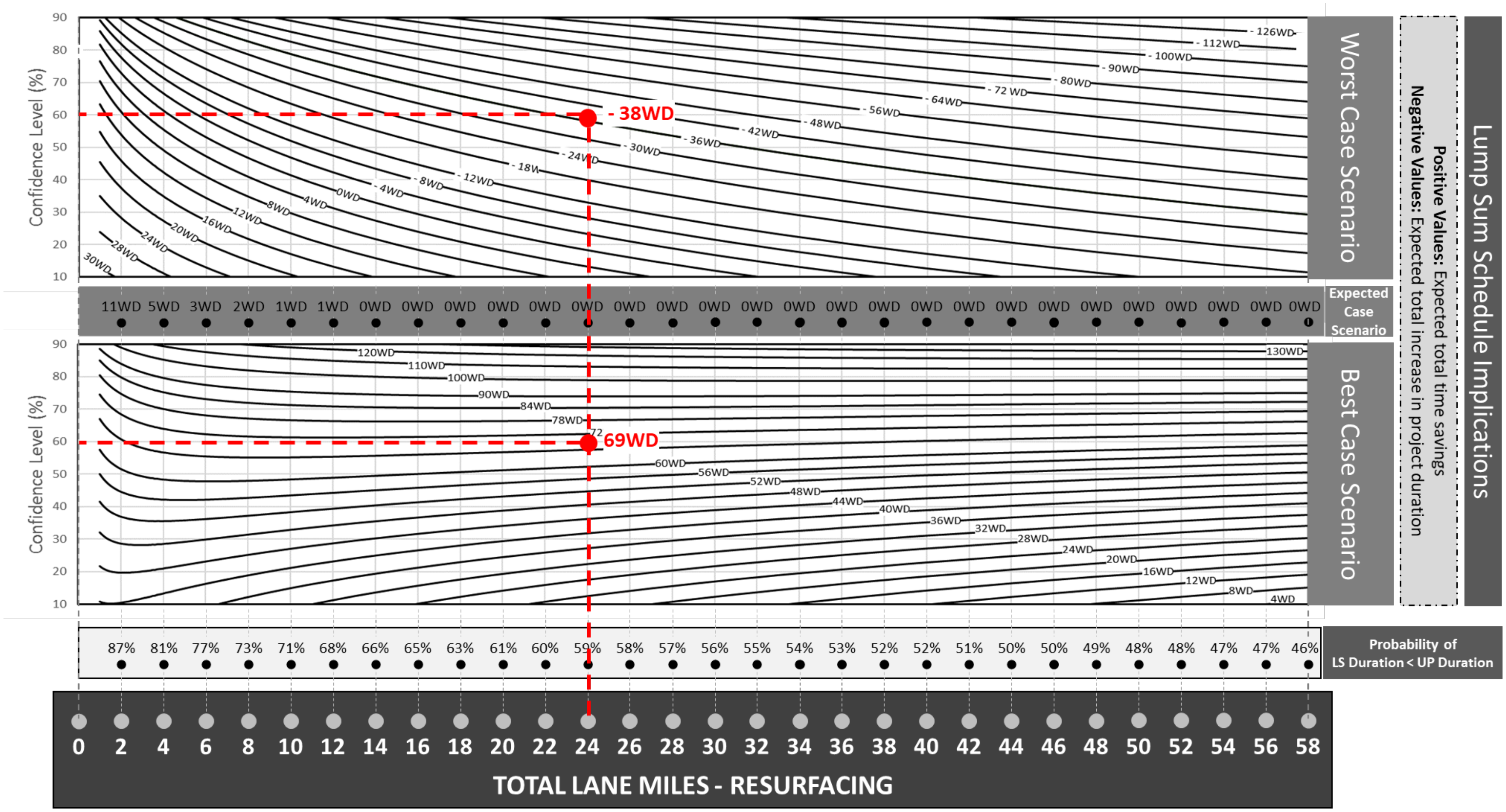

Figure 6.4 Duration-Based Nomogram – Example (24-lane-mile project)

There is not a single one-size-fits-all approach to determine most and least preferred values for all measures. Sometimes there are obvious preferred and/or undesirable values. That is the case with measures for probabilities yielding a lower cost and a shorter duration. In that case, the obvious values for the most and least preferred values would be 100% and 0%, respectively.

Other measures may require further discussion among decision-makers or a careful review of available historical data. For example, after reviewing the UP and LS stochastic cost estimates shown in Figure 4.4 and 4.5, it seems reasonable to expect that $50,000/lane-mile and $300,000/lane-mile would be realistic low and high resurfacing cost rates per lane mile for a 24-lane-mile project. Therefore, these values are set as the most and least preferred values, respectively, for the expected cost measure. In a similar way, the UP and LS duration estimating deterministic estimates in Figures 5.4 and 5.5 suggest that 150 and 400 work days would reasonably be the most and least preferred values for the expected duration of the example project.

The cost and schedule certainty measures correspond to the standard deviations of their respective cost and schedule growth models. Cost and schedule growth are measured as percentages, which explains the units used in Table 6.1 for these measures. Standard deviation values are indicators of uncertainty, and lower standard deviations should be preferred if the objective is to minimize uncertainty. Thus, a logical preferred value for these two measures would be 0%. Contrarily, the least preferred values for these measures are not easy to determine. What would be the largest acceptable standard deviation accepted under this measure? This is not an easy question, and it is not necessarily an answer to it. In those cases, Chelst and Canbolat (*48*) recommend the use of the least desirable current value among all alternatives under this measure as the least preferred value needed to develop the SAUF. It should be noted that these extreme values are not intended to represent the absolute most and least preferred values the agency should always pursue or avoid in all similar decisions. Rather, most and least preferred values should only be seen as the boundaries of the SAUFs for decision analysis and their application as such must be limited to the decision at hand. In both the cost certainty and the schedule certainty measure the UP alternative have the highest values: 4.3% and 30.7%, respectively (see Table 6.1). Thus, these values have been set as the least preferred values for these two measures and will be assigned a utility value of zero by their respective SAUF. Table 6.2 summarizes the measured values for each alternative as well as the most and least preferred values for each measure.

Table 6.2 Most and Least Preferred Measured Values

Objective	Measure	LS	UP	Most Preferred Value (Utility Value = 1)	Least Preferred Value (Utility Value = 0)
Minimize Construction Costs	Probability of yielding a lower cost	27%	73%	100%	0%
	Expected Cost	$202K/LM	$197K/LM	$50K/LM	$300K/LM
Minimize Construction Duration	Probability of yielding a shorter duration	59%	41%	100%	0%
	Expected Duration	168 WD	168 WD	150 WD	350 WD
Maximize Cost Certainty	Cost Certainty	2.6%	4.3%	0%	4.3%
Maximize Schedule Certainty	Schedule Certainty	24.5%	30.7%	0%	30.7%

The next step is to select the type of function to calculate utility values for those measure values that are in-between the most and least preferred values. For example; in the “probability of yielding a lower cost” measure, it has been already established that 100% and 0% are the greatest and least values for that measure. However, that is not enough information to calculate the utility value for LS under this measure, whose value is 27% (neither the most preferred nor the least preferred). The simplest type of SAUF is a linear function, which is the one assumed for all measures in this study in an attempt to keep the proposed model as straightforward and user-friendly as possible. Figure 6.5 illustrates the SAUFs for all six measures.

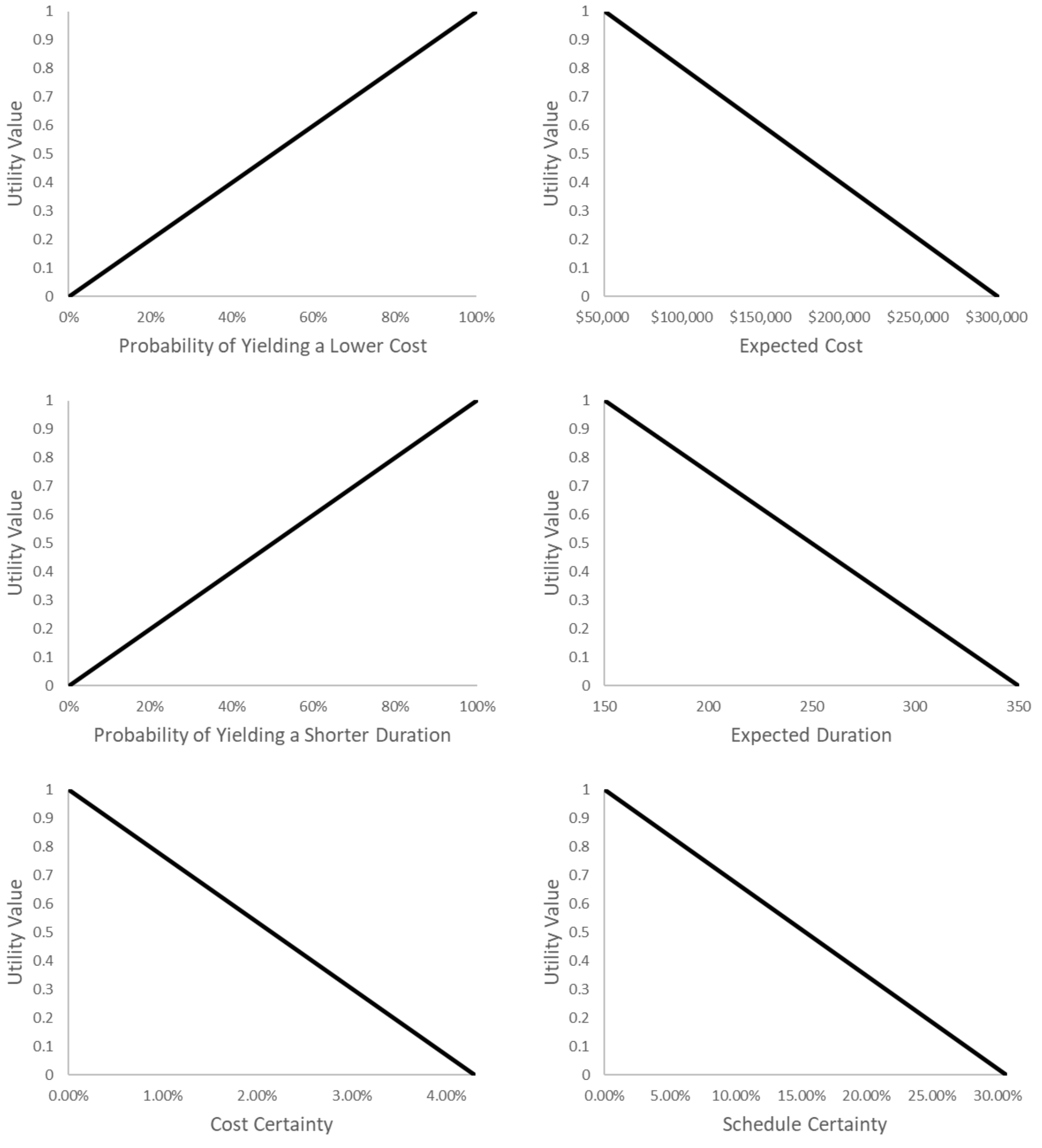

Figure 6.5 Single-Attribute Utility Functions

6.2.4 Calculate Utility for each Measure

As per Figure 6.1, the next step is to convert the measure values into utility functions using the SAUF in Figure 6.5. This is process can be easily accomplished using Equation 6.1 in any of the SAUFs. This equation also shows an example of the calculation of the utility values for the LS alternative on the cost certainty measure. Table 6.3 shows all utility values for each compensation alternative.

$$\mathbf{Utility} = \frac{\mathbf{Current\ Value - Least\ Preferred}}{\mathbf{Most\ Preferred - Least\ Preferred}} = \frac{\mathbf{2.6\% - 4.3\%}}{\mathbf{0\% - 30.7\%}} = \mathbf{0.395} \qquad \mathbf{(6.1)}$$

Table 6.3 Utility Values for the Example

Objective	Measure	LS Utility Values	UP Utility Values
Minimize Construction Costs	Probability of yielding a lower cost	0.270	0.730
	Expected Cost	0.392	0.412
Minimize Construction Duration	Probability of yielding a shorter duration	0.590	0.410
	Expected Duration	0.910	0.910
Maximize Cost Certainty	Cost Certainty	0.395	0.00
Maximize Schedule Certainty	Schedule Certainty	0.202	0.00

6.2.5 Overall Utility Values and Final Recommendation

Using the set of weights calculated in Chapter 3 for the example to illustrate the swing weighing method and the utility values in Table 6.3, the last step would be to calculate the overall utility value for each alternative and to make a recommendation on whether or not to use LS compensation provisions on this 24-lane-mile resurfacing project. The overall utility value of an alternative is equal to the weighted sum of the utility values for all measures based on the weight assigned to each of them, as shown in Equation 6.2. Table 6.4 summarizes the final results of the MAUT model.

$$\boldsymbol{Overall\ Utility} = \sum_{i}^{n} \boldsymbol{U_i} \times \boldsymbol{W_i} \qquad \textbf{(6.2)}$$

Where: $U_i = Utility\ value\ for\ measure\ i$

$W_i = Weight\ assigned\ to\ measure\ i$

$n = number\ of\ measures$

Table 6.4 Overall Utility Values for the Example

Objective	Measure	Weight (W)	LS Utility Values (U_{LS})	UP Utility Values (U_{UP})	LS Weighted Sum (WxU_{LS})	UP Weighted Sum (WxU_{UP})
Minimize Construction Costs	Probability of yielding a lower cost	16%	0.270	0.730	0.043	0.116
	Expected Cost	15%	0.392	0.412	0.058	0.061
Minimize Construction Duration	Probability of yielding a shorter duration	21%	0.590	0.410	0.123	0.086
	Expected Duration	19%	0.910	0.910	0.172	0.172
Maximize Cost Certainty	Cost Certainty	11%	0.395	0.00	0.043	0
Maximize Schedule Certainty	Schedule Certainty	18%	0.202	0.00	0.036	0
				Overall Utility Value	**0.478**	**0.437**

Based on the overall utility values shown in Table 6.3, the final recommendation made to decision-makers on the 24-lane-mile resurfacing project considered in this example would be to use LS compensation provisions instead of the traditional unit price approach. As mentioned in Chapter 3, the set of weights used in Table 6.3 were determined for a case in which schedule performance is more important that securing cost savings. Thus, even though the use of LS provisions in the example project implies an increase in construction costs, the MAUT model revealed that this increase is not high enough to offset the needed schedule benefits offered by this payment approach. In other words, FDOT should consider the possibility of paying this additional cost for the use of LS provision in order to address the unique schedule requirements of this projects. This trade-off would have been difficult to perceive using traditional subjective decision-making techniques. It should be noted that the use of MAUT techniques does not disregard the important role of engineering judgment in the selection of compensation approaches. It is possible that engineering judgment is more suitable for assessing certain measures. MAUT offers a method to formalize and standardize alternative provision evaluation in lieu of unstructured subjective assessments. The ability of MAUT to combine outputs assessment with those obtained from more formal objective techniques aids in building a more effective, integral, and transparent evaluation process.

6.4 Summary

This chapter describes the steps followed in the development of a MAUT framework that integrates the cost and schedule sub-frameworks developed in Chapters 4 and 5. The model facilitates the trade-offs among four decision objectives, which, if satisfactorily achieved, would serve to demonstrate value-for-money in FDOT resurfacing investments. The model is illustrated through a hypothetical resurfacing project. The development of the model begins by defining four decision objectives which are minimized construction cost and duration and maximized cost and schedule certainty. Six measures were proposed to evaluate the level of achievement of the four decision objectives; Probability of yielding a lower cost, Expected cost, Probability of yielding a shorter duration, Expected duration, and Cost and Schedule certainty. Based on the relative importance of each measure different weights were assigned to each measure. To normalize the utility values between zero and one SAUFs were calculated to indicate the least and most preferred values for each measure which were then converted into utility functions. The last step is to calculate the overall utility value for each alternative and to make a recommendation on whether or not to use LS.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions and Major Contributions

Alternative project delivery methods have become increasingly popular during the last couple of decades, attracting the attention of DOTs and researchers. However, traditional DBB contracting techniques are still the most common contracting method used by transportation agencies, meaning that any research efforts towards the improvement of DBB contracting could potentially have a considerable impact on DOTs' construction programs. This dissertation was intended to generate such type of impact by improving decision-making on the selection of DBB contract provisions. More specifically, this dissertation presented the research efforts that led to the development of an objective decision-making framework to assist FDOT with the identification of DBB resurfacing projects suitable for LS compensation provisions.

The proposed framework has been the result of an exhaustive data analysis intended to assess the cost and schedule implications of using LS instead of traditional UP compensation provisions in DBB resurfacing projects. This data analysis was conducted using historical bid data from 86 resurfacing projects completed by FDOT between January 2015 and March 2017; 63 UP and 23 LS projects. Cost and schedule implications were stochastically assessed by two separate sub-frameworks and for different amounts of resurfacing work measured in lane miles. To facilitate their interpretation, the stochastic outputs of both sub-frameworks was comprised into two nomograms: a cost-based and a duration-based nomogram.

After identifying a LS resurfacing candidate project, and estimating the number of lane miles to be resurfaced, FDOT could use the nomograms to determine the probability of having lower construction costs and/or a shorter project duration if LS provisions are used instead of a UP compensation approach. Likewise, the nomograms facilitate the assessment of LS cost and schedule implications under three different scenarios: expected case scenario if LS provisions are used; worst case scenario if LS provisions are used; and best case scenario if LS provisions are used. The worst and best case scenarios are given by the confidence level set by the agency and are presented in the form of cost and time savings and losses.

Even though there is great value in the development of two separate tools to assess LS cost and schedule implications, it is still not enough to assist FDOT with an effective selection of payment provisions in DBB resurfacing projects. An effective methodology to assist with these decisions should allow for trade-offs among cost and schedule performance objectives based on project specific needs. For example, according to the cost-based nomogram, in a 24-lane-mile resurfacing project with LS provisions, and with a 60% confidence level, FDOT should expect losses of about $14,000 in the worst case scenario or gains around $2,000 in the best case scenario, with an overall probability of 73% of achieving better cost performance with UP provisions. Thus, the cost-based nomogram would favor a UP approach. However, the duration-based nomogram would indicate a better schedule performance with LS provisions in the same project. The duration-based nomogram shows a 59% probability of getting a shorter project duration with LS payment provisions, with a worst and best case scenarios predicting a schedule performance between 38 additional work days and time savings of 69 work days, respectively. In this case, FDOT would have to determine if time savings are more important than cost savings in this project (a decision that depends on the specific needs and objectives of each project), but that it still not enough.

Giving more importance to schedule performance would not mean that FDOT is willing to pay any amount of money towards an early project completion. Now it is needed to determine if the potential time savings are worth the expected additional cost. To address this situation and facilitate an effective selection of payment provisions, the author had to look for a methodology that facilitates trade-offs between conflicting objectives, taking into consideration different levels of importance among the objectives. MAUT decision modeling was the methodology proposed by the author. For this purpose the author proposed the use of a multi-objective decision-making methodology called Multi-Attribute Utility Theory (MAUT).

MAUT is a multi-objective decision-analysis technique designed to evaluate and compare the performance of multiple alternatives on multiple weighted objectives using utility values. Measuring the level of achievement of each objective in the same terms (utility) is what allows trade-offs between objectives. The two alternatives compared in this study by the proposed MAUT model are the two compensation approaches used by FDOT in its DBB resurfacing projects: LS and UP. The output of the MAUT model for each alternative is an overall utility value, representing the overall level of achievement of all decision objectives by each payment approach. The higher the overall utility value, the more preferred the compensation approach. Thus, the recommended alternative is the one with the highest overall utility value. The MAUT model evaluates each alternative based on four performance objectives: 1) minimize construction costs; 2) minimize construction duration; 3) maximize cost certainty; and 4) maximize schedule certainty. Inputs for the MAUT model on each objective is provided by the nomograms and the data analysis.

The 24-lane-mile project mentioned above corresponds to the same example used to illustrate the implementation of the MAUT model in Chapter 6. When the proposed MAUT model was applied to this project with a set of weights established under the assumption that an early project completion is the top priority in this project, the MAUT model yielded a scenario in which FDOT should consider paying the additional costs associated with the use of LS provisions in order to pursue the potential time savings. This example has demonstrated the ability of the proposed methodology to handle multiple conflicting objectives towards the identification of the compensation approach that would offer the best value for taxpayers' money in DBB resurfacing projects awarded by FDOT. This study is contributing to the improvement of the contracting methodology most commonly used by FDOT, and by virtually all state transportation agencies. It is also helping FDOT to achieve a more efficient and effective utilization of its limited available resources, which is critically needed to face the increasingly challenging transportation construction industry.

7.3 Recommendations and Limitations

Future research might consider the study of additional project areas affected by the selected contract compensation provisions, such as quality, agency's design costs and efforts, and contract administration/inspection cost and efforts. This study assumed no significant changes in project quality due to the use of LS provisions since that decision is not expected to change the construction means and methods used by contractors. However, this assumption is still to be tested. Likewise, the cost performance assessment in this study was performed considering only construction costs, but the use of LS provisions is also expected to reduce design and construction inspection costs and efforts. In fact, the use of LS provisions sometimes seems to be motivated by these type of benefits.

It should be noted that the proposed decision-making framework and sub-frameworks presented in this dissertation are only applicable to resurfacing DBB projects awarded by FDOT. However, future research could be aimed to replicate these research efforts for other types of work and for other state transportation agencies. Likewise, the selection of suitable compensation approaches is not only challenging DBB contracting programs. Some agencies using Design-Build (DB) contracting techniques are also facing a similar decision challenge, but in that case LS is the traditional compensation approach and UP is emerging as a possible valuable alternative for some construction programs. Nonetheless, those transportation agencies continue to make this decision without fully understanding the implications of selecting a DB-UP approach.

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APPENDIX A: DESIGN BID-BUILD RESURFACING PROJECT DATABASE

This appendix contains all the project information that was used in the analysis of this study. The appendix is composed into two tables. The first table shows the project data for unit price projects data and the second table shows the project data foe the lump sum projects data.

Table A.1 Unit Price Project Database

Contract ID	District	Work Begin	No of Lanes	Total lane miles	Orig. Days	Current Days	Actual Days	DOT Estimate	Orig. Amount	Current Amount	Actual Pay
E1O03	1	6/15/2015	5	9.31	155	210	210	$ 3,010,192.40	$ 3,069,378.46	$ 3,093,215.58	$ 2,906,324.38
E1O52	1	4/9/2016	4	10.65	145	179	179	$ 2,466,348.00	$ 2,386,059.87	$ 2,389,112.11	$ 2,290,475.30
T1A06	1	2/21/2015	4	11.73	170	206	206	$ 2,442,140.00	$ 2,539,890.92	$ 2,539,890.92	$ 2,497,433.75
E1N64	1	12/20/2014	2	16.14	150	176	175	$ 3,419,370.60	$ 3,021,171.51	$ 3,021,171.51	$ 2,921,086.34
T1560	1	11/15/2015	2	17.63	150	268	268	$ 5,451,824.59	$ 4,883,159.85	$ 4,883,159.85	$ 4,581,603.56
T1602	1	6/1/2015	2	24.04	250	314	288	$ 6,060,537.10	$ 4,933,423.90	$ 4,933,423.90	$ 4,649,829.70
E1O51	1	7/18/2016	2	25.16	200	237	234	$ 7,615,266.00	$ 6,085,725.81	$ 6,210,863.85	$ 5,952,142.50
T1591	1	7/9/2014	6	60.26	270	452	447	$ 8,889,524.26	$ 7,824,412.70	$ 8,062,183.82	$ 7,721,970.60
T2603	2	4/13/2016	1	0.66	75	95	95	$ 510,081.72	$ 521,217.55	$ 521,217.55	$ 506,672.13
E2U47	2	7/5/2016	2	2.10	90	97	93	$ 750,871.00	$ 841,046.90	$ 841,046.90	$ 781,434.70
T2552	2	2/9/2015	4	5.28	90	114	114	$ 2,021,176.83	$ 1,940,620.07	$ 1,940,620.07	$ 1,856,551.56
E2T05	2	9/15/2014	2	6.74	120	161	127	$ 1,793,903.12	$ 1,656,116.65	$ 1,656,116.65	$ 1,659,137.45
T2644	2	1/17/2017	2	6.85	90	93	86	$ 1,869,641.00	$ 1,424,722.42	$ 1,424,722.42	$ 1,391,631.60
E2T37	2	8/31/2015	5	7.12	100	154	162	$ 1,728,947.87	$ 1,728,947.87	$ 1,728,947.87	$ 1,633,505.84
E2T07	2	11/17/2014	2	7.58	120	144	144	$ 2,000,478.35	$ 1,865,344.96	$ 1,865,344.96	$ 1,622,084.47
T2538	2	11/12/2014	6	9.82	130	198	198	$ 3,330,302.73	$ 3,648,201.75	$ 3,648,201.75	$ 3,514,981.59
T2626	2	3/21/2016	2	10.23	210	255	255	$ 3,672,061.00	$ 3,284,461.01	$ 3,284,461.01	$ 3,131,127.75
E2T73	2	10/28/2015	2	17.47	130	160	160	$ 4,375,218.75	$ 3,529,617.70	$ 3,529,617.70	$ 3,475,221.87
E2S75	2	7/10/2014	2	21.07	135	162	159	$ 4,265,996.45	$ 3,983,484.70	$ 3,983,484.70	$ 3,695,174.48
E2T29	2	3/4/2015	2	22.09	130	139	178	$ 4,199,999.48	$ 4,199,999.48	$ 4,199,999.48	$ 3,826,661.87
E2S97	2	11/10/2014	2	22.65	145	175	151	$ 4,562,243.28	$ 4,007,551.55	$ 4,007,551.55	$ 3,641,742.32
E2U35	2	5/4/2016	2	23.91	280	320	314	$ 6,137,176.00	$ 5,333,715.73	$ 5,333,715.73	$ 5,049,334.18
T2554	2	1/21/2015	2	26.44	140	151	150	$ 4,996,678.96	$ 4,054,389.57	$ 4,054,389.57	$ 3,749,496.73
T2580	2	8/19/2015	2	28.96	180	207	207	$ 5,602,150.67	$ 4,962,037.99	$ 4,962,037.99	$ 4,756,358.08
E2T30	2	3/15/2015	2	31.10	145	216	216	$ 7,127,770.10	$ 6,196,552.04	$ 6,196,552.04	$ 5,669,933.59
T2604	2	1/15/2016	2	34.84	200	233	237	$ 9,660,990.21	$ 7,717,553.92	$ 7,717,553.92	$ 7,576,664.71
T2613	2	5/2/2016	2	35.28	190	227	227	$ 8,014,110.00	$ 7,289,392.69	$ 7,289,392.69	$ 7,140,234.06
T2550	2	1/5/2015	4	45.48	240	318	318	$ 10,276,016.07	$ 8,823,739.00	$ 8,823,739.00	$ 7,800,286.81
T2558	2	2/5/2015	6	48.32	365	530	530	$ 11,419,266.79	$ 11,419,266.79	$ 11,419,266.79	$ 9,884,931.68
E3P60	3	10/3/2016	2	3.96	45	48	43	$ 939,110.13	$ 966,283.04	$ 966,283.04	$ 953,705.99
T3406	3	10/10/2016	4	7.81	166	247	253	$ 2,386,446.00	$ 2,166,252.79	$ 2,166,252.79	$ 2,363,041.96

Table A.1 Unit Price Project Database continued

Contract ID	District	Work Begin	No of Lanes	Total lane miles	Orig. Days	Current Days	Actual Days	DOT Estimate	Orig. Amount	Current Amount	Actual Pay
T3548	3	4/11/2016	2	11.30	90	110	110	$ 2,269,438.00	$ 1,961,731.16	$ 1,961,731.16	$ 1,958,164.54
T3495	3	10/7/2015	2	11.43	90	226	225	$ 1,991,519.93	$ 1,619,320.78	$ 1,619,320.78	$ 1,566,710.74
T3558	3	3/1/2016	4	11.74	189	216	212	$ 4,720,446.00	$ 3,745,728.33	$ 3,745,728.33	$ 3,415,842.50
T3483	3	8/11/2015	5	11.78	250	386	386	$ 3,857,910.06	$ 4,039,522.34	$ 4,047,995.23	$ 4,226,492.10
E3O47	3	3/7/2016	2	12.70	100	128	128	$ 2,649,534.01	$ 2,030,029.00	$ 2,030,029.00	$ 2,045,054.57
T3409	3	11/3/2014	2	15.22	145	201	197	$ 2,813,050.27	$ 2,097,226.82	$ 2,097,226.82	$ 1,978,887.02
T3491	3	5/18/2016	2	16.73	90	161	159	$ 2,971,789.00	$ 3,493,487.41	$ 3,493,487.41	$ 3,547,934.65
T3514	3	9/21/2015	2	18.46	175	307	308	$ 4,144,189.92	$ 3,802,688.89	$ 3,802,688.89	$ 3,479,142.77
T3553	3	7/25/2016	4	20.00	180	231	229	$ 5,858,556.00	$ 5,112,998.18	$ 5,217,096.13	$ 5,211,856.39
E3N24	3	6/6/2016	2	21.35	130	153	152	$ 3,817,848.00	$ 3,543,343.50	$ 3,600,104.61	$ 3,802,307.75
T3443	3	2/25/2015	5	27.22	247	408	408	$ 4,397,278.78	$ 4,037,986.70	$ 4,183,811.68	$ 3,846,478.33
T3515	3	11/17/2014	4	27.70	240	568	567	$ 8,827,284.67	$ 8,076,272.17	$ 8,066,272.17	$ 7,667,982.38
E3P11	3	7/11/2016	2	32.05	210	314	313	$ 6,237,409.00	$ 6,922,952.99	$ 6,922,952.99	$ 6,966,761.31
E3P75	3	9/30/2016	2	36.48	100	210	210	$ 2,591,913.00	$ 2,702,300.94	$ 2,702,300.94	$ 2,819,949.84
T3550	3	4/22/2016	4	37.98	195	323	318	$ 9,047,925.00	$ 9,008,955.84	$ 9,008,955.84	$ 8,863,555.68
T3469	3	1/15/2015	2	38.53	140	252	278	$ 5,880,616.04	$ 4,926,846.56	$ 4,957,958.46	$ 4,585,418.50
T3482	3	4/6/2015	2	43.07	300	396	388	$ 8,733,987.91	$ 7,416,925.38	$ 7,437,264.70	$ 7,441,691.97
T3556	3	5/5/2016	2	43.15	205	251	244	$ 7,266,475.00	$ 6,785,910.43	$ 6,785,910.43	$ 7,183,335.97
T3544	3	6/23/2015	4	49.88	240	490	504	$ 12,349,087.00	$ 9,957,902.43	$ 9,957,027.43	$ 9,419,098.68
T4443	4	12/12/2016	2	3.69	120	131	131	$ 1,458,807.00	$ 1,312,213.59	$ 1,312,213.59	$ 1,254,212.88
E5Y63	5	1/9/2017	2	1.41	90	116	132	$ 776,696.00	$ 862,770.36	$ 868,516.86	$ 791,326.63
T6386	6	7/20/2016	5	0.77	180	206	206	$ 711,332.00	$ 648,208.71	$ 648,208.71	$ 638,066.90
T6377	6	1/26/2015	2	1.09	100	102	97	$ 658,907.50	$ 759,549.53	$ 759,549.53	$ 735,190.97
E6I91	6	3/29/2016	4	2.80	150	180	179	$ 1,376,235.85	$ 1,483,128.17	$ 1,483,128.17	$ 1,430,102.15
T6369	6	2/23/2015	5	4.38	120	180	199	$ 973,033.40	$ 896,919.51	$ 896,919.51	$ 777,644.27
T6373	6	6/22/2015	5	5.40	230	328	326	$ 2,292,101.60	$ 2,376,742.36	$ 2,426,742.36	$ 2,384,891.78
T6370	6	2/2/2015	5	6.38	140	221	221	$ 1,605,781.15	$ 1,463,327.52	$ 1,519,910.95	$ 1,424,598.85
T6335	6	9/9/2015	5	7.56	150	189	189	$ 2,014,476.20	$ 1,885,541.29	$ 1,885,541.29	$ 1,821,043.74
E6I46	6	6/16/2014	2	11.42	220	251	246	$ 5,304,016.15	$ 5,490,800.16	$ 5,796,772.16	$ 5,404,113.44
T6376	6	4/30/2015	5	12.79	435	468	375	$ 6,429,680.27	$ 6,621,886.77	$ 6,805,679.41	$ 6,552,074.16
T6349	6	8/15/2016	2	19.88	240	263	195	$ 5,124,942.00	$ 4,178,282.93	$ 4,236,995.80	$ 4,017,351.92
E7I81	7	9/8/2014	2	2.98	120	157	156	$ 992,000.00	$ 1,095,029.24	$ 1,095,029.24	$ 997,606.57

Table A.2 Lump Sum Project Database

Contract ID	District	Work Begin	No of Lanes	Total lane miles	Orig. days	Current Days	Actual Days	DOT Estimate	Orig. Amount	Current Amount	Actual Paid
E1N09	1	9/15/2014	2	1.48	80	92	95	$ 694,287.64	$ 862,414.80	$ 862,414.80	$ 823,651.81
E1O48	1	4/25/2016	2	13.69	240	295	295	$5,444,557.00	$5,895,900.00	$ 5,903,040.79	$5,818,679.95
T1557	1	1/19/2015	2	9.32	175	202	201	$2,840,170.10	$2,509,778.30	$ 2,509,778.30	$2,358,043.58
T1629	1	3/14/2016	6	5.41	85	88	74	$ 857,875.38	$ 910,000.00	$ 910,000.00	$ 883,226.89
T1A15	1	11/16/2015	2	0.98	70	97	97	$ 200,589.29	$ 219,504.00	$ 219,504.00	$ 213,917.00
E2T58	2	3/14/2016	2	19.39	140	181	181	$4,878,401.01	$3,757,548.78	$ 3,757,548.78	$3,684,887.35
T2524	2	7/24/2014	5	19.80	150	304	302	$3,923,781.30	$3,832,891.28	$ 3,864,529.89	$3,786,450.72
E3N82	3	12/7/2015	2	12.15	100	123	108	$2,500,624.22	$1,947,842.63	$ 1,947,842.63	$1,891,898.60
E3O53	3	1/5/2016	2	12.94	128	173	173	$3,103,650.00	$2,754,000.00	$ 2,754,000.00	$2,686,703.58
E3O62	3	3/11/2016	2	7.75	90	131	129	$1,564,334.70	$1,298,500.00	$ 1,382,401.29	$1,319,720.21
E3P12	3	2/20/2017	2	2.92	90	105	105	$ 851,593.00	$ 751,984.30	$ 801,537.38	$ 761,553.08
E3P15	3	2/2/2017	2	7.71	90	95	88	$1,595,361.00	$1,296,000.00	$ 1,296,000.00	$1,293,176.12
T3516	3	7/10/2016	5	2.73	70	83	83	$ 599,580.00	$ 664,503.82	$ 664,503.82	$ 636,000.00
T3552	3	11/3/2015	4	17.03	125	237	237	$4,236,500.00	$3,670,000.00	$ 3,738,759.59	$3,621,208.52
T3575	3	2/6/2017	2	9.36	65	72	72	$1,644,577.00	$1,223,500.00	$ 1,223,500.00	$1,216,824.17
T5491	5	8/25/2014	6	13.26	180	268	250	$4,001,181.95	$3,276,000.00	$ 3,276,000.00	$3,298,885.66
T5494	5	9/8/2014	4	7.56	180	247	247	$1,761,956.22	$1,795,728.27	$ 1,795,728.27	$1,760,006.21
T5495	5	9/2/2014	2	26.28	300	328	303	$7,479,522.66	$6,951,000.00	$ 6,886,781.94	$6,782,907.00
T5500	5	11/3/2014	2	6.23	120	162	162	$1,390,516.46	$1,558,478.00	$ 1,558,478.00	$1,525,500.59
T5526	5	8/3/2015	2	10.11	120	127	127	$2,533,092.67	$2,084,540.00	$ 2,084,540.00	$2,051,990.95
E7K15	7	9/28/2015	5	7.41	120	136	128	$1,900,000.00	$1,563,213.43	$ 1,563,213.43	$1,512,750.97
E7K17	7	11/2/2015	2	9.54	220	258	212	$3,200,000.00	$2,888,000.00	$ 2,888,000.00	$2,634,048.09
T7340	7	9/22/2014	5	4.98	150	188	187	$2,156,800.00	$1,688,000.00	$ 1,688,000.00	$1,606,582.22
T7358	7	3/2/2015	4	3.01	110	136	134	$1,010,220.00	$1,033,200.00	$ 1,033,200.00	$ 920,104.14

APPENDIX B: STATES LUMP SUM GUIDELINES

<u>Appendix B-1: Alaska Department of Transportation Lump Sum Guidelines</u>

Lump Sum Project Guidelines

1. General

1.1. Definition

A lump sum project is a fixed-price contract that requires a bidder to submit a price for completing an entire project as opposed to bidding on individual pay items. It may also require the bidder to develop quantities from the contract package. This method is typically used for simple projects such as resurfacing, bike paths, box culvert extensions, and minor bridge widening.

1.2. Purpose

This contracting technique is designed to reduce contract administration effort related to quantity measurement and verification, allowing field personnel to spend more time on inspection of the work.

1.3. Limitations

The only changes allowed to a fixed price are for extras or change orders. Any additional work not covered in the contract must be covered by change documents, which must indicate how estimated quantities were calculated. Any costs associated with changed or unforeseen conditions as well as added or deleted work are negotiated using standard practices.

2. Project Selection

The decision to use lump sum contracting should be made by the design group chief in consultation with the construction project manager, and the decision should be identified during the scope development process rather than during the design process.

For partially complete plans and completed "plans on the shelf" that were originally developed as conventional bid-item-type projects, conversion to the lump sum technique may require significant rework and is generally not recommended.

Lump sum contracting should be used on fixed projects. "Fixed" refers to the work activity, not the project cost. Fixed projects are:

- Projects with well-defined scope, quantities, and limits of work, and a low probability of change
- Projects with low risk of unforeseen conditions (for example, projects that do not involve such things as significant underground utilities, earthwork variations, underground drainage pipes, or permafrost under pavement in urban areas)
- Projects with low possibility for change (for example, limited possibilities for added driveways, median modifications due to developments)
- Projects with limited opportunity for contractors to provide less than the required quantities, such as asphalt thickness, steepened slopes, and culvert lengths

Examples of projects that may be good lump sum contracting candidates

- Bridge painting
- Bridge projects (with limited earthwork or pile driving)
- Fencing
- Guardrail
- Intersection improvements (with known utilities)
- Landscaping
- Lighting
- Mill/resurface (without complex overbuild requirements)
- Minor road widening (with limited earthwork)

- Sidewalks
- Signing
- Signalization
- Simple transportation enhancement projects
- Traffic markings

Examples of projects that may not be good candidates for lump sum contracting

- Urban construction/reconstruction
- Major bridge rehabilitation/repair projects where there are many unknown quantities
- Projects where quantities of work, such as excavation, cannot be estimated with sufficient confidence to permit a lump sum offer without a substantial contingency
- Projects where estimated quantities of work required may change significantly during construction
- Projects on which offerors would have to expend unusual effort to develop adequate estimates
- Overlays where pre-level quantities may vary significantly

3. Design

You should detail plans, either by detailed drawings or plan notes, to clearly describe the work to be performed by the contractor. Following are some of the desired elements in a set of lump sum plans:

- Typical sections
- Plan sheets to accurately depict existing conditions and detail all work to be performed by the contractor. (i.e., show all limits of milling and resurfacing, pipe installations, limits of sod when different from typical section, all concrete work, guardrail removal/installation, etc.)
- Summary boxes to define work
- Details of work not covered by typical section or standard drawings
- A list of items of work corresponding to descriptions of the standard specifications and work described by special provisions
- Quantities, if applicable. The designer, in consultation with the construction project manager, decides whether to show quantities in the contract documents.
- An indication in the Bid Schedule and the Invitation for Bids (IFB) that it is a lump sum contract

4. Specifications

The specifications must connect the work described in the plans with the construction and material requirements of the standard specifications and special provisions. Means to accomplish this include:

- Using the work items on the plans included in a new Section 801, shown in Appendix C
- Using the new Section 801-2.1. General and 801-3.1. Materials and Construction, referencing corresponding sections of the standard specifications, as appropriate, for the listed items of work. See Example Lump Sum Bid Item in Appendix C.
- Using the Lump Sum Contract Division 100 General Provisions in Appendix D
- Referencing the standard specification book edition on the cover of bidding documents, when the standard specifications are used according to 1 and 2 above. If the standard specifications are modified and included in the contract, it is not necessary to reference the book edition.

5. Bidding

Consider the effort required for the contractor to compute quantities when establishing the advertising period.

6. Construction Contract Administration

1. Progress payments are to be submitted by the contractor and verified by the project engineer. Make the payments based on methodology established under Section 109-1.6.

2. Construction inspection personnel should not be required to document quantities except for items subject to contingent sum or material contract requirements (i.e. stockpiled material). The Department does the measurements and computations for price adjustments. As-builts will not show quantities.

3. Measurement and completion of final quantity are not required. Focus on inspection and achieving a quality final product. For example, the project engineer will not be concerned with how many square yards of sod it takes or the linear feet of pipe. The project engineer will ensure that the sod, striping, embankment, pipe, etc., meet the lines and grades of the plans and specifications (this will require some measuring).

7. Materials Sampling and Testing

The material testing frequency relies on the items of work identified in the plans and specifications to generate materials testing requirements based on the FHWA-approved Materials Sampling and Testing Frequency. Derive the material testing requirements from the Schedule of Values, if the quantities are not provided. When quantities are provided, derive the material testing requirements from them. Materials not included in the Materials Sampling and Test Accept frequency in accordance with the contract specifications and/or other pertinent contract documents.

Appendix B-2: California Department of Transportation Lump Sum Guidelines

Lump Sum Bidding

Description

In lump sum bidding, a contractor is provided with a set of bid documents that do not contain detailed quantity tables. The contractor develops quantity take-offs from the plans and estimates a lump sum price based on this take-off.

Objective

- Reduce costs design and contract administration costs associated with quantity calculation, verification, and measurement
- Reduce quantity overruns due to errors in quantity calculations or changed field conditions

Past Experience

DOTs have been increasingly applying lump sum payment, a commonly used payment mechanism in design-build contracts, to traditional low-bid highway contracts for various bid items, and to contracts involving categories of work that lend themselves to lump sum pricing (e.g., maintenance of traffic, paint, lighting, and landscaping).

According to a 35-state survey of contracting techniques for work zone traffic control conducted in 2000 by Montana DOT and FHWA, a significant percentage of the states surveyed had moved to lump sum pricing or a combination of lump sum and unit prices for traffic control items. Some agencies have standardized the use of lump sum payment for traffic control. For example, Washington State DOT has developed criteria, procedures, and special provisions for lump sum traffic control. Florida and Alaska DOTs have moved even further towards lump sum payment, developing guidelines for lump sum projects for various types or items of work.

Performance Outcomes

Based on total actual expenditures on lump sum contracts completed statewide between fiscal years 1997 and 2001, Florida DOT reported a 2.2 percent cost increase with respect to original lump sum contract amounts, in comparison to a 12.9 percent cost increase reported for all contracts completed statewide during the same time period. (Florida DOT 2006a)

Project Types/Selection Criteria

Lump sum payment methods are appropriate for relatively simple projects having a well-defined scope, low risk of unforeseen conditions (i.e., minimal underground utility issues, low likelihood of quantity variations), and low possibility for changes in scope during design and construction (i.e., limited possibility for added driveways, median modifications, or changes due to political involvement). Based on these considerations, project types that would and would not make suitable candidates for lump sum bidding techniques are summarized below.

Good Candidates

Projects having a well-defined scope, with few design uncertainties. For example:

- Fencing or guardrail installation
- Landscaping
- Lighting
- Signing
- Signalization
- Bridge painting

Poor Candidates

Projects involving the following:

- Urban construction/reconstruction
- Projects with subsoil earthwork
- Concrete pavement rehabilitation
- Major bridge rehabilitation/repair projects with many unknown quantities and conditions

Advantages

- During design development, reduces the effort spent by design staff on obtaining detailed computations or quantity take-offs
- During construction, reduces the time spent by field inspectors on measuring quantities and preparing invoices, allowing staff to concentrate on monitoring the quality of the work
- Streamlines unit items into bundled items, reducing the administrative burden (e.g., traffic control can be a single pay item, rather than multiple items that must be priced and tracked separately)
- Creates a built-in incentive for contractors to control costs and work more efficiently
- Eliminates requirements for detailed quantity measurements by the DOT, allowing for faster processing of payments, which can lead to improved coordination and cooperation among all the project parties

Disadvantages

- Contractors may add more contingency to bid prices, particularly if there is uncertainty in the estimated quantities for the lump sum items
- Potential that the agency will pay the lump sum price when total quantities under run estimated amounts
- For contracts with multiple lump sum items, there is the potential for front-end loading
- The contractor's focus on cost and schedule may compromise quality.
- Changes that affect lump sum price require more effort than simply adjusting the quantity of a unit-priced item.*

* Florida DOT (2006b) has developed internal guidelines for contract modifications on lump sum projects. These guidelines require that the contractor submit a detailed estimate for the additional work and caution that the engineer should not rely on the contractor's schedule of values, but should rather develop an independent estimate based on historical data or statewide averages, and conduct an entitlement analysis before issuing a contract modification.

Appendix B-3: Colorado Department of Transportation Lump Sum Guidelines

C.2 Lump Sum

What is it?

Lump sum is a payment method where the contractor agrees to provide contractually specified work at a one specific price *(1–4)*. Here the State Transportation Agency (STA) agrees to pay the price upon completion of the work or according a negotiated payment schedule *(1)*. This provision is widely used by STAs as an alternative or complement to unit price contracts.

Why use it?

Lump sum payment provisions are a good alternative to the traditional unit price payment used by STAs. These provisions can have the following advantages:

- Lower the financial risks to the STA *(1)*
- Require less STA administrative resources thus resulting in reduced engineering costs *(1, 2)*
- Construction cost is defined at the bid *(1)*
- During construction, it reduces the time spent by field inspectors on measuring quantities and preparing invoices, allowing them to focus on controlling quality of the work *(2)*
- Reduced the time required to deliver a program or project to advertisement *(1, 4)*
- Creates an incentive for contractor to control costs and work more efficiently *(2)*

What does it do?

The main purpose of the lump sum payment provision is to reduce the design and administrative costs incurred with the unit price contract *(1)*. The lump sum contract is the most basic form of agreement between a contractor and the STA *(1)*. Here, the STA will estimate the project cost by breaking down the work into several construction pay items and applying current average unit prices. The contractor uses the same method when developing the bid but adds up a contingency to cover for the risks that it bears *(1)*.

How to use it?

Compared to the traditional unit price payment system, under lump sum provisions the STA does not provide quantity estimates in the bid package. The contractor is responsible for developing quantity take-offs from the plans for estimating a lump sum item or items for a project *(2)*. Within this lump sum amount the contractor includes the costs of the risks associated with this type of contract, and the STA awards the project to the contractor that proposes the lowest lump sum. During construction, the STA generally reimburses the contractor in monthly payments that are proposed by the contractor in the proposal as a percentage of the lump sum.

The STA should provide a lump sum contract changes clause to allow for scope changes or adjustments to material quantities. A good solution to deal with lump sum changes is to include a contingency price for the lump sum contract that facilitates reimbursing the contractor for additional work not initially covered by the contract *(3)*.

When to use it?

Lump sum payment provisions are adequate for:

- Projects where scope of work is well-defined *(1)*,
- Scope is unlikely to change and delays are unlikely to happen *(1)*,
- Project with few bid item and short completion duration *(1)*, and
- Projects using Design-Build delivery *(1)*.

Some of these project items can be pavement marking, bridge painting, fencing, guardrail, intersection improvements with known issues, landscaping, lighting, mill/resurfacing, minor road widening, sidewalks, signing, and signalization *(2)*.

These provisions are not suitable for urban construction/reconstruction projects, complex or unique projects, project with potential for utility delays, projects with sub-soil earthwork or underground utility work, concrete pavement rehabilitation projects, major bridge rehabilitation/repair projects with unknown quantities *(1, 2)*.

Limitations?

Some risks and disadvantages resulting from lump sum payment provisions are:

- Changes can be difficult and costly *(1)*
- Higher financial risks to the contractor may increase bids, especially when there is an uncertainty associated with the project *(1, 2)*
- STA will pay the total lump sum even when the actual quantities used under run the estimated amounts *(2)*
- For contracts with multiple lump sum items, there is the potential for front-end loading *(2)*

Who uses it?

All STAs have used lump sum/fixed price for contracting highway projects.

Chapter 22

Lump Sum Project Guidelines

Modification for Non-Conventional Projects:
Delete ***PPM*** Chapter 22.

22.1 General

The purpose of Lump Sum projects is to reduce the costs of contract administration associated with quantity, verification and measurement. This contracting technique requires the Contractor to submit a lump sum price to complete a project as opposed to bidding on individual pay items. The Contractor will be provided a set of bid documents (plans, specifications, etc.) and will develop a Lump Sum bid for all work specified in the contract drawings.

The decision to use the Lump Sum Contracting Technique on a project should be made by the District Design Engineer in consultation with the District Construction Engineer. Lump Sum Projects should be identified during the scope development process, rather than during or after the design process. Conversion of partially complete plans and completed "plans on the shelf" that were originally developed as conventional bid item type projects to the Lump Sum Technique may require significant rework and is generally not recommended.

The contingency pay item is recommended on a Lump Sum project. This tool is used to compensate the Contractor for any additional work requested, which is not covered in the contract documents. District Construction should be consulted for the contingency amount.

22.2 Project Selection

Lump Sum contracting should be used on simple projects. "Simple" is defined by the work activity, not by the project cost. "Simple" projects are:

1. Projects with a well-defined scope for all parties (Design and Construction)
2. Projects with low risk of unforeseen conditions (i.e., projects that do not involve such things as significant underground utilities, earthwork variations, underground drainage pipes, bricks under pavement in urban areas, etc.)
3. Projects with low possibility for change during all phases of work – Design and Construction (i.e., limited possibilities for added driveways, median modifications due to developments, changes due to political involvement, etc.)

Examples of projects that may be good Lump Sum contracting candidates:

1. Bridge painting
2. Bridge projects
3. Fencing
4. Guardrail
5. Intersection improvements (with known utilities)
6. Landscaping
7. Lighting
8. Mill/Resurface (including Interstate) without complex overbuild requirements
9. Minor road widening
10. Sidewalks
11. Signing
12. Signalization

Examples of projects that may not be good Lump Sum contracting candidates are listed below. Use of Lump Sum contracting on these type projects requires written approval by the State Roadway Design Engineer:

1. Urban construction/reconstruction
2. Rehabilitation of movable bridges
3. Projects with subsoil earthwork
4. Concrete pavement rehabilitation projects
5. Major bridge rehabilitation/repair projects where there are many unknown quantities
6. JPA Projects with local agency funds

4.3 Payment

[redacted]

4.3.B: Lump Sum

Description

Lump Sum is when the contractor agrees to provide specified construction for one specific price. The department agrees to pay the price upon completion of the work or according to a negotiated payment schedule. This innovative construction contracting method requires the contractor to submit a Lump Sum price to complete a project (or a portion of a project) as opposed to bidding on individual pay items with quantities provided.

A Lump Sum contract is the most basic form of agreement between a contractor and the department. In developing a Lump Sum bid, the department will estimate the cost usually by breaking down the work to be included into typical construction pay items and applying current average unit prices. The contractor will use a similar method when developing their bid but may increase the bid based on the contractor's assessment of risk. It may be determined that a portion of the work should remain as a unit price because the perceived risk to the contractor would push the bids higher. In Design-Build, this is called "shared risk" items. If the actual costs are higher than the contractor's estimate, the contractor's profit will be reduced. If the actual costs are lower, the contractor gets more profit. Either way, the cost to the department is the same. In practice, however, costs that exceed the estimates may lead to disputes over the scope of work or attempts to substitute less expensive materials for those specified.

The primary purpose of Lump Sum projects is to reduce the costs of design and contract administration associated with quantity calculation, verification, and measurement. If the department is designing the project, the contractor will be provided a set of bid documents (plans, specifications, etc.) and will develop a Lump Sum bid for all work specified in the contract drawings as "Lump Sum". In Design-Build, the Lump Sum includes the design and construction of the project.

Advantages

- May lower financial risk to the department
- Staffing needed for construction administrative may be reduced, thus reducing engineering costs*
- Construction cost is defined at bid
- May alleviate some department oversight related to quality and schedule*
- Contractor should/would assign best personnel due to maximum financial motivation to achieve early completion and superior performance
- Contractor selection is easier as compared to other innovative construction contracting methods
- May reduce time required to deliver program or project to advertisement

Disadvantages

- Changes can be difficult and costly
- Additional MDOT resources needed to establish pay schedule for contractor if partial payments are to be made on large Lump Sums
- Higher financial risk to contractor may result in higher bids
- Competition may be reduced if fewer contractors want to bid Lump Sum items
- Since contractor is free to choose lowest cost means, methods, and materials consistent with the specifications, only minimum specifications may be provided
- May need conversion to dollars after letting and prior to award in order to facilitate payments through Field Manager

*For federal aid projects, unless performance specifications and/or warranties are provided and approved by FHWA, certain work items will still need to be inspected and tracked in Field Manager. This is done to assure the work and materials meet specifications and to verify testing requirements are satisfied. Because standard work items are not available (they are replaced with a Lump Sum), an additional shadow contract must be developed in Field Manager which creates some additional work.

Recommendations for Use

Preferred Candidates:

- Projects where work is well-defined
- Stable project conditions - scope unlikely to change; delays unlikely
- Projects with very few bid items and short completion duration
- Projects using Design-Build delivery process
- Pavement marking
- Bridge painting
- Fencing
- Guardrail
- Intersection improvements (with known utilities)
- Landscaping
- Lighting
- Mill/Resurfacing (without complex overbuild requirements)
- Minor road widening
- Sidewalks
- Signing
- Signalization

Undesirable Candidates:

- Urban construction/reconstruction projects
- Complex or unique projects
- Projects with potential utility delays
- Rehabilitation projects of movable bridges
- Projects with sub-soil earthwork or underground utility work
- Concrete pavement rehabilitation projects
- Major bridge rehabilitation/repair projects where there are many unknown quantities

Implementation Steps

As stated above, Lump Sum contracts were used and will be used for all the Design-Build contracts. There are several standard Lump Sum pay items the department currently uses ranging from bridge rehabilitation to maintaining traffic items.

A special provision must be developed for Design-Bid-Build Lump Sum contracts. The special provision must include information on all work included in the lump sum item and the process MDOT and the contractor will follow for making partial payments.

Lump Sum contracting can be used on projects with federal aid without additional approval from FHWA. Coordination with an FHWA area engineer is recommended even if the project does not require FHWA oversight. The contract language for making partial payment must be reviewed by the FHWA.

If a Lump Sum item will have partial payments during construction, it should be converted to "dollars" after the letting and prior to award in order to facilitate payments through Field Manager. Payment amounts must be quantifiable on federal aid projects.

If an office would like to expand the concept to include an entire project or significant amount of work as Lump Sum, they should contact the Engineer of Design for assistance and coordination.