DEVELOPMENT OF QUALITY ASSURANCE METHODS FOR PERFORMANCE-BASED MAINTENANCE CONTRACTS FOR ROADWAY ASSETS

A Thesis

by

DEBORA BROOKE SHELTON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Civil Engineering

DEVELOPMENT OF QUALITY ASSURANCE METHODS FOR PERFORMANCE-BASED MAINTENANCE CONTRACTS FOR ROADWAY ASSETS

A Thesis

by

DEBORA BROOKE SHELTON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Nasir Gharaibeh
Committee Members,	Ivan Damnjanovic
	David Ellis
Head of Department,	John Niedzwecki

December 2010

Major Subject: Civil Engineering

ABSTRACT

Development of Quality Assurance Methods for Performance-Based Maintenance Contracts for Roadway Assets. (December 2010)

Debora Brooke Shelton, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Nasir Gharaibeh

Performance-based Maintenance Contracts (PBMCs) are increasingly being used for roadway maintenance as an alternative to method-based specifications. However, this technique is still relatively new and several issues have not been adequately addressed in the literature. The paper provides a systematic process for developing quality assurance measures to be used within these contracts. The process addresses key issues, including the development of performance standards and targets, a method for monitoring the roadside performance, and a methodology for developing pay adjustment factors.

The developed performance standards presented in the paper are easily measured and assigned grades of pass, fail, or not applicable. The required sample size is a function of the project characteristics, including performance variability along the project, required confidence level, and allowable tolerance. Finally, the pay adjustment curves are a function of the initial project LOS, the target LOS, and the maintenance cost to achieve the target LOS.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Gharaibeh, and my committee members, Dr. Damnjanovic, and Dr. Ellis, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the Transportation Scholars Program and the Texas Department of Transportation (TxDOT) for providing full funding for my master's degree.

Finally, thanks to my family for their encouragement and support.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

1. INTRODUCTION

1.1 Background

Performance-based maintenance contracts (PBMCs) are a relatively new method for state Departments of Transportations (DOTs) to outsource roadway maintenance work to contractors. Under performance-based contracting and specifications, the agency does not specify any method or material requirements. Instead, it specifies measurable performance standards and targets that the maintenance contractor is required to meet. According to Stankevich et al. (2005), performance should be measured using indicators that are SMART (Specific, Measurable, Achievable, Realistic, and Timely to schedule). To achieve this, performance requirements for roadway assets are defined by standards, targets, and timeliness. Performance standards are short descriptive statements of what is expected from each asset type; performance targets represent the overall condition of a project and can be expressed in several ways such as the percentages of assets of one type that must meet the stated standards; and timeliness is a parameter to specify the timeframe within which a roadside deficiency must be corrected. Table 1.1 shows an example of performance requirements for vegetation asset types obtained from a performance-based roadway maintenance contract in Virginia (Queiroz, 2008).

This thesis follows the style of the *Journal of Infrastructure Systems.*

Table 1.1 Example Performance Requirements for a Sample Roadside Asset

Asset Type	Standard	Target	Timeliness
Vegetation	• < 10% of mowable area to exceed 12” in height • All sight distances are clear • Neat / trimmed around guardrail, headwalls, paved ditches, signs • No cut less than 4” in height	90%	Vegetation affecting sight distance presenting a safety hazard shall be removed within 24 hours of notification or discovery.

Several PBMCs for roadways have already been implemented in the United States in Texas, Virginia, Washington DC, North Carolina, and Florida. PBMCs for roadways have also been used abroad, including Canada, Australia, several South American countries (such as Argentina, Uruguay, Brazil, Chile, Columbia, Ecuador, and Peru), and several European countries (such as the United Kingdom, Sweden, Netherlands, Norway, France, and Estonia) (Stankevich et al. 2005, Zietlow 2004a, 2004b). However, a performance based contract used solely for the maintenance of roadside assets is a new concept. Stankevich et al. (2005) suggested that the benefits for highway agencies to implement performance-based roadside maintenance specifications and contracting to achieve one or more of the following;

- Cut costs,
- Implement higher level government directive,
- Manage the road network with fewer staff,
- Receive long-term funding for maintenance program, and/or
- Improve customer satisfaction.

1.2 Problem Statement

There is general agreement in the literature that the key to the success of PBMCs is clearly defined performance requirements, a condition assessment method for evaluating compliance with these requirements, and rational pay adjustments (Hyman 2009, Stankevich et al. 2005, Schexnayder et al. 1997). Currently, engineering judgment is most often used to develop pay adjustment formulas for PBMCs. While these pay adjustment (PA) formulas may be practical, they may not be optimal. Optimum PA formulas are defined here as ones that motivate the contractor to maintain the roadway assets at the target performance level specified by the highway agency. Additionally, there is a need for consensus on how to define performance (i.e., what performance standards and overall measure should these PA formulas be based on) and how to measure performance (i.e., what condition assessment methods should be used for evaluating the contractor's compliance with the performance requirements). The development of these formalized methods for maintenance quality assurance helps the highway agency to achieve the desired level of quality and minimizes the guesswork in the performance evaluation process.

The Texas Department of Transportation (TxDOT) is currently undergoing research to successfully adopt performance-based contracts for roadside maintenance and will be used as a case study. Field trials of the developed quality assurance methods for PBMCs have been conducted in five districts of TxDOT (Waco, San Antonio, El Paso, Tyler, and Dallas) (see Figure 1.1) to determine the effectiveness of PBMCs in Texas.

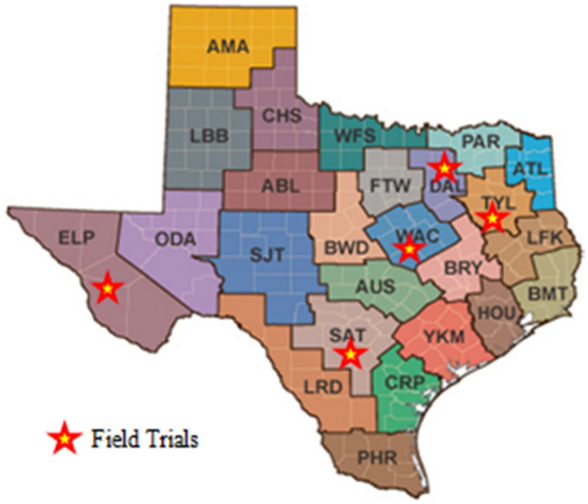

Figure 1.1 Field Trials in TxDOT Districts

These districts were chosen in an effort to capture the different roadway network size (i.e., mileage), climate, geographic location, and population density (urban vs. rural) conditions across Texas. Table 1.2 shows relevant characteristics for theses districts, including centerline miles, population, maintenance expenditures, and climate conditions (Ahmed et al, 2010).

Table 1.2 Districts Characteristics

District	Centerline Miles	Population	Non-Contracted Maintenance expenditures, Million $/year	Contracted Maintenance Expenditures, Million $/year	Average Annual Precipitation, inch	Average Annual Snowfall, inch
Dallas	3,289	4,072,605	40	217	33.7	2.7
El Paso	1,927	759,525	14	48	9.43	5.4
San Antonio	4,270	2,082,123	37	303	30.98	0.7
Tyler	3,704	642,277	33	111	47.59	0.7
Waco	3,431	678,256	25	109	36.54	1.15

1.3 Research Objective and Approach

The goal of this research is to develop formal quality assurance methods for PBMCs for roadside assets. This entails the following primary objectives:

1. Develop performance standards for roadside assets.
2. Develop a condition assessment method for evaluating the contractor's compliance with the performance standards.
3. Develop a methodology for optimizing pay adjustment formulas.

The following steps have been followed to accomplish the objectives of this research study:

Step 1: Perform Literature Review

The literature review is an important step in conducting this research. The purpose of the literature review is to identify the current state-of-the-practice as well as the current state-of-the-art in the subject area (i.e., PBMCs) so existing limitations can be identified and improvements can be made. The literature review will focus on performance standards, condition assessment methods, and pay adjustment schemes.

Step 2: Develop Performance Standards and Condition Assessment Method

The performance standards will be developed based on an online survey of TxDOT's districts and a review of the literature. A condition assessment method (i.e., field inspection method) suitable for the performance standards will also be developed by customizing current methods to the developed performance standards. The precision, reproducibility, and sample size (for a given confidence level) will be determined using data generated from field trials (see Step 4).

Step 3: Develop Methodology for Optimizing Pay Adjustment Schemes

A methodology to optimize pay adjustment schemes will be developed. This methodology should be applicable to any state DOT and will be designed to motivate the contractor to perform at a desired performance target. The methodology will be applied using actual cost data and performance data obtained from TxDOT's databases and the field trials.

Step 4: Evaluation of the Developed Quality Assurance Methods using Field Trials

The developed performance standards, condition assessment method, and optimum pay adjustment formulas will be evaluated using field trials. Each field trial will consist of approximately a 10-mi segment of a highway in Texas. These field trials will be distributed throughout different districts of TxDOT, including Waco, Tyler, San Antonio, Dallas, and El Paso.

1.4 Thesis Organization

- Section 1 presents the background of the research problem and describes the research objectives and scope.
- Section 2 focuses on the performance standards, including both a literature review and proposed maintenance performance standards for roadside maintenance.
- Section 3 presents current and proposed condition assessment methods.
- Section 4 discusses the pay adjustment schemes for performance-based maintenance contracts.
- Section 5 presents the conclusions and recommendations of this study.

2. PERFORMANCE STANDARDS

2.1 Literature Review

A process for determining the performance standards most amendable to PBMCs has been developed, as illustrated in the flow chart shown in Figure 2.1. This process has been published in Ahmed et al. (2010).

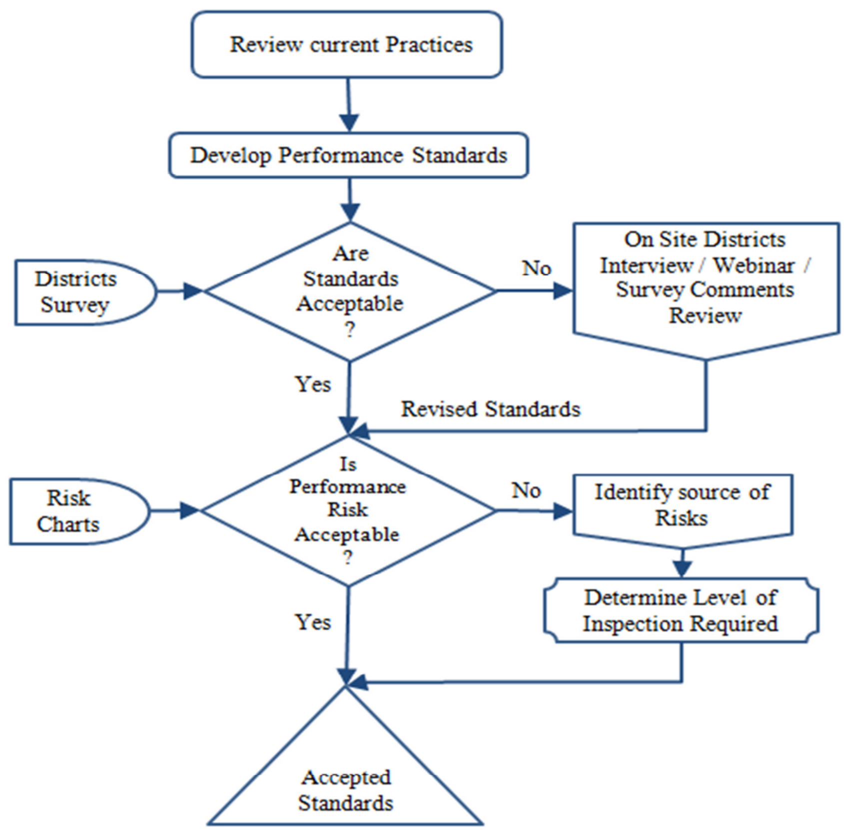

Figure 2.1 Process for Developing Performance Standards for PBMCs

Different studies have identified different performance standards that are best related to PBMCs. AASHTO has developed national performance standards for highway assets and maintenance activities. Below are the relevant assets to this study developed by AASHTO (AASHTO 2006):

- Roadsides: vegetation and aesthetics, trees, shrubs and brush, historic makers, and right-of-way fence
- Drainage Structures: cross pipes and box culverts, entrance pipes, curb and gutter, paved ditches, unpaved ditches, edgedrains and underdrains, stormwater ponds, and drop inlets
- Traffic: attenuators, guardrail, pavement striping, pavement markings, raised pavement markers, delineators, signs, and highway lighting

Individual highway agencies have also developed their own performance standards (Ahmed et al. 2010).

According to this literature review, little research has been done to verify that these standards are measurable in the field.

2.2 Develop Performance Standards

The performance standards were developed based on an extensive literature review, a survey of states that have used performance-based contracts, and a statewide survey of the different districts in Texas. Thirty one state DOTs were chosen to answer a questionnaire based on a review of the proceeding of two Maintenance Quality Assurance (MQA) Peer Exchanges (held in 2004 in Madison, Wisconsin and in 2008 in Raleigh, North Carolina) and are representative of the states currently implementing roadway maintenance quality assurance and performance-based specifications. The questionnaire requested information and the specifications type (performance-based vs. conventional) and maintenance provider (private contractors vs. in-house services) for 14 roadside asset types and maintenance activities. The State DOTs were also given an opportunity to provide comments on their uses of performance based contracts.

Thirteen of the contacted state DOTs responded to the questionnaire and request for information (representing a 42% response rate). The responses are illustrated in Table 2.1 (Ahmed 2010).

Table 2.1 Usage of Performance-based Specifications for Roadside Maintenance (Based on Response to Questionnaire)

Roadside Item	Private-Sector Contracting		In-House Service Provision	
	Performance-Based Specification	**Other Type of Specification**	**Performance-Based Service Measurement**	**Other**
Median Barrier Maintenance	FL,NC	AL, FL,NY, NC,PA, SC,WIS,WY	CA,IN, NC	PA,WY
Guardrail Repair	FL, NC	AL, FL, NY, NC, PA, SC, WIS, WY	CA, IN	NC, PA, WY
Vegetation Management (including tree trimming and removal)	FL, NC	AL, FL, NY, PA, SC, WIS, WY	CA, IN, NC	PA, SC, WY
Litter Pick-up	FL, NC	FL, NY, PA, WIS	CA, IN, NC	PA, SC, WY
Debris Pick-up (such as tires, appliance, dead animals, etc)	FL	AL, FL, NY, NC, WIS	CA, IN	NC, PA, SC, WY

Table 2.1 continued

Roadside Item	Private-Sector Contracting		In-House Service Provision	
	Performance-Based Specification	**Other Type of Specification**	**Performance-Based Service Measurement**	**Other**
Removal of Encroachments (such as illegal signs)		AL, FL, NY, WIS		IN, NC, PA, SC, WY
Emergency Clean-up after Storms	FL	FL, NY, NC, SC, WIS, WY		IN, NC, PA, SC, WY
Roadside Drainage Maintenance	FL, NC	AL, FL, NY, SC, WIS, WY	CA, NC	IN, PA, SC, WY
Culverts and Storm Drains	FL, NC	AL, FL, NY, PA,SC, WIS	CA, NC	IN, PA, SC, WY
Stockpiles on Right of Way	FL	AL, FL, WY	IN	SC, WY
Traffic Lightning Maintenance	FL, NC	AL, FL, NY, NC, WIS, PA, SC,	CA, NC	IN, PA, SC, WY

The questionnaire revealed that the state DOTs of Florida and North Carolina use performance-based (PB) specifications for roadside maintenance under comprehensive roadway asset management contracts. While Virginia DOT did not respond to the questionnaire, it is known that is also used PB specification under asset management contracts (FHWA 2008). South Carolina DOT's response indicated that it has used PB specifications for rest areas and major bridges only. Oklahoma DOT's response suggests that it is important to know what your forces are capable of "performing" via performance standards prior to adopting PB specifications.

A survey was then sent to the 25 districts of TxDOT to collect their individual responses and view on best practices for each roadside type and maintenance activities developed based on the state questionnaire. Complete responses were received from 17 out of 25 TxDOT districts and partial responses were received from one district representing a response rate of 68%. These 17 districts are shown in Figure 2.2. The positions held by the respondents included Director of Operations (4 districts), Director of Maintenance (8 districts), District Engineer (2 districts) and Maintenance Engineer (3 districts). The survey included two parts: the first part consisted of questions that address the performance standards and targets for the roadside asset types and activities identified earlier, while the second part covered the contract aspects. The results of this survey are provided in Appendices A through D.

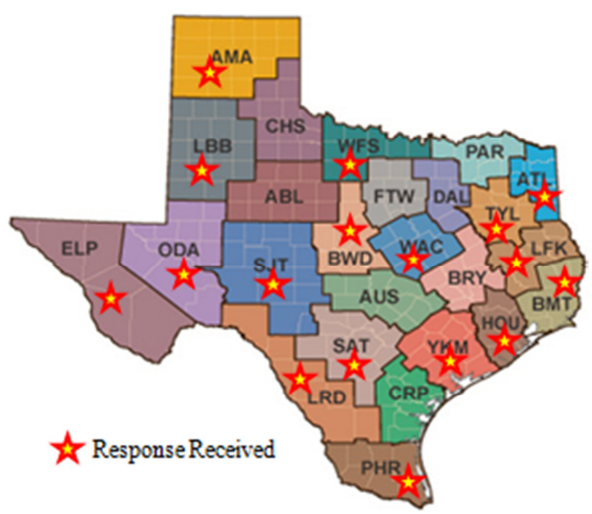

Figure 2.2 Districts Responded to the Online Survey

Survey questions regarding Performance Standards and targets included the following roadside assets:

1. Mowing and Roadside Grass
2. Landscaped Areas
3. Trees, shrubs, and vines
4. Ditches and Front Slopes
5. Culver and Cross-Drain Pipes
6. Drain Inlets
7. Chain Link Fence
8. Guard Rails
9. Attenuators
10. Litter and Debris
11. Graffiti

The roadside asset types and maintenance activities can be grouped as follows:

- Vegetation-related: Mowing and roadside grass; landscaped areas; and trees, shrubs, and vines.
- Safety-related: Attenuators; guard rails; and chain link fence.
- Drainage-related: Ditches and front slopes; culverts and cross-drain pipes; and drain inlets.
- Cleanness-related: Removal of litter and debris; and removal of graffiti.

A summary of the results of the survey regarding feasible performance standards are presented in Tables 2.2-2.5. Out of the 53 standards that were included in the survey, 42 standards were supported by a clear majority of the respondents (more than 70% of the respondents agreed with these standards). Eight standards were supported by 50-70 percent of the respondents. Only 2 standards were supported by less than 50 percent of the respondents (between 40 to 49% of the respondents agreed with these standards).

For the vegetation-related performance standards, mowing grass height seemed to be the most controversial item. Comments received from the districts raised concern over safety issues related to clear sight distances in rural areas, and aesthetics aspects in urban areas. Based on this feedback, roadside grass height standards may need to be adjusted to 7-24 inches for rural areas and 7-18 inches for urban areas. While this standard will be proposed to TxDOT, it is also understood that different climate conditions and district sizes may make this standard difficult to achieve across all of the TxDOT districts. Using these grass standards as a baseline, however, should provide the districts with the option to adjust PBMCs to reflect achievable standards.

Table 2.2 Vegetation-related Performance Standards

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
Mowing and Roadside Grass	TxDOT approval of herbicides is required	100%
	Paved shoulders, medians, islands and edge of pavement should be free of Bermuda grass	82%
	Unpaved shoulders, slopes, and ditch lines free of bare or weedy areas	71%
	Roadside vegetation should be 85% free of noxious weeds	71%
	Roadside grass height (rural areas): 7-30 inches	53%
	Roadside grass height (urban areas): 7-24 inches	47%
Landscaped Areas	TxDOT approval of herbicides is required	100%
	90% of landscaped areas is free of weeds and dead or dying plants	82%
	Grass height: 12 inches maximum.	59%
Trees, shrubs and Vines	No trees and/or vegetation that obscure the message of a roadway sign	100%
	No dead trees and no leaning trees that present a hazard	100%
	Vertical clearance over sidewalks and bike paths is at least 10 ft	94%
	Vertical clearance over roadway and shoulder is at least of 18 ft	88%
	Clear horizontal distance behind guardrail is at least 5 ft for trees	71%

For the drainage related standards, a few comments indicated that the standard concerning the percentage of drain inlets that is unobstructed is too lenient and should be increased to 95 percent. Additionally, a few general comments indicated that it may be difficult for maintenance contractors to bid on drainage assets. This may be the reasoning behind the lower approval percentages for some of the drainage-related standards.

For the safety-related performance standards, feedback from the districts revealed that in order to prevent human access through chain linked fences, the maximum opening dimension should be revised to no more than 1.0 ft and the suggested maximum opening area is 1.0 ft^2. Districts also recommended that there should be no wooden posts or blocks in the guard rails that are rotten or deteriorated; however, this standard may be too stringent and unnecessarily increase the cost of the performance based contract. Additionally, three days may be insufficient to repair or replace damaged guard rails, especially in districts that often experience inclement weather such as snow and roads that have heavy traffic. Thus, this specification can be categorized by setting different timeliness factors considering road classifications.

Table 2.3 Drainage-related Performance Standards

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
Ditches and Front Slopes	There are no eroded areas, washouts, or sediment buildup that adversely affects the flow of water in the ditch	88%
	No erosion that will endanger the stability of the front slope, creating an unsafe recovery area.	88%
	No washouts or ruts greater than 3-in deep and 2-ft wide, in front slope	76%
	90% of the ditch structure (90% of the length and 90% of the depth) functions as intended	71%
	No joint separation, misalignment, or undermining in concrete ditches	71%
	No deviations (hills, holes, etc.) greater than 3 inches in depth or height, in front slope	53%

Table 2.3 continued

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
Culvert and Cross-Drain Pipes	At least 75% of the cross sectional area of each pipe is free of obstructions and functions as intended with no evidence of flooding	94%
	The grates are of the correct type and size, unbroken, and in place	94%
	No water infiltration causing pavement failures, shoulder failures, or roadway settlement.	76%
	No cracking, joint failures, or erosion of culverts and cross-drain pipes	71%
Drain Inlets	The grates are of the correct size and are unbroken. Manhole lids are properly fastened.	94%
	No hazard from exposed steel or any deformation of the inlet	94%
	No erosion, settlement, or sediment around boxes	82%
	Outlets are not damaged and are functioning properly	76%
	85% of the opening area is not obstructed.	65%
	No surface damage 0.5 ft^2 or more.	47%

Table 2.4 Safety-related Performance Standards

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
Chain Link Fence	No open gates	75%
	No opening in the fence fabric greater than 2 ft^2	69%
	No opening in the fence fabric with a dimension greater than 2 ft	69%
Guard Rails	No missing posts, offset blocks, panels or connection hardware	94%
	No damaged end sections	94%
	No penetrations in the rail	88%
	No panel lapped incorrectly	88%
	No more than 10% of the guardrail blocks in any continuous section are twisted.	76%
	Contractor to address guardrail deficiencies (listed above) within 3 days	76%
	No 25 continuous feet that is 3 inches above or 1 inch below the specified elevation	71%
	No more than 10% of the wooden posts or blocks in any continuous section are rotten or deteriorated	59%
Attenuators	Each device functions as intended	100%
	No visually-observed malfunctions, such as water or sand containers that are split, compression of the device, misalignment, etc.	100%
	No missing parts	94%
	Contractor to address attenuator deficiencies (listed above) within 3 days	76%

For the cleanness-related performance standards, the districts feedback focused on the amount of allowable litter and removal of dead animals from the right of way. A consensus regarding litter control cannot be found from the district's responses; some district suggested that the litter control standards should be more stringent while others prefer more lenient litter control standards. For practical reasons, timeliness for removal of dead animals should be relaxed to 24 hours. Additionally, several districts suggested that there is no need for removing small dead animals from the ROW in rural areas.

Table 2.5 Cleanness-related Performance Standards

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
Litter and Debris	No litter that creates a hazard to motorist, bicyclist, or pedestrian traffic is allowed	88%
	Less than 50 pieces of fist size or larger litter/debris within 0.1 miles	62%
	The volume of litter does not exceed 3 cubic feet per acre of right-of-way	44%
	Remove dead animals from the right of way within 2 hours	44%
Graffiti	No damaged surface or coating due to graffiti removal	94%
	Obscene, sexually or racially explicit or "gang-related" graffiti shall be removed within 3 days	88%
	Restore the surface to an appearance similar to adjoining surfaces	81%
	Non-obscene graffiti shall be removed within two weeks of discovery	75%

The performance standards developed for Texas were compared to those used by Florida DOT, Virginia DOT, North Carolina DOT, and Ontario Ministry of Transportation (MTO). These standards have been extracted from performance based specifications of actual projects being executed under performance-based contracting scheme, except for Florida DOT where the standards have been obtained from the

Maintenance Rating Program (MRP) Handbook. Standards that vary significantly from those developed for Texas are listed below:

Mowing and Landscaped Areas Performance Standards

- For all grass species, grass height not to exceed 15 inches, nor less than 6 inches (NCDOT)
- <10% bare grounds per 10th mile section (VDOT)
- No cut less than 2" in height (VDOT)
- Litter pickup shall occur in advance of each mowing cycle (VDOT)
- Must follow Integrated Roadside Vegetation Management (IRVM) program as established by the National Roadside Vegetation Management Association (NRVMA) and as adopted by NCDOT
- Contractor will utilize and be evaluated on the “Roadside Environmental Landscape Plant Bed Inspection Report” (NCDOT)
- No excessive “brown-out”, pre-approval of herbicides from the Engineer required (NCDOT)
- No landscaping is within the limits of the clear sight window as per Design Standard Index 546. (FDOT)
- Bulb Beds: a) <10% of bed contains weeds b) Bed is mulched c) <10% of bed not growing (VDOT)
- Vegetation between curb and asphalt joints in curb and gutter and between asphalt shoulders and a concrete barrier is eradicated during the months of July and August every year. (MTO)

Trees, Shrubs and Vines Performance Standards

- Vertical clearance of 30 ft over roadway (Includes shoulders) (VDOT)
- No Brush or trees that affect the inspection or repair of bridges or other structures (VDOT)
- No brush or trees that affect utility company reading or inspection (VDOT)

Cleanness

- No dump sites on right-of-way (VDOT)
- Owner of household pets to be notified if identification is available (VDOT)
- <20 items (greater than the "size of a fist or bar of soap") per 10th mile section (VDOT)

Drainage

- Lateral ditches no more than 50% blocked (NCDOT)
- No erosion greater than 1' below original ditch line (NCDOT)
- The ditch bottom elevation varies no more than 1/4 of the difference between the edge of pavement elevation and the ditch design elevation. (FDOT)
- <25% spalling of surface area (VDOT)
- Sumps not filled to capacity (MTO)
- Roadside storm water management ponds are inspected in the spring (by May 1st) and Fall (by October 15th) of each year (MTO)
- End walls/wing-walls are clear of vegetation and debris (NCDOT)

- Weep holes are clean and free of foreign material and properly functioning (NCDOT)
- There are no construction joints opened greater than ¼ inch (NCDOT)

Safety-related Items

- No dents or deterioration that decrease structural integrity (NCDOT)
- Each single run of guardrail does not meet MRP standards when Nuts fully threaded within 1 inch of the anchor plate on end treatment cables and anchor rods (FDOT)
- Each single run of guardrail does not meet MRP standards when the backup plate does not fit snugly behind the rail. There should be some point of contact.(FDOT)
- Each single run of guardrail does not meet MRP standards when the bearing plate does not fit snugly to the post. The bearing plate should be in contact with the post. (FDOT)
- No "used' guard rail to be utilized (VDOT)
- For attenuators, no obvious malfunctions, such as water or sand containers that are split, compression of the device, misalignment, etc. (FDOT)
- No inspection rating of attenuators less than GOOD (FDOT)
- Systems are inspected, tested and reviewed at least twice per year (VDOT)
- Operational test and Inspection shall be done weekly on barrier gates (VDOT)
- All systems that contain moving parts are cleaned by June1st every year (MTO)

The final roadside activities and assets found most amendable to performance-based contracts with the adjustments made from the survey comments and 2 onsite interviews with the Waco and Dallas districts are shown in Table 2.7.

Table 2.6 Proposed Roadside Assets

Inspector's Name: **Inspection Date:**

District: **Highway:** **Milepoint:** **Sample Unit No.:** **Urban/Rural:**

Roadside Element	No.	Performance Standard	Grade (Pass, Fall, NA)
Mowing and Roadside Grass	1	Obtained TxDOT approval of herbicides	
	2	Paved areas (shoulders, medians, islands and edge of pavement) are free of grass	
	3	Unpaved areas (shoulders, slopes, and ditch lines) are free of bare or weedy areas	
	4	Roadside vegetation in the mowing area is at least 85% free of noxious weeds (undesired vegetation)	
	5	Roadside grass height (rural areas): 7-30 inches	
	6	Roadside grass height (urban areas): 7-24 inches	
Landscaped Areas	7	Obtained TxDOT approval of herbicides	
	8	90% of landscaped areas is free of weeds and dead or dying plants	
	9	Grass height: 12 inches maximum.	
Trees, shrubs and Vines	10	No trees and/or vegetation that obscure the message of a roadway sign	
	11	No dead trees and no leaning trees that present a hazard	
	12	Vertical clearance over sidewalks and bike paths is at least 10 ft	
	13	Vertical clearance over roadway and shoulder is at least of 18 ft	
	14	Clear horizontal distance behind guardrail is at least 5 ft for trees	

Table 2.6 continued

Roadside Element	No.	Performance Standard	Grade (Pass, Fall, NA)
Ditches and Front Slopes	15	There are no eroded areas, washouts, or sediment buildup that adversely affects the flow of water in the ditch	
	16	No erosion that will endanger the stability of the front slope, creating an unsafe recovery area.	
	17	No washouts or ruts greater than 3-in deep and 2-ft wide, in front slope	
	18	90% of the ditch structure (90% of the length and 90% of the depth) functions as intended	
	19	No joint separation, misalignment, or undermining in concrete ditches	
	20	No deviations (hills, holes, etc.) greater than 6 inches in depth or height, in front slope	
Culvert and Cross-Drain Pipes	21	At least 75% of the cross sectional area of each pipe is free of obstructions and functions as intended with no evidence of flooding	
	22	The grates are of the correct type and size, unbroken, and in place	
	23	No water infiltration causing pavement failures, shoulder failures, or roadway settlement.	
	24	No cracking, joint failures, or erosion of culverts and cross-drain pipes	
Drain Inlets	25	The grates are of the correct size and are unbroken. Manhole lids are properly fastened.	
	26	No hazard from exposed steel or any deformation of the inlet	
	27	No erosion, settlement, or sediment around boxes	
	28	Outlets are not damaged and are functioning properly	
	29	85% of the opening area is not obstructed.	
	30	No surface damage 0.5 sq.ft or more.	

Table 2.6 continued

Roadside Element	No.	Performance Standard	Grade (Pass, Fall, NA)
Chain Link Fence	31	No open gates	
	32	No opening in the fence fabric greater than 1.0 sq.ft	
	33	No opening in the fence fabric with a dimension greater than 1.0 ft	
Guard Rails	34	No missing posts, offset blocks, panels or connection hardware	
	35	No damaged end sections	
	36	No penetrations in the rail	
	37	No panel lapped incorrectly	
	38	No more than 10% of the guardrail offset blocks in any continuous section are twisted.	
	39	Contractor to address guardrail deficiencies (listed above) within 3 days	
	40	No 25 continuous feet that is 3 inches above or 1 inch below the specified elevation	
	41	No more than 10% of the wooden posts or blocks in any continuous section are rotten or deteriorated	
Cable Median Barrier	42	No missing or damaged posts, cables, and connections	
	43	Damaged end sections	
	44	No loose cable, incorrect weave or installation	
Attenuators	45	Each device functions as intended	
	46	No visually-observed malfunctions, such as water or sand containers that are split, compression of the device, misalignment, etc.	
	47	No missing parts	
	48	Contractor to address attenuator deficiencies (listed above) within 3 days	

Table 2.6 continued

Roadside Element	**No.**	**Performance Standard**	**Grade (Pass, Fall, NA)**
Litter and Debris	49	No litter that creates a hazard to motorist, bicyclist, or pedestrian traffic is allowed	
	50	Less than 50 pieces of fist size or larger litter/debris within 0.1 miles	
	51	The volume of litter does not exceed 3 cubic feet per acre of right-of-way	
	52	In Urban areas, remove dead animals from the right of way within 24 hours	
	53	In rural areas, remove large dead animals from the traffic lanes within 24 hours	
Graffiti	54	No damaged surface or coating due to graffiti removal	
	55	Obscene, sexually or racially explicit or "gang-related" graffiti shall be removed within 3 days	
	56	Restore the surface to an appearance similar to adjoining surfaces	
	57	Non-obscene graffiti shall be removed within two weeks of discovery	

3. CONDITION ASSESSMENT METHOD

3.1 Literature Review

As part of maintenance quality assurance, the condition of highway assets and maintenance activities under PBMCs and conventional maintenance contracts should be evaluated regularly using a reliable method. Many highway agencies have implemented the Maintenance Quality Assurance (MQA) process on their highway systems. A survey of 39 highway agencies in the US and Canada (located in 36 states and 3 Canadian provinces) found that 83% of these agencies have an MQA program (Schmitt et al. 2006). Hyman (2009) conducted a survey to see if agencies using PBMC agreed on the importance of using a MQA program. Of those who responded to the survey, 60% reported that a MQA program had been adopted. Howard et al. (1997) suggests that in order for pay adjustments to be effective, there must be a reliable and objective way to measure performance. Therefore, a roadway monitoring system, such as a MQA, is necessary for PBMCs to be effective.

The MQA process uses the Level of Service (LOS) concept as an overall performance measure. LOS is measured in the field using visual condition assessment methods such as the Maintenance Rating Program (MRP). MRP was originally developed in 1985 by Florida DOT and then refined under the National Cooperative Highway Research Program (NCHRP) Project 12-12 by Stivers et al. (1999). The MRP process includes randomly selected inspections of sample units of 0.1 or 0.2 mile long. For each sample unit, each asset types (e.g., culverts, drain inlets, etc.) are inspected against a performance standard to assign either a passing or failing grade (Mallela et al.

2001) or to assign a numerical score (typically 0-5, with 5 being perfect score). For the pass/fail rating method, the percent conforming (rating) of an asset type within a sample unit is then determined as a ratio of passing performance standards to inspected performance standards. For the numerical score method, a score for each asset type within a sample unit is then determined as the average of all applicable scores. Both methods allow for the use of weights that represent the agency's priorities. Figure 3.1 shows an example of the Texas Department of Transportation (TxDOT) Maintenance Assessment Program (TxMAP), an adaptation of the MQA process.

Component/Element	Rating	Element Score	Priority Multiplier	Component Score
Pavement (Weight = 50%)				
Main Lane - Rutting	4	80%	6.5	5.2
Main Lane - Cracking	5	100%	6.5	6.5
Main Lane - Failures	4	80%	9	7.2
Main Lane - Ride	4	80%	6	4.8
Edges	5	100%	4.5	4.5
Shoulders	5	100%	5	5
			Sub-Total	33.2
			Perfect Sub-Total	37.5
			Pavement Component Score = 33.2 /37.5 =	88.5%
Traffic Operations (Weight = 20%)				
Signs - Small	5	100%	3	3
Striping-Pavement Graphics	5	100%	4	4
			Sub-Total	7.0
			Perfect Sub-Total	7.0
			Traffic Operations Component Score = 7.0 /7.0 =	100.0%
Roadside (Weight = 30%)				
Vegetation Management	5	100%	5.5	5.5
Litter	5	100%	2.5	2.5
Trees and Brush	5	100%	3.5	3.5
Drainage	5	100%	5	5
Encroachments	5	100%	3.5	3.5
Guard Rail	0	0%	0	0
			Sub-Total	20.0
			Perfect Sub-Total	20.0
			Traffic Operations Component Score = 7.0 /7.0 =	100.0%
			Overall Score = 88.5*0.5 + 100 * 0.2 + 100 * 0.3 =	**94.3%**

Figure 3.1 TxMAP Example of LOS Computation for a Sample Unit

Since sampling the entire length of the project to determine a LOS is labor intensive, statistical procedures are often used to determine an appropriate sample size to approximate the performance of a project. For ease of computation, some highway agencies use a fixed percentage of the population to determine sample size. Typically, this percentage ranges between 5% and 15%. Schmitt et al. (2006) suggested that a sample size of 2-5% is adequate to determine the average condition of a highway network; however, they recommended a sample size of 10-15% for determining the distribution of condition and the percentage of the network below a given target score. While this approach for determining sample size is relatively simple; it is statistically unsound. In order to correctly define a sampling procedure, the characteristics of “overall population, sample units, asset items within each sample unit, and acceptable quality levels” must be understood (de la Garza et al. 2008). Several methods have been proposed for computing the number of sample units needed to be inspected (i.e., sample size). For a given precision and confidence level, the necessary sample size should be a function of (Medina et al. 2009):

- The total number of centerline miles in each shop (districts),
- The stratification of the total asset population in the region (maintenance sections within a district),
- The approximate distribution of assets in the system (highway to be inspected), and
- The estimates of the population variance in each stratum (sample unit).

Given a standard deviation found from the current condition of the highway, a sample size (n) for PBMC inspections can be found according to Equation 3.1;

$$n = \frac{z_{\alpha/2}^2 S^2}{e^2 + z_{\alpha/2}^2 \frac{S^2}{N}} \qquad \textbf{Eq. 3.1}$$

where

e = desired precision rate that should be specified by road administrators,

$z_{\alpha/2}$ = z-statistic for desired confidence level,

N = population size (i.e., total number of sample units in the project), and

S^2 = variance.

This method for determining sample size is founded on basic statistical theory and has been used by Virginia DOT for both PBMC projects and a state-wide MQA program (Kardian and Woodward 1990, de la Garza et al. 2008).

3.2 Developed Condition Assessment Method

The LOS for the highway project is found from the element score and sample unit score, as follows:

1. The highway maintenance project is divided into *N* sample units (each 0.1-mi long)
2. *n* sample units are selected randomly for field survey (*n* is computed using Eq. 3.1).
3. The randomly-selected sample units are inspected and rated on a "Pass/Fail/Not Applicable" basis using the performance standards shown in Table 2.7 (a total of 57 performance standards for 11 roadside asset types and maintenance activities).

4. A 0-100 sample score (SS) is computed as a weighted average score for all elements within the sample unit, as follows:

$$SS = \frac{\sum_{i=1}^{k} \frac{PS_i}{AS_i} \times w_i}{\sum_{i=1}^{k} 100 \times w_i} \qquad \textbf{Eq. 3.2}$$

where *PS* is the number of passing performance standards; *AS* is the number of applicable performance standards; *w* is an agency-specified priority multiplier (or weight) for each roadside element, and *k* is the total number of roadside elements within the sample unit. A set of priority multipliers were developed based on feedback from TxDOT's districts and are discussed in the following paragraphs.

5. A roadside $\overline{LOS}$ for the highway maintenance project is computed, as follows

$$\overline{LOS} = \frac{\sum_{j=1}^{n} SS_j}{n} \qquad \textbf{Eq. 3.3}$$

where SS_j is the sample score for sample unit *j* and *n* is the total number of inspected sample units (i.e., sample size).

6. Because the LOS is computed based on a random sample, it is recommended that a confidence interval (CI_{LOS}) be computed for the LOS, as follows:

$$CI_{LOS} = \overline{LOS} \pm z_{\alpha/2} \times \frac{s}{\sqrt{n}} \qquad \textbf{Eq. 3.4}$$

where s is the standard deviation of SS; z is the z-statistic for a desired confidence level (e.g., $z_{0.025} = 1.96$ for 95% confidence).

Based on the responses received from 17 TxDOT districts regarding the designation of performance risk for each roadside element, a priority multiplier was computed for each one of these elements. Figure 3.2 is a visual representation of the risk matrix for mowing and roadside grass with risk assessed by TxDOT's districts (risk matrices for the remaining roadside elements are shown in Appendix C). The vertical axis is the probability that the element will fail inspection and the horizontal axis is the negative effect of failing to pass inspection. The numbers in the boxes represent the number of TxDOT districts that agree with that risk position. The priority multiplier is calculated as a weighted average of the responses for each classification (minor, moderate, major, and severe) where the minor classification is given a consequence value of 1, moderate 2, major 3, and severe is given a value of 4 (see Equation 3.4).

$$PM = \frac{(1*1)+(2*6)+(3*5)+(4*4)}{16} \qquad \textbf{Eq. 3.4}$$

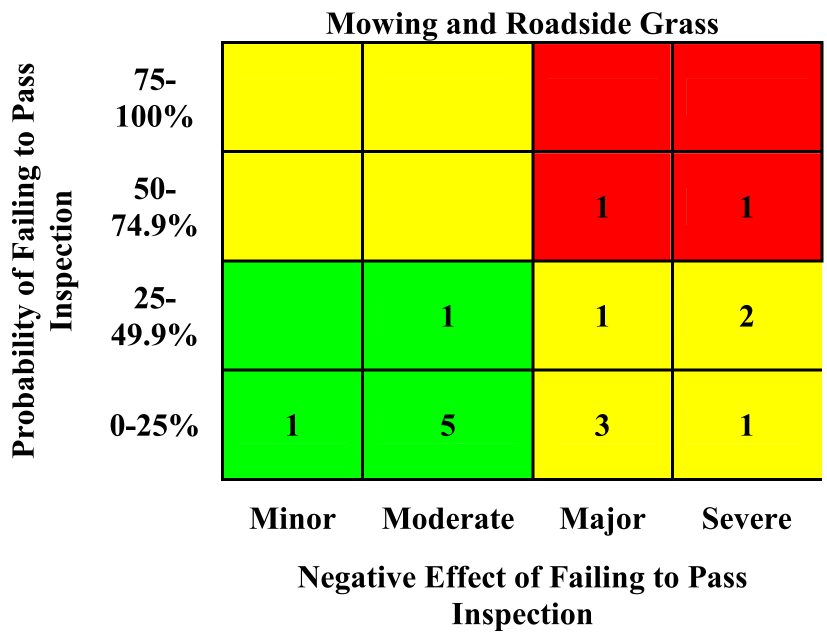

Figure 3.2 Example Risk Matrix for Mowing and Roadside Grass

Table 3.1 shows the calculated priority multipliers for each roadside element. The original survey of TxDOT's districts did not include the roadside element "cable median barrier" so the priority multiplier for this element is taken as an average of the safety related assets as related to traffic (guard rails and attenuators).

Table 3.1 Priority Multipliers

Roadside Element	Priority Multipliers (1-4 scale)
Mowing and Roadside Grass	2.8
Landscaped Areas	1.6
Trees, shrubs, and vines	2.1
Ditches and Front Slopes	2.7
Culvert and Cross-Drain Pipes	2.9
Drain Inlets	2.9
Chain Linked Fence	1.7
Guard Rails	3.3
Cable Median Barrier	3.5
Attenuators	3.7
Litter and Debris	1.7
Graffiti	1.6

Figure 3.3 shows an example of how to calculate the sample unit score.

Roadside Element	No. of Standards	No. of Passed Standards	Priority Multipliers	Element Score (0-100)
Mowing and Roadside Grass	6	5	2.75	83.33
Landscaped Areas	3	NA	1.63	
Trees, shrubs, and vines	5	NA	2.07	
Ditches and Front Slopes	6	NA	2.70	
Culvert and Cross-Drain Pipes	4	2	2.86	50.00
Drain Inlets	6	NA	2.87	
Chain Link Fence	3	NA	1.73	
Guard Rails	8	6	3.33	75.00
Cable Median Barrier	3	NA	3.52	
Attenuators	4	NA	3.71	
Litter and Debris	5	3	1.69	60.00
Graffiti	4	NA	1.60	
			Total	723.27
			Perfect Total	1062.8
			Sample Unit Score=727.83/1062.8=	**68.5%**

Figure 3.3 Sample Unit Score Computation Example

A key component of this condition assessment method is the determination of sample size. This method uses random sampling in order to determine the project's LOS without inspecting the entire project (i.e., without 100% sampling). The statistical procedures presented in Equation 3.1 will be utilized to determine sample size (*n*). As discussed earlier, this method for determining sample size is founded on statistical theory and has been used in PBMCs in Virginia (de la Garza et al. 2008, Kardian and

Woodward 1990). A sample size analysis was conducted based on data gathered from the field trials. Key inputs to the sample size equations are discussed as follows:

Standard Deviation among Sample Scores

The variance (S^2) of the inspectors for each trial was calculated based on the condition of the highway. Equation 3.5 shows the formula used to calculate the standard deviation (s) for each inspector;

$$s = \sqrt{\frac{\sum(SS_i - \bar{S})^2}{n}} \qquad \textbf{Eq. 3.5}$$

where

SS= the sample score at sample i,

$\overline{SS}$= the average sample score, and

n= the number of samples inspected.

A pooled standard deviation (s_p) between the common three inspectors for every field trial was found to calculate the appropriate sample size for any given project length (Equation 3.6);

$$s_p = \left(\frac{(n_1-1)s_1^2+(n_2-1)s_2^2+(n_3-1)s_3^2}{n_1+n_2+n_3-3}\right)^{1/2} \qquad \textbf{Eq. 3.6}$$

where

n_i= the number of inspection performed by inspector i, and

s_i- the standard deviation of the sample unit scores found from inspector i.

Since the inspections were performed by walking along the roadside for each sample, a relatively short inspection length of 0.1 miles is used so that within each sample every asset can be correctly identified and evaluated. Due to the short sample length and the high level of specificity of the performance standards used for evaluating the sample, an inventory of every asset within the project was not compiled in an effort to keep the time required to perform the inspections manageable. This may be a shortcoming of this method, but further analysis would have to be performed to determine if that in fact is the case.

Figure 3.4 tracks the pooled standard deviation for each trial field inspections performed in the Tyler District. Because the standard deviation is a function of the differences in the sample scores, the condition of the roadside will affect the required sample size. Depending on the time of year the inspections are performed, the sample unit scores may be closer to 100% and the pooled standard deviation values will be lower; resulting in a smaller sample size. For example, in the winter it is likely that the vegetation related standards will pass inspection (or be Not Applicable) because maintenance requirements are low; however, during the spring time when the grass is growing, there is a greater likelihood that sample will not pass inspection and greater variance in the sample scores are created (resulting in a larger sample size).

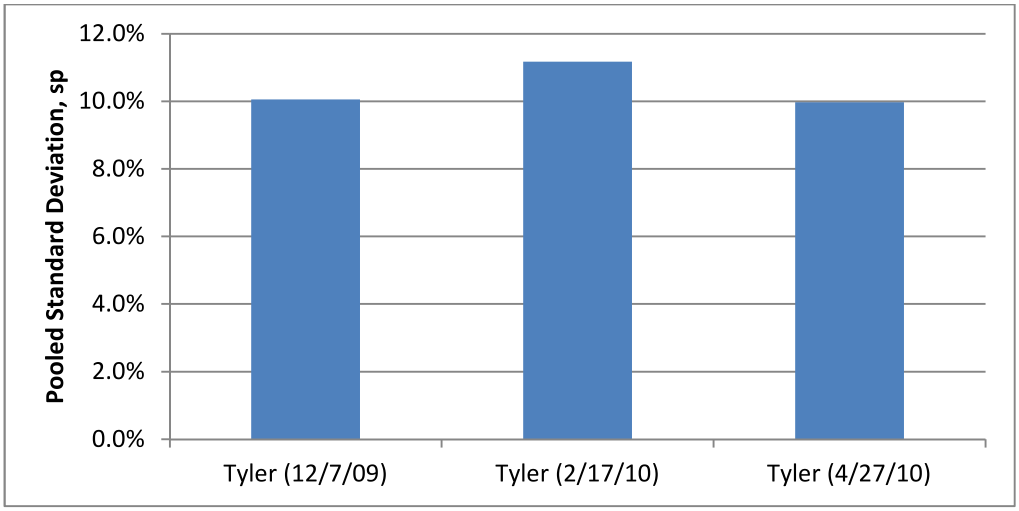

Figure 3.4 Pooled Standard Deviation Values in Tyler District

Desired Precision Level and Confidence Level

From a review of the literature, a common precision value (e) of 0.04 will initially be used to determine the required inspection sample size. This represents a 4% tolerance that the samples selected will accurately represent the score of the entire project. For a precision value (e) of 0.04 and a confidence level of 90%, Figure 3.5 shows the required number of samples for a given project length. The required sample size, n, increases with increasing standard deviation.

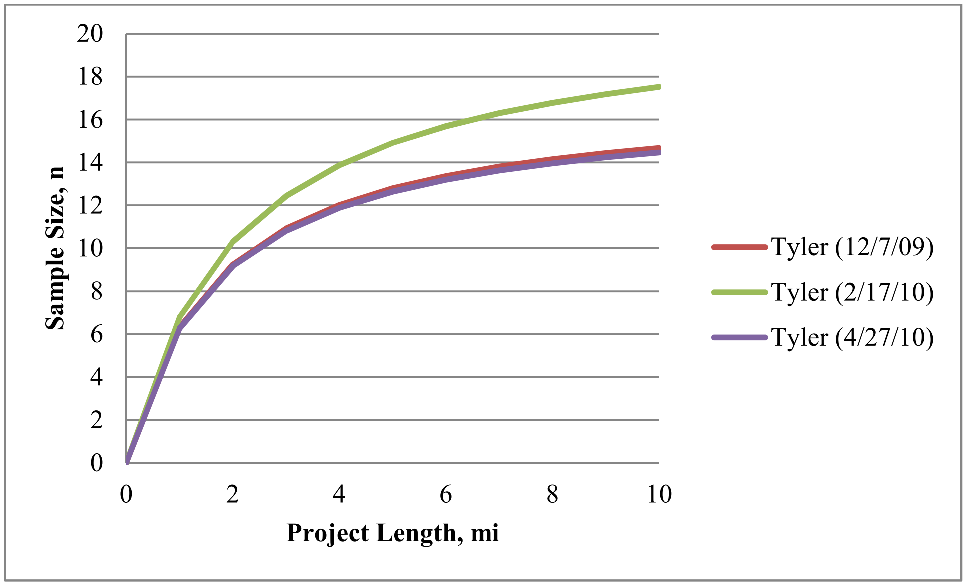

Figure 3.5 Required Sample Size for e=0.04, CL=90%

In order to increase the confidence that the samples are representing the entire project, the confidence level can be increased. Figure 3.6 shows this trend for a confidence level of 95%. The tradeoff for a higher confidence level is the increased time and money that will be spent on collecting inspection data.

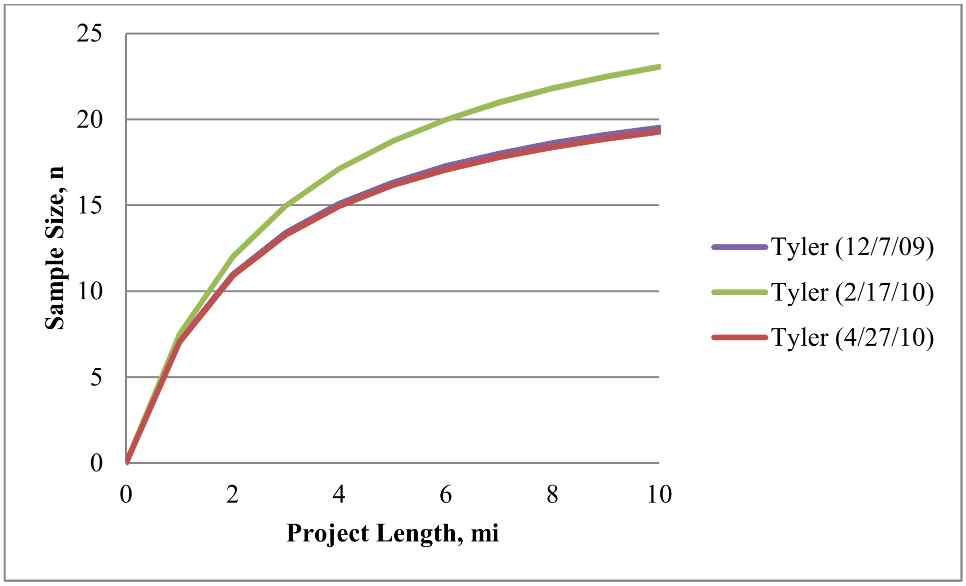

Figure 3.6 Required Sample Size for e=0.04, CL=95%

The effect of the precision value, e, is recorded for the Tyler (4/27/2010) survey (Figure 3.7). As shown, the precision value has the greatest effect on the sample size where decreasing e increases n. The pooled standard deviation for this survey is similar to the other surveys and this graph is only presented once as an illustrative tool.

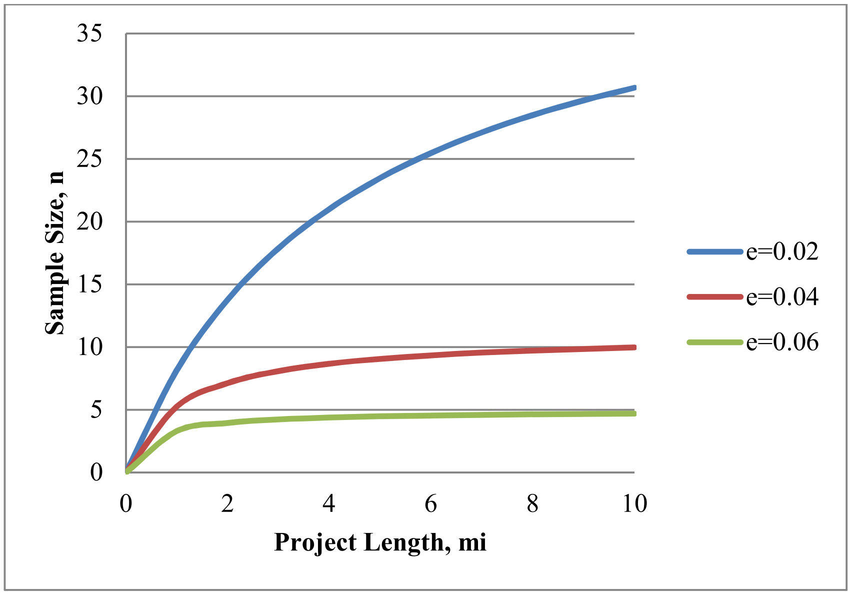

Figure 3.7 Required Sample Size for CL=95%, Tyler (4/27/10)

Figure 3.8 summarizes the required sample size, n, for both the 90% and 95% confidence levels with a precision value of 0.04 for a common project length of 10 miles.

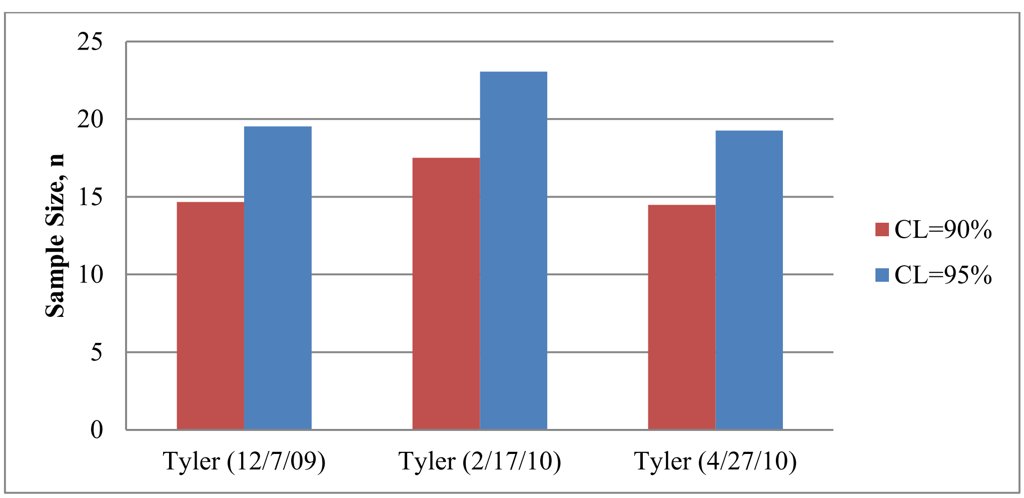

Figure 3.8 Required Sample Size for 10 Mile Project (Tyler), e=0.04

3.3 Inspection Rates for Other TxDOT Districts

The pooled standard deviation values for four different districts in Texas are presented in Figure 3.9. Except for the Dallas district, the pooled standard deviation values are within 0.02 of each other. The higher value for Dallas may be accounted for by the following;

- The increased traffic volumes in the Dallas site (I-35 in urban area, near Denton) made inspections difficult, and
- Increased maintenance was required in Dallas at the time of inspection.

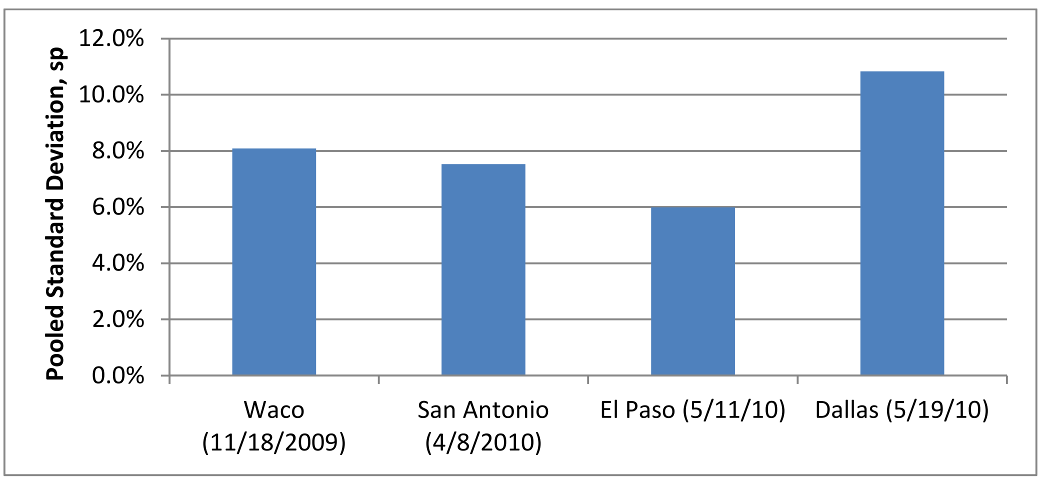

Figure 3.9 Pooled Standard Deviation Values for TxDOT Districts

The required sample sizes for a precision value of 0.04 and both 90% and 95% confidence levels are presented in Figures 3.10 and 3.11. As expected, due to its higher pooled standard deviation, the Dallas district requires significantly more samples than the other districts.

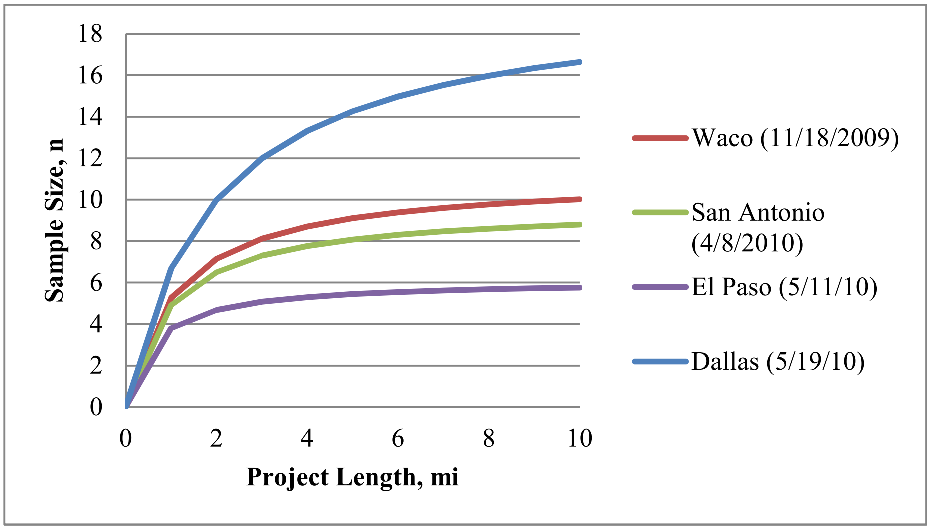

Figure 3.10 Required Sample Size for e=0.04, CL=90%

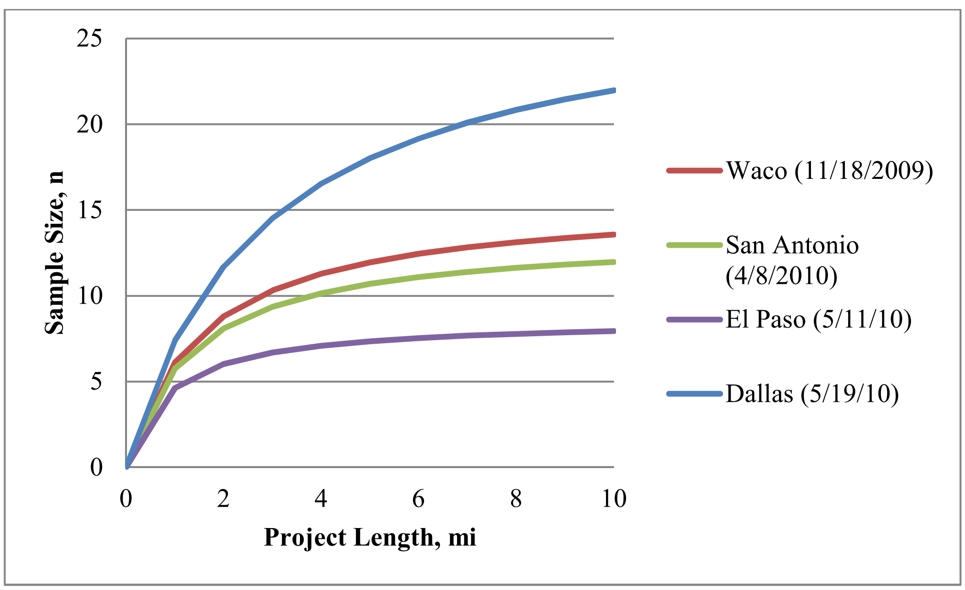

Figure 3.11 Required Sample Size for e=0.04, CL=95%

Figure 3.12 summarizes the results shown in Figures 3.11 and 3.12 for a typical 10 mile project. The El Paso site requires the smallest sample size while Dallas site requires the largest, illustrating the importance of calculating the sample size based on the initial condition of the project.

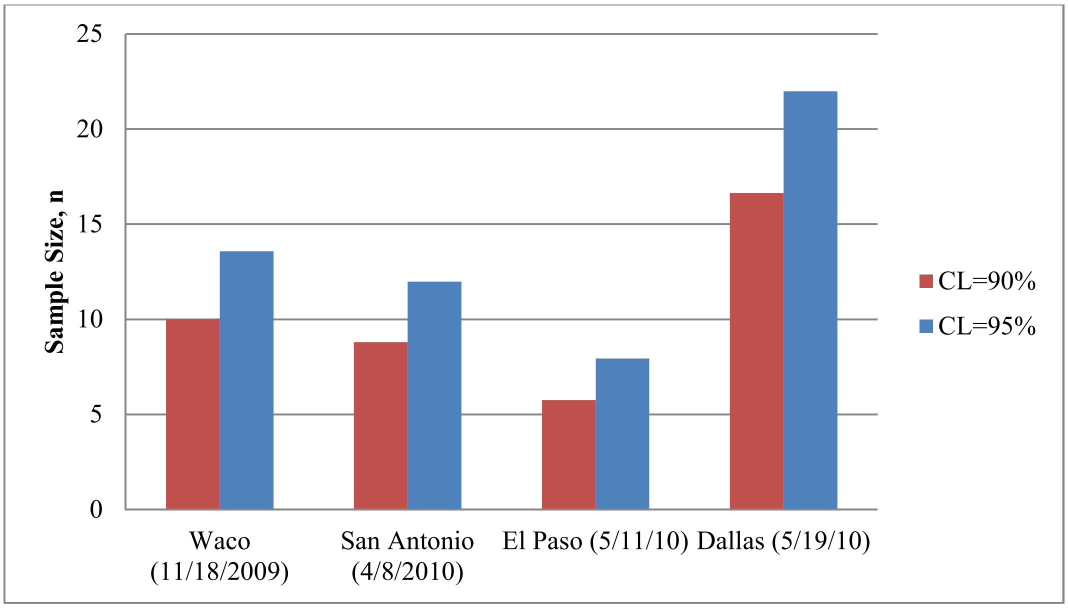

Figure 3.12 Required Sample Size for 10 Mile Project, e=0.04

3.4 Feedback from TxDOT Districts

The survey of TxDOT's districts provided an overall assessment of the opinions of maintenance practitioners regarding who should perform the field inspection and the sampling rate.

Figure 3.13 shows that the overwhelming majority of the respondents prefer TxDOT's personnel to conduct the performance inspection. About 13% of the respondents prefer the inspection to be performed by a third-party that is hired by and reports to TxDOT. An interview with the Waco District revealed that when systematic inspection and rating methods (such as the one developed in this study) are required, the inspection and rating process may need to be performed by a third-party due to the districts' shortage of staff. The Dallas interview suggested that, in addition to TxDOT's monthly inspections, an annual inspection by an independent third-party (hired by and reports to both the contractor and TxDOT) may be advantageous because it serves as a referee.

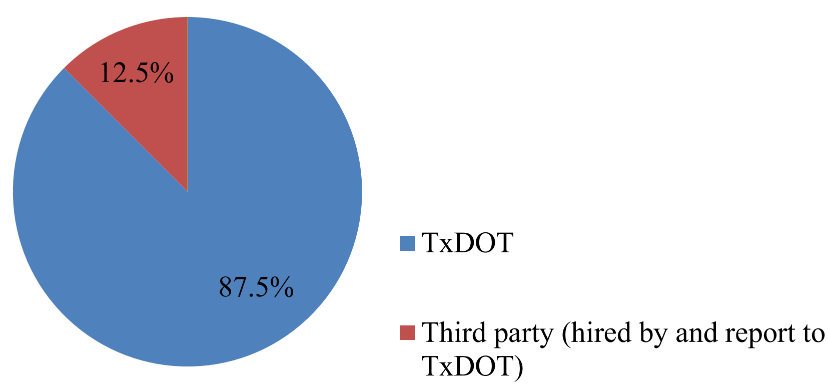

Figure 3.13 Inspection Responsibility

4. PAY ADJUSTMENT SCHEMES

4.1 Literature Review

In PBMCs, public agencies must act as the monitor and enforcer of the contract and find methods such as the application of pay adjustments to ensure that the contractor is meeting the level of service (LOS) target and performance standards. Hyman (2009) cites several methods for a state DOT to encourage contractors to perform at a desired target value. These methods include the use of a lump sum disincentives, a combination of incentives and disincentives, A+B+C contracting for a multiphase project where A is the total price for the bid items, B is the amount of time to complete the work, and C might be the warranty cost for performance-based maintenance. Based on this literature review, it appears that most agencies prefer a monetary incentive and/or disincentive to encourage the contractor to perform at a required level of service. The purpose of disincentives is to aver or recover the damages the agency incurs by the contractor's failure to meet the specifications of the contract (McGhee and Gillespie 2006). Incentives are defined as a "process by which a provider is motivated to achieve extra 'value added' services over those specified originally (Bower et al. 2002)."

Figure 4.1 shows the results of a survey performed by Hyman (2009) of selected responses from agencies to the question "do agencies seek agreement from bidder as to whether incentive and disincentives are reasonable?"

State/Province	Responses
District of Columbia	The department spent enough time preparing the RFP, tries to take all possible scenarios into consideration, and believes that whatever is incorporated is very reasonable.
Florida	We do not seek bidder approval for each contract; instead, we send out our "standard scope" for industry review. Potential bidders have the opportunity to comment on incentives/disincentives at the time of the industry review.
Idaho	No. Goal-oriented reasons and the bidders are the same two firms regardless of the type of contract used.
Virginia	There are no incentives in the performance-based contracts that we use for maintenance. The contractor already has overhead and profit built into the bid price (lump-sum). The contractor has a real internal financial incentive to perform as efficiently as possible to increase his level of profit. Disincentives or penalties are used in Virginia's performance-based contracts as a way to ensure contract compliance.
New Brunswick	The RFP submission in addition to the question and answer period will ensure all the contract requirements are understood.

Figure 4.1 Selected Agency Responses to the Use of Incentives/Disincentives

4.2 Developed Methodology for Pay Adjustment Scheme

The purpose of this methodology is to determine the optimum pay adjustment formula to incentivize the contractor to aim at the agency's specified performance target. The concept here is that maintenance contractors will aim at the quality level (LOS score) that minimizes their total cost, which is computed as follows:

Total Cost = Initial Cost to Contractor + Pay Adjustment

where the decision variable is the slope of the pay adjustment curve. This concept is illustrated in Figure 4.2 from the perspective of the contractor. This approach ensures that the pay adjustment formula (incentives/disincentives) and LOS target value are in sync.

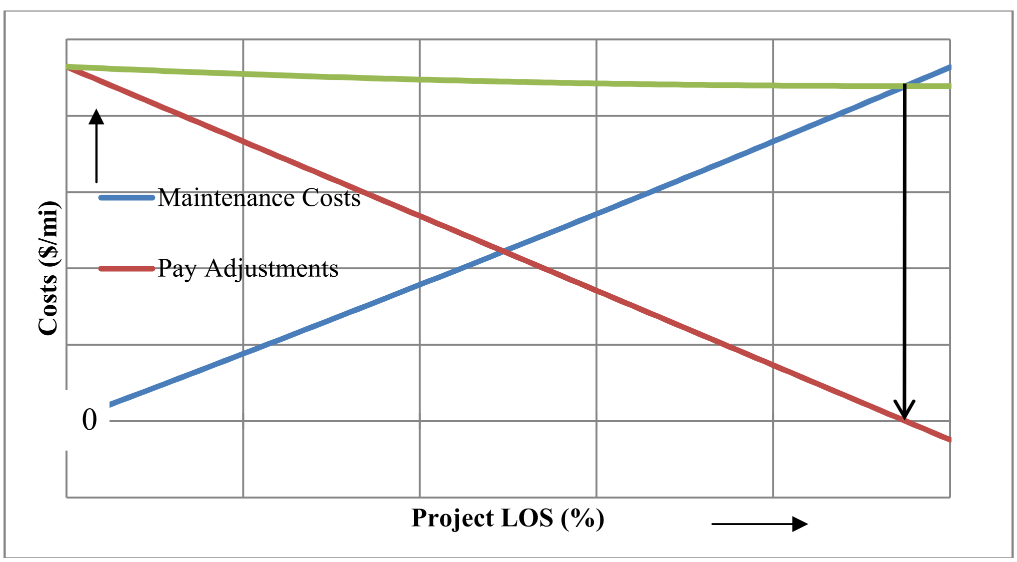

Figure 4.2 Conceptual Model for Determining Optimum Combination of Target and Pay Adjustment

Curves that represent the relationship between LOS score and maintenance cost to achieve that LOS were developed for the field trials (as discussed in subsequent sections of this report). A Genetic Algorithm (GA) was then applied to determine the optimum pay adjustment curve for various LOS targets. GAs are an effective optimization tool that have been applied to several complex civil engineering problems. Fwa et al. (1996) applied a genetic algorithm to a road maintenance and rehabilitation problem, citing its ability to optimize within constraints to only generate valid solutions. The application of a genetic algorithm in this problem is simple and an Excel-based genetic algorithm (Evolver) will be utilized.

Relationships between Maintenance Cost and LOS

Initially, an attempt was made to develop these relationships using LOS data obtained from TxDOT's TxMAP rating system and maintenance cost data obtained from TxDOT's Maintenance Management Information System (MMIS). Figures 4.3 and 4.4 show these relationships for both Farm to Market (FM) roads and non-FM roads, respectively. However, all the values are concentrated around 80% and a trend cannot be developed based on this data. This can be attributed to the miss-match between the locations of TxMAP's random sample units and the aggregated maintenance cost data (stored in MMIS).

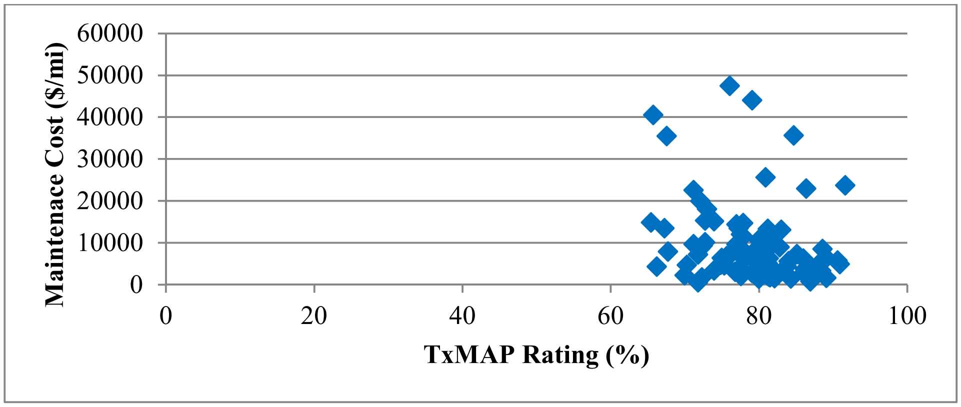

Figure 4.3 Maintenance Costs vs. TxMAP Rating (FM Roads)

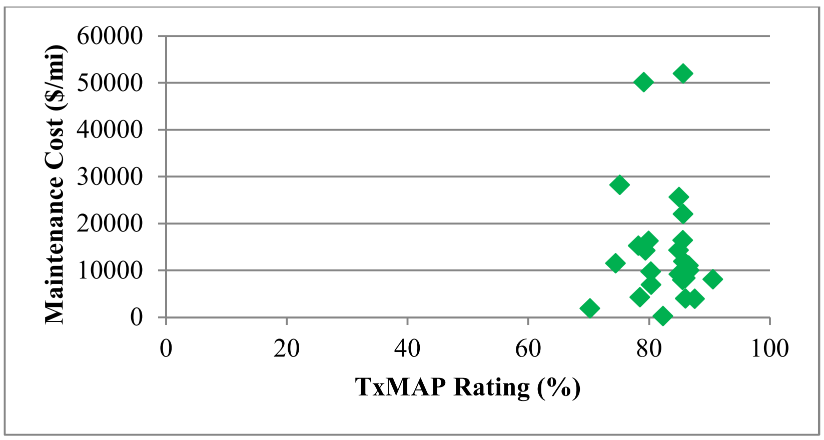

Figure 4.4 Maintenance Costs vs. TxMAP Rating (Non FM Roads)

Due to the range and amount of maintenance cost data needed to have confidence in the resulting pay adjustment scheme, simulated performance scores were developed. The following procedure was developed to find optimal pay adjustment schemes:

1. TxDOT provided maintenance cost data for various maintenance function codes (each maintenance activity is assigned a function code by TxDOT) from the MMIS database for the fiscal year 2009 for the Waco and Tyler Districts. Table 4.1 shows the matches

between the TxDOT function codes and the standards used in this project. The cost data was sorted by road type (Farm to Market, State Highway, US Highway, and Interstates) and the total length or roadway for each maintenance activity (i.e., function code) was recorded. For ease of using the cost data to calculate maintenance cost on a per sample unit basis (i.e., $/0.1 mile), the cost data was normalized along the length of the roadway, converted to a cost per sample, and averaged by road type.

Table 4.1 TxDOT Function Codes

Roadside Element	**TxDOT Function Code**
Mowing and Roadside Grass	511: Mowing
	542: Chemical Veg. Control Overspray
	548: Seeding/ Sodding Hydromulching
Landscaped Areas	551: Landscaping
Trees, shrubs, and vines	552: Tree and Brush Control
Ditches and Front Slopes	561: Ditch Maintenance
	562: Reshaping Ditch
	563: Slope Repair/Stabilization
Culvert and Cross-Drain Pipes	570: Culvert and Storm Maintenance
Drain Inlets	570: Culvert and Storm Maintenance
Chain Link Fence	595: Guard Fence
Guard Rails	596: Guardrail End Treatment Services
Cable Median Barrier	593: Cable Median Barrier
Attenuators	Not available
Litter and Debris	521: Litter
	523: Debris
Graffiti	530: Removal of Graffiti

Tables 4.2 and 4.3 show the maintenance costs for the Waco and Tyler Districts, which were obtained from MMIS. Since the Waco district field trial was performed on IH 35 and the Tyler district field trial was performed on IH 20; IH cost data was used with exception of Function Codes 548, 562, 593, and 596. For these function codes, SH or US data is used, instead.

Table 4.2 Maintenance Costs for Waco District (Fiscal Year 2009)

Function Code	Amount of Units	Average Cost/Unit	Average Cost	Total Mileage (mi)
511	5,811	$23.84/AC		116
521	27,036	$9.74/AC		116
523	55,481	$4.72/MI		116
530	544	$28.95/SF		101
542	3,510	$66.83/AC		116
548*	54,184	$0.585/SY		53
551	---	---	$65,594.60	116
552	---	---	$61,659.09	101
561	496	$6.39/CY		109
562	3,134	$6.02/LF		116
563	6	$399.23/SY		108
570	---	---	$51,722.82	132
593	1	$37.32/LF		93
595	6,989	$25.95/LF		101
596*	322	$1012.905/EA		208

* Data is for SH and US roadways

Table 4.3 Maintenance Costs for Tyler District (Fiscal Year 2009)

Function Code	Amount of Units	Average Cost/Unit	Average Cost	Total Mileage (mi)
511	5198	$38.92/AC		83
521	8416	$12.71/AC		83
523	11821	$15.46/MI		83
530	---	---	$20.63	17
542	1136	$45.20/AC		83
548*	2830	$0.59/SY		42
551	---	---	$19,664.01	36
552	---	---	$30,673.76	83
561	187	$8.56/CY		66
562*	2458	$8.36/LF		182
563	487	$7.15/SY		17
570	---	---	$1,933.04	37
593*	1	$37.32/LF		93
595	2221	$24.5/LF		83
596	19	$3384.27/EA		83

*Data is for SH and US roadways

Equation 4.1 shows an example of how the information from Tables 4.2 and 4.3 was converted to cost/sample data for function code 511 for Waco.

$$Cost\ per\ Sample = \frac{\$38.92}{AC} \cdot 5198\ AC \cdot \frac{1}{83\ mi} \cdot \frac{.1\ mi}{1\ sample} = \$243.74/sample \qquad \textbf{Eq. 4.1}$$

2. Using the inspection data of the field trials, various hypothetical scenarios of failing to meet the performance standards were simulated. For each scenario, the sample score and the project LOS were computed. Also, the maintenance cost to improve the failed assets (i.e., make the sample meet the performance standards) was computed using the "cost per sample" data (generated in Step 1). The simulated sample scores and LOS were developed in order to develop a range of maintenance costs that the contractor might

incur. The following assumptions were made in calculating the maintenance cost for the project:

- Maintenance would not be performed on a sample unless the sample score fell below the target LOS.
- If maintenance activity on the sample was required, the maintenance would bring every standard in the sample to a Pass rating (and thus bring the sample score to 100%).
- Each sample is taken to be continuous along a roadway. For example, if 20 inspections were performed, this corresponds to a project length of 2 miles.

3. The maintenance costs as developed by the assumptions laid out in step #2 reflect the costs associated with increasing the LOS from some initial score to a LOS of 100%. By subtracting the maintenance cost at a LOS score of 0% from a given LOS, the maintenance costs will show the costs to maintain a LOS score. Figure 4.5 shows a plot of the maintenance costs to the contractor for various values of initial LOS for interstate highways in the Waco and Tyler Districts.

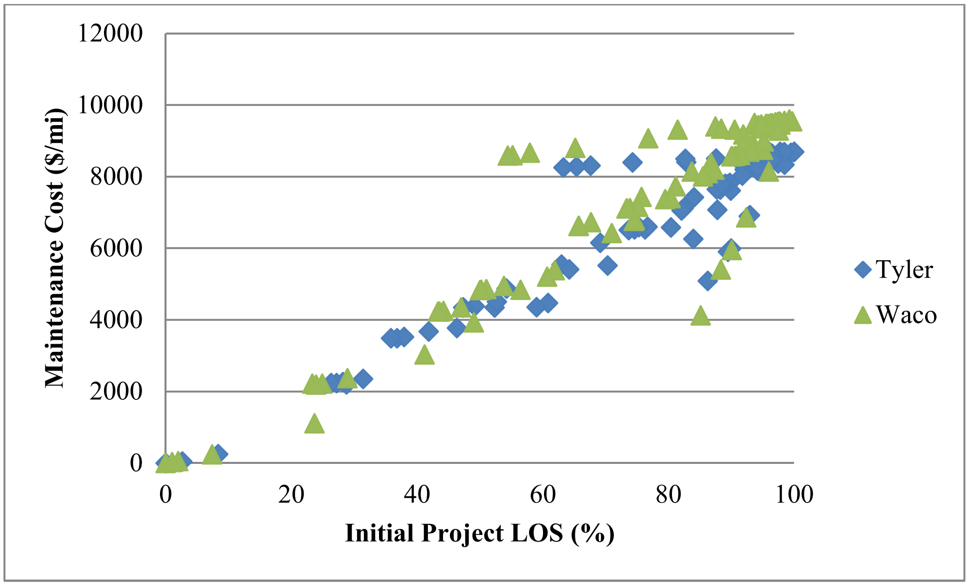

Figure 4.5 Simulated Maintenance Cost Data for Waco and Tyler Field Trials

4. As seen in Figure 4.4, a few data points (the high data points in the 50-90% range and the low data points in the 80-100% range) do not follow the same trend. Upon further inspections of these points, they reflect the isolated costs of maintaining the litter and debris, and ditches and front slope assets. Because these points represent specific assets, uncertainty exists as to if the costs for these performance standards were accurately captured in the model. These costs contain a noticeably high variability and since the match between the MMIS function codes and the performance standards are not perfect, inaccuracies exist. Due to the uncertainty present in those data points, these points were removed before further analysis took place (Figure 4.6).

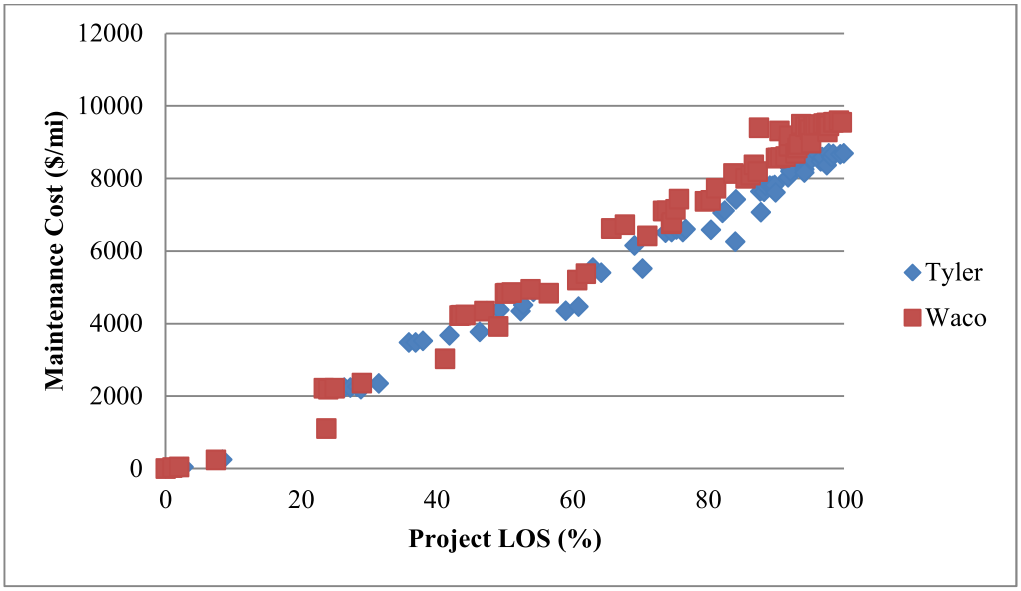

Figure 4.6 Edited Maintenance Cost Data for Waco and Tyler Field Trials

5. A best fit curve for the maintenance data was then developed. Given the spread of data points, a trend line cannot capture every possible cost option, but it is the most reasonable method to work with the data. The R^2 value was maximized under the constraint that at a LOS score of 0%, the maintenance cost should be close to 0.

   The error, represented by Equation 4.2, was also minimized;

$$Error = \sum(y_i - f_i) \qquad \textbf{Eq. 4.2}$$

   where

   y_i= the real maintenance cost per mile at a given LOS score, and

   f_i= the calculated maintenance cost per mile at a given LOS score from a best fit line.

   Equation 4.3 shows the best fit curve for the data points with an R^2 value of 0.971 and an error of $5257.87/mi;

$$C = 0.082 \cdot P_i^2 + 86.498 \cdot P_i - 141.71 \quad \textbf{Eq. 4.3}$$

where P_i is the LOS of the project and C is the maintenance unit cost ($/mi).

Figure 4.7 shows the best fit line for the combined Waco and Tyler districts maintenance cost data.

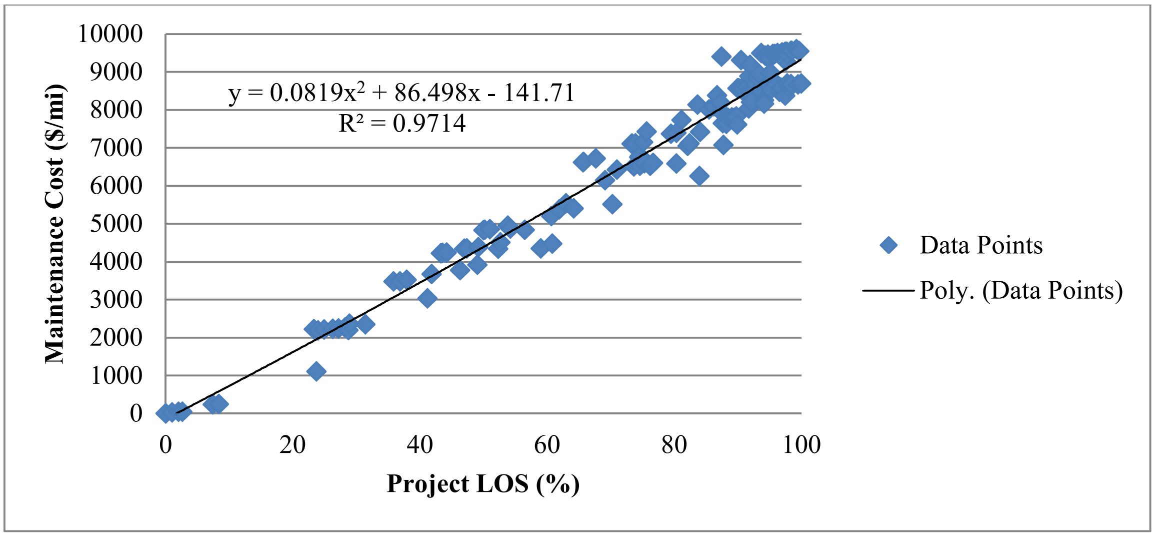

Figure 4.7 Best Fit Line for Waco and Tyler Maintenance Cost Data

Pay Adjustment Curves

Once the LOS vs. maintenance cost curve was established, Evolver was utilized to minimize the maintenance cost to the contractor (see Appendix E for excel chart). Assuming a linear regression for the pay adjustment (PA) curve, Evolver solved for the coefficient "*a*" in Equation 4.4,

$$PA = a \cdot (T - LOS) \quad \textbf{Eq. 4.4}$$

where T is the target LOS and LOS is the score assigned to the highway. This formula indicates that at a LOS above the target value, the pay adjustment will be negative and act as a cost savings to the contractor (i.e. the contractor receives an additional payment from the agency). However, from the perspective of the agency, a negative pay adjustment represents an additional cost.

This problem is constrained by the requirement that the minimum total cost to the contractor must occur at the target value (95%). This constraint ensures that the approach ensures that the pay adjustment formula and LOS target value are in sync and thus the contractor will aim at the target LOS to minimizes his/her total cost.

For example, for a 95% LOS target (i.e., T=95%), the above equation becomes

$$PA = a \cdot (95 - LOS) \quad \textbf{Eq. 4.4}$$

Figure 4.8 shows the pay adjustment (PA) curve, maintenance cost curve, and the sum of the two curves plotted against the performance score for an interstate highway project with a target LOS of 95%. The minimum total cost per mile was $8814.74 at a project score of 95%. Equation 4.5 shows the resulting pay adjustment curve formula:

$$PA = 102.13 \cdot (95 - LOS) \quad \textbf{Eq. 4.5}$$

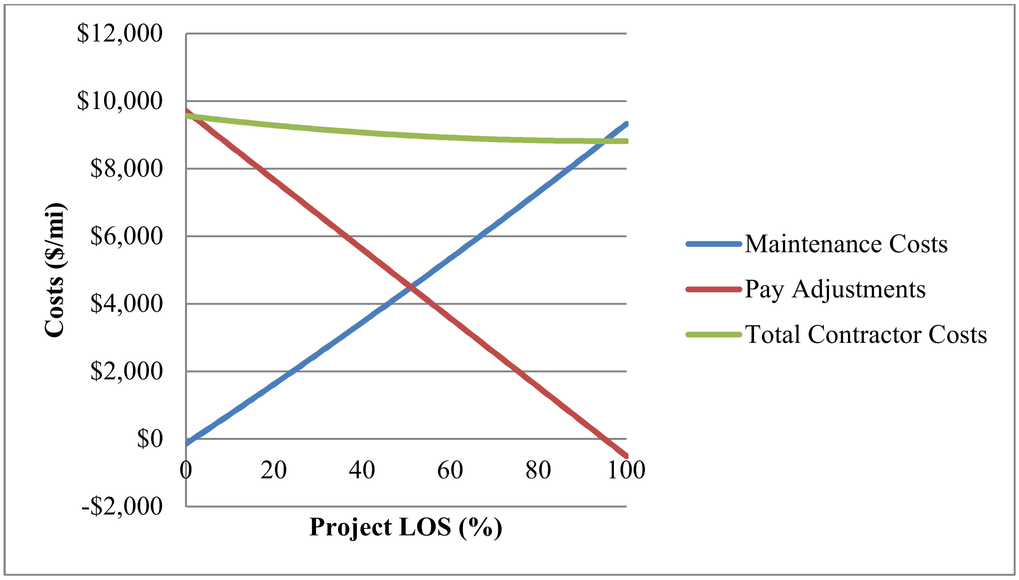

Figure 4.8 Total Cost to the Contractor

Table 4.4 shows the genetic algorithm parameters that were used for solving this optimization problem.

Table 4.4 GA Model Parameters

Mutation Rate	0.1
Crossover Rate	0.5
Population Size	50

For use in specification documents, Equation 4.5 can be rewritten as shown in Equation 4.6 to reflect the amount the agency should pay to the contractor for performing above the target value (i.e., contractor's pay increase) and the amount the contractor should pay to the agency for failing to achieve the target value (i.e., contractor's pay decrease).

$$PA = 102.13 \cdot (LOS - 95) \quad \textbf{Eq. 4.6}$$

4.3 Pay Adjustment Curves for Field Trials

The total contractor cost can reflect the real conditions in the field. For the Waco (IH 35) and Tyler (IH 20) field trials, the average LOS scores are 90% and 85%, respectively. Thus, the cost to maintaining these sites is the difference between the total contractor costs at a target value of 95% and the LOS scores of the highways. The difference between the sites is seen in the total cost to the contractor (Table 4.5) and captures the significance of a low initial level of service.

Table 4.5 Total Cost to Contractor to Maintain LOS at 95%

District	Total Cost ($/mi)
Waco	508.25
Tyler	1012.40

It should be mentioned that, according to the 2009 Texas Condition Assessment Program (TxCAP) report, the statewide average for roadside of 80.76%.

4.4 Limitations

While the above method for developing pay adjustment schemes is an improvement to the current practices (where pay adjustments are determined subjectively), the methodology has limitations. These limitations are summarized as follows:

- Since the maintenance cost data used in the simulation was an average of a roadway type across the district, these costs may not accurately represent the true cost to maintain a given roadway.
- The function codes used by TxDOT do not perfectly match the developed performance standards.

- The method to capture the project score may mask samples that have a low score by higher scoring samples. This can be corrected by placing a penalty value on sample scores that are lower than a predetermined threshold.

While these limitations may affect the application of the methodology to the field trials, the methodology itself can still be applied with confidence.

4.5 Feedback from TxDOT Districts

The survey of TxDOT's districts provided an overall assessment of the opinions of maintenance practitioners regarding pay adjustment schemes.

As shown in Figure 4.9, 40% of the responses did not agree with assigning incentives (pay increase) for exceeding performance targets. The remaining 60% of the responses preferred the use of incentives. For those who preferred the use of incentives, the maximum pay increase rate ranged between 1% and 20% of the bid price. The Waco and Dallas interviews revealed that no incentives were used in Waco's and Dallas's PBMCs. The Waco interview suggested that when the performance based standards are enforced properly, there is no need for using incentives. However, the district's personnel also indicated that the lack of incentive provisions can put pressure on the contractor's personnel to barely achieve the target performance level because "over-performance" is not rewarded.

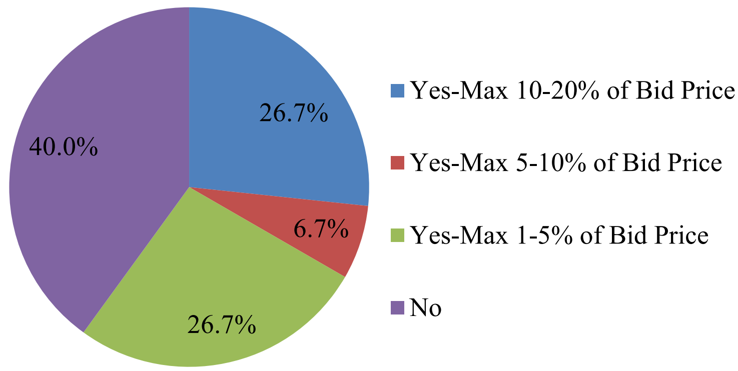

Figure 4.9 Districts Feedback Regarding the Use of Incentive Provisions

As shown in Figure 4.10, the majority of the responses (approximately 93%) agreed with assigning disincentives (pay reduction) for failing to meet the performance targets or standards. There was a general agreement that disincentives should be assigned as a percentage of the bid price. The Waco and Dallas interviews revealed that liquidated damages (measured in $ per item per day) have been used in both Dallas's and Waco's PBMCs. In Waco's IH 35 contract, the contractor is charged $5,000 of liquidated damages per day (including Saturdays, Sundays, and holidays), per item of work, per performance standard; until the standard is met. The Waco interview indicated that this "fixed rate" has been an effective technique in helping to enforce the specifications. However, the Dallas interview revealed that, in some cases (such as snow removal), it was more economical to the contractor to pay the liquidated damages instead of performing the required maintenance. This may have been caused by "under bidding" the contract in the first place. As a result, it is unlikely that the Dallas District will use performance based standards unless it is bid on a "best-value" basis, not on a lowest bid basis. Also, the Dallas interview revealed that a contract award method that is modeled after TxDOT's Comprehensive Development Agreements (CDAs) should be investigated for PBMCs.

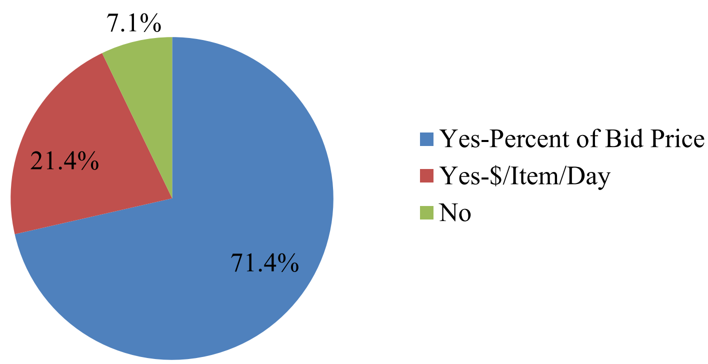

Figure 4.10 Districts Feedback Regarding the Use of Disincentive Provisions

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

For performance-based maintenance contracts to succeed, performance requirements must be clearly defined, a condition assessment method for evaluating compliance with these requirements must exist, and rational pay adjustments should be tied to contractor performance (Hyman 2009, Stankevich et al. 2005, Schexnayder et al. 1997). Currently, engineering judgment is most often used to develop pay adjustment (PA) formulas for PBMCs and may not be optimal. Optimum PA formulas motivate the contractor to maintain the roadway assets at the target performance level specified by the highway agency. Additionally, there should be a consensus on how to define performance (i.e., what performance standards and overall measure should these PA formulas based on) and how to measure performance (i.e., what condition assessment methods should be used for evaluating the contractor's compliance with the performance requirements). The development of these formalized methods for maintenance quality assurance helps the highway agency to achieve the desired level of quality and minimizes the guesswork in the performance evaluation process. This thesis addresses these three issues associated with PBMCs.

5.2 Conclusions

The performance standards presented in the paper are a result of a literature review, a survey of TxDOT districts, and trial field inspections. These performance standards are easily measured and designating each standard as either pass or fail takes out some of the subjectivity in assessing these standards.

The required sample size is a function of the project characteristics, including performance variability along the project, required confidence level, and allowable tolerance. Performance varies from project to project and within project for various reasons. For example, the vegetation grows differently in Texas based on the different climates; the drainage requirements vary depending on the rainfall in the different districts; roadway utilization (i.e., traffic volume) varies from one location to another. The field trials show that highly urbanized districts may need more inspection samples due to increased variation in the sample scores.

Finally, the pay adjustment curves are a function of the initial project LOS, the target LOS, and the maintenance cost to achieve the target LOS. It is important to accurately capture the maintenance costs for various LOS values so that the pay adjustment equation can be optimized to motivate the contractor to perform at the target LOS.

5.3 Recommendations

In order for inspections to accurately reflect the project, the inspectors must receive continual training to insure that all the roadside assets are correctly identified and rated. Correctly assigning sample scores allows for the correct identification of the standard deviation and a recommended sample size. Also, while the results presented are conservative, if there is doubt as to if the assigned project score is accurate, additional samples should be surveyed and an effort to capture every asset should be made.

The pay adjustment curves should be a result of accurate relationships between LOS and maintenance costs. Without an accurate relationship, the pay adjustment curve may not work as intended and the state DOT's attempt to enforce a target LOS may not be successful.

REFERENCES

Ahmed, J., Shelton, D., and Gharaibeh, N. G. (2010) "A Process for Developing Performance-based Specifications for Contracted Roadside Maintenance in Texas" 89^{th} Annual Transportation Research Board Conference. Washington DC. January 2010.

American Association of State Highway and Transportation Officials (AASHTO). (2006) "Asset Management Data Collection Guide." *Task Force 45 Report*, AASHTO-AGC-ARTBA Joint Committee.

Bower, D., Ashby, G., and Smyk, W. (2002) "Incentive Mechanisms for Project Success." *Journal of Management in Engineering,* 18(1), 37-43.

Fwa, T.F., Chan, W.T., and Tan, C.Y. (1996) "Genetic-Algorithm Programming of Road Maintenance and Rehabilitation." *Journal of Transportation Engineering*, 122(3), 246-253.

Garza, J. M. de la, Pinero, J. C., and Ozbek, M. E. (2008) "Sampling Procedure for Performance-Based Road Maintenance Evaluations." *Journal of the Transportation Research Board*, 2044, 11-18.

Howard, W. E., Bell, L. C., and McCormick, R. E. (1997) "Economic Principles of Contractor Compensation." *Journal of Management in Engineering*, 13(5), 81-89.

Hyman, W.A. (2009) "Performance-Based Contracting for Maintenance." *National Cooperative Highway Research Program (NCHRP) Synthesis No. 389*, Transportation Research Board of the National Academies, Washington, D.C.

Kardian, R.D., and Woodward, W.W. (1990) "Virginia Department of Transportation's Maintenance Quality Evaluation Program." *Transportation Research Record 1276*, Transportation Research Board, Washington DC. 90-96.

Medina, R. A., Haghani, A., and Harris, N. (2009) "Sampling Protocol for Condition Assessment of Selected Assets", *Journal of Transportation Engineering*, 135(4), 183-196.

McGhee, K. K. and Gillespie, J. S. (2006) "Impact of a Smoothness Incentive/Disincentive on Hot-Mix Asphalt Maintenance Resurfacing Costs." *Report No. FHWA/ VTRC 06-R2.* Virginia Transportation Research Council, Charlottesville.

Queiroz, C. (2008) "Case Study Performance-based Management and Maintenance of Roads in the USA." Presentation at the Regional Seminar on Performance-Based Management and Maintenance Contracts, Arusha, Tanzania, February 2008.

Schexnayder, C. and Ohrn, L. G. (1997) "Highway Specifications- Qualities versus Pay." *Journal of Construction Engineering and Management*, 123(4), 437-443.

Schmitt, R.L., Owusu-Ababio, S., Weed, R.M., and Nordheim, E.V. (2006) "Understanding Statistics in Maintenance Quality Assurance Programs." *Journal Transportation Research Record: Journal of the Transportation Research Board,* 148, 17-25.

Stankevich, N., Qureshi, N. and Queiroz, C. (2005) "Performance-based Contracting for Preservation and Improvement of Road Assets." *Transport Note*, No. TN-27, World Bank, Washington DC, September 2005.

Stivers, M. L., Smith, K. L. Hoerner, T. E. and Romine A. R. (1999) "Maintenance QA Program Implementation Manual." *NCHRP Report 422*, Transportation Research Board, Washington, D.C.

Texas Condition Assessment Program (TxCAP). (2009) "Overall, Interstate, and Non-Interstate Assessments." Prepared by Maintenance Division, Traffic Division, and Construction Division, Austin, Texas.

Zietlow, G. (2004) "Using Micro-Enterprises to Create Local Contracting Capacity: The Latin American Experience in Road Maintenance." www.zietlow.com/docs/Using%20Micro-Enterprises-05.pdf, Accessed December 6, 2008.

Zietlow, G. (2004) "Implementing Performance-based Road Management and Maintenance Contracts in Developing Countries: An Instrument of German Technical Cooperation." Eschborn, Germany. http://www.zietlow.com/docs/PBMMC-GTZ.pdf, Accessed December 6, 2008.

APPENDIX A

TXDOT RESPONSES TO PERFORMANCE STANDARDS

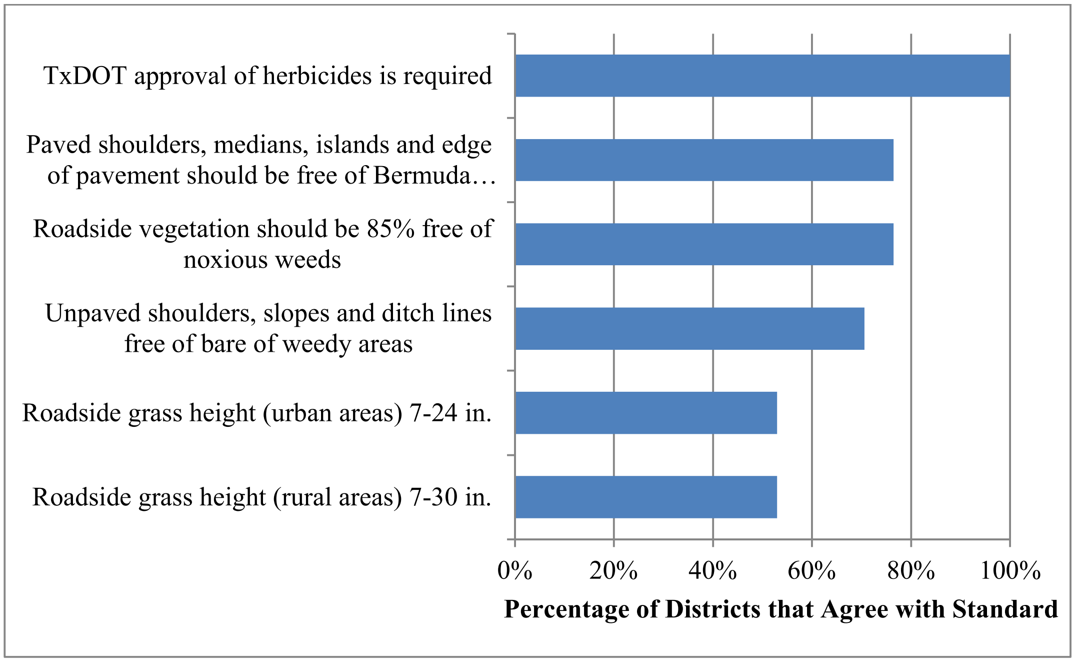

Figure A-1 Mowing and Roadside Grass Performance Standards

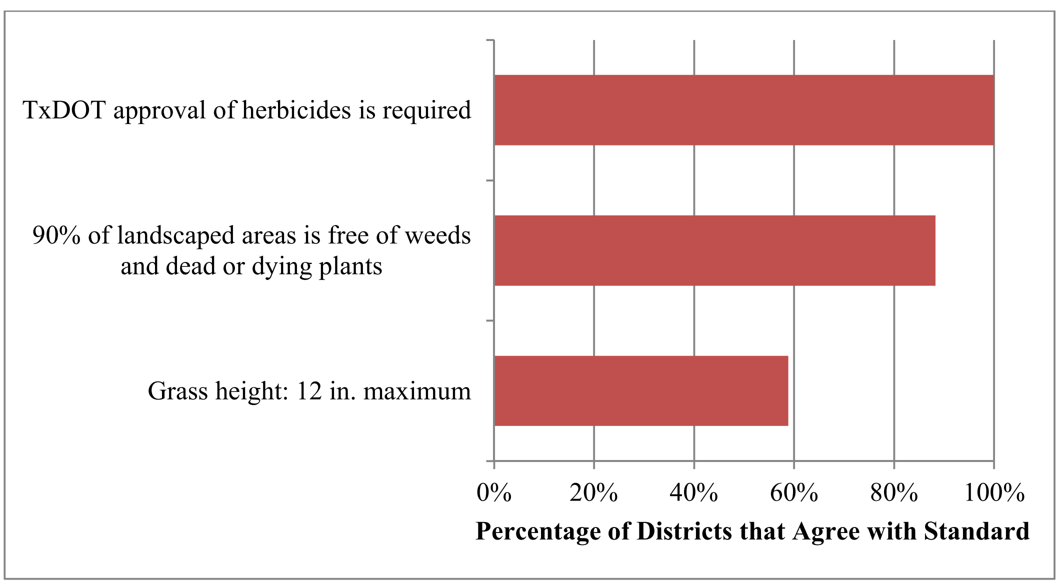

Figure A-2 Landscaped Areas Performance Standards

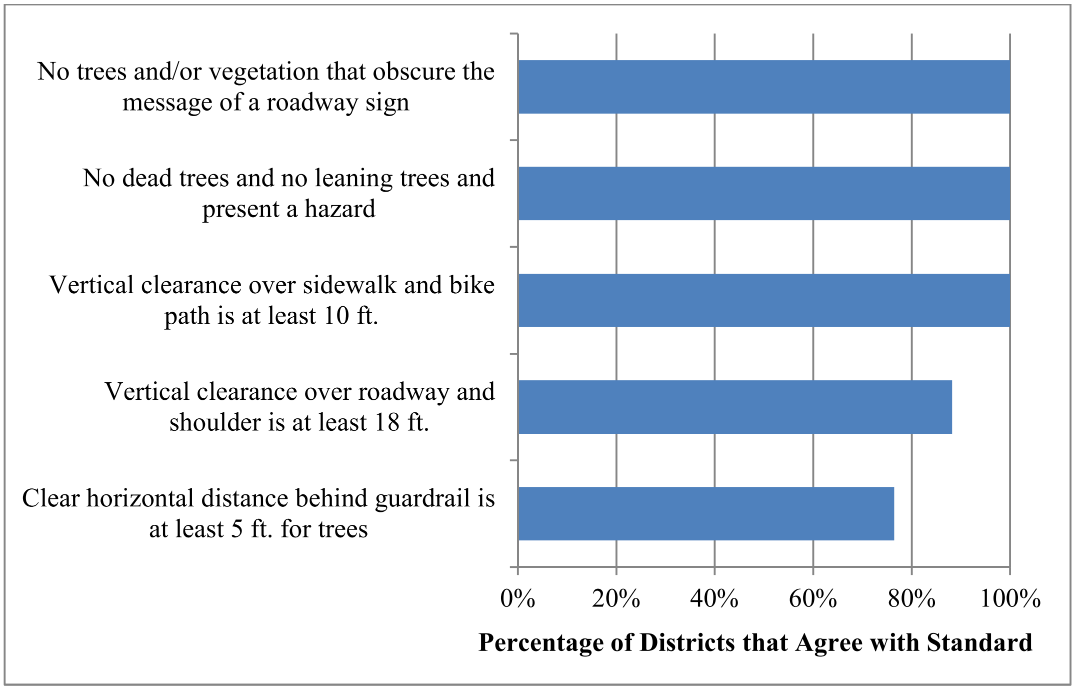

Figure A-3 Trees, Shrubs, and Vines Performance Standards

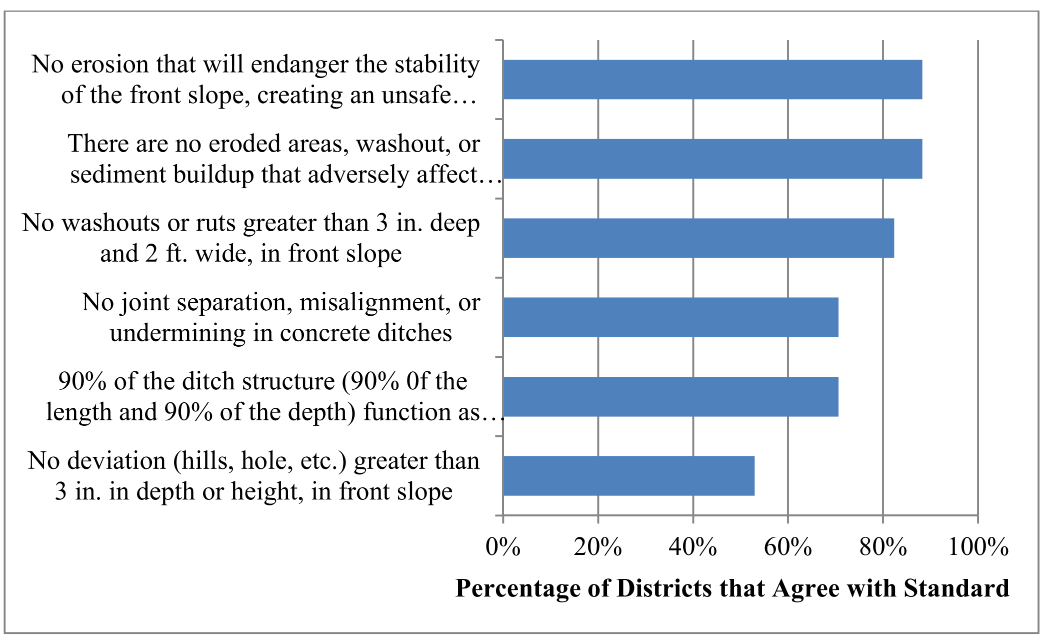

Figure A-4 Ditches and Front Slopes Performance Standards

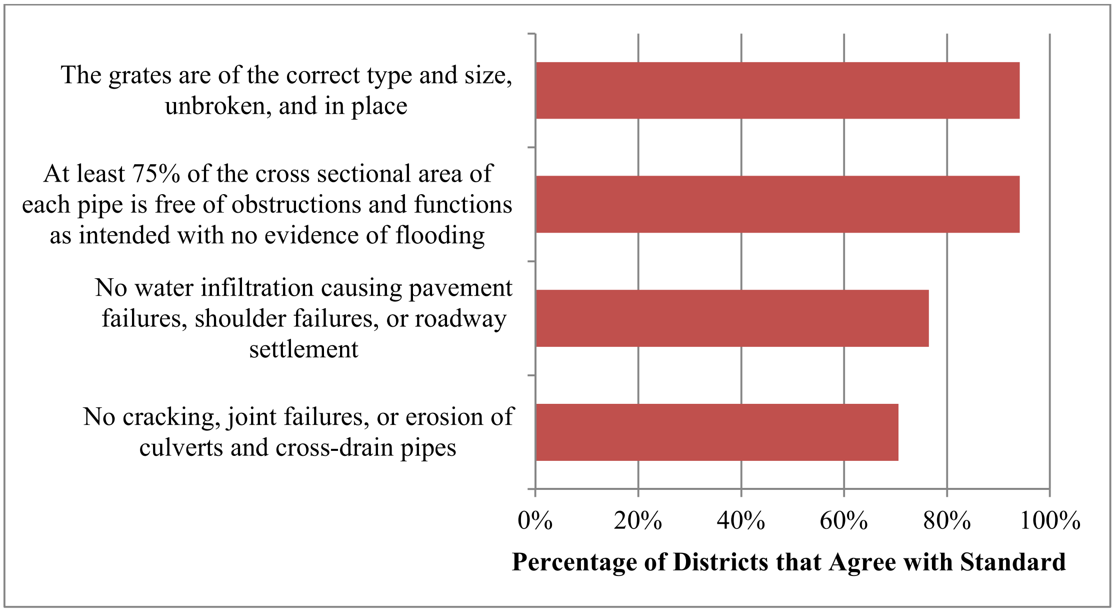

Figure A-5 Culverts and Front Slopes Performance Standards

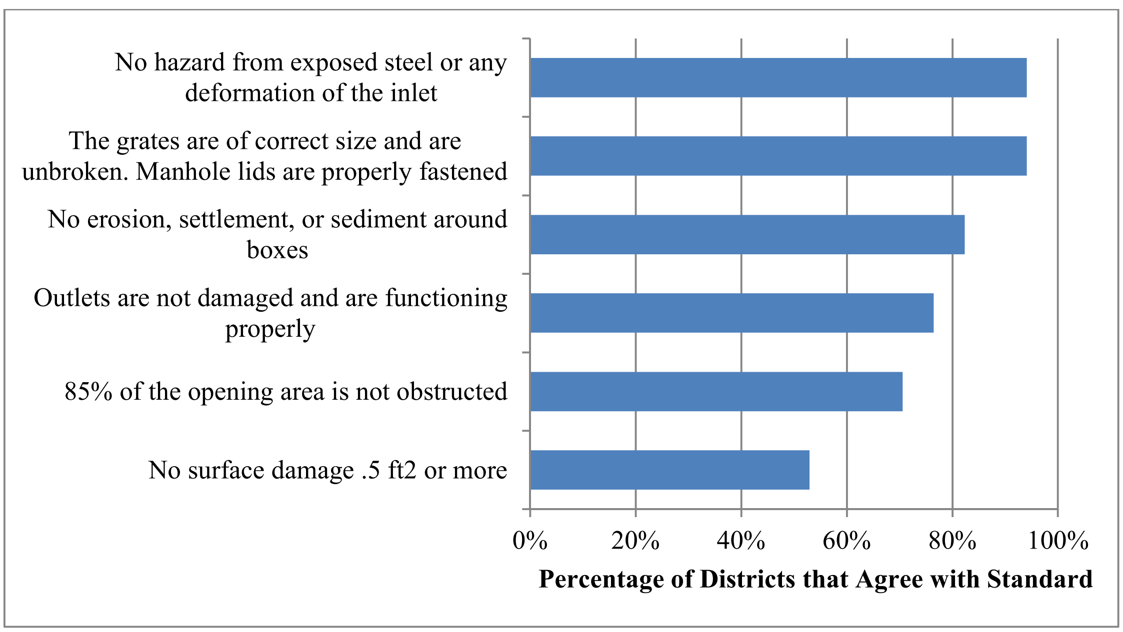

Figure A-6 Drain Inlets Performance Standards

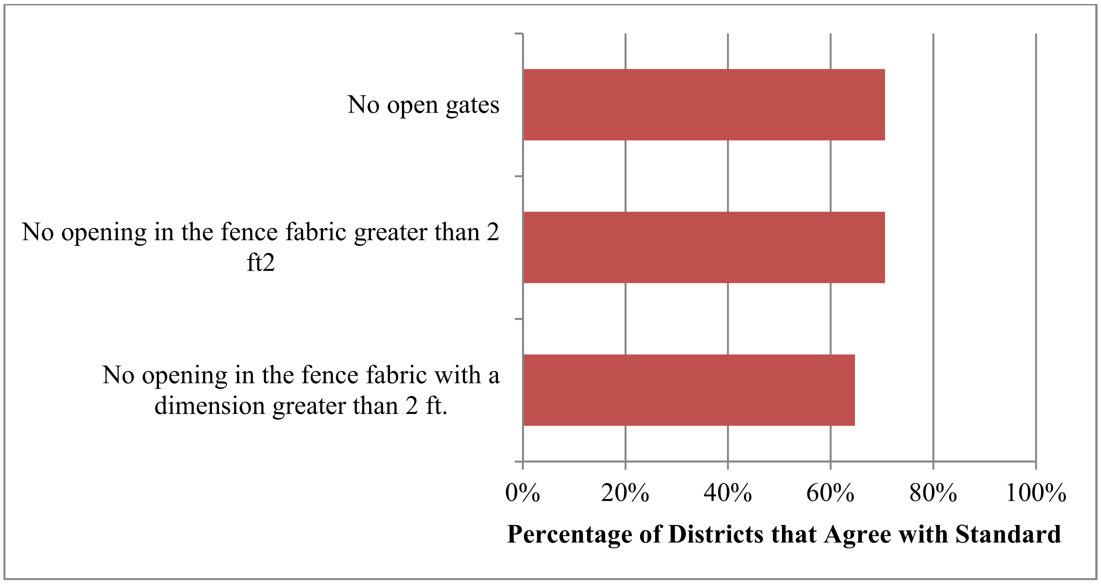

Figure A-7 Chain Link Fence Performance Standards

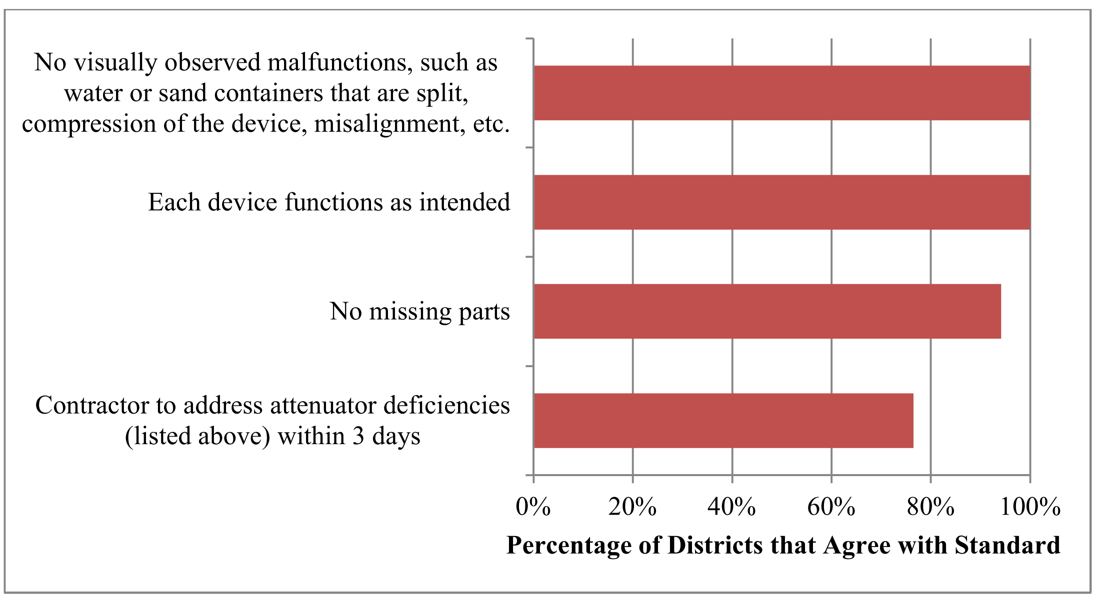

Figure A-8 Attenuators Performance Standards

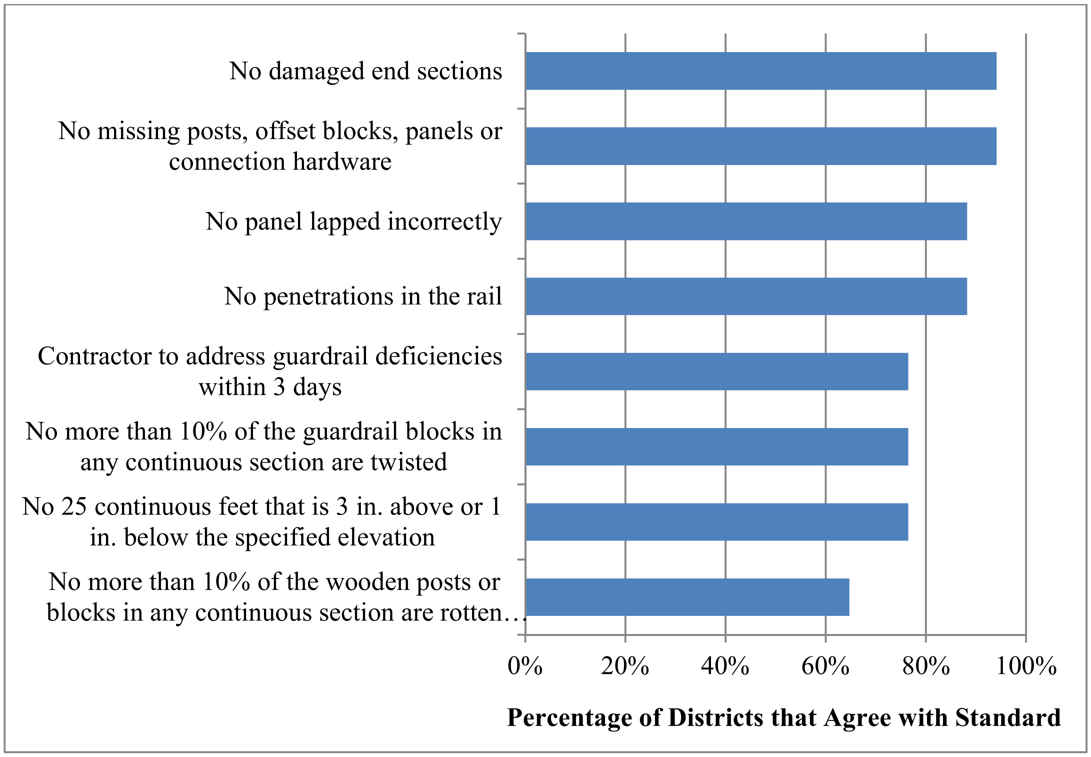

Figure A-9 Guardrails Performance Standards

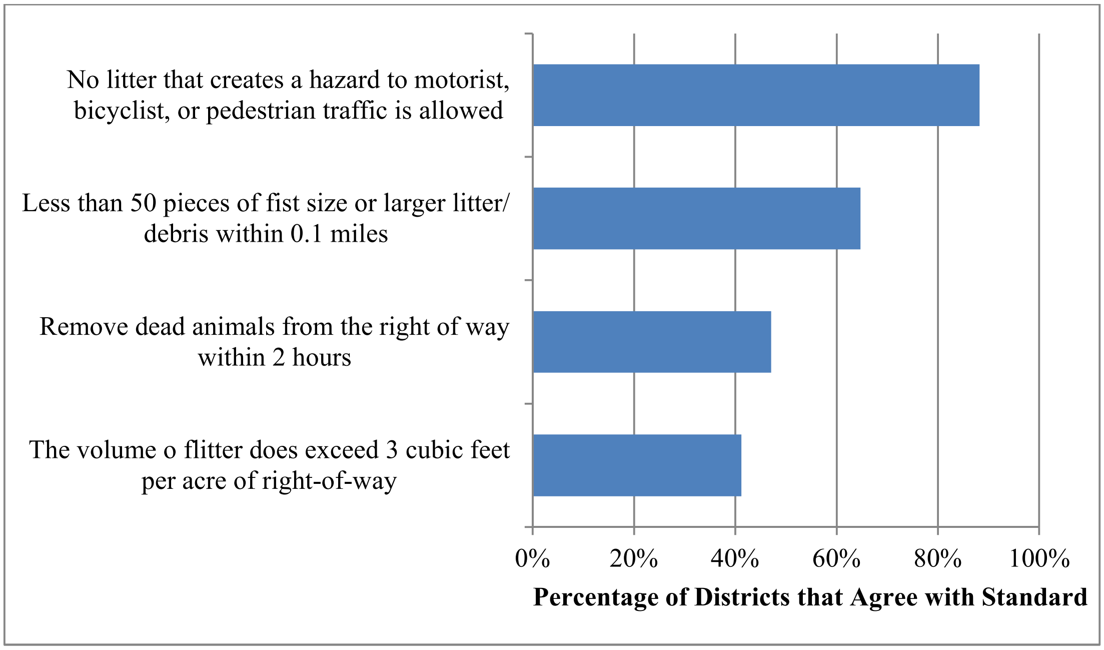

Figure A-10 Litter and Debris Removal Performance Standards

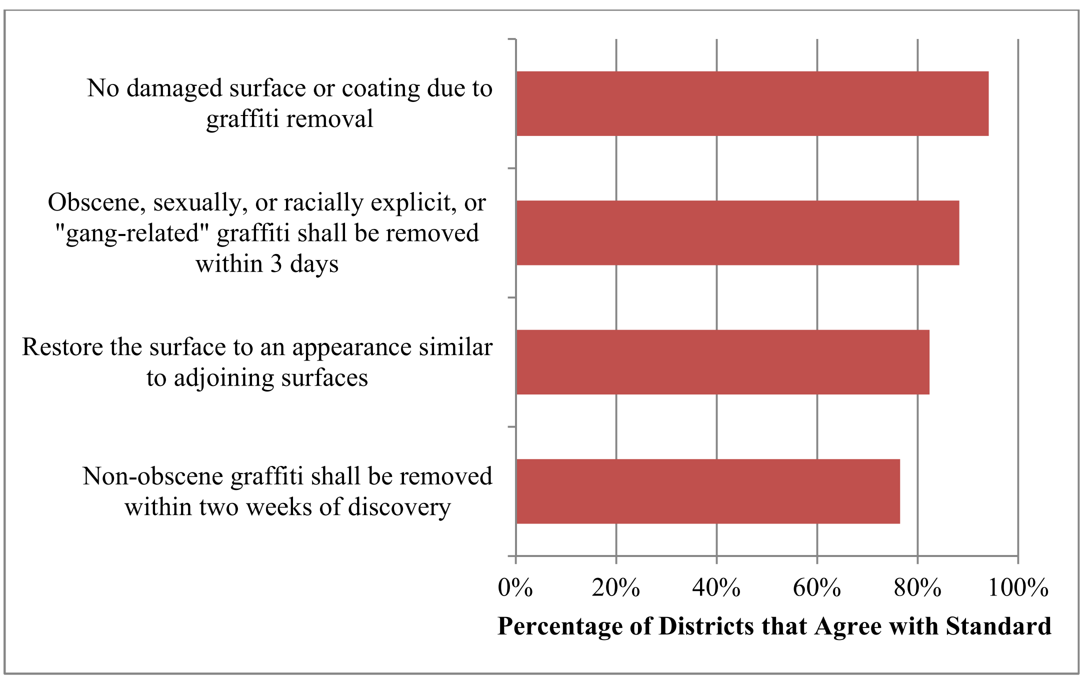

Figure A-11 Graffiti Removal Performance Standards

APPENDIX B

TXDOT RESPONSES TO PROJECT TARGET VALUES

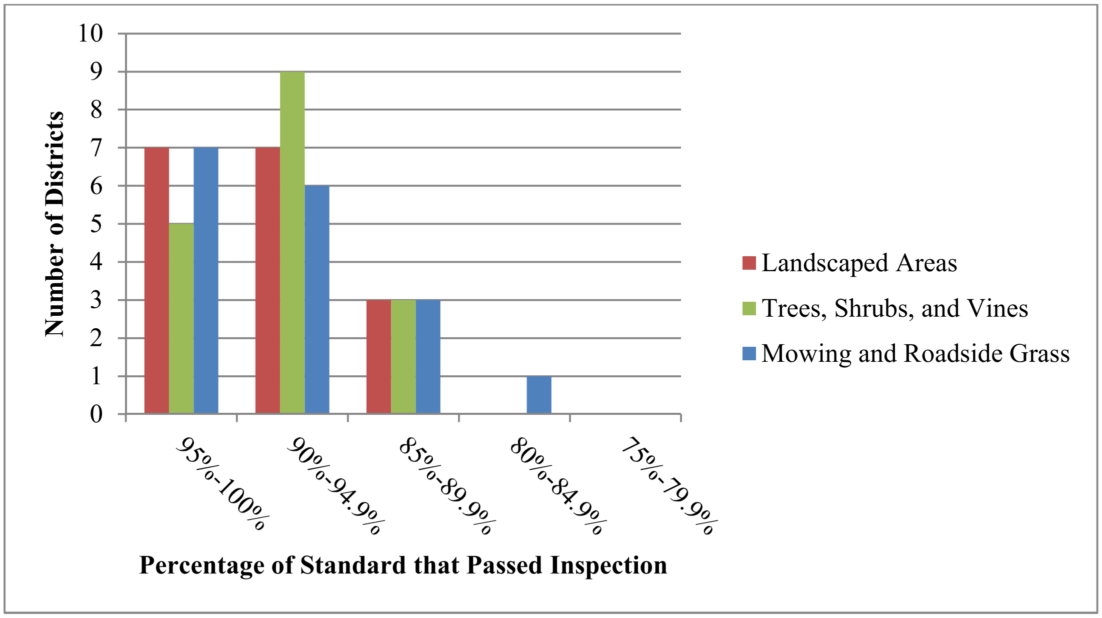

Figure B-1 Vegetation Performance Targets

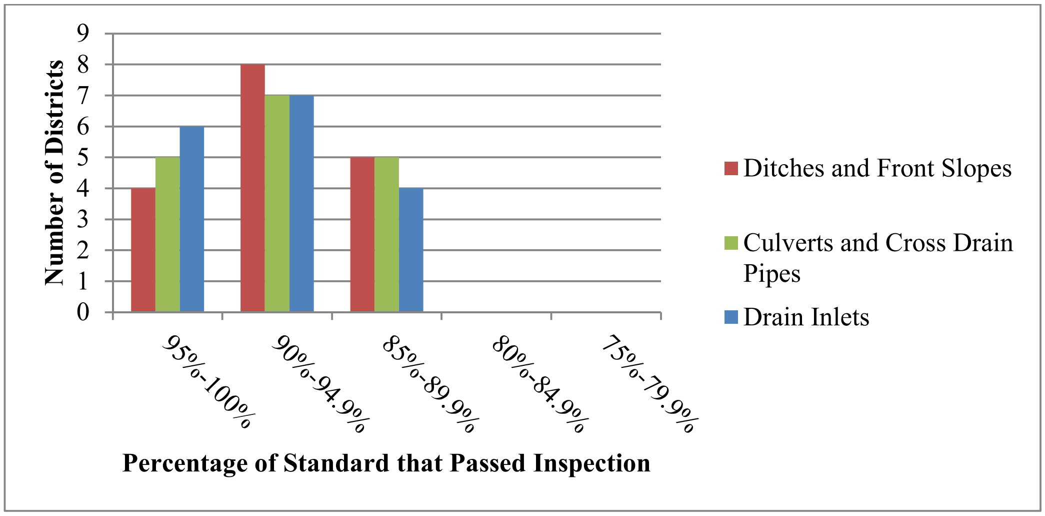

Figure B-2 Drainage Performance Targets

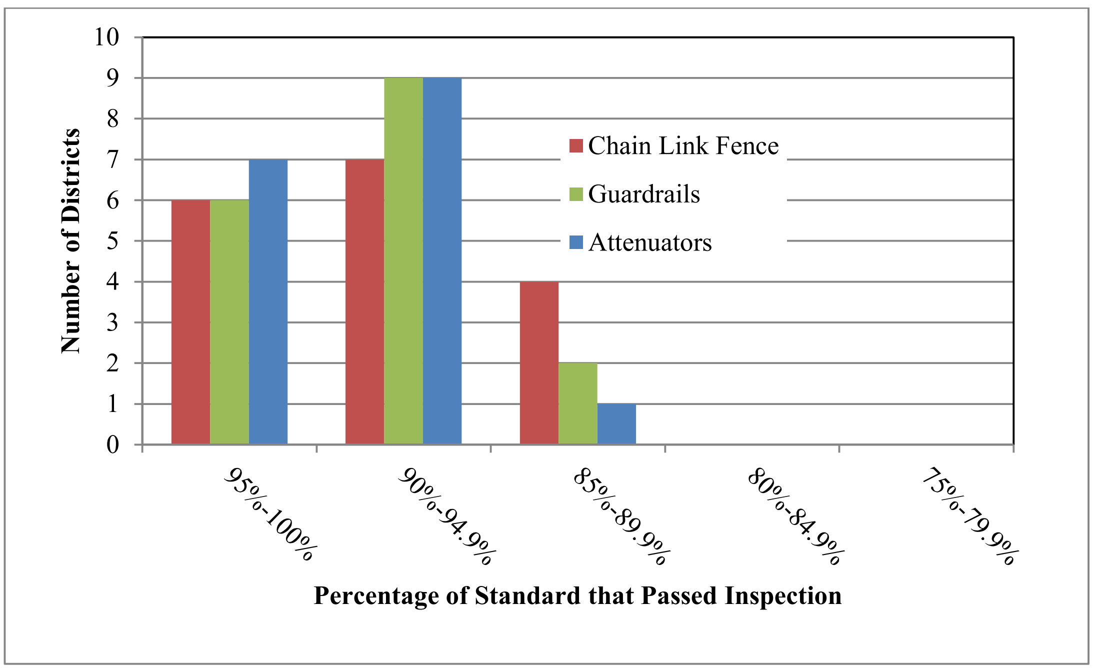

Figure B-3 Safety Performance Targets

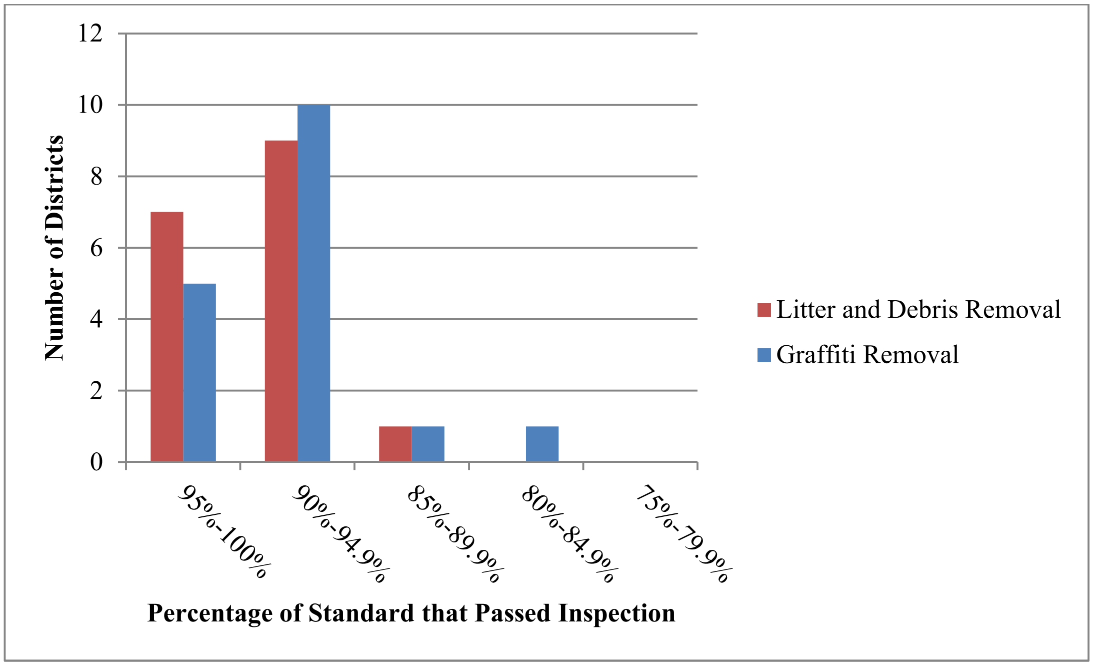

Figure B-4 Cleanness Performance Targets

APPENDIX C

TXDOT RESPONSES TO RISK

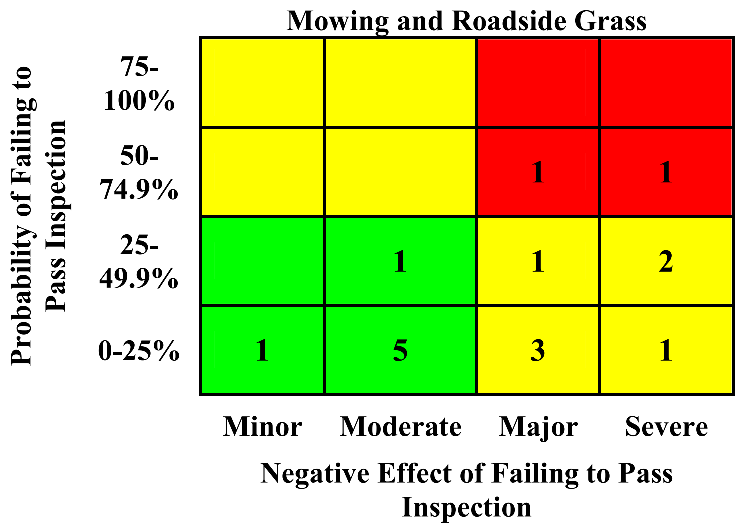

Figure C-1 Mowing and Roadside Grass Risk

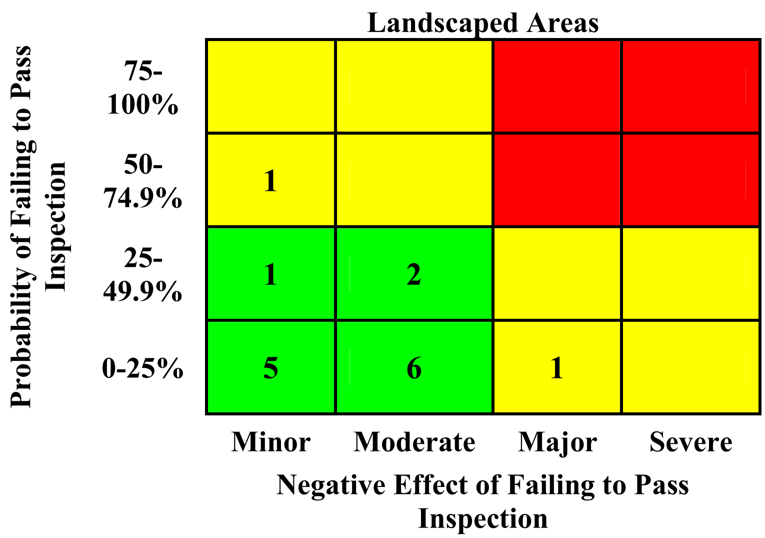

Figure C-2 Landscaped Areas Risk

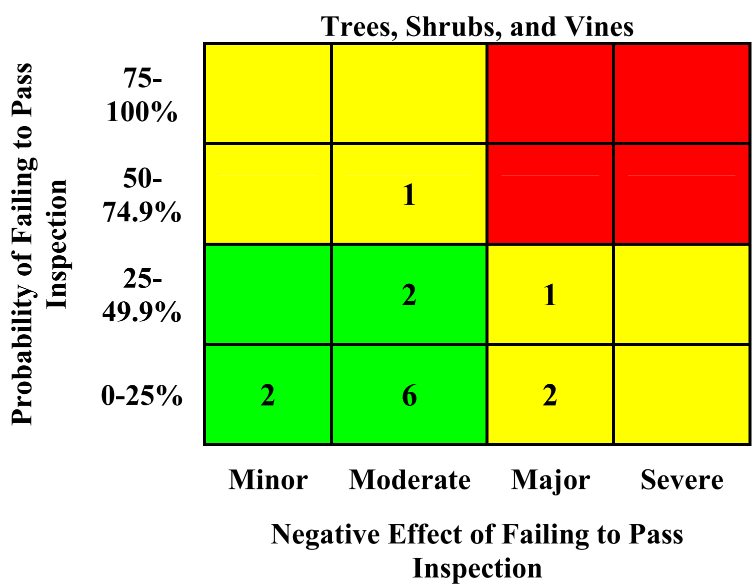

Figure C-3 Trees, Shrubs, and Vines Risk

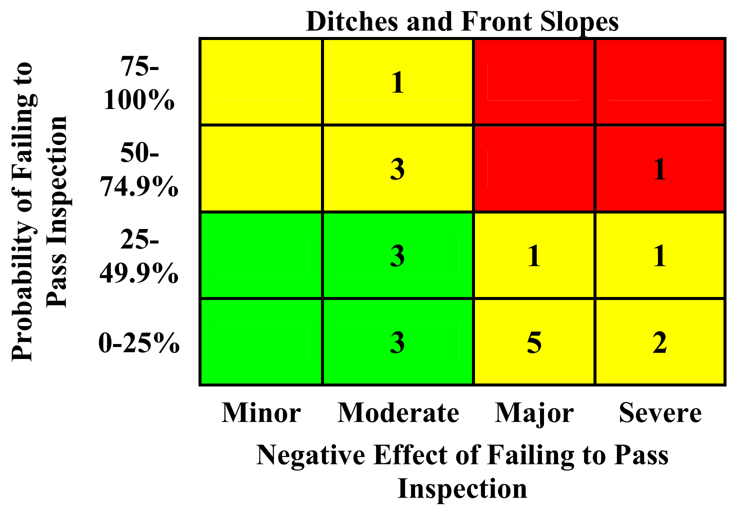

Figure C-4 Ditches and Front Slopes Risk

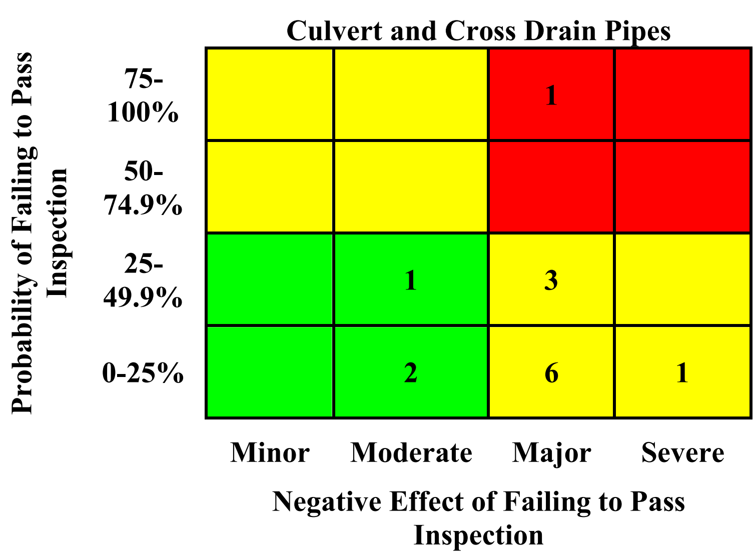

Figure C-5 Culvert and Cross Drain Pipes Risk

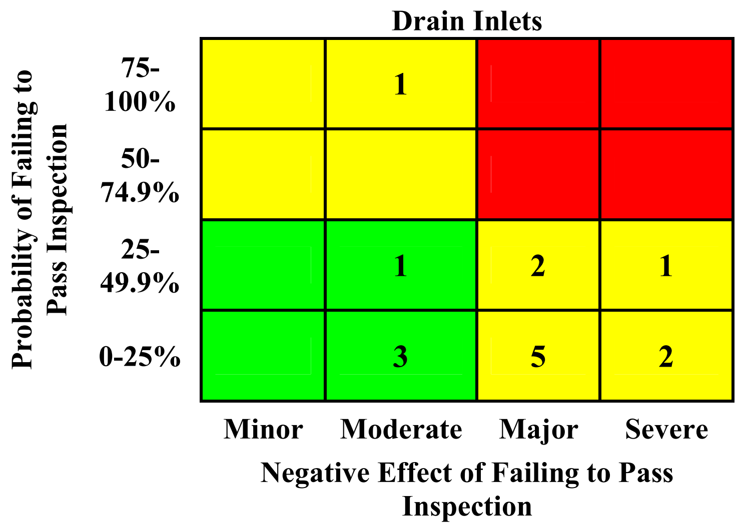

Figure C-6 Drain Inlets Risk

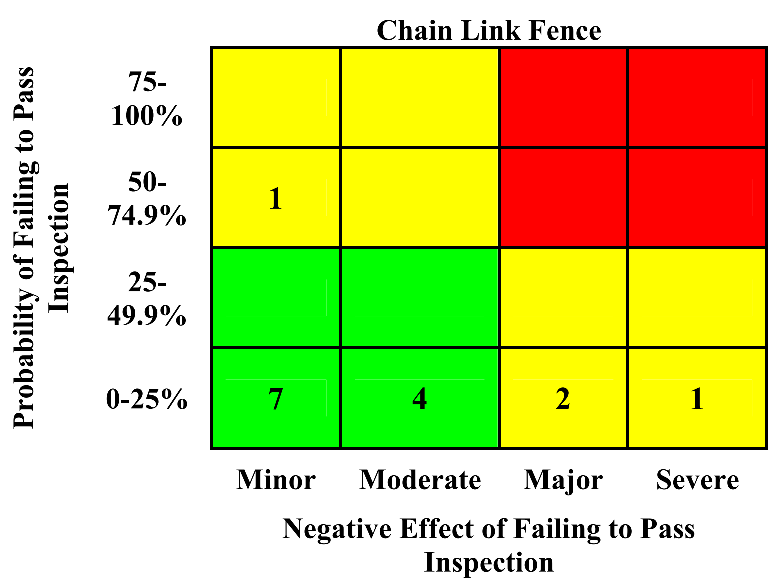

Figure C-7 Chain Link Fence Risk

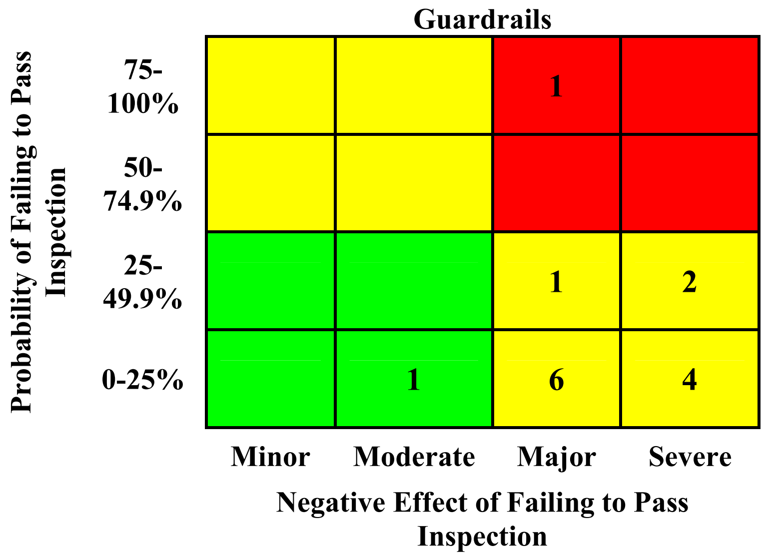

Figure C-8 Guardrails Risk

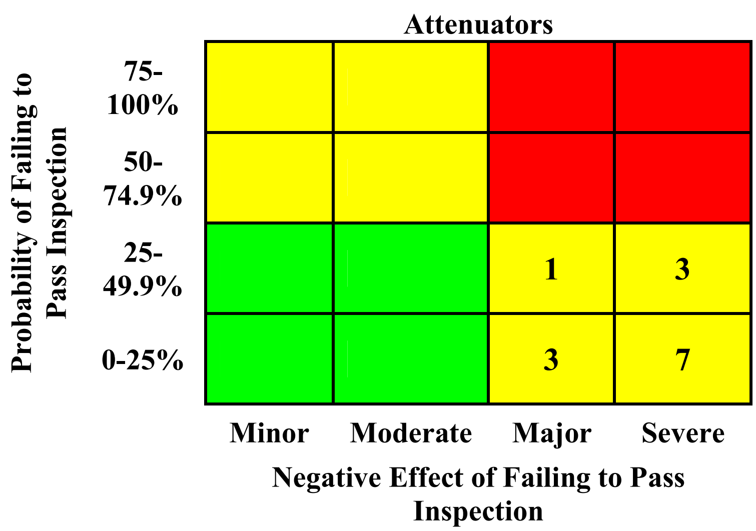

Figure C-9 Attenuators Risk

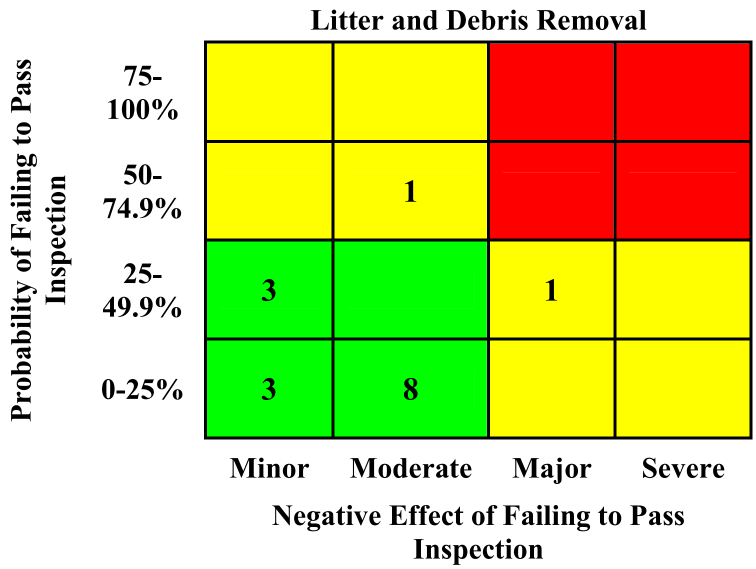

Figure C-10 Litter and Debris Removal Risk

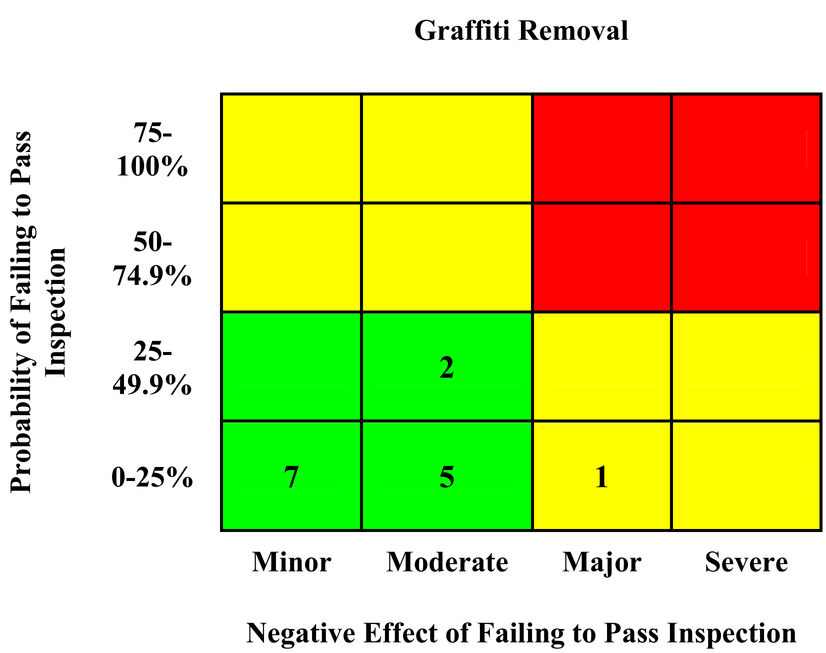

Figure C-11 Graffiti Removal Risk

APPENDIX D

TXDOT RESPONSES TO PAY ADJUSTMENTS AND SAMPLING

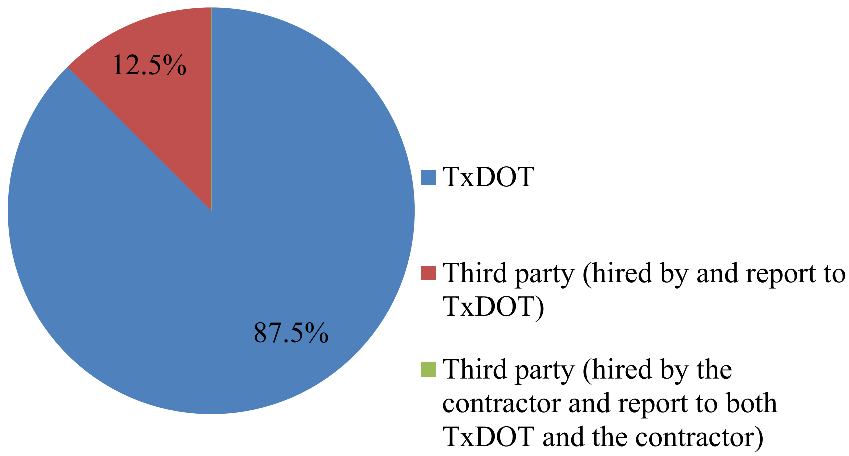

Figure D-1 Party Responsible for Inspections

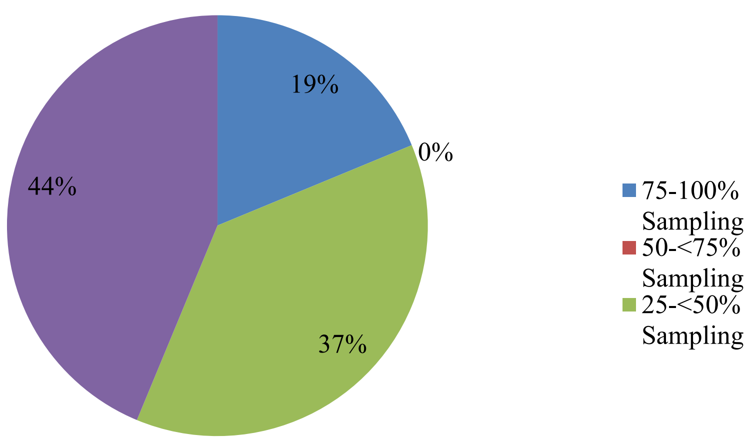

Figure D-2 Sampling Rate

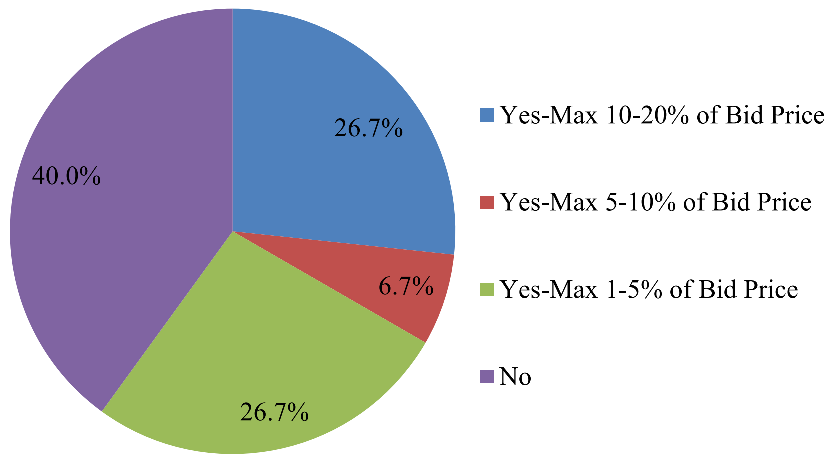

Figure D-3 Use of Incentives

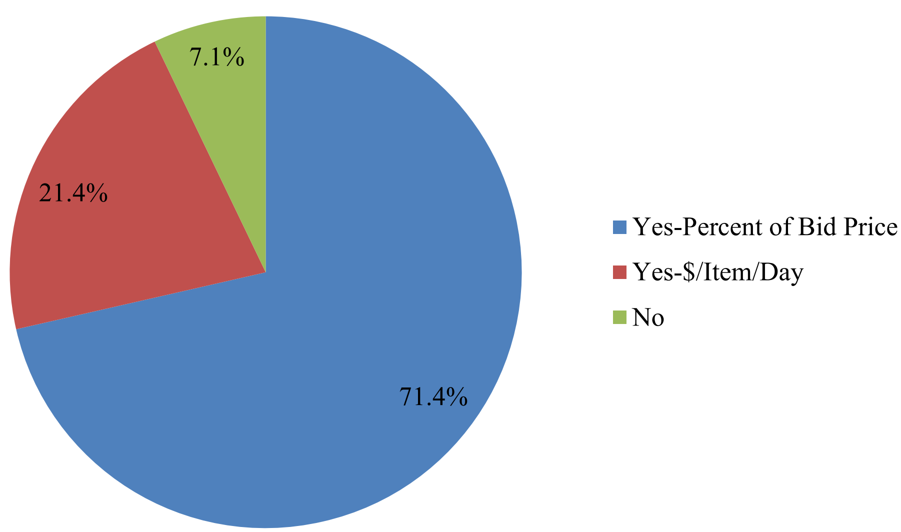

Figure D-4 Use of Disincentives

APPENDIX E

EXCEL EVOLVER SHEETS

Project Score (PS)	Maint Cost/mi	Project Adjust (PA) Cost	Sum
0	-141.71	9702.29	9560.58
1	-55.13	9600.16	9545.03
2	31.61	9498.03	9529.64
3	118.52	9395.90	9514.42
4	205.59	9293.77	9499.36
5	292.83	9191.64	9484.47
6	380.23	9089.51	9469.74
7	467.79	8987.38	9455.17
8	555.52	8885.25	9440.77
9	643.41	8783.13	9426.53
10	731.46	8681.00	9412.46
11	819.68	8578.87	9398.54
12	908.06	8476.74	9384.80
13	996.61	8374.61	9371.21
14	1085.31	8272.48	9357.79
15	1174.19	8170.35	9344.54
16	1263.22	8068.22	9331.44
17	1352.43	7966.09	9318.52
18	1441.79	7863.96	9305.75
19	1531.32	7761.83	9293.15
20	1621.01	7659.70	9280.71
21	1710.87	7557.57	9268.44
22	1800.89	7455.44	9256.33
23	1891.07	7353.31	9244.38
24	1981.42	7251.18	9232.60
25	2071.93	7149.06	9220.98
26	2162.60	7046.93	9209.53
27	2253.44	6944.80	9198.24
28	2344.44	6842.67	9187.11
29	2435.61	6740.54	9176.15
30	2526.94	6638.41	9165.35

a	0.0819
b	86.498
c	-141.71

Target	**Cost**
95	8814.74

PA Cost: D =a*ΔLOS

a **102.13**

31	2618.43	6536.28	9154.71
32	2710.09	6434.15	9144.24
33	2801.91	6332.02	9133.93
34	2893.90	6229.89	9123.79
35	2986.05	6127.76	9113.81
36	3078.36	6025.63	9103.99
37	3170.84	5923.50	9094.34
38	3263.48	5821.37	9084.85
39	3356.28	5719.24	9075.53
40	3449.25	5617.12	9066.37
41	3542.38	5514.99	9057.37
42	3635.68	5412.86	9048.53
43	3729.14	5310.73	9039.86
44	3822.76	5208.60	9031.36
45	3916.55	5106.47	9023.02
46	4010.50	5004.34	9014.84
47	4104.61	4902.21	9006.82
48	4198.89	4800.08	8998.97
49	4293.33	4697.95	8991.28
50	4387.94	4595.82	8983.76
51	4482.71	4493.69	8976.40
52	4577.64	4391.56	8969.21
53	4672.74	4289.43	8962.17
54	4768.00	4187.30	8955.31
55	4863.43	4085.17	8948.60
56	4959.02	3983.05	8942.06
57	5054.77	3880.92	8935.68
58	5150.69	3778.79	8929.47
59	5246.77	3676.66	8923.42
60	5343.01	3574.53	8917.54
61	5439.42	3472.40	8911.82
62	5535.99	3370.27	8906.26
63	5632.73	3268.14	8900.86
64	5729.62	3166.01	8895.63
65	5826.69	3063.88	8890.57
66	5923.91	2961.75	8885.67
67	6021.31	2859.62	8880.93
68	6118.86	2757.49	8876.35
69	6216.58	2655.36	8871.94

70	6314.46	2553.23	8867.69
71	6412.51	2451.10	8863.61
72	6510.72	2348.98	8859.69
73	6609.09	2246.85	8855.94
74	6707.63	2144.72	8852.34
75	6806.33	2042.59	8848.91
76	6905.19	1940.46	8845.65
77	7004.22	1838.33	8842.55
78	7103.41	1736.20	8839.61
79	7202.77	1634.07	8836.84
80	7302.29	1531.94	8834.23
81	7401.97	1429.81	8831.79
82	7501.82	1327.68	8829.50
83	7601.83	1225.55	8827.39
84	7702.01	1123.42	8825.43
85	7802.35	1021.29	8823.64
86	7902.85	919.16	8822.01
87	8003.52	817.03	8820.55
88	8104.35	714.91	8819.25
89	8205.34	612.78	8818.12
90	8306.50	510.65	8817.15
91	8407.82	408.52	8816.34
92	8509.31	306.39	8815.70
93	8610.96	204.26	8815.22
94	8712.77	102.13	8814.90
95	8814.75	0.00	8814.75
96	8916.89	-102.13	8814.76
97	9019.19	-204.26	8814.93
98	9121.66	-306.39	8815.27
99	9224.29	-408.52	8815.78
100	9327.09	-510.65	8816.44

VITA

Name: Debora Brooke Shelton

Address: 3136 TAMU College Station, TX 77843-3136

Email Address: brooke.shelton@sbcglobal.net

Education: B.S., Civil Engineering, Texas A&M University, 2009
M.S., Civil Engineering, Texas A&M University, 2010