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16. Abstract

This report documents the work performed during Project 0-6387, "Performance Based Roadside Maintenance Specifications." Quality assurance methods and specifications for roadside performance-based maintenance contracts (PBMCs) were developed for potential use by TxDOT. These methods include a set of performance standards and timeliness requirements, a statistical condition assessment method for evaluating compliance with these performance standards, and a method for developing performance-based pay adjustment formulas. The developed performance standards, condition assessment method, and pay adjustment formulas were tested and refined using field trials. The field trials consisted of five 10-mi roadway segments located in TxDOT's Dallas, El Paso, San Antonio, Tyler, and Waco Districts. Finally, current practices in best-value bid evaluation methods for procuring PBMCs were identified and evaluated using simulation techniques.

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DEVELOPMENT OF PERFORMANCE-BASED EVALUATION METHODS AND SPECIFICATIONS FOR ROADSIDE MAINTENANCE

by

Nasir G. Gharaibeh
Assistant Professor
Assistant Research Engineer

Debora (Brook) Shelton
Graduate Student Researcher

Jubair Ahmed
Graduate Student Researcher

Arif Chowdhury
Assistant Research Engineer

and

Paul E. Krugler
Research Engineer

Texas Transportation Institute
Texas A&M University

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The Researcher in charge of the project was Nasir G. Gharaibeh, P.E. (Ohio License Number 68391).

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CHAPTER 1. INTRODUCTION AND RESEARCH SIGNIFICANCE

BACKGROUND

Performance-based specifications are increasingly being used for roadway maintenance as an alternative to method-based specifications. With performance-based maintenance contracts (PBMCs) and specifications, the agency (i.e., owner) specifies measurable performance standards, targets, and timeliness requirements that the maintenance contractor is required to meet throughout the contract period. Performance standards are short descriptive statements of the physical condition required for each roadway asset type. Stankevich et al. (2005) suggested that performance standards should be measured using indicators that are SMART (Specific, Measurable, Achievable, Realistic, and Timely to schedule). Performance targets represent the desired overall level of service (LOS) of a roadway. Timeliness is the timeframe within which a roadway deficiency must be corrected. Typically, performance-based maintenance contracts extend over 3–10 years, divided into an initial term and subsequent renewals (Pakkala 2005).

Several departments of transportation (DOTs) in the U.S. and internationally are using PBMCs, such as Virginia DOT (VDOT), Texas DOT (TxDOT), Florida DOT (FDOT), North Carolina DOT (NCDOT), and the District of Columbia DOT (DCDOT) (Hyman 2009, Arnold et al. 2009). Roadway PBMCs have also been used abroad. Since the mid 1990s, PBMCs have been used in 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).

Stankevich et al. (2005) and Pakkala (2002) suggested several reasons that might motivate a highway agency to consider PBMCs: 1) reduced maintenance cost through economy of scale; 2) augmentation of agency expertise; 3) improved customer satisfaction; 4) securing long-term (multi-year) funding for maintenance programs; 5) encouraging contractor's innovation; 6) development of a new industry; and 7) sharing of performance risk with contractors. However, these desired benefits remain conjectures that need to be proved using objective data from actual PBMC implementation projects.

The Texas Department of Transportation (TxDOT) began to use the private sector in roadway maintenance in the 1970s (in mowing contracts). In the late 1990s, TxDOT awarded two pilot multi-year roadway maintenance contracts that have performance-based aspects: approximately 60 centerline miles (400 lane miles) of IH-20 in the Dallas District and 120 centerline miles (1000 lane miles) of IH-35 in the Waco District (Texas Comptroller of Public Accounts 2001). In this research project, TxDOT is investigating the use of performance-based specifications and contracts in roadside maintenance. TxDOT's Maintenance Operations Manual (TxDOT 2005) defines roadside as the areas between the outside edges of the shoulders and the right-of-way boundaries. On multi-lane highways, the median and/or outer separations are included. Diverse maintenance activities are performed on the roadside, such as litter pickup, vegetation management, roadside drainage maintenance, culverts and storm drains maintenance and repair, barrier maintenance, and guardrail repair.

PROBLEM STATEMENT AND OBJECTIVES

There is a general agreement in the literature that the key to the success of PBMCs is clearly defined performance requirements, a sound condition assessment method for evaluating compliance with these requirements, a rational performance-based pay adjustment system, and a best-value bid evaluation method (Hyman 2009, Stankevich et al. 2005, Schexnayder et al. 1997). However, PBMCs are still relatively new, and researchers have not adequately addressed these issues in the literature.

There is a need for consensus on how to define performance requirements (i.e., what performance standards, timeliness, and targets should be used) and how to measure performance (i.e., what condition assessment methods should be used for evaluating the contractor's compliance with the performance requirements). Also, there is a need for optimum pay adjustment formulas that motivate the contractor to maintain the roadway assets at the target performance level specified by the highway agency. Finally, because PBMCs extend over multiple years (typically 3-10 years) and shift the risk of failing to meet performance standards and targets to contractors, it is critical that contractors be selected based on a form of best-value method rather than the conventional low-bid method.

The goal of this research is to develop formal quality assurance methods and specifications for performance-based roadside maintenance for possible use by TxDOT. This entails the following objectives:

1. Develop performance standards and timeliness requirements for roadside maintenance.

2. Develop a condition assessment method for evaluating the contractor's compliance with the performance requirements.
3. Develop a methodology for establishing performance-based pay adjustment systems.
4. Prepare performance-based roadside maintenance specifications for potential use by TxDOT.
5. Evaluate current methods for identifying best-value bid with optimum combination of price and technical quality for roadside PBMCs.

WORKPLAN

The objectives of this research project were achieved by executing the tasks described in the following sections.

Task 1: Define Feasible Scope and Performance Requirements for Roadside PBMCs

Roadside assets and maintenance activities that are most amenable to PBMCs and performance standards and timeliness requirements for these activities and assets were developed based on an online survey of TxDOT's districts and a review of the literature.

Task 2: Develop Roadside Condition Assessment Method

A condition assessment method suitable for the roadside performance standards (identified in Task 1) was developed by customizing existing roadway level of service (LOS) assessment methods.

Task 3: Develop a Method for Optimizing Pay Adjustment System

A methodology for developing optimum pay adjustment formulas was developed. This methodology is designed to motivate the contractor to perform at the desired performance target (specified by the agency) through both incentives and disincentives.

Task 4: Prepare Performance-Based Specifications for Roadside Maintenance

Based on the results of Tasks 1 through 3, draft performance-based roadside maintenance specifications were developed. The initial draft specifications were tested in field trials (as discussed in Task 5.

Task 5: Evaluate the Developed Quality Assurance Methods Using Field Trials

The developed performance standards, condition assessment method, and optimum pay adjustment formulas were tested and then refined using field trials. The field trials consisted of five 10-mi roadway segments located in TxDOT's Dallas, El Paso, San Antonio, Tyler, and Waco Districts.

Task 6: Evaluate Current Best-Value Bid Evaluation Methods for Procuring PBMCs

Current practices in best-value bid evaluation methods for procuring PBMCs were identified. The theoretical soundness and possible drawbacks of these existing methods were evaluated using simulation techniques.

REPORT ORGANIZATION

This report documents the research efforts outlined in Tasks 1 through 6 and is organized in six chapters as follows:

- Chapter 1 presents the background of the research problem and describes the research objectives and scope.
- Chapter 2 focuses on identifying roadside maintenance assets and activities that are the most amenable to PBMCs and the performance standards for these assets and activities.
- Chapter 3 presents the developed roadside condition assessment methods.
- Chapter 4 presents a method for developing pay adjustment systems for PBMCs.
- Chapter 5 discusses and evaluates five case studies of best-value bid evaluation methods for PBMCs.
- Chapter 6 presents the conclusions and recommendations of this study.

In each chapter, a review of relevant national and international literature was conducted to identify the current state-of-the-practice as well as the current state-of-the-art in the subject matter, so that existing limitations can be identified and improvements can be made.

CHAPTER 2. PERFORMANCE STANDARDS

Figure 2-1 illustrates the process used for determining performance standards most amendable to roadside PBMCs. The primary steps of this process are discussed as follows.

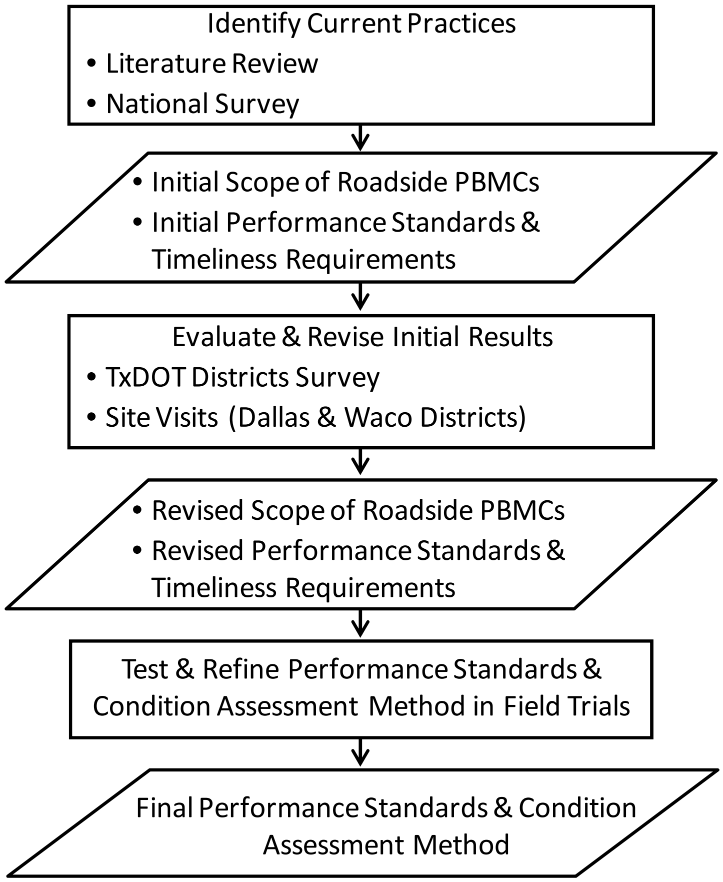

Figure 2-1. Process for Developing Performance Standards for PBMCs.

CURRENT PRACTICES

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. Thus, a questionnaire was sent to 31 state DOTs currently implementing roadway maintenance quality assurance and performance-based specifications. These agencies were chosen 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). The questionnaire was designed to determine the specification's type (performance-based vs. conventional) and maintenance provider (private contractors vs. in-house services) for 14 roadside asset types and maintenance activities. Additionally, the questionnaire included a request to provide the research team with available relevant information such as specifications, manuals, and research reports. Also, the state DOTs were given the opportunity to provide comments on their experience with PBMCs.

Thirteen of the contacted state DOTs (AL, CA, CO, FL, IN, NC, NY, OK, PA, SC, TN, WI, WY) responded to the questionnaire (representing a 42 percent response rate). Table 2-1 illustrates the responses. Based on these responses and a review of the literature, current practices in quality assurance and performance-based specifications for roadside maintenance can be grouped into two categories as follows:

- **Performance-based Specifications for Contracted Maintenance:** The questionnaire revealed that the state DOTs of Florida and North Carolina use PB specifications for roadside maintenance under comprehensive roadway asset management contracts. While Virginia DOT did not respond to the questionnaire, it is known that it has 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 provided some suggestions for state DOTs that are considering adopting PB specifications for roadway maintenance: 1) know what your own forces are capable of "performing" via performance standards prior to adopting PB specifications, 2) implement PB specifications gradually; perhaps starting with one section of road or one corridor, before adopting PB specifications at the statewide level, and 3) include both incentives and disincentives.

- **MQA Programs for In-house Maintenance:** MQA Programs for In-house Roadside Maintenance: Several state DOTs have implemented maintenance quality assurance programs for their in-house maintenance services (also known as maintenance auditing programs). These MQA programs have some aspects of PB specifications, including performance standards and targets. TxDOT's TXMAP is an example MQA program. Of the state DOTs that have responded to the questionnaire, Tennessee DOT, Indiana DOT, and Caltrans have MQA programs. Alabama is in the process of developing one (a draft MQA program has been developed). Additionally, the literature review indicated that Washington State DOT, Ohio DOT, and Utah DOT have MQA programs.

Table 2-1. Usage of Performance-Based Specifications for Roadside Maintenance (Based on Response to a National 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 Pickup	FL, NC	FL, NY, PA, WIS	CA, IN, NC	PA, SC, WY
Debris Pickup (such as tires, appliances, dead animals, etc.)	FL	AL, FL, NY, NC, WIS	CA, IN	NC, PA, SC, WY
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

Based on the results of this national survey and review of the literature, initial performance standards and timeliness requirements were established. TxDOT's 25 districts were surveyed to obtain feedback on these initial performance standards and timeliness requirements, and other aspect of PBMCs. These surveys are discussed in the following section of this report.

FEEDBACK FROM TXDOT'S DISTRICTS

The researchers of this study conducted an online survey of all TxDOT districts to collect feedback on these initial performance standards and timeliness requirements, contract duration, project size, inspection practices, and incentives/disincentives for roadside maintenance. Appendix A shows the full survey instrument. Responses were received from 17 districts out of TxDOT's 25 districts, representing a 68 percent response rate. Figure 2-2 shows these 17 districts. The positions held by the personnel 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; the second part covered the contract aspects.

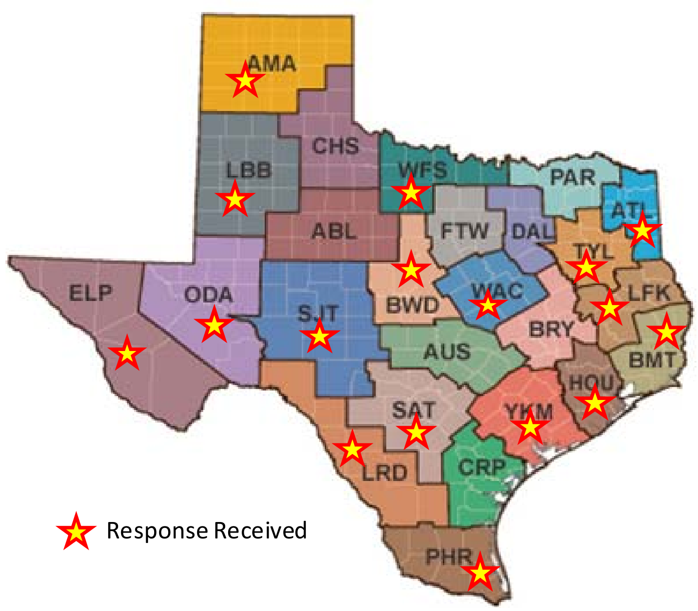

Figure 2-2. Districts Responded to the Online Survey.

For illustration purposes, the roadside asset types and maintenance activities included in the survey are grouped as follows:

- Vegetation-related: Mowing and Roadside Grass; Landscaped Areas; Trees, Shrubs and Vines.
- Safety-related: Attenuators; Guard Rails; Chain Link Fence.
- Drainage-related: Ditches and Front Slopes; Culvert and Cross-Drain Pipes; Drain Inlets.
- Cleanness-related: Removal of Litter and Debris; Removal of Graffiti.

The results of the districts' survey regarding feasible performance standards are summarized in Tables 2-3 through 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 percent 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 percent of the respondents agreed with these 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%

Table 2-3. Initial 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%
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. Initial 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%

Table 2-5. Initial 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 mi	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%

Table 2-5. Initial Cleanness-Related Performance Standards (cont.).

Roadside Asset Type/Maintenance Activity	Performance Standard	%Agree with Standard
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 2 weeks of discovery	75%

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. These comments explain 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-link 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.

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 right-of-way (ROW) in rural areas.

Risk charts were developed to assess the performance risk for each of the 11 roadside asset types and maintenance activities. The respondents assigned a subjective value to the probability of failing inspection (y-axis in the risk chart). Also, they assigned a description to the consequences of failing the inspection as minor, moderate, major, severe (x-axis of the risk chart). These descriptions represent the consequences of failing to meet the performance standards to the public and TxDOT. Appendix B shows the risk charts for each roadside asset type and maintenance activity included in this study. Based on where the majority of respondents placed each roadside asset type and maintenance activity in the risk charts, the performance risk for these asset types and maintenance activities can be described as follows:

- Mowing and Roadside Grass: Low-Moderate
- Landscaped Areas: Low
- Trees, shrubs and Vines: Low
- Ditches and Front Slopes: Moderate
- Culvert and Cross-Drain Pipes: Moderate
- Drain Inlets: Moderate
- Chain Link Fence: Low
- Guard Rails: Moderate
- Attenuators: Moderate
- Removal of Litter and Debris: Low
- Removal of Graffiti: Low

Thus, none of the proposed performance standards is expected to pose a high risk of familiar and thus are considered achievable. However, the initial standards were revised based on the districts' comments and two on-site interviews with the Waco and Dallas districts. The revised performance standards and timeliness requirements (timeframe with which the contractor must correct deficiencies before penalty is applied) are shown in Tables 2-6 through 2-9.

Table 2-6. Vegetation-Related Performance Standards and Timeliness Requirements.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Roadside Grass	1. Any use of herbicide requires advance approval of the Engineer. 2. Paved areas (shoulders, medians, islands, slope, and edge of pavement) shall be free of grass 3. Roadside vegetation in the mowing area shall be at least 85% free of noxious weeds (undesired vegetation) 4. In rural areas, roadside grass height shall be maintained below 24 inches and shall not be cut to below 7 inches. 5. In urban areas, roadside grass height shall be maintained below 18 inches and shall not be cut to below 7 inches. 6. Unpaved areas (shoulders, slopes, and ditch lines) shall be free of bare or weedy areas	7 days
Landscaped Areas	1. Any use of herbicide requires advance approval of the Engineer. 2. Landscaped areas shall be maintained to be 90 percent free of weeds and dead or dying plants. 3. Grass height in landscaped areas shall be maintained at a maximum height of 12 inches.	7 days
Trees, Shrubs and Vines	1. No trees or other vegetation shall obscure the message of a roadway sign. 2. No leaning trees presenting a hazard shall remain on the roadside. 3. Vertical clearance over sidewalks and bike paths shall be maintained at 10 ft or more. 4. Vertical clearance over roadways and shoulders shall be maintained at 18 ft or more. 5. Clear horizontal distance behind guardrail shall be at least 5 ft for trees. 6. No dead trees shall remain on the roadside.	7 days

Table 2-7. Drainage-Related Performance Standards and Timeliness Requirements.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Ditches and Front Slopes	1. Ditches and front slopes shall be maintained free of eroded areas, washouts, or sediment buildup that adversely affects water flow. 2. Erosion shall not endanger stability of the front slope, creating an unsafe recovery area. 3. Front slopes shall not have washouts or ruts greater than 3 inches deep and 2 ft wide. 4. No part of the ditch can have sediment or blockage covering more than 10% of the depth and width of the ditch 5. Concrete ditches shall not be separated at the joints, misaligned, or undermined. 6. Front slopes shall not have holes or mounds greater than 6 inches in depth or height.	7 days
Culvert and Cross-Drain Pipes	1. A minimum of 75% of pipe cross sectional area shall be unobstructed and function as designed. There shall be no evidence of flooding if the pipe is obstructed to any degree. 2. Grates shall be of correct type and size, unbroken, and in place. 3. Installations shall not allow pavement or shoulder failures or settlement from water infiltration. 4. Culverts and cross-drain pipes shall not be cracked, have joint failures, or show erosion.	7 days
Drain Inlets	1. Grates shall be of correct size and unbroken. Manhole lids shall be properly fastened. 2. Installation shall not present a hazard from exposed steel or deformation. 3. Boxes shall show no erosion, settlement, or have sediment accumulation. 4. Outlets shall not be damaged and shall function properly. 5. Inlet opening areas shall be a minimum of 85% unobstructed. 6. Installations shall have no surface damage greater than 0.5 square ft.	7 days

Table 2-8. Safety-Related Performance Standards and Timeliness Requirements.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Guard Rails	1. Installations shall be free of missing posts, offset blocks, panels or connection hardware. 2. End sections shall not be damaged. 3. Rails shall not be penetrated. 4. Panels shall be lapped correctly. 5. No more than 10% of guard rail blocks in any continuous section shall be twisted. 6. No 25-foot continuous section shall be more than 3 inches above or 1 inch below the specified elevation. 7. No more than 10% of wooden posts or blocks in any continuous section shall be rotten or deteriorated.	3 days
Attenuators	1. Each device shall be maintained to function as designed. 2. Installations shall have no visually observable malfunctions (examples – split sand or water containers, compression dent of the device, misalignment, etc.) 3. Installations shall have no missing parts.	3 days
Chain Link Fences	1. Installations shall have no open gates. 2. Installations shall have no openings in the fence fabric greater than 1.0 square ft. 3. Installations shall have no openings in the fence fabric with a dimension greater than 1.0 ft.	14 days
Cable Median Barrier	1. Installations shall be free of missing or damaged post, cable, or connections 2. Installations shall be free of missing or damaged end sections 3. Installations shall be free of loose cable or cable with incorrect weave	3 days

Table 2-9. Cleanness-Related Performance Standards and Timeliness Requirements.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Litter and Debris	1. No litter or debris that creates a hazard to motorists, bicyclists, or pedestrians is allowed. 2. No 0.1-mi roadway section shall have more than 50 pieces of fist-size or larger litter or debris on either side of the centerline of the highway. 3. Litter volume shall not exceed 3.0 cubic ft per 0.1-mi roadway section on both sides of the pavement. 4. In rural areas, traffic lanes shall be free of dead large animals. 5. In urban areas, traffic lanes and right of way shall be free of dead animals.	1. In rural areas, remove large dead animals from the traffic lanes within 24 hours. 2. In urban areas, remove dead animals from the right of way within 24 hours.
Graffiti	1. No graffiti is allowed. 2. Surfaces and coatings shall not be damaged by graffiti removal. 3. Surfaces from which graffiti has been removed shall be restored to an appearance similar to adjoining surfaces.	1. Obscene, sexually or racially explicit, or "gang-related" graffiti shall be removed within 3 days. 2. Other graffiti shall be removed within 2 weeks.

Districts Feedback on Other Aspects of PBMCs

The following contract aspects have been included in the districts' survey and subsequent interviews of the Directors of Maintenance in the Waco and Dallas Districts:

- Contract duration.
- Project size.
- Inspection responsibility.
- Amount of inspection.
- Use of incentives and disincentives.

Five respondents prefer long-term contracts (7–10 years) and eight respondents prefer short-term contracts (1–3 years). Only one response indicated that a mid-term contract (4–6 years) is preferred. It appears that the majority of the districts (which have not used PBS) prefer a gradual approach to adopting PBS that starts with short-term contracts. However, the Waco and Dallas interviews revealed that short-term contracts may not be economically attractive to major maintenance contractors. Also, capitalization of equipment requires a minimum contract period of 5 years.

Majority of responses indicated that PBMCs is most suitable for large highway projects (greater than 75 centerline miles). The Waco interview revealed that small projects may not be economically attractive to major maintenance contractors. For example, it may not be economical for the contractor to appoint a full-time project manager for small project (e.g., less than 100 centerline mile in length). However, the Dallas interview suggested that, in small districts, a 100-centerline mile contract may require the inclusion of multiple roadways in the contract (which is normally not preferred by contractors).

The overwhelming majority of the respondents prefer TxDOT's personnel to conduct the performance inspection. About 13 percent of the respondents prefer the inspection to be performed by a third-party that is hired by and reports to TxDOT. The Waco interview revealed that when formal inspection and rating methods 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.

Forty-four percent of the respondents indicated that an inspection rate of 5–25 percent of the project is appropriate. Thirty-seven percent indicated that an inspection rate of 25–50 percent is appropriate. The Dallas interview revealed that an inspection rate of more than 25 percent is excessive and treats PBMCs as method specifications.

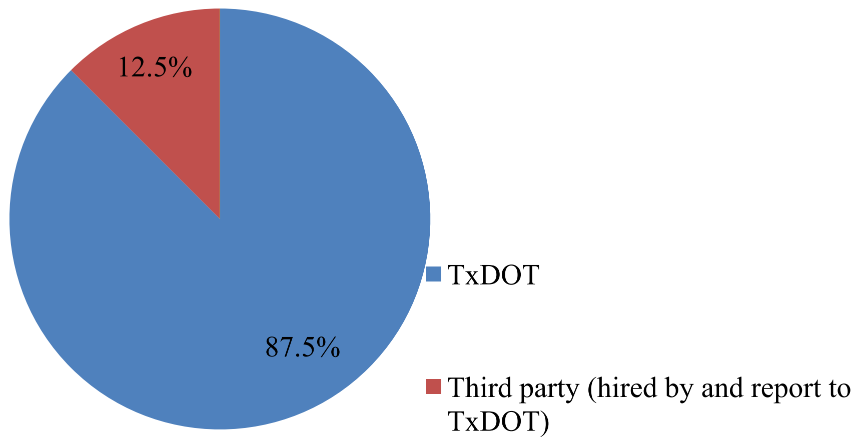

Figure 2-3 Districts Responses to Party Responsible for Inspections.

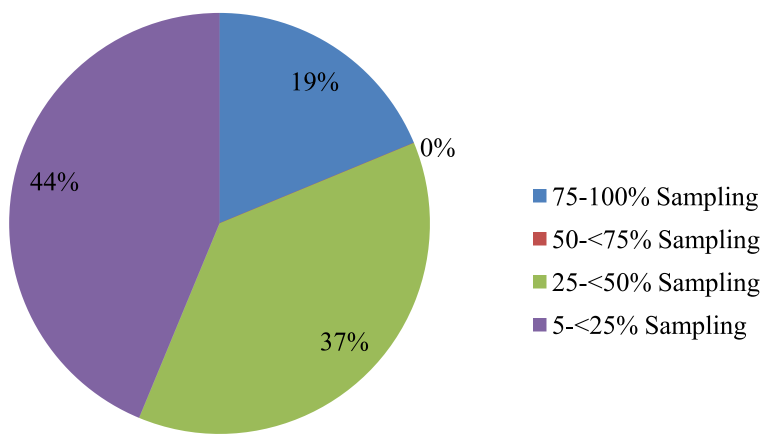

Figure 2-4 Districts Responses to Sampling Rate.

As shown in Figure 2-5, 40 percent of the responses did not agree with assigning incentives (pay increase) for exceeding performance targets. The remaining 60 percent of the responses preferred the use of incentives. For those who preferred the use of incentives, the maximum incentive rate ranged between 1 percent and 20 percent of the bid price. The Waco and Dallas interviews revealed that no incentives were used in Waco's and Dallas's PBMCs contracts. The Waco interview suggested that when the PBMCs 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 required performance targets because "over-performance" is not rewarded.

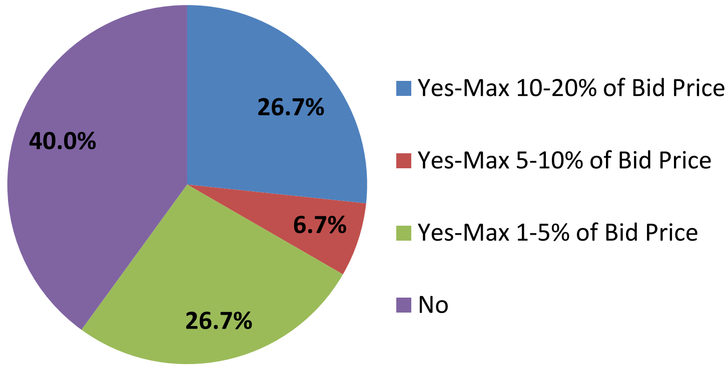

Figure 2-5. Districts Responses to the Use of Incentive Provisions.

As shown in Figure 2-6, the majority of the responses (approximately 93 percent of the responses) 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 a fixed disincentive rate (liquidated damages) of per item per day has been used in both Dallas's and Waco's PBS contracts. 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" disincentive 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.

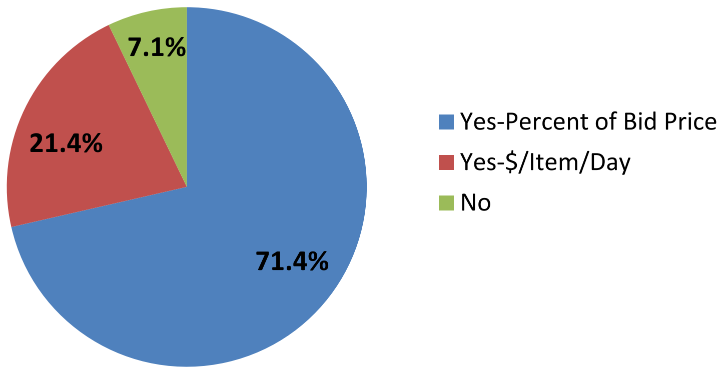

Figure 2-6. Districts Responses to the Use of Disincentive Provisions.

CHAPTER 3. CONDITION ASSESSMENT AND PAY ADJUSTMENT METHODS

BACKGROUND

As part of maintenance quality assurance, the condition of highway assets and maintenance activities under PBMCs should be evaluated regularly using a reliable method. Many highway agencies have implemented the Maintenance Quality Assurance (MQA) process for monitoring the quality of maintenance on their highway systems, for conventional contracts, in-house forces, and PBMCs. A survey of 39 highway agencies in the United States and Canada (located in 36 states and 3 Canadian provinces) found that 83 percent of these agencies have an MQA program (Adam 2004, Schmitt et al. 2006). A reliable condition assessment method is also critical for implementing pay adjustment systems. Howard et al. (1997) suggested that in order for pay adjustments to be effective, there must be a reliable and objective way to measure performance. Therefore, a roadside condition monitoring system that is customized to the performance standards 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 TxDOT's Maintenance Assessment Program (TxMAP), Florida DOT's Maintenance Rating Program (MRP), Tennessee DOT's Maintenance Rating Program, North Carolina DOT's Maintenance Condition Assessment Program, California DOTs (Caltrans) Level of Service Program, Washington State DOT's Maintenance Accountability Process (MAP), and Wisconsin DOT's Compass Program. Florida DOT's MRP process was 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 mi long. For each sample unit, each asset type (e.g., culverts, drain inlets, etc.) is inspected against a set of performance standards to assign either a passing or failing grade or to assign a numerical score (typically 0–5, with 5 being a perfect score). Both methods allow for the use of weights that represent the agency's priorities.

Since sampling the entire length of a PBMC project to determine a LOS is labor intensive, statistical procedures are often used to determine an appropriate sample size to estimate 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 percent and 15 percent. Schmitt et al. (2006) suggested that a sample size of 2–5 percent is adequate to determine the average condition of a highway network; however, they recommended a sample size of 10–15 percent for determining the distribution of condition and the percentage of the network below (or above) a given target score. While this approach for determining sample size is relatively simple; it may not be justified statistically. In order to correctly define a sampling procedure, de la Garza et al. (2008) suggested that the characteristics of the "overall population, sample units, asset items within each sample unit, and acceptable quality levels must be understood." Several methods have been proposed in the literature 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 size of project or maintenance zone (i.e., population size), estimates of the population variance, desired precision rate, and desired confidence level (Medina et al. 2009, Kardian and Woodward 1990, de la Garza et al. 2008). This approach for determining sample size is founded on basic statistical theory and is adopted in this study. Virginia DOT has used this approach for determining sample size for both PBMC projects and its statewide MQA program (Kardian and Woodward 1990, de la Garza et al. 2008).

CONDITION ASSESSMENT METHOD

Figure 3-1 illustrates the developed LOS assessment method for roadside PBMC projects. The process begins by dividing the PBMC project into sections and then performing visual field inspections (using the developed performance standards) on a randomly selected sample of these sections. The LOS of each sample unit is computed and then aggregated to determine the LOS for the entire project. Finally, pay adjustment is made based on the project LOS and the target LOS (as specified by the owner agency). Appendix C presents roadside maintenance performance-based specifications that encompass this process.

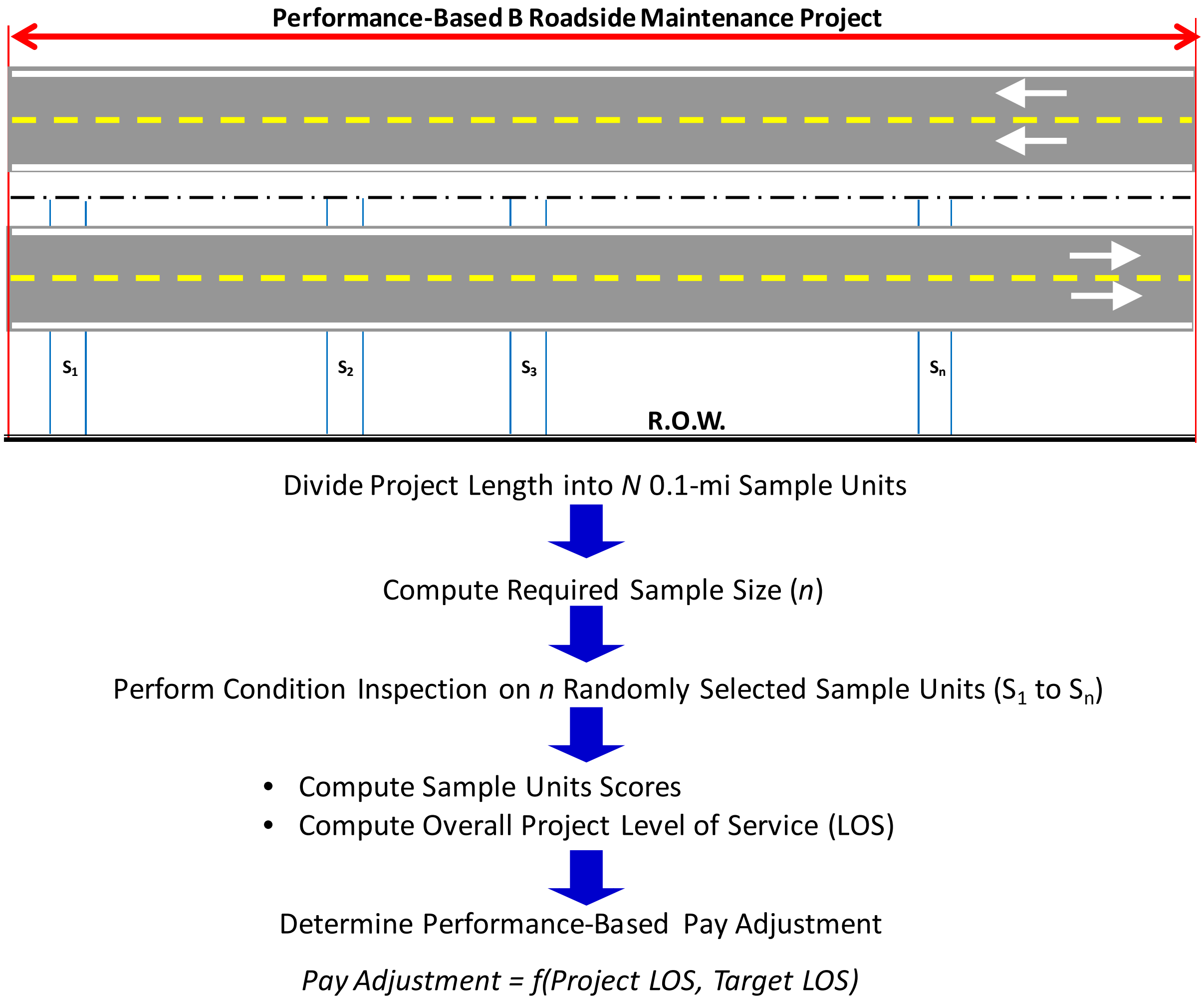

Figure 3-1. Illustration of the Developed LOS Assessment Method for Roadside Maintenance.

The sampling process and LOS computations consist of the following steps:

1. The highway maintenance project is divided into *N* sample units (each is 0.1- to 0.2-mi long).
2. *n* sample units are selected randomly for field survey. The sample size (*n*) is computed as follows:

$$n = \frac{s^2 N}{s^2 + \frac{(N-1)e^2}{Z^2}} \tag{3-1}$$

where *e* = Sampling error, which is the maximum acceptable difference between the true average and the sample average (to be specified by the highway agency); *Z* = Z-statistic associated with a desired confidence level that the error doesn't exceed *e; N* = population size (i.e., total number of sample units in the project); and *s* = estimate of the population's standard deviation. If no historical data exist to estimate s, an s value of 6-11 can be used based on the results of the field trials conducted as part of this study (see Chapter 4 of this report).

3. The randomly selected sample units are inspected and rated on a "Pass/Fail/Not Applicable" basis using the inspection form shown in Figure 3-1. The form includes a total of 57 performance standards for 11 roadside elements (i.e., asset types and maintenance activities).
4. A 0-100 sample unit score (SUS) is computed as a weighted average score for all elements within the sample unit, as follows:

$$SUS = \frac{\sum_{i=1}^{k} \frac{PS_i}{AS_i} \times PM_i}{\sum_{i=1}^{k} 100 \times PM_i} \tag{3-2}$$

   where *PS* is the number of passing performance standards; *AS* is the number of applicable performance standards; *PM* 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 later in this section of the report.
5. A roadside average LOS for the PBMC project is computed, as follows

$$LOS = \overline{SUS} = \frac{\sum_{j=1}^{n} SUS_j}{n} \tag{3-3}$$

   where SUS_j is the sample score for sample unit *j* and *n* is the total number of inspected sample units (i.e., sample size).
6. **Optional Step:** Because the LOS is computed based on a random sample, it is recommended that a confidence interval be computed for the LOS. However, to compute confidence interval for LOS (CI_{LOS}), the probability distribution of SUS must be determined. Data gathered from the field trials (see next section of this report) showed that the SUS follows a Beta probability distribution. The Beta distribution density

function is implemented in many statistical software tools. For example, it can be solved using Microsoft Excel's function *BetaDist*, as follows:

PD = BetaDist(x,α, β, A, B), where *BetaDist* returns cumulative Beta probability density function; x is the SUS variable; α and β define the shape of the curve; A is the SUS lower limit (i.e., zero); and B is the SUS upper limit as a fraction (i.e., 1.0). α and β are computed as functions of the average SUS ($\overline{SUS}$) and the variance of SUS (v_{SUS}) as follows:

$$v_{SUS} = \frac{\sum_{j=1}^{n}(SUS_j - \overline{SUS})^2}{n} \tag{3-4}$$

$$\alpha = \overline{SUS}\left(\frac{\overline{SUS}(1-\overline{SUS})}{v_{SUS}} - 1\right) \tag{3-5}$$

$$\beta = (1-\overline{SUS})\left(\frac{\overline{SUS}(1-\overline{SUS})}{v_{SUS}} - 1\right) \tag{3-6}$$

The confidence interval for any desired confidence level can be determined using the inverse of the Beta distribution. The inverse Beta distribution density function is implemented in many statistical software tools. For example, it can be solved using Microsoft Excel's function *BetaInv*, as follows:

SUS_P = BetaInv(P,α, β, 0, 1), where *BetaDist* returns the SUS that corresponds to probability *P*. For example, the 95 percent confidence interval can be determined as follows:

Lower Bound = $SUS_{2.5\%}$ = BetaInv(0.025,α, β, 0, 1) (3-7)

Upper Bound = $SUS_{97.5\%}$ = BetaInv(0.975,α, β, 0, 1) (3-8)

Inspector's Name:			Inspection Date: Time:	
District:		Highway: Milepoint:	Sample Unit No.: Urban/Rural:	

Roadside Asset Type/Mainten	No.	Performance Standard	Grade (Pass, Fail, NA)
Mowing and Roadside Grass	1	Any use of herbicide requires advance approval of the Engineer.	
	2	Paved areas (shoulders, medians, islands, slope, and edge of pavement) shall be free of grass	
	3	Unpaved areas (shoulders, slopes, and ditch lines) shall be free of bare or weedy areas	
	4	Roadside vegetation in the mowing area shall be at least 85% free of noxious weeds (undesired vegetation)	
	5	In rural areas, roadside grass height shall be maintained below 24 inches and shall not be cut to below 7 inches.	
	6	In urban areas, roadside grass height shall be maintained below 18 inches and shall not be cut to below 7 inches.	
Landscaped Areas	7	Any use of herbicide requires advance approval of the Engineer.	
	8	Landscaped areas shall be maintained to be 90 percent free of weeds and dead or dying plants.	
	9	Grass height in landscaped areas shall be maintained at a maximum height of 12 inches.	
Trees, shrubs and Vines	10	No trees or other vegetation shall obscure the message of a roadway sign.	
	11	No leaning trees presenting a hazard shall remain on the roadside.	
	12	Vertical clearance over sidewalks and bike paths shall be maintained at 10 feet or more.	
	13	Vertical clearance over roadways and shoulders shall be maintained at 18 feet or more.	
	14	Clear horizontal distance behind guardrail shall be at least 5 ft for trees	
	15	No dead trees shall remain on the roadside.	
Ditches and Front Slopes	16	Ditches and front slopes shall be maintained free of eroded areas, washouts, or sediment buildup that adversely affects water flow.	
	17	Erosion shall not endanger stability of the front slope, creating an unsafe recovery area.	
	18	Front slopes shall not have washouts or ruts greater than 3 inches deep and 2 feet wide.	
	19	No part of the ditch can have sediment or blockage covering more than 10% of the depth and width of the ditch	
	20	Concrete ditches shall not be separated at the joints, misaligned, or undermined.	
	21	Front slopes shall not have holes or mounds greater than 6 inches in depth or height.	
Culvert and Cross-Drain Pipes	22	A minimum of 75% of pipe cross sectional area shall be unobstructed and function as designed. There shall be no evidence of flooding if the pipe is obstructed to any degree	
	23	Grates shall be of correct type and size, unbroken, and in place.	
	24	Installations shall not allow pavement or shoulder failures or settlement from water infiltration.	
	25	Culverts and cross-drain pipes shall not be cracked, have joint failures, or show erosion.	
Drain Inlets	26	Grates shall be of correct size and unbroken. Manhole lids shall be properly fastened.	
	27	Installation shall not present a hazard from exposed steel or deformation.	
	28	Boxes shall show no erosion, settlement, or have sediment accumulation.	
	29	Outlets shall not be damaged and shall function properly.	
	30	Inlet opening areas shall be a minimum of 85% unobstructed.	
	31	Installations shall have no surface damage greater than 0.5 square feet.	
Chain Link Fence	32	Installations shall have no open gates.	
	33	Installations shall have no openings in the fence fabric greater than 1.0 square feet.	
	34	Installations shall have no openings in the fence fabric with a dimension greater than 1.0 feet.	
Guard Rails	35	Installations shall be free of missing posts, offset blocks, panels or connection hardware.	
	36	End sections shall not be damaged.	
	37	Rails shall not be penetrated.	
	38	Panels shall be lapped correctly.	
	39	No more than 10% of guard rail blocks in any continuous section shall be twisted.	
	40	No 25-foot continuous section shall be more than 3 inches above or 1 inch below the specified elevation.	
	41	No more than 10% of wooden posts or blocks in any continuous section shall be rotten or deteriorated.	
Cable Median Barrier	42	Installations shall be free of missing or damaged post, cable, or connections	
	43	Installations shall be free of missing or damaged end sections	
	44	Installations shall be free of loose cable or cable with incorrect weave	
Attenuators	45	Each device shall be maintained to function as designed.	
	46	Installations shall have no visually observable malfunctions (examples – split sand or water containers, compression dent of the device, misalignment, etc.)	
	47	Installations shall have no missing parts.	
Litter and Debris	48	1. No litter or debris that creates a hazard to motorists, bicyclists, or pedestrians is allowed.	
	49	2. No 0.1 mile roadway section shall have more than 50 pieces of fist-size or larger litter or debris on either side of the centerline of the highway.	
	50	Litter volume shall not exceed 3.0 cubic feet per 0.1 mile roadway section on both sides of the pavement.	
	51	In rural areas, traffic lanes shall be free of dead large animals.	
	52	In urban areas, traffic lanes and right of way shall be free of dead animals.	
Graffiti	53	No graffiti is allowed	
	54	Surfaces and coatings shall not be damaged by graffiti removal.	
	55	Surfaces from which graffiti has been removed shall be restored to an appearance similar to adjoining surfaces.	

Figure 3-2. Field Inspection Form.

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 3-3 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 B). The vertical axis is the probability that the element will fail inspection and the horizontal axis is an adjective describing the negative consequences of failing to pass inspection (minor, moderate, major, and severe). 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 consequence 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.

Mowing and Roadside Grass

Probability of Failing to Pass Inspection	Minor	Moderate	Major	Severe
75-100%				
50-74.9%			1	1
25-49.9%		1	1	2
0-25%	1	5	3	1

Negative Effect of Failing to Pass Inspection

$$\boldsymbol{Priority\ Multiplier\ (PM) = \frac{(1*1)+(2*6)+(3*5)+(4*4)}{16} = 2.8}$$

Figure 3-3. 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 3-2 shows an example of how to calculate the sample unit score.

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-Link Fence	1.7
Guard Rails	3.3
Cable Median Barrier	3.5
Attenuators	3.7
Litter and Debris	1.7
Graffiti	1.6

Table 3-2. Sample Unit Score Computation Example.

Roadside Element	No. of Applicable Standards	No. of Passed Standards	Priority Multiplier	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 (SUS) = 727.83/1062.8 =	**68.5%**

PAY ADJUSTMENT METHOD

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 = Maintenance Cost + Pay Adjustment

Figure 3-4 illustrates this concept from the perspective of the contractor. In this diagram, incentives are represented as negative cost to the contractor (i.e., pay increase) and disincentives are represented as positive costs (i.e., pay decrease). This method ensures that the pay adjustment curve (incentives/disincentives) and LOS target value are in sync. The inputs to this method are:

- LOS Target (set by TxDOT).
- A model representing the relationship between maintenance cost and project LOS.

Once these inputs are provided, commercially available optimization software tools (or simply trial and error procedures) can be employed to find the pay adjustment curve that ensures that the minimum total cost occurs at the project's target LOS.

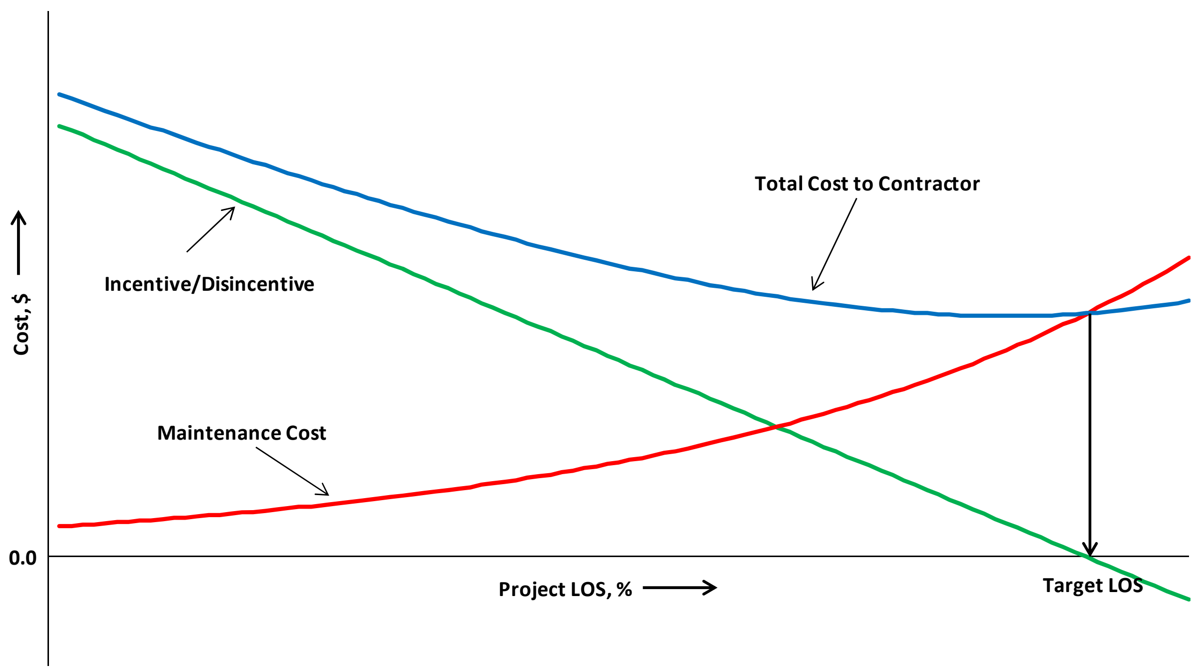

Figure 3-4. Conceptual Model for Determining Optimum Combination of Target and Pay Adjustment.

Once the LOS vs. maintenance cost curve is established and a target LOS is chosen for any given PBMC project, the pay adjustment curve that ensures that the total cost to the contractor occurs at the target LOS can be found. A linear pay adjustment curve can be represented as follows:

$$PA = a \times (T - \overline{LOS}) \tag{3-5}$$

where T is the target LOS and $\overline{LOS}$ is the average LOS for the project (computed based on the results of the field inspection). This formula indicates that at an $\overline{LOS}$ above the target value, the pay adjustment will be negative cost to the contractor (i.e., a pay increase or incentive). However, from the perspective of the agency, a negative pay adjustment represents an additional cost. This optimization problem is constrained by the requirement that the minimum total cost to the contractor must occur at the target value (95 percent). For example, for a 90 percent LOS target (i.e., T=90 percent), the above equation becomes:

$$PA = a \times (90 - \overline{LOS}) \tag{3-6}$$

Curves that represent the relationship between LOS score and maintenance cost to achieve that LOS were developed for the field trials (as discussed in Chapter 4 of this report). A Genetic Algorithm (GA) software tool (named Evolver) was then applied to determine the optimum pay adjustment curve for various LOS targets. Evolver was used to solve for the coefficient "*a*" in Equation 3-5. Evolver is a commercially available GA optimization add-in for Microsoft Excel. 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 generate only valid solutions. However, as mentioned earlier, other optimization techniques can also be used to solve this optimization problem.

Note that the incentives/disincentives developed here complement the liquidated damage rates used in many PBMCs. Liquidated damage rates are intended to recover the damages the agency incurs by the contractor's failure to meet the specifications of the contract. The incentives/disincentives developed here, on the other hand, are designed to motivate the contractor to achieve the target LOS (specified by the agency).

CHAPTER 4. FIELD TRIALS

SITE CHARACTERISTICS AND SURVEY PROCEDURE

The developed performance standards, LOS condition assessment method, and pay adjustment method were tested in five 10-mi highway segments located in five districts of TxDOT (Waco, San Antonio, El Paso, Tyler, and Dallas) (see Figure 4-1). The same team of inspectors (which consisted of one engineer and two engineering technicians) inspected all sites.

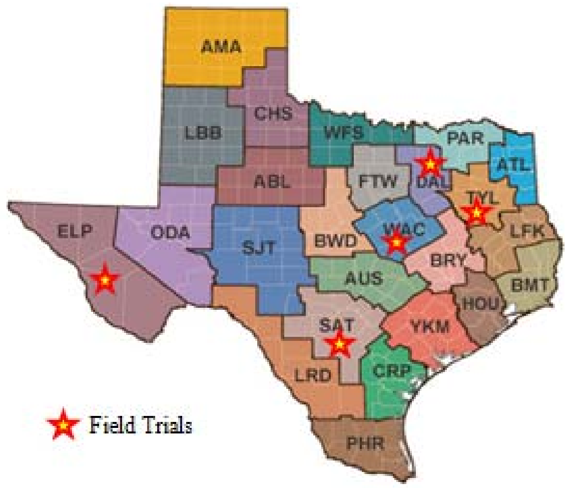

Figure 4-1. Field Trials in TxDOT Districts.

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 4-1 shows relevant characteristics for theses districts, including centerline miles, population, maintenance expenditures, and climate conditions.

Table 4-1. Characteristics of Districts Selected for Field Trials.

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

The research team contacted the districts to select specific highways for the field surveys. Based on discussions with district personnel, the research team selected the beginning and end limits of each site in consultation with the district personnel. Each site is 10-m long. The characteristics of each site are discussed as follows:

- **IH-35 in Waco District:** This is the first field trial and it was performed in November 2010. The site is 10-mi long starting from TRM 351 to 361 and is located between Waco and Hillsboro (see map in Figure 4-2). It is characterized as a rural site and was rated accordingly. The team performed the survey only on the northbound direction of the highway.
- **IH-20 in Tyler District:** This site was surveyed three times: December 2009, February 2010, and April 2010. This site starts at TRM 556 and ends at TRM 566 in Smith County (see map in Figure 3-4). It is characterized as a rural site area and was rated accordingly.
- **IH-35 in San Antonio District:** This 10-mi long segment of IH-10 was surveyed in April 2010. The site is located in the east side of the city of San Antonio, between TRM 582 and 592 in Bexar County (see map in Figure 4-2). Samples closer to TRM 582 were characterized as urban; while the rest were characterized as rural. The entire length had frontage road. Most part of the center median was divided by cable median barrier.
- **IH-35 in Dallas District:** This 10-mi long segment of IH-35E was surveyed in May 2010. The site is located in the north side of the Dallas metropolitan area, between Lewisville and Denton (see map in Figure 4-2). The survey was conducted on the northbound direction only. The entire length was characterized as urban. Due to its proximity to a large city, this site has high traffic volume. The entire length is divided by a concrete barrier at the median, and it has frontage road on both sides.
- **IH-10 in El Paso District:** This 10-mi long segment of IH-10 was surveyed in May 2010. The site is located in the east side of the city of El Paso, between TRM 24 and 34 (see map in Figure 4-2). The survey was conducted on the westbound direction only. The entire length was characterized as urban. This site is significantly different from the four other sites; as it had very little or no vegetation in either median or slopes, and it has a noticeably larger number of overpasses and underpasses. Most of the site was divided by a concrete barrier, and it has a frontage road in both directions throughout its entire length. Similar to the Dallas site, this site has high traffic volume.

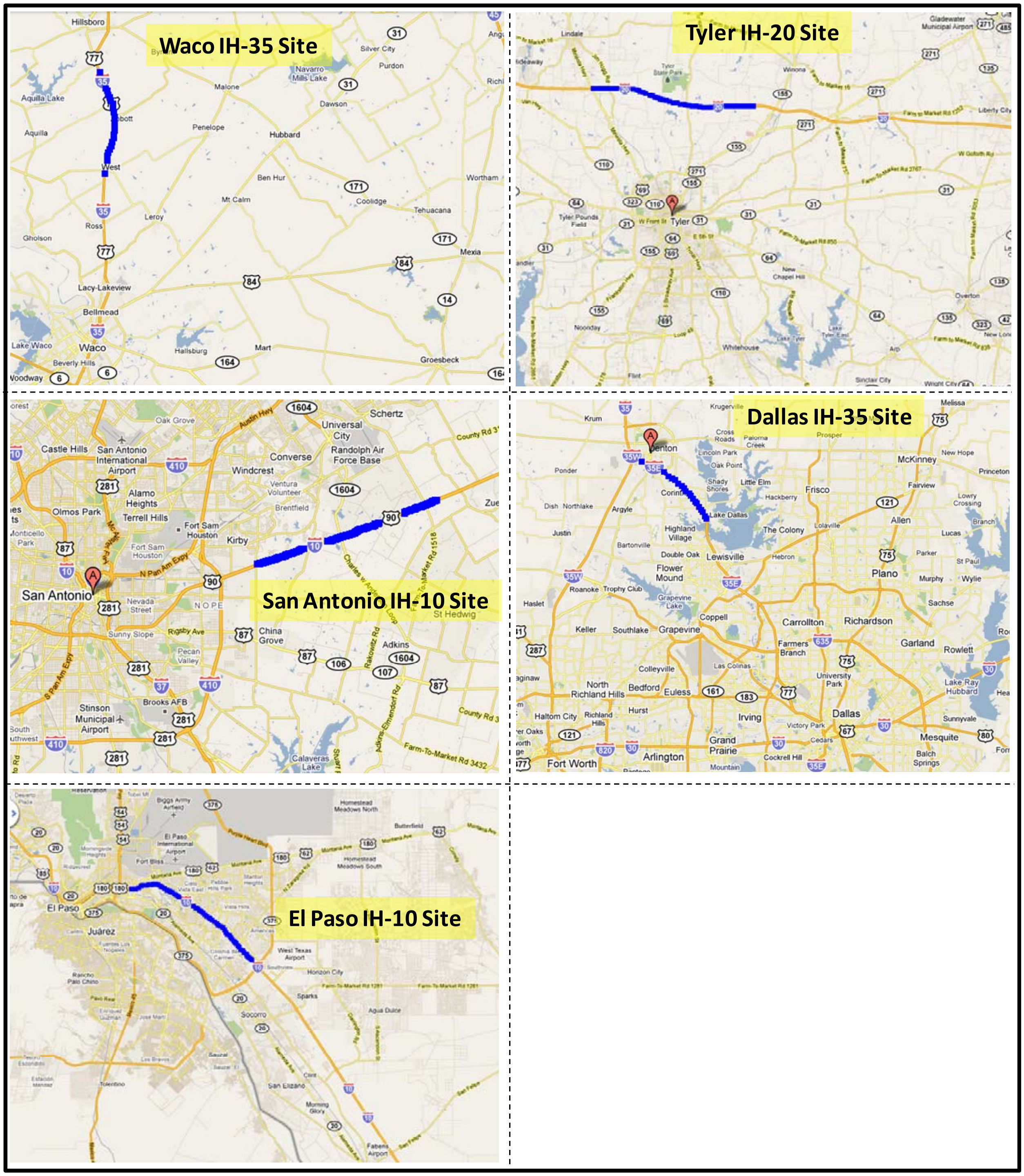

Figure 4-2. Locations of Field Trials Sites.

Procedure of Field Condition Survey

Inspectors divided each 10-mi long highway segment into 100 0.1-mi long sections. Each section was identified as 1 through 100. The location of these sections was referenced to

Texas Reference Marker (TRM), or commonly known as mile marker. The sample units to be surveyed were then randomly selected from the pool of 100 sections. Researchers marked those sample units each shoulder to demarcate their starting and ending points (Figure 4-3).

Figure 4-3. Sample Unit Limits Marked on Roadway Shoulder.

Typically, the inspectors drove slowly on the shoulder and parked their vehicle at the beginning of the sample unit to be surveyed. Then they walked along the shoulder or slope toward the end of the sample unit while surveying the maintenance elements. Then, they walked back to the vehicle for the next section. In general, the survey included maintenance elements located between the centerline of the roadway and one end of the ROW; (i.e., only one direction of the highway was inspected). All five sites were located on Interstate highways. Each inspector carried printed copies of the inspection form (presented earlier in Figure 3-1) with them. Each inspector completed the survey form individually. To maintain the integrity of the survey, the inspectors were instructed not discuss their ratings during the survey.

Table 4-2 presents the average inspection time per 0.1-mi sample for each field survey. On average, it took 11–13 minutes to inspect a 0.1-mi sample unit. Since the IH-35 in Waco survey was the first to be conducted, it took the longest time to inspect. As the inspectors gained experience in the process, average inspection time per 0.1-mi sample decreased to 11–12 minutes. This average time required to inspect each sample unit was calculated by dividing the total time required for inspecting the site (minus any rest time) by the number of sample units inspected.

Table 4-2. Time Required for Field Condition Surveys.

Site	Survey Date	Number of Samples Inspected	Average Inspection Time per 0.1-mi Sample (min)
IH-35, Waco District	Nov 18, 2009	30	13
IH-20, Tyler District	Dec 07, 2009	20	12
IH-20, Tyler District	Feb 17, 2010	20	11
IH-10, San Antonio District	April 08, 2010	20	12
IH-20, Tyler District	April 27, 2010	20	11
IH-10, El Paso District	May 11, 2010	20	12
IH-35E, Dallas District	May 19, 2010	20	12

Safety Measures

The survey team maintained appropriate safety procedures by wearing hard hats, safety vests, and steel-toe boots. Also, the vehicle had a safety flashlight. While parking the vehicle or walking along the shoulder, they maintained a safe distance from the travel lane. Inspectors participated in hands-on training before conducting the field trials. The training took place at the Texas A&M Riverside campus and at IH-35 in Waco. At the beginning of the training, the inspectors viewed the items in the field to demonstrate the pass/fail criteria. Later on, inspectors participated in surveys for several short sections and compared their results among themselves to ensure consistency among inspectors.

Selection of Length and Number of Sample Units Used in Field Trials

The selection of sample length (0.1 mi in this case) is always arguable. Two alternatives were considered: 1) windshield survey on long sample units, and 2) walking survey on shorter sample units. Due to the specificity of the performance standards used for evaluating each sample unit and the relatively high number of performance standards to be evaluated (57 performance measures), a close observation through a walking survey is needed to assess compliance with these standards accurately. Thus, a relatively short sample unit (0.1 mi) was necessary for the survey to be practical. It is very difficult for the inspectors to objectively assess compliance with some of the performance standards (such as amount of litter, amount of weed, grass height, etc.) using a windshield survey. Also, the inspector cannot give a pass/fail rating for certain standards until he/she completes the whole sample unit. If the sample unit is too long, it is naturally difficult for the inspector to remember the condition of the sample unit from start to end. The field trials showed that a 0.1-mi sample unit is appropriate as one can always look back and can see the whole area at a glance and assign ratings more objectively.

A fixed sampling rate was used in these field trials because no historical data are available to determine the inputs necessary for computing a statistical sample size (e.g., standard deviation of Sample Score). For the Waco site, 30 randomly selected sample units were surveyed (providing a 30 percent sampling rate). For the other sites, inspectors surveyed 20 randomly selected sample units (providing a 20 percent sampling rate). A higher sampling rate was used in the Waco site since it was the first field trial. Researchers analyzed the data gathered from these field surveys to provide inputs for computing a statistical sample size in future implementation of this condition assessment method (see the "Discussion of Results" section of this chapter).

RESULTS OF FIELD TRIALS

This section of the report discusses the results of the field trials, including reproducibility of sample unit scores, LOS for each field trial site, required sample size, and pay adjustment system. The initial performance-based specifications for roadside maintenance were refined based on the results of these trials (see Appendix C).

Sample Unit Scores

Figure 4-4 shows the sample unit scores (SUSs) for each field trial site and each inspector. As discussed earlier, the same three inspectors inspected each sample unit in each field trial site. The Analysis of Variance (ANOVA) with multiple population approach was employed to test the reproducibility of the sample score (SS) among the three inspectors. In this test, the null hypothesis signifies that there is no difference in the mean values of the sample score between the three inspectors. Table 4-3 shows the results of this reproducibility test. Since the p-value is greater than 0.05 (p-value =0.1558), one cannot reject the null hypothesis at the 95 percent confidence level. Therefore, one can conclude (with 95 percent confidence) that the developed condition assessment procedure is reproducible.

Table 4-3. ANOVA Results for the Reproducibility Test of the Developed Scoring System.

Source	Degree of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Model	2	0.0372	0.0186	1.87	0.1558
Error	270	2.6823	0.0099	--	--
Corrected Total	272	2.7195	--	--	--

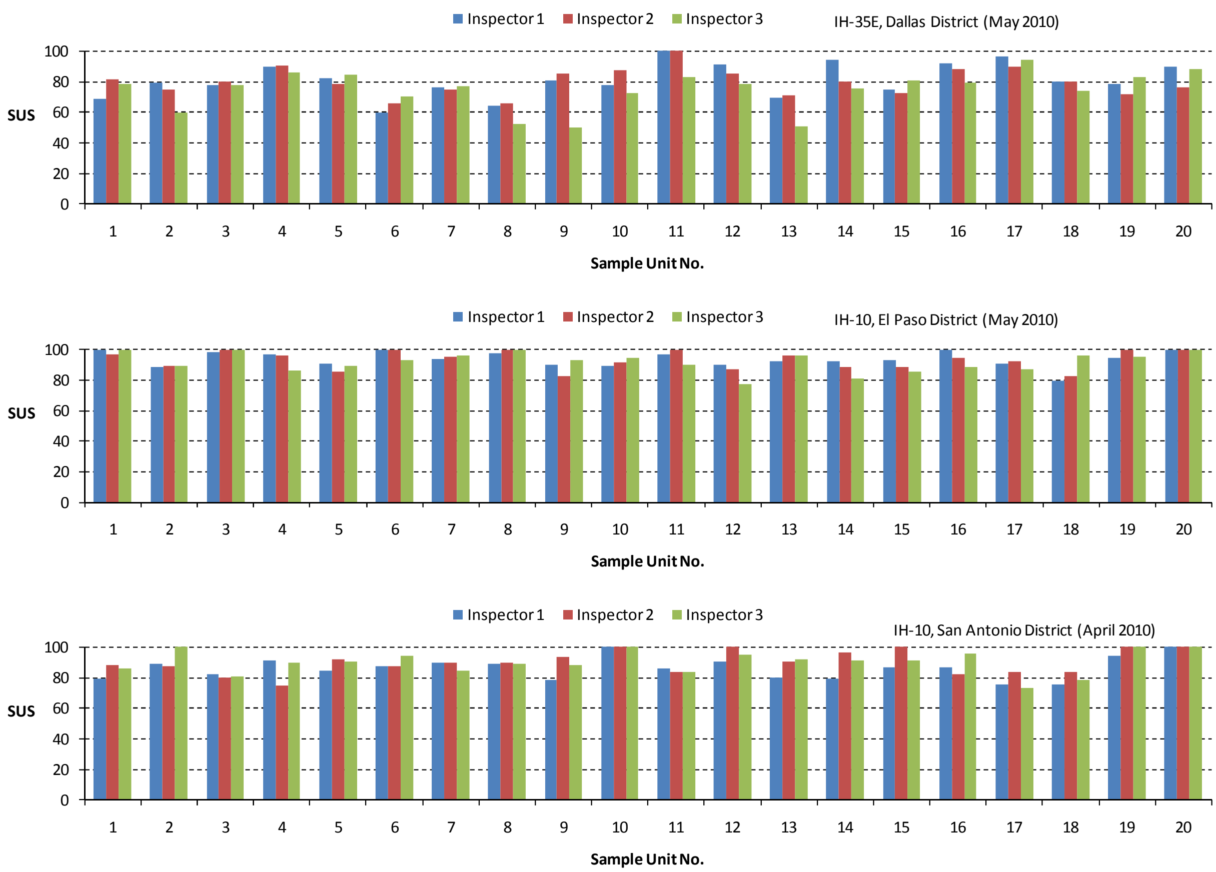

Figure 4-4. SUSs for Each Field Trial.

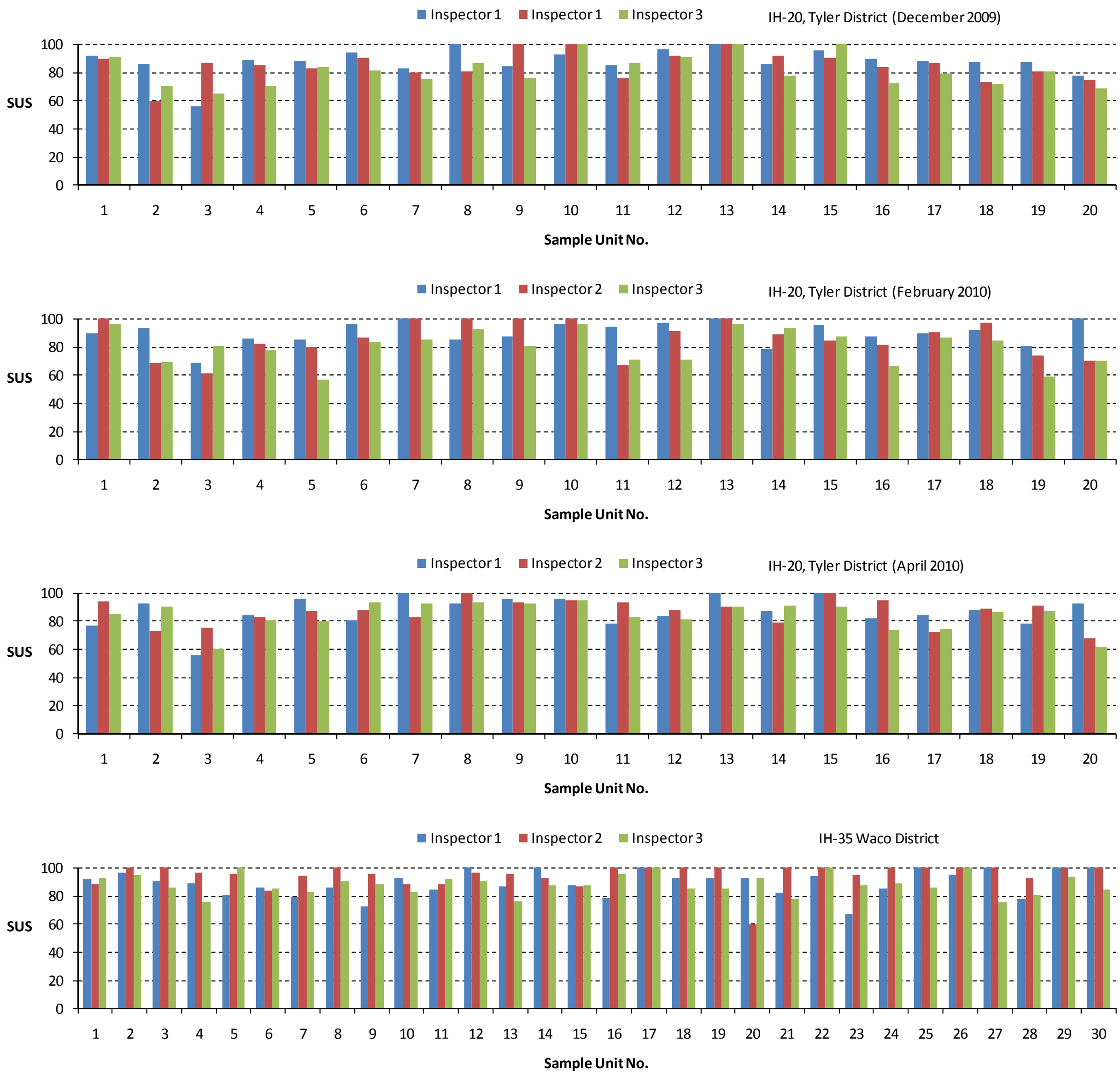

Figure 4-4. SUSs for Each Field Trial (continued).

Project LOS

Figure 4-5 shows the frequency distribution of SUS for each site. It can be seen that the SUS follows a Beta probability distribution (i.e., SUS values are shifted to the right of the SUS scale). This observation is expected since maintenance efforts strive to maximize the SUS score (which has an upper value of 100).

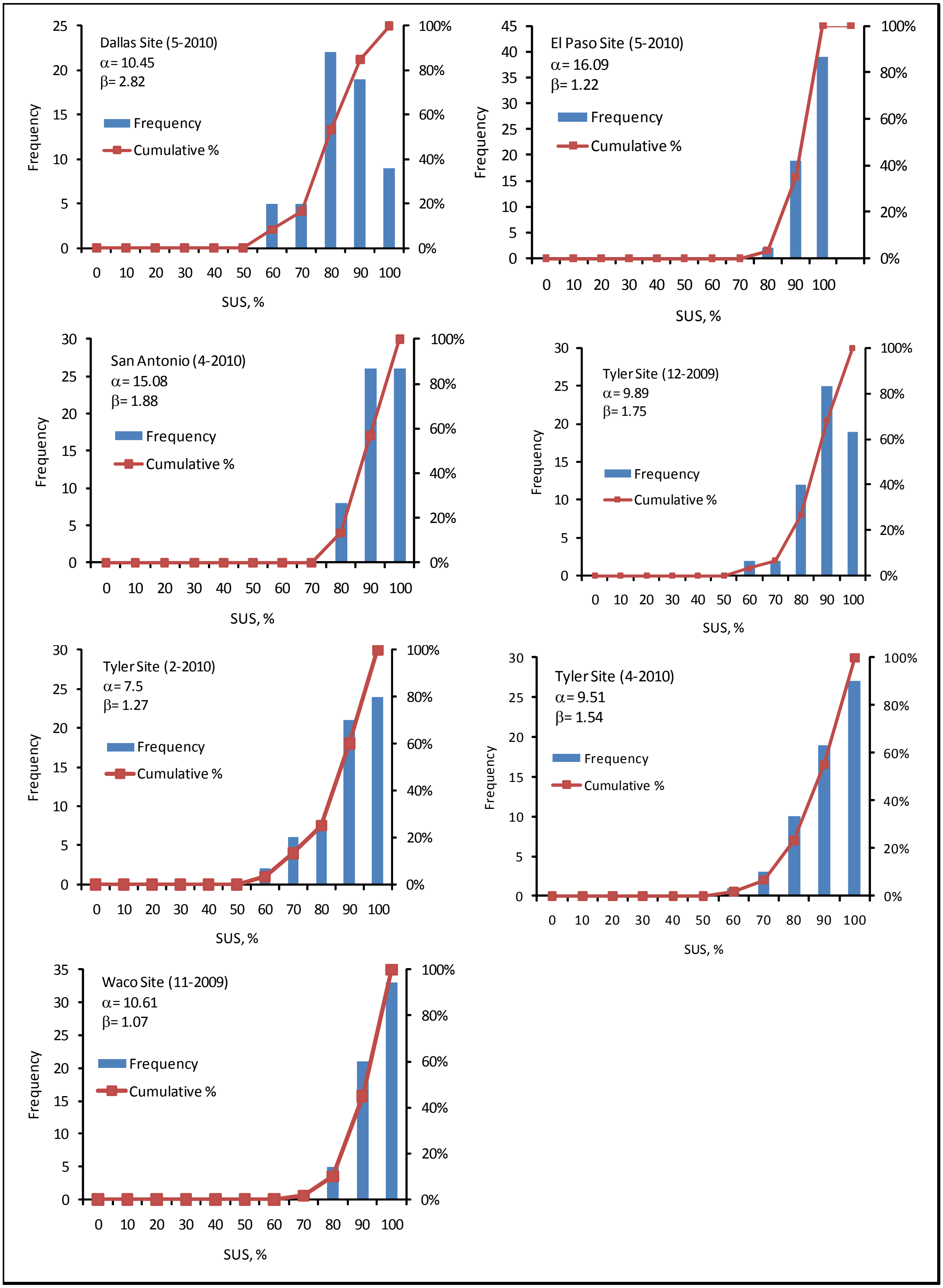

Figure 4-5. Frequency Distribution of SUSs for Each Field Trial.

To assess both the central tendency (i.e., mean values) and variability (i.e., confidence intervals) of each trial's LOS, it is necessary to determine the SUS standard deviation and the Beta distribution parameters (α and β) for each field trial. Since each site was inspected by three inspectors, a pooled standard deviation (S_p) for these inspectors was computed, as follows:

$$S_p = \sqrt{\frac{(n_1 - 1)s_1^2 + n_2 - 1)s_2^2 + n_3 - 1)s_3^2}{n_1 + n_2 + n_3 - 3}} \qquad \text{(4-1)}$$

where

n_i = the number of sample units inspected by inspector i.

s_i = the SUS standard deviation for sample units inspected by inspector i.

Figure 4-5 shows the pooled standard deviation values for each site. The Beta distribution parameters (α and β) were computed for each site using Equations 3-5 and 3-6, along with the pooled standard deviation. These parameters were used for determining the 95 percent confidence intervals (as shown in Equations 3-7 and 3-8).

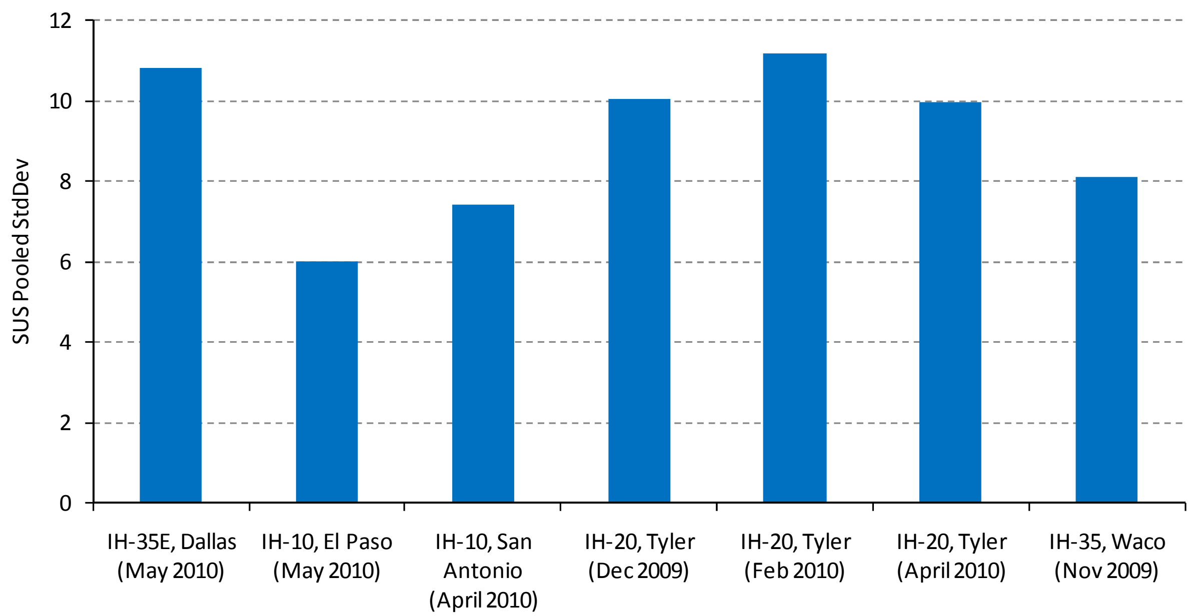

Figure 4-5. SUS Pooled Standard Deviation for Each Field Trial.

Figure 4-6 shows the 95 percent confidence interval for the LOS of each field trial, along with the LOS mean values. With the exception of the El Paso site, the other four sites (including the three inspection cycles performed in the Tyler site) have relatively similar average LOS (ranging between 79 for the Dallas site and 91 for the Waco site) and 95 percent confidence intervals. The El Paso site has the highest average LOS (93) and least variability (as exhibited by a narrow 95 percent confidence interval of 77.7–99.6). This is perhaps due to the lower number of vegetation and drainage maintenance elements present at the El Paso site, compared to the other sites.

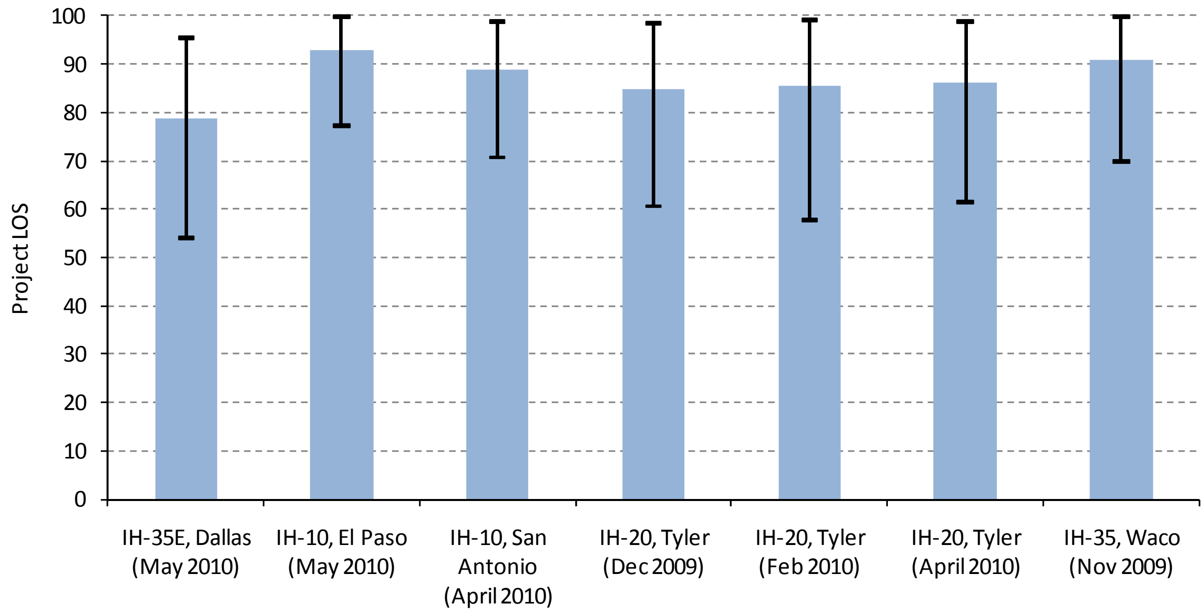

Figure 4-6. Project LOS Scores (Average Values Shown as Columns and 95 Percent Confidence Interval Shown as Vertical Lines).

Sample Size

A statistical sample size (*n*) was computed for each site using Equation 3-1. The inputs to Equation 3-1 include pooled standard deviation (computed earlier and the results are shown in Figure 4-5), 90 percent and 95 percent confidence level, 4 percent precision level [obtained from the literature, see de la Garza et al. (2008)], a population size of 100 sample units (N=100 for a 10-mi roadway segment and a 0.1-mi sample unit). As can be seen from Figure 4-7, for a 95 percent confidence level, the required statistical sample size ranges from 7 sample units (El Paso site) to 23 sample units (Dallas trial and Tyler February 2010 trial). For a 90 percent confidence level, the required statistical sample size ranges from 6 sample units (El Paso site) to 17 sample units (Dallas trial and Tyler February 2010 trial). This analysis shows that sites with higher variability require greater amount of inspection. It also shows that the sample sizes used in the field trials (30 sample units for the Waco site and 20 sample units for the other sites) are conservatively high. Also, this analysis suggests that the amount of inspection can be increased or decreased, depending on site condition and climatic season. For example, in the winter it is likely that the vegetation-related standards will pass inspection (or be Not Applicable); however, during the spring time when the grass is growing, it is likely there will be greater variability in the sample scores (resulting in a larger sample size).

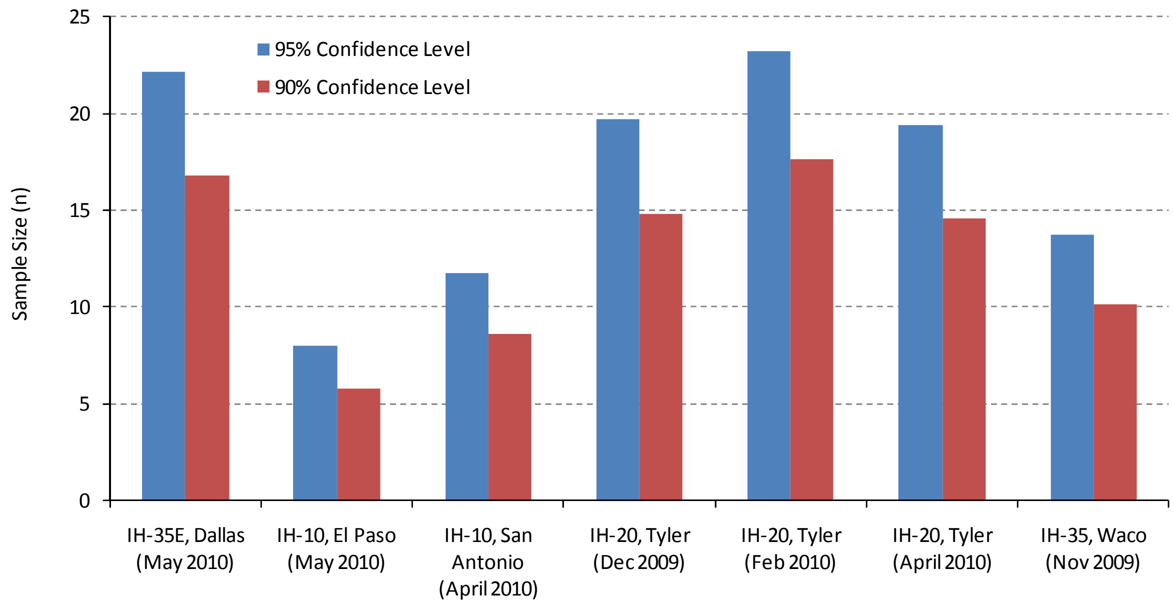

Figure 4-7. Statistical Sample Size for Each Field Trial.

Pay Adjustment Systems

As discussed earlier, the inputs to pay adjustment evaluation method are: 1) a project LOS Target (set by TxDOT), and 2) a model representing the relationship between maintenance cost and project LOS. Initially, an attempt was made to develop relationships between maintenance cost and LOS using data obtained from TxDOT's TxMAP rating system and maintenance cost data obtained from TxDOT's Maintenance Management Information System (MMIS). Figures 4-8 and 4-9 show these relationships for both Farm to Market (FM) roads and non-FM roads, respectively. However, no pattern can be found in these data; and thus a no reliable LOS vs. maintenance cost relationships can be developed based on these data. The large scatter in these data can be attributed to the mismatch between the locations of TxMAP's sample units and the aggregated maintenance cost data (stored in MMIS).

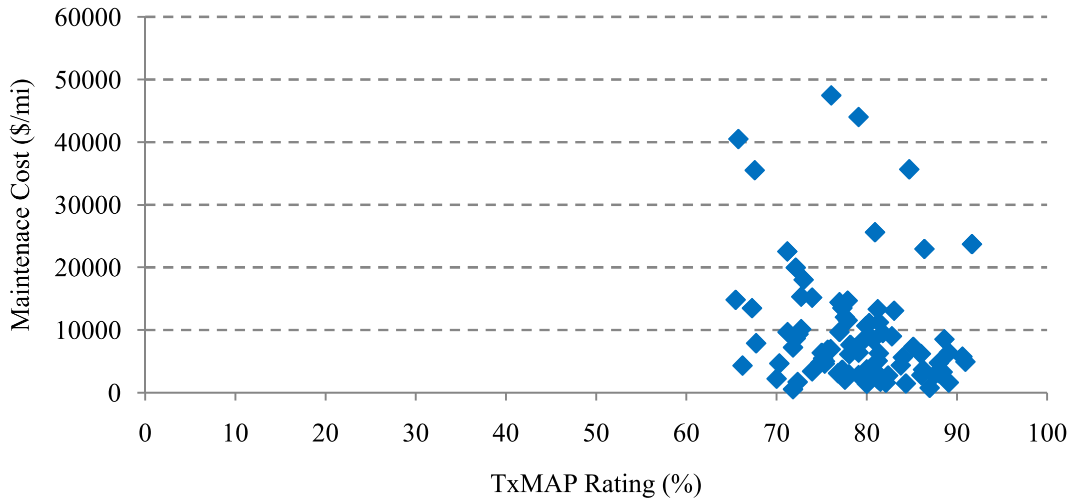

Figure 4-8. Maintenance Costs vs. TxMAP Rating (FM Roads).

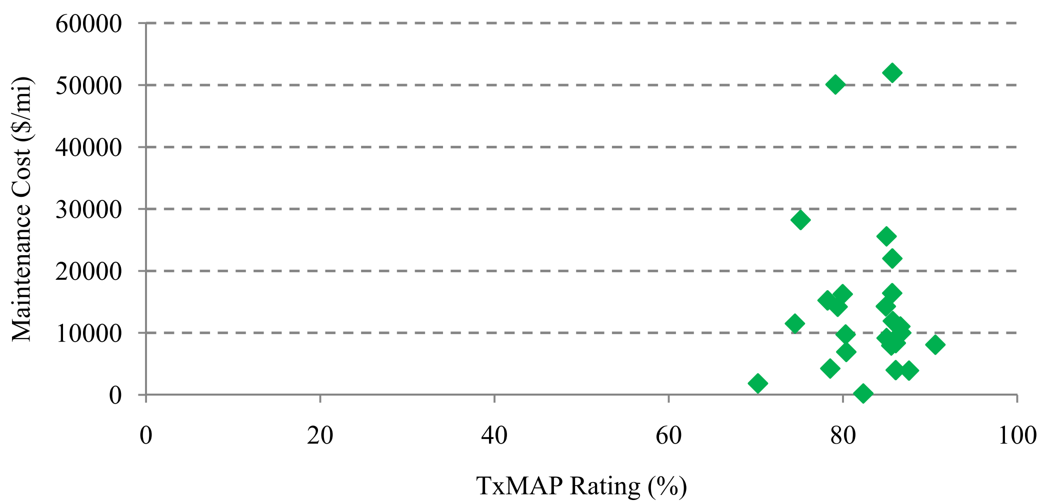

Figure 4-9. Maintenance Costs vs. TxMAP Rating (Non-FM Roads).

Consequently, these relationships were simulated using condition data obtained from the inspections of the field trials and typical unit costs obtained from TxDOT's MMIS. The simulation process consisted of the following steps:

1. Maintenance cost data for various maintenance function codes were obtained from TxDOT's MMIS database for the fiscal year 2009 for each of the districts of the field

trials. Table 4-4 shows the matches between the TxDOT function codes and the performance standards used in this project. Tables 4-5 to 4-9 show the maintenance unit costs for the districts where the field trials are located. These data were obtained from TxDOT's MMIS. Since the field trials were performed on Interstate highways; IH cost data was used with the exception of Function Codes 548, 562, 593, and 596 (for which no IH data were available). For these function codes, State Highway (SH) or US Highway (US) data are used instead. The unit costs were converted to total cost and then to cost per 0.1 sample unit (by dividing the total cost by the number of 0.1-mi sample units within the total mileage).

2. Using the inspection data of the field trials, various hypothetical scenarios of failing to meet the performance standards were simulated in the computer. For each scenario, the sample score and the project average 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 following assumptions were made in calculating the maintenance cost for each project:
    - Maintenance would not be performed on a sample unit unless the sample unit score fell below the target LOS.
    - If maintenance on the sample unit was required, the maintenance would bring every standard in the sample unit to a Pass rating (and thus bring the sample unit score to 100 percent).
    - Samples are assumed be continuous along a roadway. For example, if 20 inspections were performed, this corresponds to 20 sample units and a total length of 2 mi.
3. A curve was fitted to the maintenance cost ($/mi) and project LOS data points for each field trial. These best-fit curves represent the theoretical relationship between project LOS and maintenance cost for each field trial, as shown in Figures 4-10 through 4-14.

Table 4-4. 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

Table 4-5. Estimated Maintenance Costs for Dallas Field Trial (Fiscal Year 2009).

Function Code	Unit	Quantity	Average Unit Cost ($/Unit) or Lump Sum (LS)	Total Mileage (mi)
511	acre	1,985	38.0	32
521	acre	60,061	16.2	342
523	mile	67,387	31.2	357
530	sq.ft	5,262	3.3	85
542	acre	9,140	70.8	247
548	sq.yd	7,000	0.09	8
551	ls	---	17375.6	63
552	ls	---	128,838	342
561	cu.yd	3,183	45.0	249
562	ft	16,597	6.6	161
563	sq.yd	10,334	325.8	105
570	ls	---	357,909	297
593	ft	28,893	19.0	159
595	ft	75,324	37.1	342
596	each	1,285	1,822.5	166

Table 4-6. Estimated Maintenance Costs for El Paso Field Trial (Fiscal Year 2009).

Function Code	Unit	Quantity	Average Unit Cost or Lump Sum (LS)	Total Mileage (mi)
511	acre	2,370	38.3	114
521	acre	18,517	7.7	80
523	mile	44,019	17.9	114
530	sq.ft	35,174	0.3	62
542	acre	2,376	68.6	114
548*	sq.yd	54,184	0.6	53
551	ls	---	250,545.9	62
552	ls	---	44,517.9	114
561	cu.yd	910	11.8	28
562*	ft	30,059	0.76	125
563*	sq.yd	11,783	13.9	194
570	ls	---	276,541.8	114
593	ft	1,740	0.7	28
595	ft	22,121	43.0	114
596	each	65	355.5	34

* Data is for SH and US roadways.

Table 4-7. Estimated Maintenance Costs for San Antonio Field Trial (Fiscal Year 2009).

Function Code	Unit	Quantity	Average Unit Cost or Lump Sum (LS)	Total Mileage (mi)
511	acre	29,644	31.5	497
521	acre	87,210	18.8	438
523	mile	76,760	8.6	497
530	sq.ft	220,107	1.2	287
542	acre	2,384	78.8	497
548	sq.yd	820	0.2	33
551	ls	---	1,812.0	53
552	ls	---	47,533.4	497
561	cu.yd	8,022	29.8	266
562	ft	20,017	3.9	242
563	sq.yd	2,200	71.7	58
570	Ls		80,045.3	363
593	Ft	84,108	3.5	383
595	ft	35,097	25.5	489
596	each	2,528	864.1	489

Table 4-8. Estimated Maintenance Costs for Tyler Field Trial (Fiscal Year 2009).

Function Code	Unit	Quantity	Average Unit Cost or Lump Sum (LS)	Total Mileage (mi)
511	acre	5,198	38.9	83
521	acre	8,416	12.7	83
523	mile	11,821	15.5	83
542	acre	1,136	45.2	83
548*	sq.yd	2,830	0.6	42
551	ls	---	19,664.0	36
552	ls	---	92,021.3	83
561	cu.yd	180	8.6	30
562*	ft	2,458	8.36	182
563	sq.yd	487	7.2	17
570	ls	---	3,866.1	47
595	ft	2,221	24.5	83
596	each	19	3,384.3	83

* Data is for SH and US roadways.

Table 4-9. Estimated Maintenance Costs for Waco Field Trial (Fiscal Year 2009).

Function Code	Unit	Quantity	Average Unit Cost or Lump Sum (LS)	Total Mileage (mi)
511	acre	5,811	23.8	116
521	acre	27,036	9.7	116
523	mile	55,481	4.7	116
530	sq.ft	543	29.0	101
542	acre	3,509	62.9	116
548*	sq.yd	54,184	$0.6	53
551	ls	---	204,201	116
552	ls	---	123,318	101
561	cu.yd	370	6.4	109
562	ft	3,133	6.0	116
563	sq.yd	5	611.9	108
570	ls	---	206,891	132
595	ft	6,989	$26.0	101
596*	each	322	1,012.9	208

* Data is for SH and US roadways.

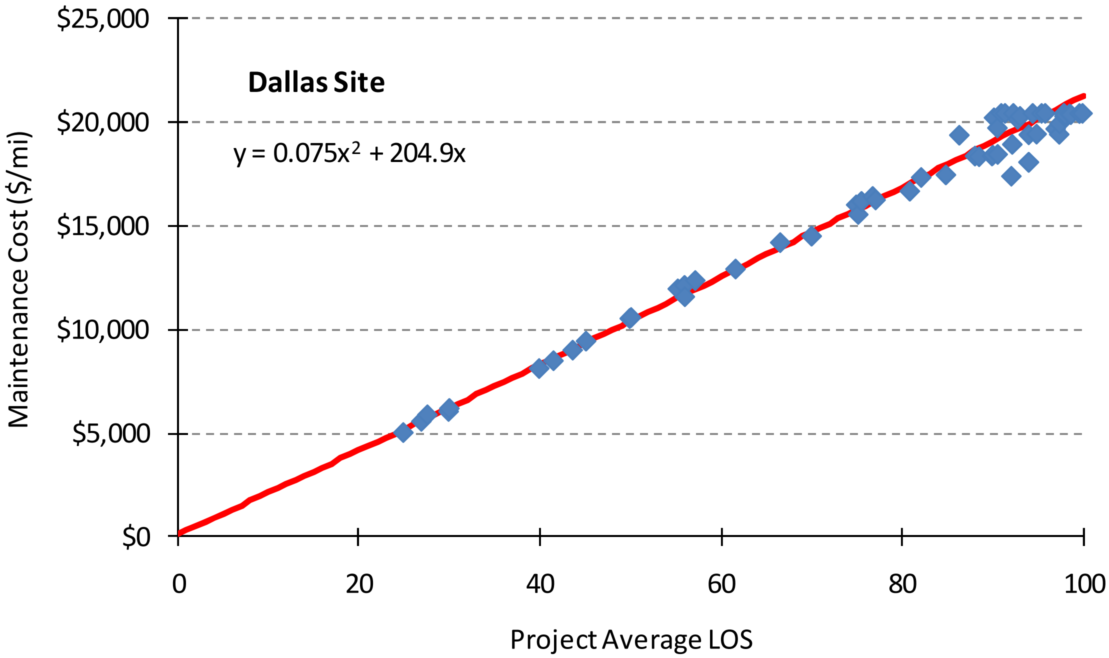

Figure 4-10. Estimated Maintenance Cost vs. Project LOS for the Dallas Field Trial.

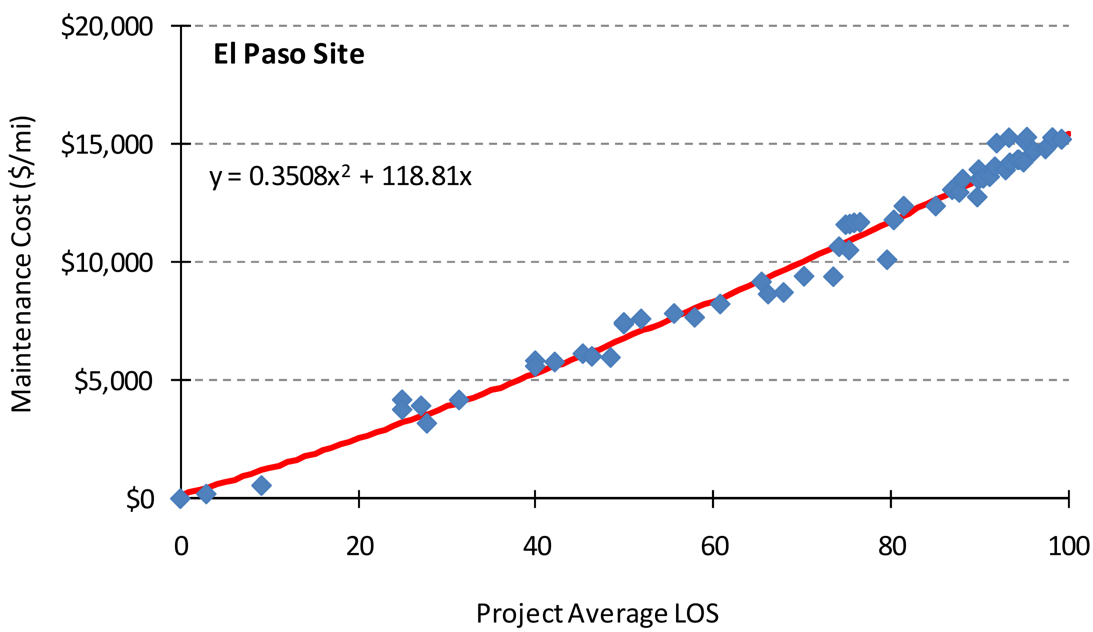

Figure 4-11. Estimated Maintenance Cost vs. Project LOS for the El Paso Field Trial.

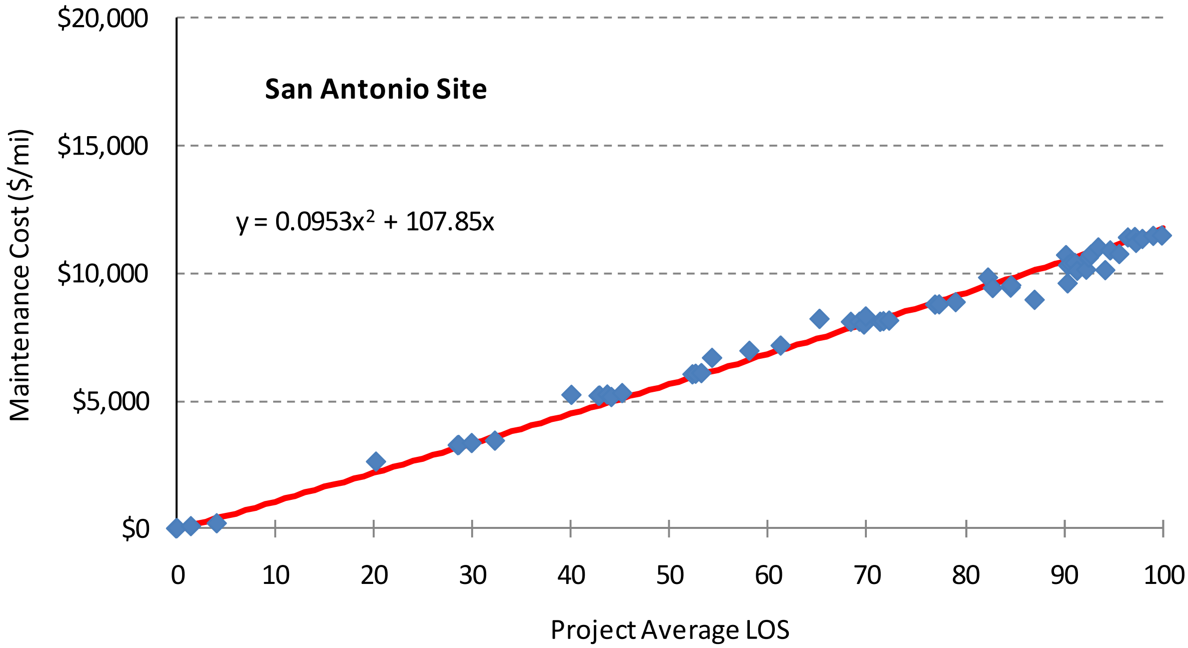

Figure 4-12. Estimated Maintenance Cost vs. Project LOS for the San Antonio Field Trial.

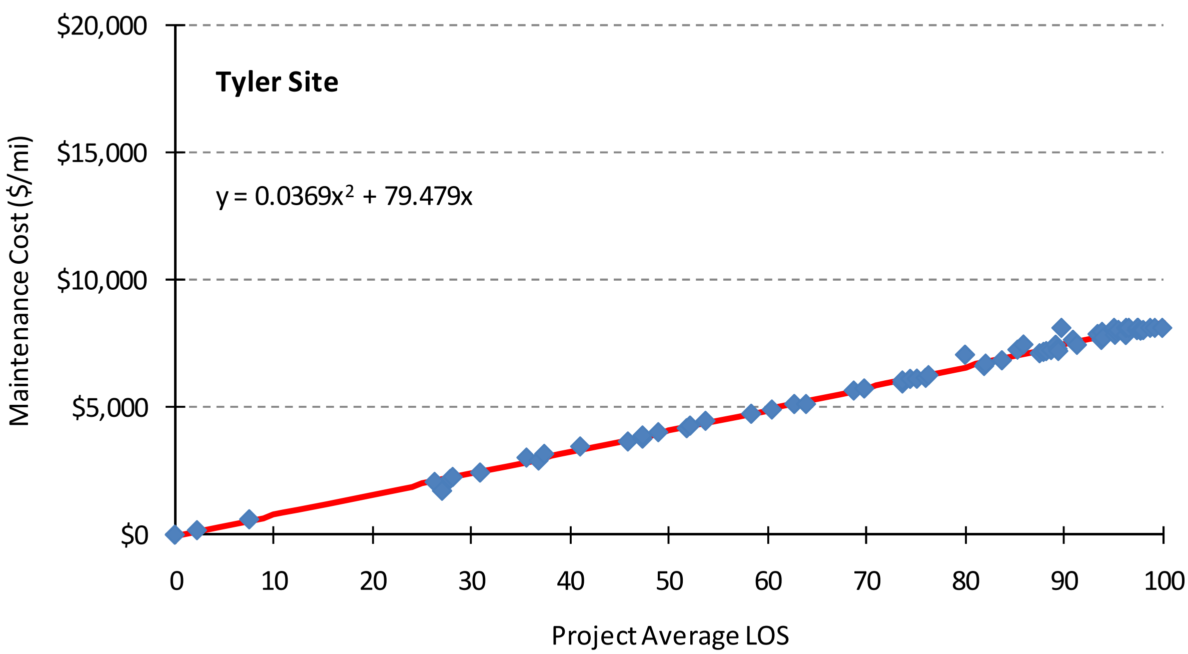

Figure 4-13. Estimated Maintenance Cost vs. Project LOS for the Tyler Field Trial.

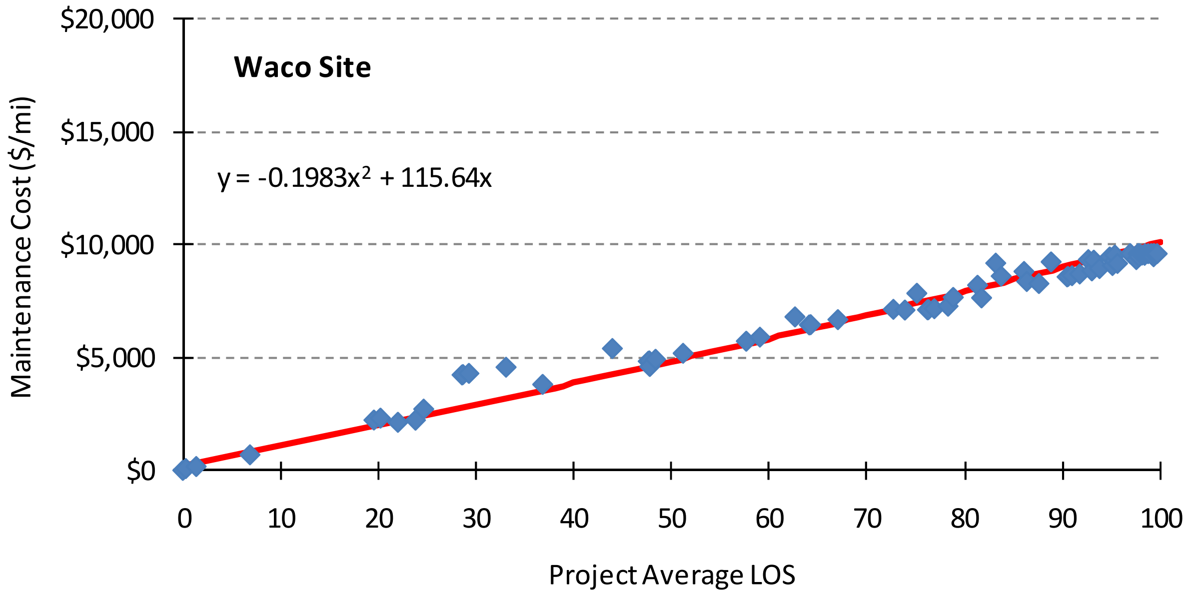

Figure 4-14. Estimated Maintenance Cost vs. Project LOS for the Waco Field Trial.

Figures 26–30 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 85, 90, and 95 for each district.

Using the above Best-fit Maintenance Cost vs. Project LOS and an assumed 95 LOS target, a commercially available optimization software tool (Evolver) was employed to find the pay adjustment curve that ensures that the minimum total cost occurs at the project's target LOS. Table 4-10 presents these pay adjustment equations. Using these PA equations, a contractor who achieves the target LOS (i.e., project average LOS = Target LOS) receives no pay adjustment; a contractor who exceeds the target LOS (i.e., project average LOS > = Target LOS) receives a positive pay adjustment (i.e., pay increase); and a contractor who cannot achieve the target LOS (i.e., project average LOS < = Target LOS) receives a negative pay adjustment (i.e., pay decrease).

Table 4-10. Pay Adjustment Equations for Field Trials.

Site	Pay Adjustment Equation (Target LOS = 85)	Pay Adjustment Equation (Target LOS = 90)	Pay Adjustment Equation (Target LOS = 95)
IH-35E, Dallas District	PA = 219.6 * (LOS-85)	PA = 220.8 * (LOS-90)	PA = 222.0 * (LOS-95)
IH-10, El Paso District	PA = 180.5 * (LOS-85)	PA = 184.5 * (LOS-90)	PA = 188.5 * (LOS-95)
IH-10, San Antonio District	PA = 123.2 * (LOS-85)	PA = 124 * (LOS-90)	PA = 124.7 * (LOS-95)
IH-20, Tyler District	PA = 85.1 * (LOS-85)	PA = 85.32 * (LOS-90)	PA = 85.57 * (LOS-95)
IH-35, Waco District	PA = 108 * (LOS-85)	PA = 109.3 * (LOS-90)	PA = 110.8 * (LOS-95)

CHAPTER 5. IDENTIFYING BEST-VALUE BID FOR PBMC

BACKGROUND

Because PBMCs extend over multiple years and shift performance risk to contractors (i.e., failure to meet performance standards and targets), it is critical that contractors be selected based on a form of best-value method rather than the conventional low-bid method. Best-value bid selection requires that certain weights be assigned to technical qualifications in the bid evaluation process; instead of assigning 100 percent values for the bid price. Gransberg and Molenaar (2004) defined best-value procurement as "the process which allows government contracting agencies to evaluate offers based on total procurement cost, technical solution, completion dates, and other criteria." Lo and Yan (2009) concluded that the contractor's overly opportunistic bidding behavior can be avoided and quality be ensured if the contractor's past performance is carefully and closely examined and reflected in the bid evaluation process. Pakkala (2002) suggested that best value and innovative PBMC procurement success is contingent upon to the extent of quality criteria taken into consideration instead of only price. Table 5-1 shows different price and quality measures used by the different countries for best-value bid evaluation in performance-based contracting.

Table 5-1. Weights of Contractor Selection Criteria in Different Countries (Pakkala 2002).

Country	Weights for Selection Criteria
Sydney, Western Australia, and Tasmania	50% price, 50% other (varies with territory)
Alberta, Canada	78% price; 22% other
British Columbia, Canada	40% price; 60% other
Ontario, Canada	90% price; 10% other
England	30-40% price; 60-70% other
Finland	75% price; 25% other
New Zealand	50% price; 50% technical criteria
Sweden	90% price; 10% other

Currently, highway agencies use various methods for determining the best-value bid based on cost and technical scores. This chapter of the report identifies and evaluates current practices in best-value bid identification methodologies for procuring PBMCs. Five best-value bid identification methods used by five different highway agencies for PBMCs have been analyzed.

CASE STUDIES

Five best-value bid identification methods that are already in practice by the state transportation agencies in Florida, Virginia, North Carolina, United Kingdom, and New Zealand were used as case studies for this research. In four of these case studies, the contract has already been awarded by the highway agency, whereas the fifth one (UK Highway Agency) is a model contract usually used as a standard contract format by the agency.

Florida Department of Transportation Case Study

This case study consists of Florida Department of Transportation's (FDOT 2008) asset maintenance contract #E5N05 for maintenance of primary highways in Brevard, Osceola, and portions of Orange and Volusia Counties in Florida. The contract period is from July 1, 2009, up to June 30, 2016, for a total of 7 years with a provision of possible renewal once or twice with mutual agreements of both parties.

The flowchart in Figure 5-1 shows the award process for the successful contractor. The minimum technical score required is 70 points. Price and Technical proposals are given 30 and 70 percent of weights as determined by formulas 5-1 and 5-2. The contractor with the highest total proposal score (i.e., weighted sum of technical and price scores) is identified as the best-value bid and wins the bid. Thus, it is clear that meeting the minimum technical score requirement is not sufficient to win the bid. The agency, by establishing price and technical proposal weights, defines its incentive scheme for the quality, which may be understood through the analysis of equivalent bid concept. Two bids can be said equivalent if, after evaluation, their total proposal scores are same although they have different technical and price score combination.

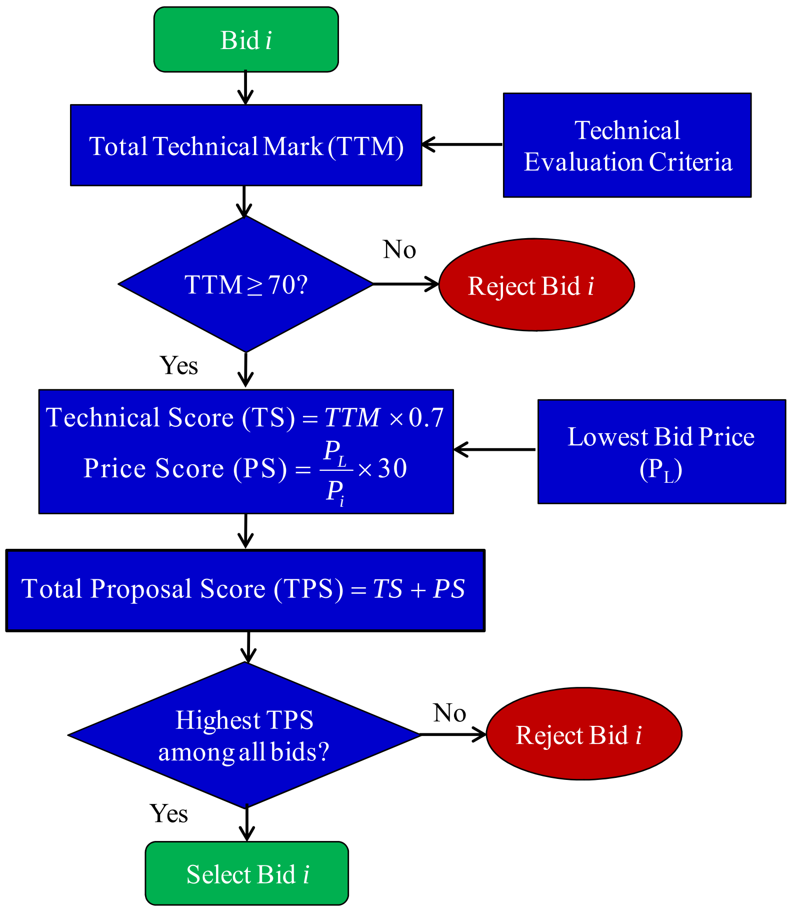

Figure 5-1. Flowchart of FDOT's PBMC Bid Evaluation Method.

Bid proposal is evaluated based on predefined project-specific technical criteria (see Table 5-2) to determine the Total Technical Marks (TTM). A Technical Score (TS), Price Score (PS), and Total Proposal Score (TPS) are computed as follows:

$$TS = TTM \times 0.7 \tag{5-1}$$

$$PS = \frac{P_L}{P} \times 30 \tag{5-2}$$

$$TPS = TS + PS \tag{5-3}$$

where P_L is the lowest bid price, and P is the Proposer's bid price.

To be able to express the total proposal score as a function of technical marks and bid price, the concept of price ratio (R) is introduced here, as follows:

$$R = \frac{P}{P_L} \tag{5-4}$$

Figure 5-2 shows a 3-D graph that represents the relationship between TPS, TTM, and R for FDOT's method.

Table 5-2. FDOT's Technical Criteria Marks (FDOT 2008) .

Technical Item	Max Mark
1. Executive Summary	5
2. Administrative Plan	25
a. Identification of Key Personnel, Organization Structure, Coordination, Communication	10
b. Contractor Experience	10
c. DBE/Respect/Agency Participation	2
d. Proposed Facilities Capabilities	3
3. Management and Technical Plan	25
a. Plan to Achieve and Maintain Maintenance Rating Program (MRP)	15
b. Permit Processing Plan	NA
c. Bridge Inspection	NA
d. Customer Service Resolution Plan	10
4. Operation Plan	35
a. Incident Response Operations	10
b. Routine/Periodic Maintenance Operations	25
c. Bridge Maintenance Operations	NA
d. Rest Area Maintenance Operations	NA
5. Plan for Compliance with Standards	10
a. Compliance with Current Department Procedures, FL Statutes, and FL Administrative Code	5
b. Compliance with Current Department Manuals, Guides, and Handbook	5

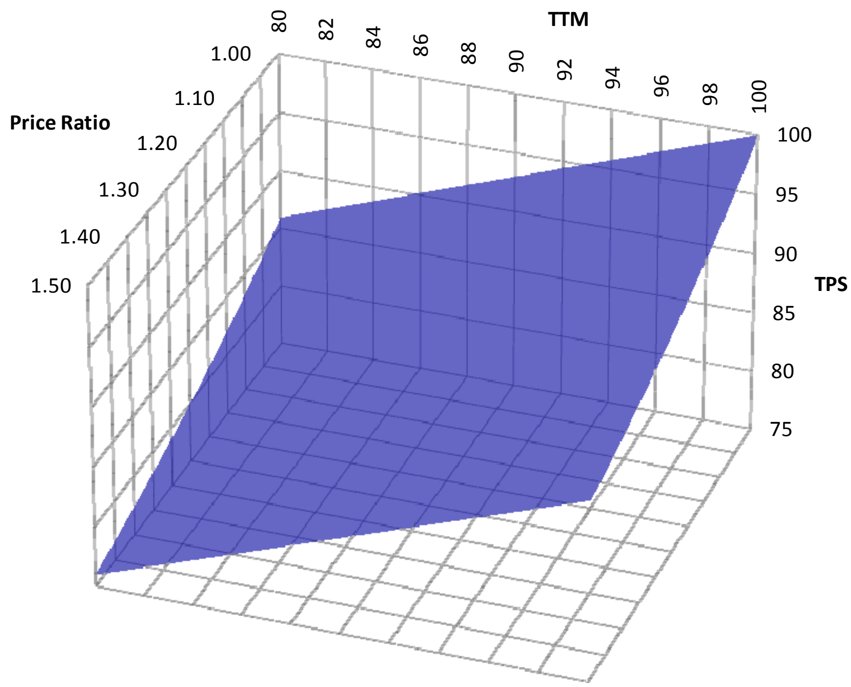

Figure 5-2. Depiction of TPS as a Function of Price Ratio and TTM for FDOT's Case Study.

Virginia Department of Transportation Case Study

This case study consists of the Virginia Department of Transportation's (VDOT) Turnkey Asset Maintenance Services (TAMS) contract on the Woodrow Wilson Bridge and associated highways. This project extends partly in the Commonwealth of Virginia and partly in the State of Maryland. The award is for five years (2010 to 2015), with a provision of two successive 2-year extension (a total of 4 years extension).

Figure 5-3 shows the flowchart for identifying the best-value bid for this maintenance contract. The score evaluation criteria are shown in Table 5-3; where, out of a total of 100 points, VDOT allocates 20 points for price criterion and the remaining 80 points for technical qualifications. The TS for the proposal is determined as the summation of technical points obtained from Table 5-3. The PS is computed relative to the lowest bid price, as follows:

$$PS = \frac{P_L}{P} \times 20 \qquad (5\text{-}5)$$

where P_L is the lowest bid price and P is the Proposer's bid price.

Total Proposal Score (TPS) are computed as TPS = TS + PS. A 3-D graph that represents the relationship between TPS, TTM, and price ratio for VDOT is shown in Figure 5-4.

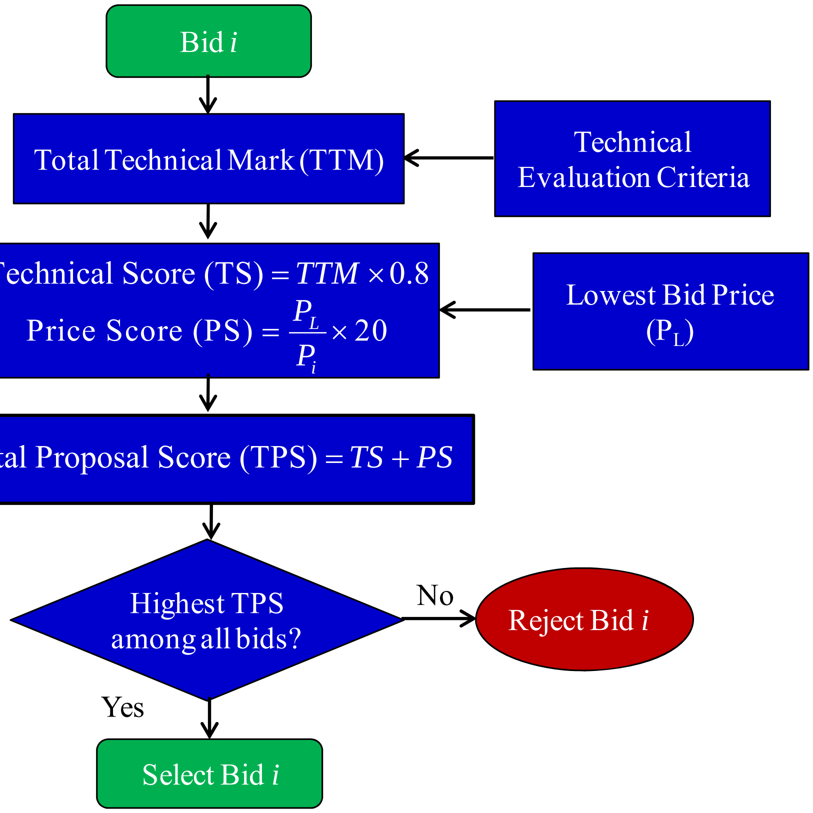

Figure 5-3. Flowchart of VDOT's PBMC Bid Evaluation Method.

Table 5-3. VDOT Evaluation Criteria Marks (VDOT 2009).

Item	**Max Mark**
1. Experience and Qualifications a. Reference b. Experience c. Qualifications	15
2. Quality of Ordinary Maintenance Plan a. Quality of Ordinary Maintenance Plan b. Widrow Wilson Bridge Inspection, Maintenance And Operations c. Quality Management Plan d. Customer Service, Timeliness Requirement and Tracking Plan e. Third Party Damages Accounting Receivable Claims Process and Reporting	30
3. Quality of Emergency Response Plan a. Quality of Emergency Response Plan b. Quality of Severe Weather Plan	15
4. Small Business Subcontracting Plan	20
5. Proposed Pricing Schedule	20

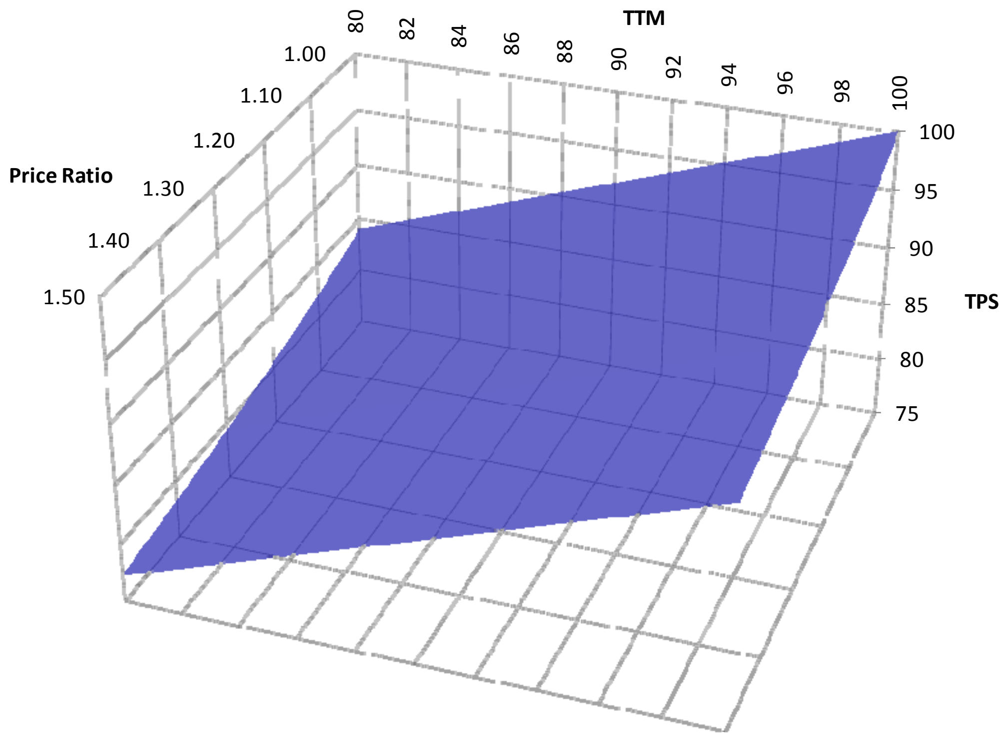

Figure 5-4. Depiction of TPS as a Function of Price Ratio and TTM for VDOT Case Study.

North Carolina Department of Transportation Case Study

The North Carolina Department of Transportation (NCDOT 2007) case study consists of an interstate maintenance contract for 131 centerline miles on I-77, I-85, I-485, and I-277 in Mecklenburg, Gaston, Cabarrus, and Cleveland counties. The contract extends from May 2007 to April 2012. The final Request for Proposal required that the contractor submits technical and financial offers separately, and the best-value bid was identified based on both price and technical evaluation.

As shown in Figure 5-5, the bid evaluation criteria for this case study is based on the concept of quality credit. NCDOT assigned a quality credit (*QC*) for each proposal based on its total technical marks (see Table 5-5). The maximum quality credit for this particular case study was 20; meaning that the proposal with 100 technical marks (i.e., full marks) receives a quality credit of 20 percent of its bid price. A quality value (*QV*) is then computed as follows:

$$QV = QC \times P \tag{5-6}$$

where *QC* is quality credit, and *P* is the Proposer's bid price. Each bid price is then adjusted based on its quality value, as follows:

$$AP = P - QV \quad (5\text{-}7)$$

where *AP* is adjusted bid price. The bid with the lowest adjusted bid price is identified as the best-value bid.

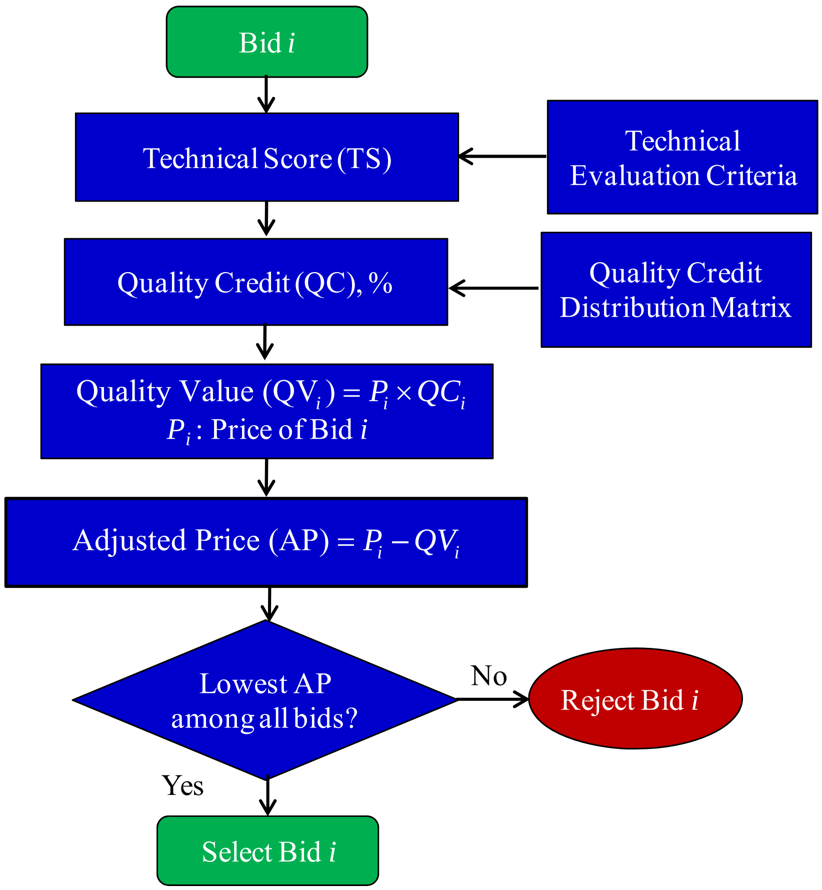

Figure 5-5. Flowchart of NCDOT's PBMC Bid Evaluation Method.

Table 5-4. NCDOT Technical Criteria Marks.

Technical Item	Max Mark
1. Management	20
2. Responsiveness to Request for Proposal	
a. General	15
b. Quality Management	15
c. Minority and Women's Business Enterprise and Small Business	5
d. Natural Environmental Responsibility	5
3. Maintenance of Traffic and Safety Plan	20
4. Timeliness Requirements and Tracking	15
5. Oral Interview	5

Table 5-5. Quality Credit Distribution for Technical Proposal (NCDOT 2007).

Technical Score	Quality Credit (%)	Technical Score	Quality Credit (%)
100	20	89	9
99	19	88	8
98	18	87	7
97	17	86	6
96	16	85	5
95	15	84	4
94	14	83	3
93	13	82	2
92	12	81	1
91	11	80	0
90	10		

Table 5-6 provides a hypothetical example to illustrate NCDOT's method. In this example, Contractor C has a total technical score of 90 and corresponding quality credit of 10 percent. This leads to an adjusted bid price of $2,520,000 (using Eq. 5-6 and 5-7). Since Contractor C has the lowest adjusted price, contractor C is selected as the best-value bid.

Table 5-6. Hypothetical Example for Calculating Adjusted Price (NCDOT 2007).

Proposal	TS	Quality Credit (%)	Price Proposal ($)	Quality Value ($)	Adjusted Price ($)
A	95	15	3,000,000	450,000	2,550,000
B	90	10	2,900,000	290,000	2,610,000
C*	90	10	2,800,000	280,000	2,520,000 (Best-Value Bid)
D	80	0	2,700,000	0	2,700,000
E	70	0	2,600,000	0	2,600,000

Figure 5-6 shows a 3-D graph that represents the relationship between Adjusted Price, TTM, and price ratio for NCDOT's method.

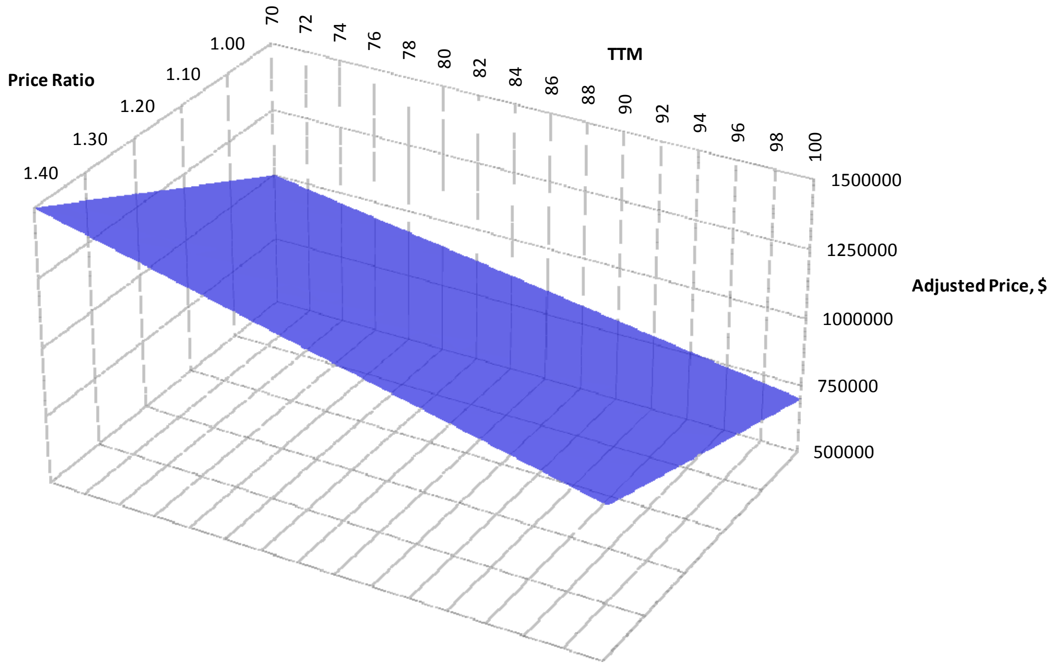

Figure 5-6. Depiction of Adjusted Price as Function of Price Ratio and TTM for NCDOT Case Study.

New Zealand Transport Agency Case Study

The New Zealand Transport Agency (NZTA 2009) awarded its Westcoast and Canterbury region highway maintenance contract for a 5-year period (2009 to 2014). The bid evaluation procedure followed the Price Quality Method (PQM), which is described in Figure 5-7. Bid prices are adjusted by subtracting the supplier quality premium (SQP) from the submitted bid price.

This bid evaluation method is described through an example. This hypothetical example consists of four bidders with different quality attributes and prices. As shown in Table 5-7, a weighted sum index is computed for each bidder based on several technical attributes (relevant experience, track record, technical skills, resources, management skills, and methodology). Each individual index is computed as the product of an assessed mark and an attribute weight. The weights are determined by NZTA, and the marks are determined by agency's evaluators. Table 5-8 shows the attributes and their weights.

Once the weighted sum (WS) is computed, then a Weighted Sum Margin (WSM) is calculated for each bidder by subtracting the weighted sum of the contractor from the lowest weighted sum of all bidders. A supplier quality premium (*SQP*) is then computed as follows:

$$SQP = AE \times \left(\frac{WSM}{W_p} \right) \quad (5\text{-}7)$$

where *AE* is the agency's estimate of bid price, and W_P is the price weight. In this hypothetical example, the agency's estimate for this project is $1,000,000, and the price weight is 70, as decided by the agency. Each bid price is then adjusted based on its *SQP*, as follows:

$$AP = P - SQP \quad (5\text{-}7)$$

where *AP* is adjusted bid price, and P is bid price. The bid with the lowest adjusted bid price is identified as the best-value bid (see Table 5-9).

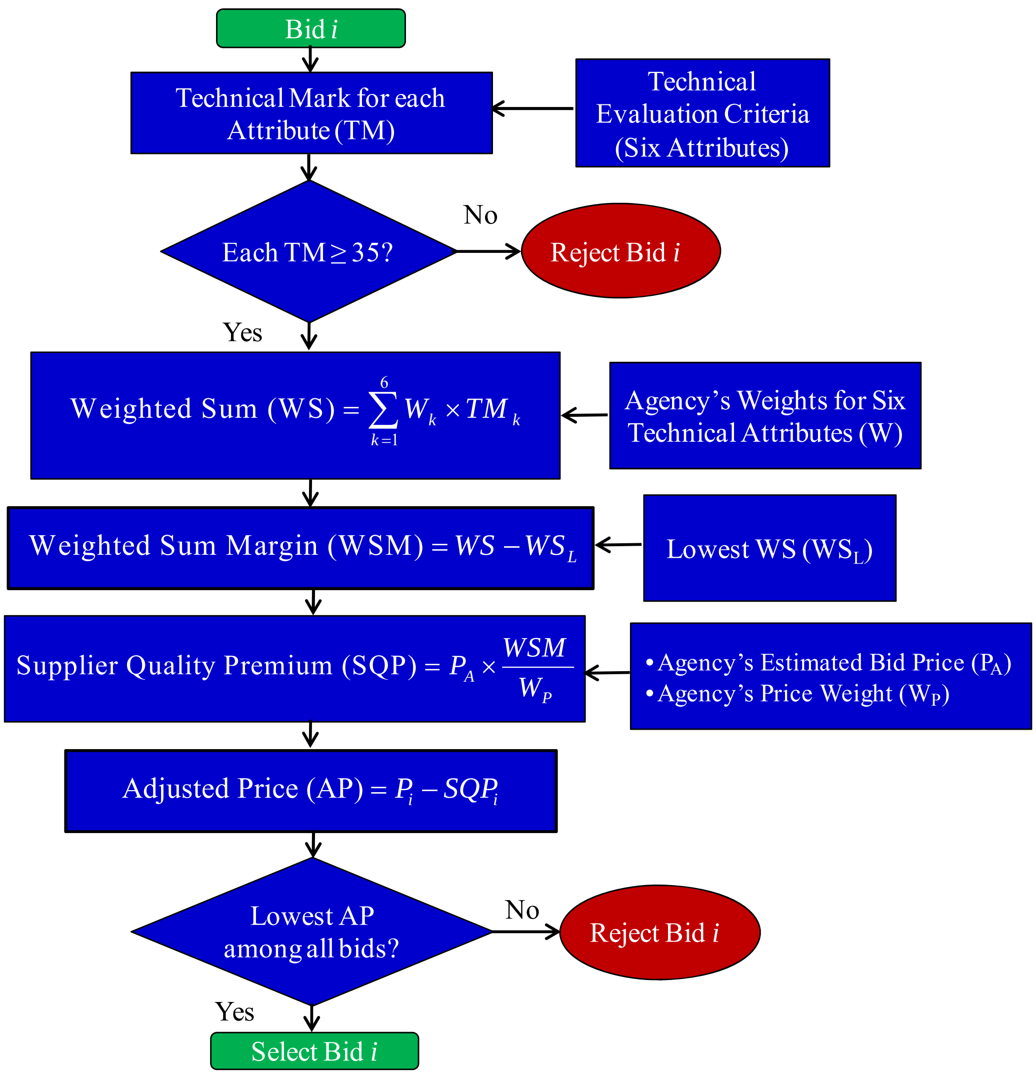

Figure 5-7. Flowchart of NZTA's PBMC Bid Evaluation Method.

Table 5-7. Weighted Sum Calculations for NZTA Case Study (Example Application) (NZTA 2009).

Attribute	Relevant Experience		Track Record		Technical Skills		Resources		Management Skills		Methodology		Weighted Sum (WS)
Bidder	Mark	Index*	Mark	Index*	Mark	Index*	Mark	Index*	Mark	Index*	Mark	Index*	
A	69	2.07	83	2.49	83	3.32	78	5.46	82	3.28	55	4.95	21.57
B	75	2.25	87	2.61	87	3.48	87	6.09	84	3.36	80	7.20	24.99
C	68	2.04	84	2.52	80	3.20	76	5.32	79	3.16	57	5.13	21.37
D	75	2.25	85	2.55	87	3.48	85	5.95	82	3.28	60	5.40	22.91
Lowest Weighted Sum =													21.37

*Index = %Weight x Mark. (see Table 5-8 for weights)

Table 5-8. Technical Score Criteria for NZTA Case Study.

Bid Attributes	Weight
Relevant Experience	3%
Track Record	3%
Technical Skills	4%
Resources	7%
Management Skills	4%
Methodology	9%
Price	70%
TOTAL	100%

Table 5-9. Identification of Best-Value Bid for NZTA (Example Application).

Bidder	WS	WSM (WS – Min. WS)	SQP (dollars)	Original Bid Price (dollars)	Adjusted Bid Price (dollars)
A	21.57	0.2	2,857.14	1,250,240	1,247,382
B*	24.99	3.62	51,714.29	1,117,030	1,065,315 (Best Value Bid)
C	21.37	0	0	1,109,470	1,109,470
D	22.91	1.54	22,000	1,182,970	1,160,970

A 3-D graph that represents the relationship between Adjusted Price, TTM, and price ratio for NZTA's method is shown in Figure 5-8.

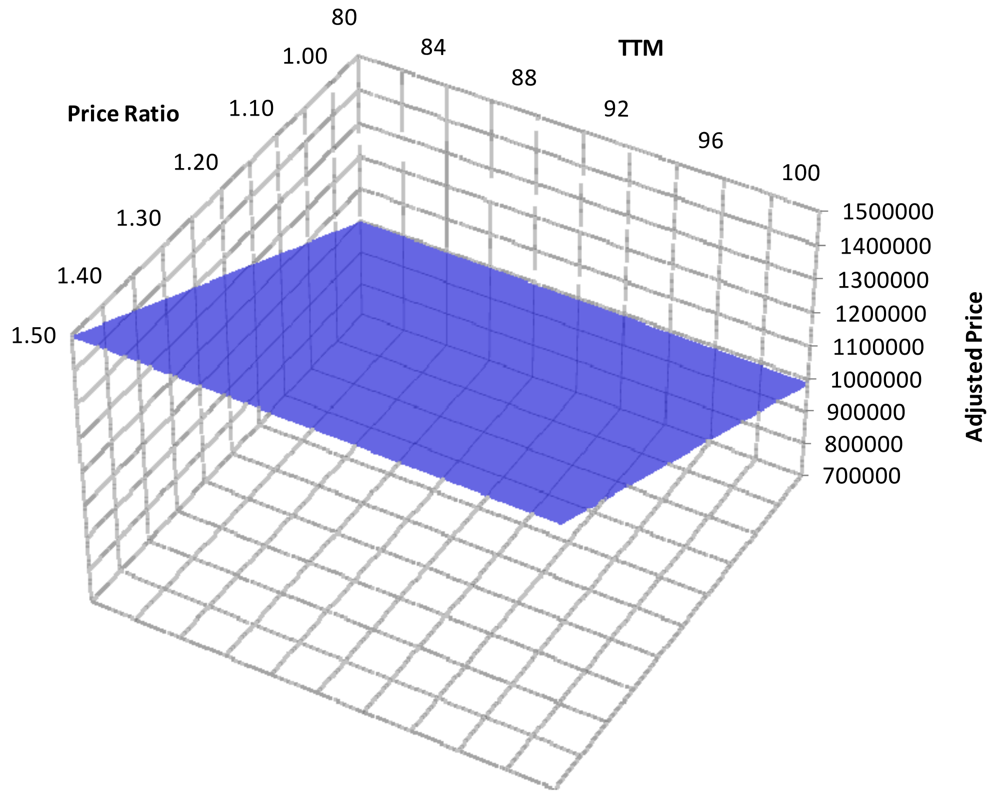

Figure 5-8. Depiction of Adjusted Price as a Function of Price Ratio and TTM for NZTA Case Study.

United Kingdom Highway Agency Case Study

The United Kingdom Highway Agency (UKHA) outsources the maintenance contract through a Managing Agent Contract (MAC). Figure 5-9 illustrates the bid evaluation process. Quality marks are assigned for project specific criteria (pre-defined by the agency) based on the contractor's approach to meet these criteria. The bidder's proposed approach is verified through supporting evidence from past performance records.

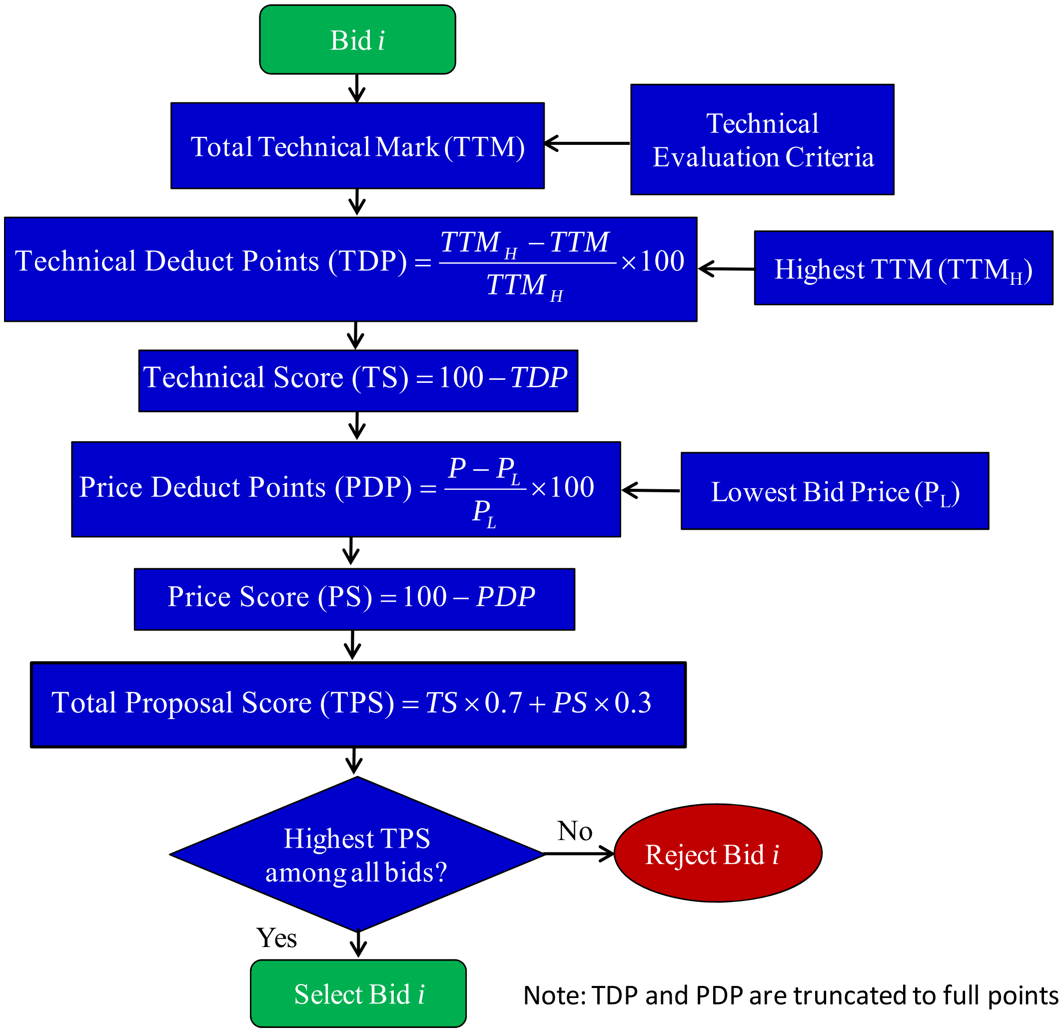

Figure 5-9. Flowchart for UKHA PBMC Bid Evaluation Method.

Table 5-10 shows the assessment criteria along with example marks (for a hypothetical bidder). It can be seen that the technical marks are assigned as the minimum of two marks: 1) Part A mark for proposed approach, and 2) Part B mark for support evidence provided by the bidder. For example, in the "Reducing Congestion" category, Part A mark is 9 and Part B mark is 8. Since Part B mark is the minimum of A and B, the quality mark assigned for this example bidder in this category is 8. A total technical mark (TTM) is computed as the sum of all technical marks. Tables 5-11 and 5-12 show the rating scales for Part A marks and Part B marks, respectively.

Table 5-10. Technical Criteria Used in UKHA PBMC Bid Evaluation Method for an Example Bidder (UKHA 2009).

Assessment Criteria	Part A Marks (Proposed Approach) (0-10)	Part B Marks Evidence from Past Projects (0-10)	Lower of Mark A and B
Maintaining Network Value	8	7	7
Enabling Network Use	8	8	8
Reducing Congestion	9	8	8
High Quality Customer Service	8	7	7
Improving Efficiency	9	8	8
Effective Management	9	7	7
Control of Quality	9	9	9
Reliability of Cost Estimates	9	8	8
Reliability of Time Estimates	9	8	8
Improvement of Safety	9	9	9
		Total Technical Mark (TTM) =	79

Table 5-11. Rating Scale for Part A Marks (UKHA 2009).

Proposed Approach	How well does the proposed approach demonstrate an understanding of the project objectives and address the main management and technical risks relating to the project?	Mark
Week	The approach fails to demonstrate an adequate understanding of the project objectives and fails to address adequately the main management and technical risks.	1-4
Acceptable	The approach demonstrates an adequate understanding of the project objectives and covers the main management and technical risks to an acceptable standard.	5-7
Good	The approach demonstrates a good understanding of the project objectives. It deals fully with the main management and technical risks and provides for delivering continual improvement over the life of the project	8-9
Excellent	The approach has been tailored specifically to suit the project objectives, uses innovative approaches to deal comprehensively with the main management and technical risks, and is likely to maximize performance against Key Performance Indicators and deliver continual improvement.	10

Table 5-12. Rating Scale for Part B Marks (UKHA 2009).

Supporting Evidence	How well does the evidence from previous projects provide confidence that the proposed approach is likely to be successfully delivered.	Mark
Week	There is little evidence that the proposed approach has been influenced by experience on other projects	1-4
Acceptable	There is an adequate level of evidence that the proposed approach has been developed as a result of successful experience on other projects	5-7
Good	There is substantial evidence that the proposed approach has been developed from other projects using formal continual improvement processes	8-9
Excellent	There is substantial evidence that the approach has been developed using continual improvement processes, which are routinely used to develop approaches and deliver the objectives successfully on all projects.	10

The bidder with the highest TTM is assigned a technical score (TS) of 100. The remaining bidders receive a deduction of one quality mark for each full percentage point below the highest TTM. A price score (PS) is determined in a similar manner. The lowest bidder receives a price score of 100, and the remaining bidders receive a deduction of one price mark for each full percentage point above the lowest bid. A total proposal score (TPS) is computed for each bidder, as follows:

$$TPS = 0.7 \times TS + 0.3 \times PS \qquad (5\text{-}8)$$

The bidder with highest TPS is determined as the Leading Bidder (or best-value bid). This process is described through the hypothetical example shown in Tables 5-13, 5-14, and 5-15. In this example, contractor D has the highest TPS and thus is determined as the best-value bidder. Thus, the best bid is neither the lowest bid nor the highest technical bid; it is a bid that balances both price and technical attributes.

A 3-D graph that represents the relationship between TPS, TTM, and price ratio for UKHA's method is shown in Figure 5-10.

Table 5-13. Technical Scores for a Hypothetical Example (UKHA 2009).

Bidder	Quality Mark	% Below Highest Quality Mark	Tech Deduct Points (TDP)	TS = 100 - TDP
A	68	13.9%	13	87
B	61	22.8%	22	78
C*	79	0.0%	0	100 (Highest TTM)
D	75	5.1%	5	95
E	65	17.7%	17	83

Table 5-14. Price Scores for a Hypothetical Example (UKHA 2009).

Bidder	Bid Price	% Above Lowest Price	Price Deduct Points (PDP)	TS = 100 - PDP
A	52,000,000	23.8%	23	77
B*	42,000,000	0%	0	100 (Lowest Bid)
C	55,000,000	30.9%	30	70
D	47,000,000	11.9%	11	89
E	44,000,000	4.8%	4	96

Table 5-15. Total Scores for a Hypothetical Example (UKHA 2009).

Bidder	70% of TS	30% of PS	TPS
A	60.9	23.1	84.0
B	54.6	30.0	84.6
C	70.0	21.0	91.0
D*	66.5	26.7	93.2 (Best-Value Bid)
E	58.1	28.8	86.9

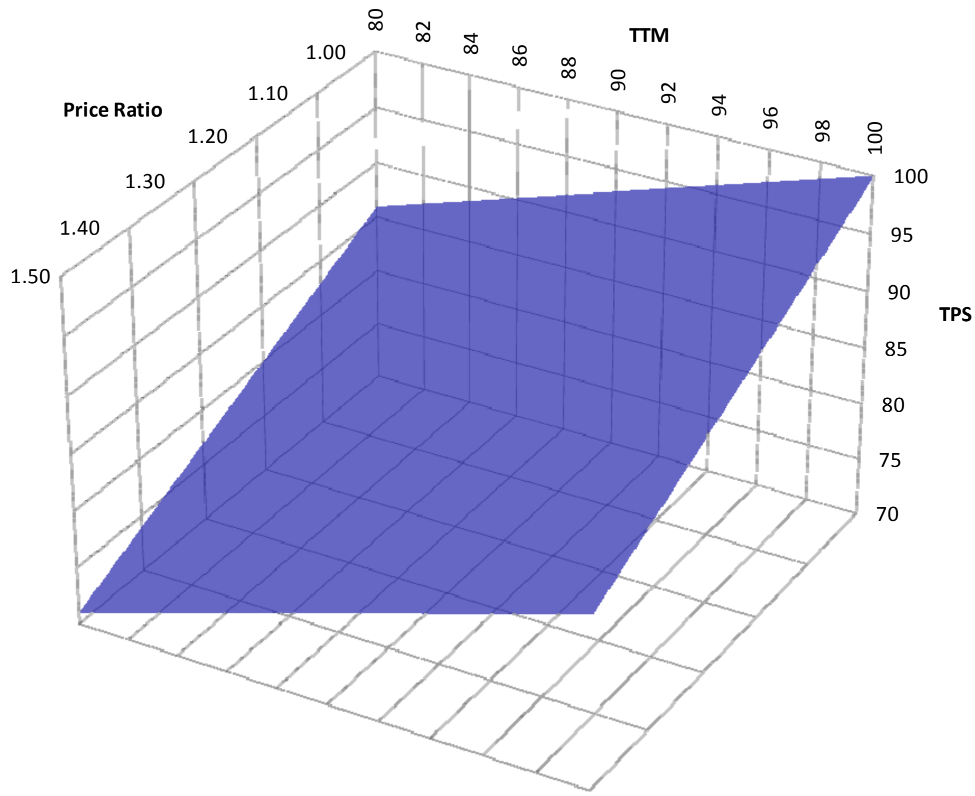

Figure 5-10. Depiction of TPS as a Function of Price Ratio and TTM for HAUK Case Study.

EVALUATION OF CASE STUDIES

The best-value bid identification methods discussed earlier are evaluated in terms the agency's willingness to pay for quality and the neutrality of these methods with respect to lowest bid and highest quality.

Evaluation of Willingness to Pay for Bid Technical Quality

A best-value bidding system represents the agency's willingness to pay for bid quality. The agency's willingness to pay for any given increment in technical score over the technical score of the lowest bidder is evaluated using the concept of equivalent bid. Suppose that the lowest bidder has a bid price P_L, total technical marks of TTM_L, and a technical score of TS_L. For any other bidder (with a bid price of P and total technical mark of TTM) to be equivalent to the lowest bidder, their total technical mark must be greater than TTM_L, so that their total proposal score (TPS) becomes equal to the total proposal score of the lowest bidder (TPS_L). The agency's willingness to pay for technical qualifications can then be measured using a curve that represents the relationship between technical mark and bid price ratio. These curves are referred to here as Willingness-to-Pay (WTP) curves. Figure 5-11 shows the WTP curves for the case studies, assuming a TTM_L of 70. Note that VDOT's and FDOT's methods use the same concept (i.e., technical and price weights). Thus, only FDOT's method is simulated.

For the specific parameters used in these case studies, agencies that use the price and technical weights concept (i.e., FDOTs and VDOT's methods) appear to be more willing to pay for technical quality than those that use the adjusted price concept (i.e., NCDOT and NZTA methods). The UKHA method is the only method that considers the maximum technical quality offered by the bidders. Thus, this bid mechanism is influenced by the quality of the highest bidder and the price of the lowest bidder.

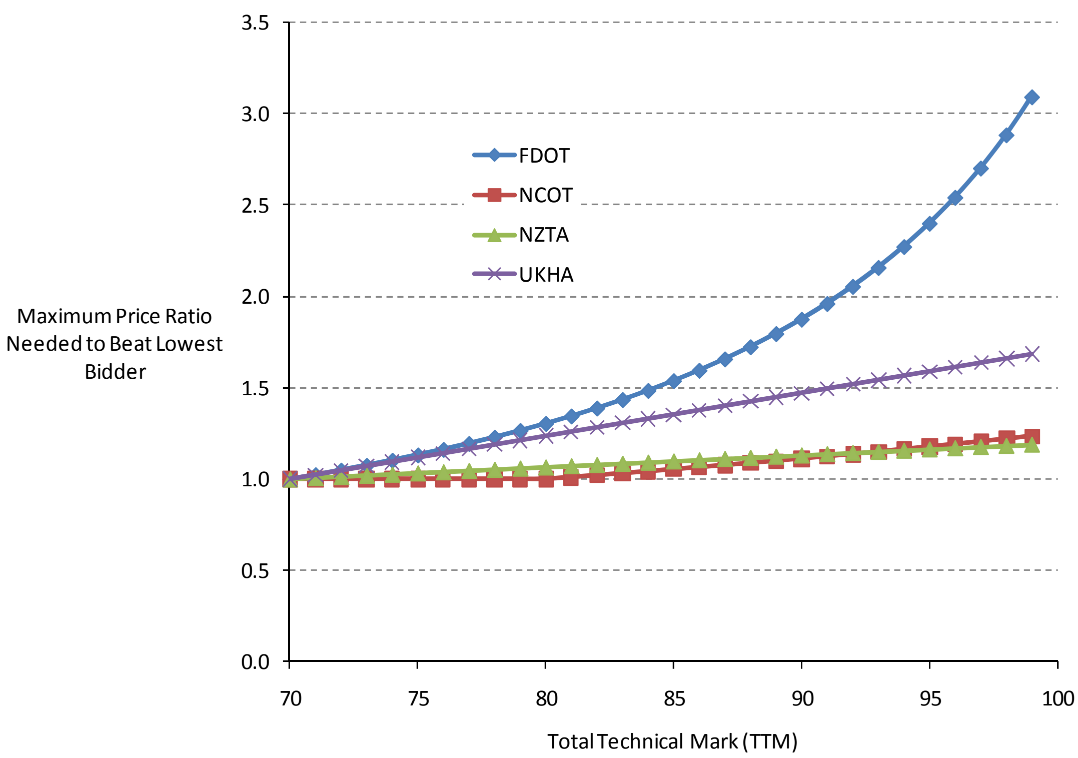

Figure 5-11. WTP Curves for Case Studies (Assuming TTM_L=70).

Neutrality in Best-Value Bid Evaluation Methods

To assess neutrality of the studied bid-evaluation methods with respect to technical attributes and price, a Monte Carlo simulation of four hypothetical bids (A through D) with different bid prices and technical marks was carried out. In this analysis, it is assumed that the bidders will choose their prices with prior knowledge of the bid evaluation method and an assumption that the lowest bidder has a total technical mark of 70 and a bid price of \$6.0 million (i.e., TTM_L=70 and P_L=\$6.0 million). It is assumed that bidders will design their bids (i.e., select their bid price and technical capabilities) according to the WTP cuves. This assumption ensures that they "beat" the lowest bidder using the maximum possible bid price and least possible technical score. Table 5-16 shows the ranges for the total technical mark and bid price for these hypothetical bids.

Table 5-16. Hypothetical Bid Price Range and Technical Marks.

Bidder	**TTM Range**	**Bid Price Range $ million**			
		FDOT	NCDOT	UKHA	NZTA
A	86–90	9.2–10.8	7.1–7.4	8.1–8.7	6.6–6.8
B	81–85	7.8–8.9	6.7–7.0	7.4–8.0	6.4–6.6
C	76–80	6.8–7.6	6.3–6.6	6.7–7.26	6.2–6.4
D	70–75	6.0–6.6	6.0–6.3	6.0–6.56	6.0–6.2

For each best-value bid evaluation method, Monte Carlo simulation was used to generate 3000 bidding cases from the TTM and corresponding bid price ranges shown in Table 5-16. A best-value bid was then identified for each simulated bidding case. The probability of being identified as the best-value bid was then computed as follows:

$$\Pr = \frac{N_D}{N_T} \times 100 \qquad (5\text{-}9)$$

where P_r is the probability of being selected as best-value bid; N_D is the number of times (i.e., number of simulation iterations) for which the bid is selected as best-value bid; and N_T is the total number of simulation iterations.

Since the bid prices were determined according the WTP curves, the behavior of the analyzed methods is classified as follows:

- Balanced: all bids have approximately equal probability of being identified as best-value bid.

- Favors Technical Attributes: bids with higher total technical mark have higher probability of being identified as best-value bid.
- Favors Low Bid Price: bids with low bid price have higher probability of being identified as best-value bid.

Figures 5-12 through 5-15 illustrate the results of the simulation. Figure 5-12 shows that, using FDOT's method, Bid D (lowest bidder and lowest TTM) has the highest probability of being identified as the best-value bid, whereas Bid A (highest bidder and highest TTM) has the lowest probability of being selected. Thus, FDOT's method appears to favor low bid prices.

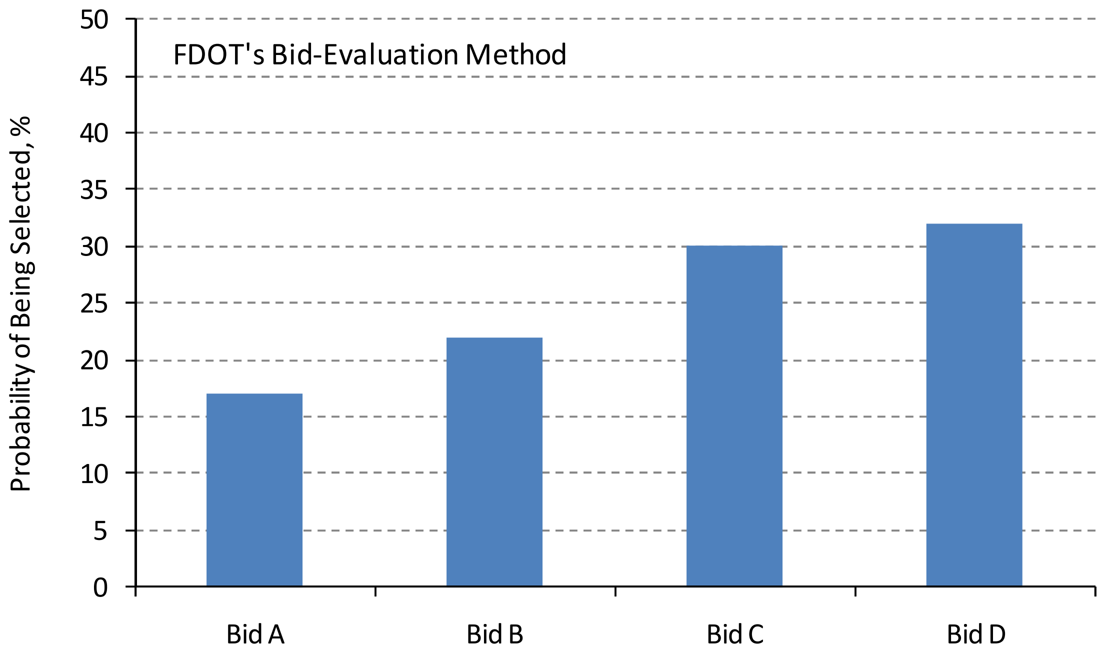

Figure 5-12. FDOT's Best Bid Simulation Results.

Figure 5-13 shows that, using UKHA's method, Bid A (highest bidder and highest TTM) has the highest probability of being identified as the best-value bid, whereas Bid D (lowest bidder and lowest TTM) has the lowest probability of being selected. Thus, UKHA's method appears to favor high-quality bids.

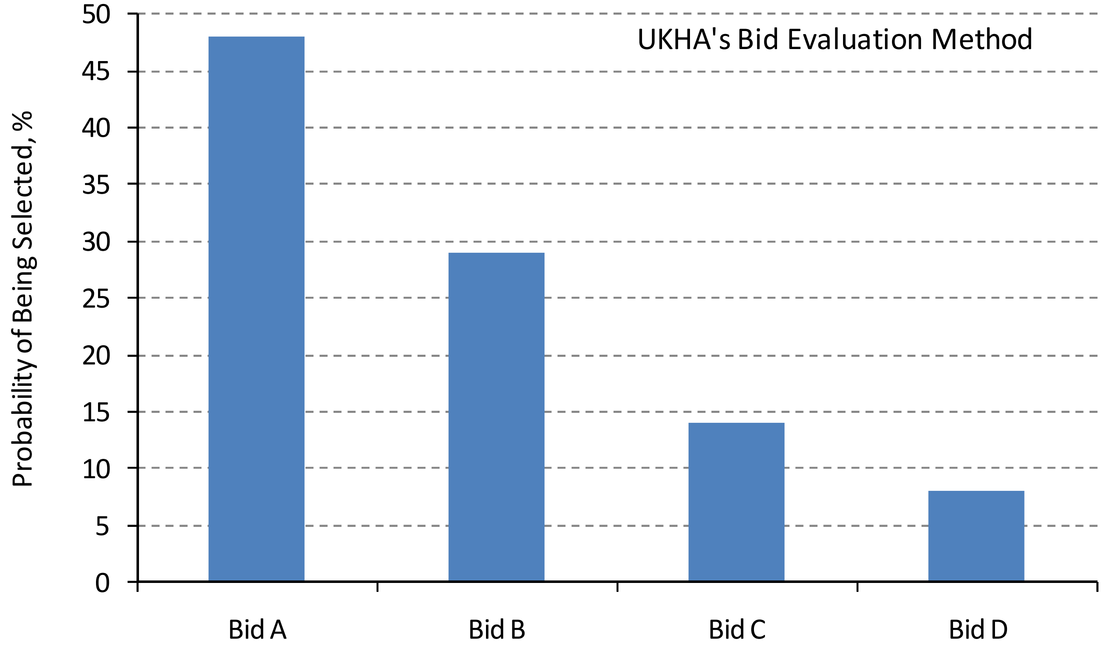

Figure 5-13. UKHA's Best Bid Simulation Results.

Figures 5-14 and 5-15 show that, using NCDOT's and NZTA's methods, approximately all bids have equal chances of being identified as the best-value bid. Thus, NCDOT's and NZTA's methods appear to be balanced.

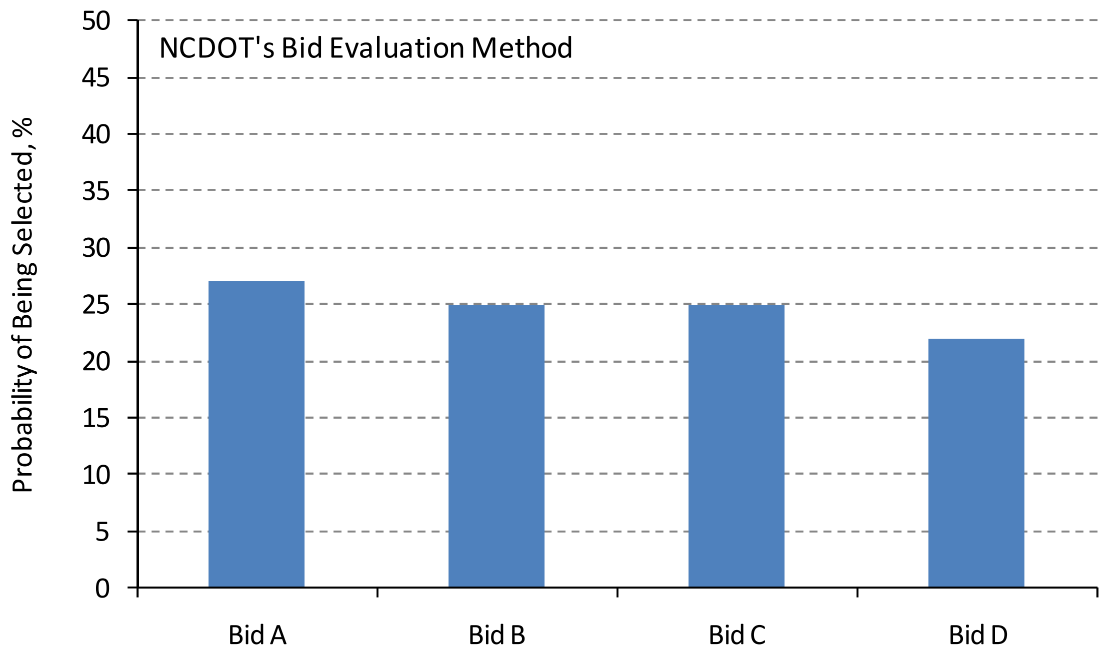

Figure 5-14. NCDOT's Best Bid Simulation Results.

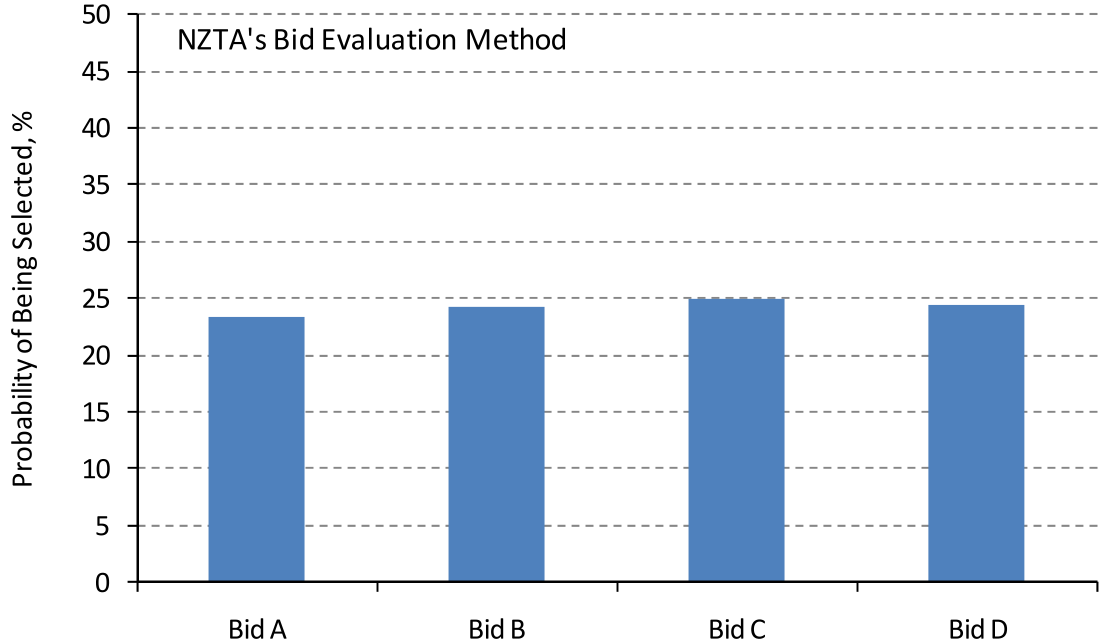

Figure 5-15. NZTA's Best Bid Simulation Results.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Performance-based Maintenance Contracts (PBMCs) are increasingly being used for roadway maintenance as an alternative to method-based specifications. There is general agreement in the literature that the key to the success of PBMCs is clearly defined performance requirements, a sound condition assessment method for evaluating compliance with these requirements, a rational performance-based pay adjustment system, and a best-value bid evaluation method (Hyman 2009, Stankevich et al. 2005, Schexnayder and Ohrn 1997, Lo and Yan 2009, and Pakkala 2002). However, PBMCs are still relatively new, and these issues have not been adequately addressed in the literature. The research documented in this report addresses these issues for roadside PBMCs. The main findings and results of this research effort are summarized as follows.

Performance Standards and Timeliness Requirements

- Initial performance standards and timeliness requirements for roadside maintenance were developed based on responses to an online survey of TxDOT's districts (17 TxDOT districts responded to the survey) and a review of the literature.
- Out of the initial 53 performance standards that were included in the survey, 41 standards were supported by at least 70 percent of the respondents, eight standards were supported by 50–70 percent of the respondents, and only four standards were supported by less than 50 percent of the respondents. These standards were later refined based on feedback from on-site interviews of maintenance personnel at the Waco and Dallas Districts.
- Performance-based roadside maintenance specifications were prepared using the developed standards and condition assessment method for potential use by TxDOT (see Appendix C).

Condition Assessment Method

- A condition assessment method for evaluating the contractor's compliance with the performance requirements was developed using the roadway level of service (LOS) concept.

- Priority multipliers that reflect the importance of various roadside elements were developed based on responses received from TxDOT's districts regarding their assessment of the performance risk of these elements.
- Due to the specificity of the performance standards and the relatively high number of performance standards to be evaluated (55 performance standards), a close observation through a walking survey is needed to assess compliance with these standards accurately. Thus, random sampling of relatively short sample units (0.1-mi long) is necessary for the condition survey to be practical.
- The appropriate sample size is determined statistically as a function of tolerable error, desired confidence level, total number of sample units in the project, and an estimate of the population's standard deviation.
- The Analysis of Variance (ANOVA) with a multiple population approach showed that the developed condition assessment method is reproducible.
- The sample unit scores (SUSs) were found to follow a *Beta* probability distribution (i.e., SUS values are shifted to the right side of the SUS scale). This shift is expected since maintenance efforts strive to maximize the SUS score (which has an upper maximum value of 100).

Pay Adjustment System

- A method for developing pay adjustment formulas was developed. This method is designed to motivate the contractor to perform at the performance target specified by the agency.
- Pay adjustment functions were developed for the five field trial sites. Pay adjustment is determined as a function of roadway LOS (measured in the field) and target LOS (specified by the agency).

Best-Value Bid Evaluation

- Five best-value bid evaluation methods that are already in practice by the state transportation agencies in Florida, Virginia, North Carolina, United Kingdom, and New Zealand were evaluated.

- Best-value bid evaluation methods that use the adjusted price concept (i.e., NCDOT and NZTA methods) appear to be balanced with respect to price and technical marks.
- Best-value bid evaluation methods that use direct price and technical weights (i.e., FDOT's and VDOT's methods) appear to favor low bids.
- Best-value bid evaluation methods that consider the maximum technical quality offered by the bidders (i.e., the United Kingdom method) appear to favor bids with high technical marks over bids with low price.

RECOMMENDATIONS

Researchers make the following recommendations based on the results of this study:

- Apply the developed performance standards, condition assessment method, and pay adjustment formulas to an actual pilot PBMC project.
- Consider using a best-value bid evaluation method (rather than the conventional low-bid method) for PBMCs. Best-value bid evaluation is critical because PBMCs extend over multiple years (typically 3-10 years) and shift the risk of failing to meet performance standards and targets to contractors.
- Link TxDOT's maintenance cost database to roadside condition databases. This linkage will allow for verifying and improving the relationships between roadside LOS and maintenance cost, and consequently improve the optimality of the pay adjustment functions.
- Investigate extending the performance standards, condition assessment method, and pay adjustment formulas developed in this research for roadside assets to pavement assets.
- Develop a training manual and a formal training program for field inspector to properly assess the condition of roadside assets and maintenance activities.

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APPENDIX A. DISTRICTS SURVEY INSTRUMENT

TxDOT-TTI Survey for Performance-Based Roadside Maintenance Specifications

The purpose of this survey is to gather input from TxDOT districts on best practices in performance-based specifications for contracted roadside maintenance. This information will be used in developing a new set of specifications that will be recommended for trial use by TxDOT.

Your response to this survey will be appreciated by TxDOT and the TTI research team.

Please provide your contact information below:
Name
District
Position
E-mail

Part A

Performance Standards and Targets

Mowing and Roadside Grass

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 8)

- Roadside grass height (rural areas): 7-30 inches
- Roadside grass height (urban areas): 7-24 inches
- Roadside vegetation should be 85% free of noxious weeds.
- Paved shoulders, medians, islands and edge of pavement should be free of bermuda grass.

- Unpaved shoulders, slopes, and ditch lines free of bare or weedy areas.
- TxDOT approval of herbicides is required.

Landscaped Areas

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 8.)

- 90% of landscaped areas is free of weeds and dead or dying plants.
- Grass height: 12 inches maximum.
- TxDOT's approval of herbicides is required.

Trees, Shrubs and Vines

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 8.)

- Vertical clearance over sidewalks and bike paths is at least 10 ft.
- Vertical clearance over roadway and shoulder is at least of 18 ft.
- Clear horizontal distance behind guardrail is at least 5 ft for trees.
- No dead trees and no leaning trees that present a hazard.
- No trees and/or vegetation that obscure the message of a roadway sign.

Performance Targets: What percentage of the inspected samples should meet the above standards so that the contractor receives 100% payment:

1	2	3	4	5
75%-79.9%	80%-84.9%	85%-89.9%	90%-94.9%	95%-100%

Mowing and Roadside Grass

1 2 3 4 5

Landscaped Areas

1 2 3 4 5

Trees, Shrubs, and Vines

1 2 3 4 5

What are the chances that an average contractor will be able to meet the performance standards and targets you selected above?

1	2	3	4
Less than 25%	25%-49.9%	50%-74.9%	75%-100%

Mowing and Roadside Grass

1 2 3 4

Landscaped Areas

1 2 3 4

Trees, Shrubs, and Vines

1 2 3 4

If the contractor does NOT meet the standards and targets selected above, what would be the negative effect on TxDOT and the public?

1	2	3	4
Minor	Moderate	Major	Severe (e.g., loss of life)

Mowing and Roadside Grass

1 2 3 4

Landscaped Areas

1 2 3 4

Trees, Shrubs, and Vines

1 2 3 4

Please enter any comments you might have on mowing, roadside grass, and trees, shrubs, and vines in the box below.

Ditches and Front Slopes

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 15.)

- 90% of the ditch structure (90% of the length and 90% of the depth) functions as intended.

- There are no eroded areas, washouts, or sediment buildup that adversely affect the flow of water in the ditch.
- No joint separation, misalignment, or undermining in concrete ditches.
- No deviations (hills, holes, etc.) greater than 3 inches in depth or height, in front slope.
- No washouts or ruts greater than 3-in deep and 2-ft wide, in front slope.
- No erosion that will endanger the stability of the front slope, creating an unsafe recovery area.

Culvert and Cross-Drain Pipes

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 15.)

- At least 75% of the cross sectional area of each pipe is free of obstructions and functions as intended with no evidence of flooding.
- The grates are of the correct type and size, unbroken, and in place.
- No water infiltration causing pavement failures, shoulder failures, or roadway settlement.
- No cracking, joint failures, or erosion of culverts and cross-drain pipes.

Drain Inlets

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 15.)

- 85% of the opening area is not obstructed.
- The grates are of the correct size and are unbroken. Manhole lids are properly fastened.
- No hazard from exposed steel or any deformation of the inlet.
- No surface damage 0.5 ft2 or more.
- Outlets are not damaged and are functioning properly.
- No erosion, settlement, or sediment around boxes.

Performance Targets: What percentage of the inspected samples should meet the above standards so that the contractor receives 100% payment:

1	2	3	4	5
75%-79.9%	80%-84.9%	85%-89.9%	90%-94.9%	95%-100%

Ditches and Front Slopes

1	2	3	4	5

Culvert and Cross-Drain Pipes

1	2	3	4	5

Drain Inlets

1	2	3	4	5

What are the chances that an average contractor will be able to meet the performance standard and target you selected above?

1	2	3	4
Less than 25%	25%-49.9%	50%-74.9%	75%-100%

Ditches and Front Slopes

1	2	3	4

Culvert and Cross-Drain Pipes

1	2	3	4

Drain Inlets

1	2	3	4

If the contractor does NOT meet the standards and targets selected above, what would be the negative effect on TxDOT and the public?

1	2	3	4
Minor	Moderate	Major	Severe (e.g., loss of life)

Ditches Front Slopes

1	2	3	4

Culvert and Cross-Drain Pipes

1	2	3	4

Drain Inlets

1	2	3	4

Please enter any comments you might have on ditches, culverts, cross-drain pipes, drain inlets, and front slopes in the box below.

Chain Link Fence

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 22.)

- No opening in the fence fabric greater than 2 ft2.
- No opening in the fence fabric with a dimension greater than 2 ft.
- No open gates.

Guardrails

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 22.)

- No 25 continuous feet that is 3 inches above or 1 inch below the specified elevation.
- No more than 10% of the guardrail blocks in any continuous section are twisted.
- No more than 10% of the wooden posts or blocks in any continuous section are rotten or deteriorated.
- No missing posts, offset blocks, panels or connection hardware.
- No damaged end sections.
- No penetrations in the rail.
- No panel lapped incorrectly.
- Contractor to address guardrail deficiencies (listed above) within 3 days

Attenuators

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 22.)

- Each device functions as intended.
- No missing parts.
- No visually-observed malfunctions, such as water or sand containers that are split, compression of the device, misalignment, etc.
- Contractor to address attenuator deficiencies (listed above) within 3 days.

Performance Targets: What percentage of the inspected samples should meet the above standards so that the contractor receives 100% payment:

	1	2	3	4	5
	75%-79.9%	80%-84.9%	85%-89.9%	90%-94.9%	95%-100%
Chain Link Fence	1	2	3	4	5
Guardrails	1	2	3	4	5
Attenuators	1	2	3	4	5

What are the chances that an average contractor will be able to meet the performance standards and targets you selected above?

	1	2	3	4
	Less than 25%	25%-49.9%	50%-74.9%	75%-100%
Chain Link Fence	1	2	3	4
Guardrails	1	2	3	4
Attenuators	1	2	3	4

If the contractor does NOT meet the standards and target selected above, what would be the negative effect on TxDOT and the public?

	1	2	3	4
	Minor	Moderate	Major	Severe (e.g., loss of life)
Chain Link Fence	1	2	3	4
Guardrails	1	2	3	4
Attenuators	1	2	3	4

Please enter any comments you might have on access fences, guardrails, and attenuators in the box below.

Litter and Debris

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 28.)

- Less than 50 pieces of fist size or larger litter/debris within 0.1 miles.
- The volume of litter does not exceed 3 cubic feet per acre of right-of-way.
- No litter that creates a hazard to motorist, bicyclist, or pedestrian traffic is allowed.
- Remove dead animals from the right of way within 2 hours.

Graffiti

Performance Standards: Please check all standards that you agree with. (Please enter any comments you might have in box No. 28.)

- Obscene, sexually or racially explicit or "gangrelated" graffiti shall be removed within 3 days.
- Non-obscene graffiti shall be removed within two weeks of discovery.
- Restore the surface to an appearance similar to adjoining surfaces.
- No damaged surface or coating due to graffiti removal.

Performance Targets: What percentage of the inspected samples should meet the above standards so that the contractor receives 100% payment:

	1	2	3	4	5
	75%-79.9%	80%-84.9%	85%-89.9%	90%-94.9%	95%-100%
Litter & Debris	1	2	3	4	5
Graffiti	1	2	3	4	5

What are the chances that an average contractor will be able to meet the performance standards and targets you selected above?

1	2	3	4
Less than 25%	25%-49.9%	50%-74.9%	75%-100%

Litter & Debris

1	2	3	4

Graffiti

1	2	3	4

If the contractor does NOT meet the standards and targets selected above, what would be the negative effect on TxDOT and the public?

1	2	3	4
Minor	Moderate	Major	Severe (e.g., loss of life)

Litter & Debris

1	2	3	4

Graffiti

1	2	3	4

Please enter any comments you might have on litter and debris, and graffiti in the box below.

Part B

Maintenance Contract Aspects

What is the appropriate project size per contract? Please select a range from the drop down list below:

What is the appropriate contract duration? Please select a duration from the drop down list below.

Who should perform the inspection?

- TxDOT.
- Contractor.
- Third party (hired by and report to TxDOT).
- Third party (hired by the contractor and report to both TxDOT and the contractor).
- Other, please specify

What percentage of the project should be inspected?

- 5%
- 10%
- 15%
- 20%
- 25%
- Other, please specify

Should incentives (pay increase) be used when the contractor exceeds the performance targets? If yes, what is an appropriate maximum incentive (as a percentage of bid price)?

Should disincentives (pay decrease) be used when the contractor does not achieve the performance targets? If yes, what is an appropriate maximum disincentive (as a percentage of bid price)?

Thank you for completing the survey. Please provide any additional comments below.

APPENDIX B. RESPONSES OF TXDOT'S DISTRICTS TO RISK ASSESSMENT

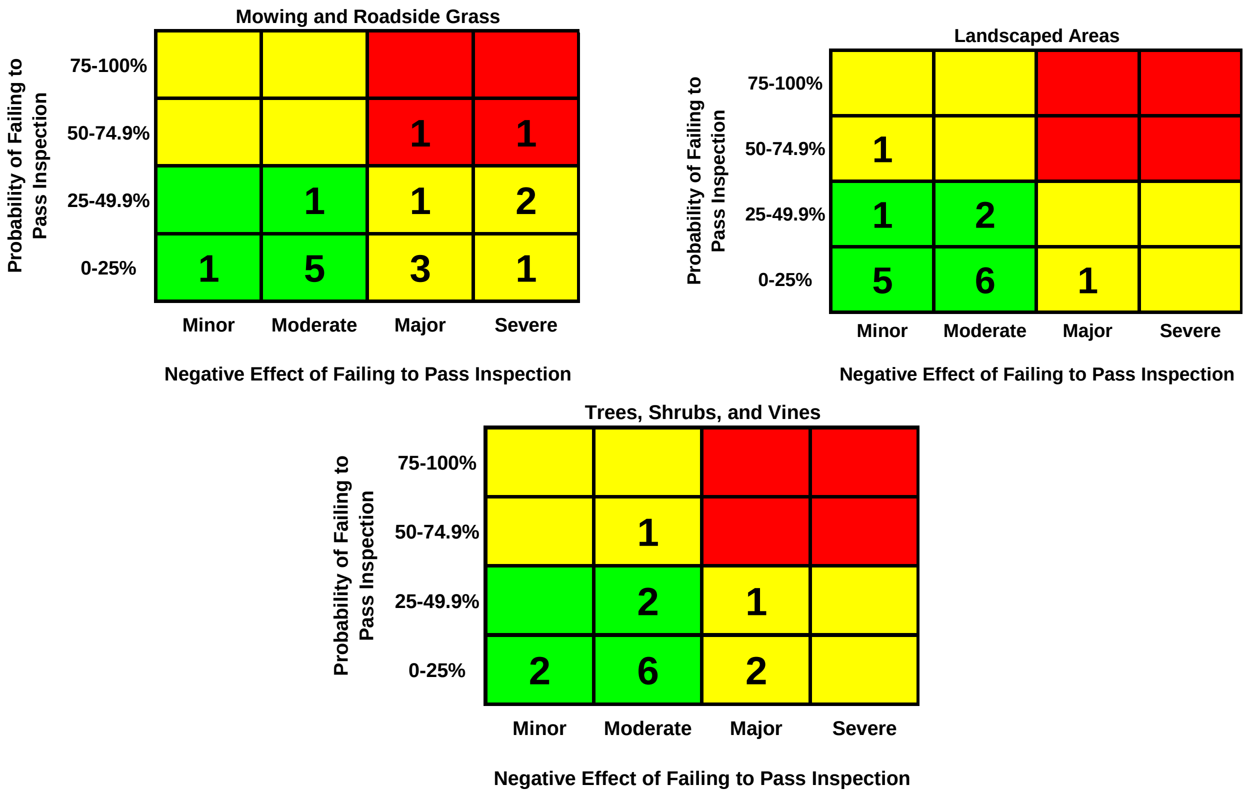


Figure C-1. Performance Risk Assessment for Vegetation-related Asset Types and Maintenance Activities (numbers in cells represent numbers of responses).

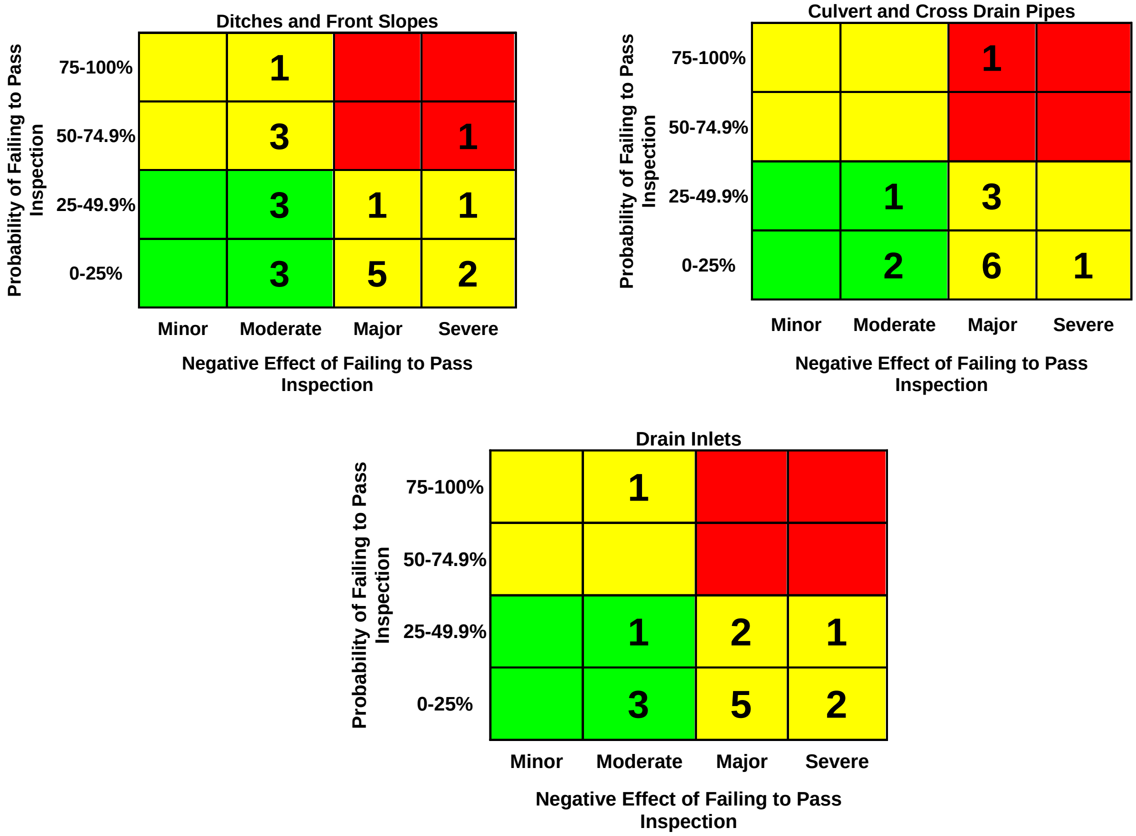


Figure C-2. Performance Risk Assessment for Drainage-related Asset Types and Maintenance Activities (numbers in cells represent numbers of responses).

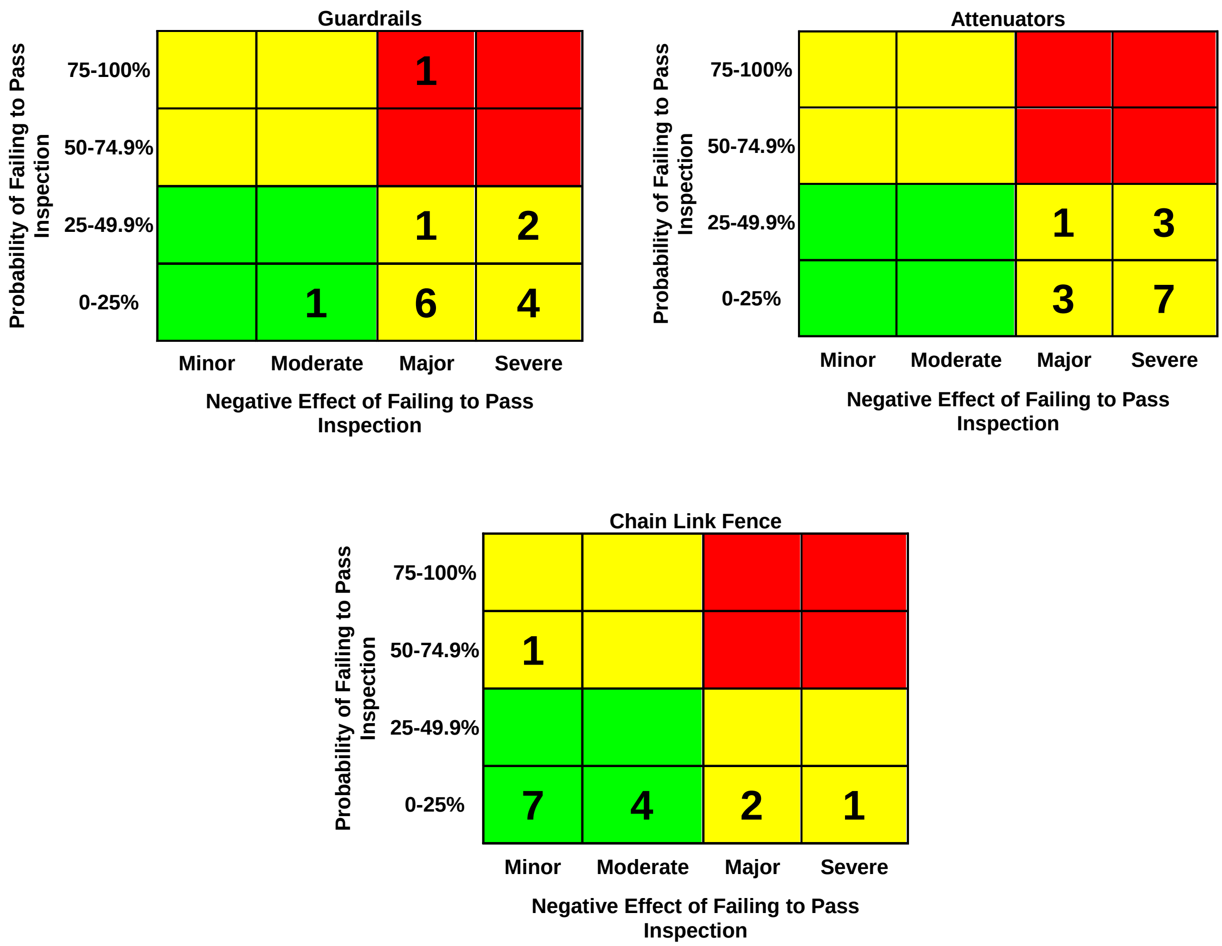
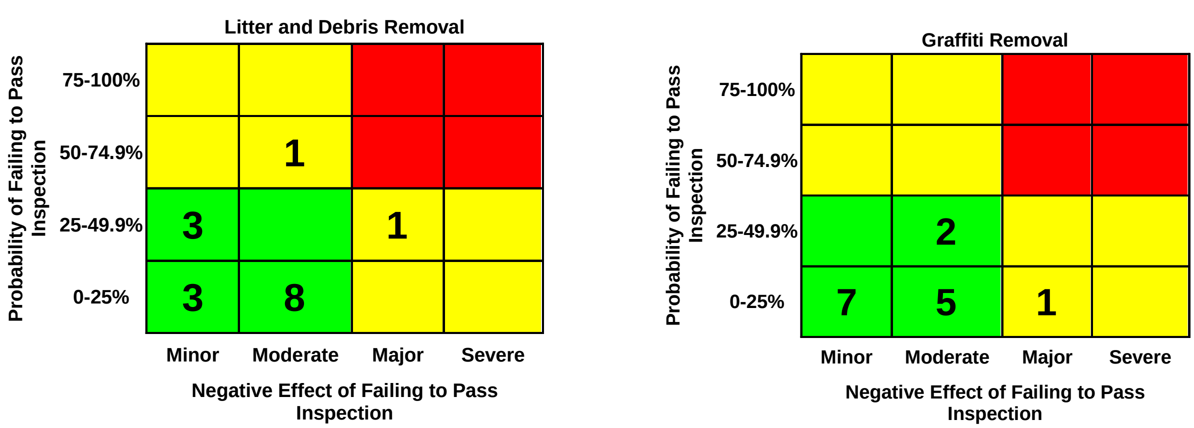


Figure C-3. Performance Risk Assessment for Safety-related Asset Types and Maintenance Activities (numbers in cells represent numbers of responses).



APPENDIX C. DRAFT PERFORMANCE-BASED SPECIFICATIONS FOR ROADSIDE MAINTENANCE

1. **Description.** This Item shall govern for provision of comprehensive roadside maintenance services, including activities related to vegetation, safety, drainage, and cleanness of the roadside. The specific roadside elements included in this work are more fully described on the attached condition inspection form. Contractor compliance is measured based upon performance-based criteria.

2. **General.** It is the intent of this specification that the Contractor identifies roadside maintenance needs and performs all roadside maintenance activities necessary to provide roadside quality meeting the performance standards and targets described herein.

   A. **Department Standards.** The Contractor is referred to the following TxDOT standards for interpretation of terms and clarification of standard department procedures, processes, and materials quality requirements.

      1. Maintenance Manual
      2. Roadside Vegetation Management Manual
      3. Herbicide Operations Manual
      4. Departmental Traffic Control Standard Sheets
      5. Texas Standard Specifications for Construction of Highways, Streets and Bridges; 2004 and applicable Special Provisions and Special Specifications
      6. Texas Manual on Uniform Traffic Control Devices for Streets and Highways (TMUTCD)
      7. Material Producer List
      8. Manual of Testing Procedures
      9. Maintenance Operations Manual
      10. Utility Accommodation Policy
      11. TxDOT's Environmental Impact Statement- Roadside Pest Management Program
      12. Maintenance Management Information System (MMIS) Manual
      13. Construction/Maintenance Contract System (CMCS) Manual
      14. Highway Condition Report (HCR) Manual
      15. Departmental Material Specifications (DMS)

16. TxDOT Standard Sheets

B. Coordination of Roadside Activities. The Contractor shall properly coordinate roadside maintenance activities with other Contractors, municipalities, cities, counties, state and local law enforcement, fire departments, utilities, and other state and federal agencies.

C. Contractor Agreements. The Contractor shall provide the Department a copy of all agreements between the Contractor and counties, cities, municipalities, and other entities associated with the work under this contract.

D. Purchasing from People with Disabilities. The Contractor shall comply with the provisions of Chapter 122 of the Texas Human Resources Code that are placed on the Department. The use of Community Rehabilitation Programs (CRP's) is outlined in this Chapter. Specifically, Section 122.008. "Procurement at Determined Prices" states "A suitable product or service that meets applicable specifications established by the state or its political subdivisions and that is available within the time specified must be procured from a CRP at the price determined by the council to be the fair market price."

The Department reserves the right to mediate disputes involving subcontracts or potential subcontracts with CRP's and central non-profit agencies (CNA) such as TIBH Industries

E. Highway Lane Closures. Lane closures will not be allowed without approval of the Engineer.

F. Complaints and Service Requests. The Contractor shall report monthly on a format approved by the Engineer information on complaints and/or service requests received from the public, cities, counties, or from any other sources during the previous month. This information will include, as a minimum, the following

1. Date and time of complaint or service request;
2. Location of the problem or service request;
3. Nature of the problem or service request;
4. Identification of person placing the complaint and/or request;
5. Date, time and action taken to address the complaint or service request;
6. Any action taken by the Texas Department of Agriculture (TDA) or Texas Structural Pest Control Service; and
7. Any legislative contact shall be immediately directed to the District Engineer's office for response.

3. **Materials.** The Contractor shall furnish all materials necessary to complete the work. The Contractor shall furnish the Engineer with documentation indicating material compliance with applicable Department specifications.

4. **Equipment.** The Contractor shall furnish all equipment, tools and machinery necessary for the proper prosecution of the work.

5. **License Requirements.** The Contractor shall possess the appropriate qualifications and/or licenses. The Contractor shall provide the Department with documentation of licenses prior to the beginning of work. Licensed personnel shall be responsible for mixing, transporting, handling, spraying, and disposal of materials. All Contractor or subcontractor personnel shall be appropriately licensed for specialized work. To apply herbicide within the transportation system, applicators shall possess a license issued by the TDA, as a commercial pesticide applicator within the Right-of-Way usage category. For work within landscaped areas, applicators shall possess a license issued by the TDA, as a commercial pesticide applicator within the Turf and Ornamental category.

6. **Scope of Work and Performance Standards.** The following items are included in this specification:

    1. Vegetation-related Items: Roadside grass; landscaped areas; and trees, shrubs and vines.

    2. Safety-related Items: Attenuators; guard rails; and chain link fence.

    3. Drainage-related Items: Ditches and front slopes; culverts and cross-drain pipes; and drain inlets.

    4. Cleanness-related Items: Litter and debris; and graffiti.

It is the responsibility of the Contractor to perform all work required to maintain the highway roadside and appurtenances as described in Tables 1 through 4 below. The identification of areas as rural or urban shall be as designated on the plans or otherwise noted by the Engineer. The timeliness requirements are discussed in Section 7 of these specifications.

Table 2. Vegetation Management Performance Standards.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Roadside Grass	1. Any use of herbicide requires advance approval of the Engineer. 2. Paved areas (shoulders, medians, islands, slope, and edge of pavement) shall be free of grass 3. Roadside vegetation in the mowing area shall be at least 85% free of noxious weeds (undesired vegetation) 4. In rural areas, roadside grass height shall be maintained below 24 inches and shall not be cut to below 7 inches. 5. In urban areas, roadside grass height shall be maintained below 18 inches and shall not be cut to below 7 inches. 6. Unpaved areas (shoulders, slopes, and ditch lines) shall be free of bare or weedy areas	7 days
Landscaped Areas	1. Any use of herbicide requires advance approval of the Engineer. 2. Landscaped areas shall be maintained to be 90 percent free of weeds and dead or dying plants. 3. Grass height in landscaped areas shall be maintained at a maximum height of 12 inches.	7 days
Trees, Shrubs and Vines	1. No trees or other vegetation shall obscure the message of a roadway sign. 2. No leaning trees presenting a hazard shall remain on the roadside. 3. Vertical clearance over sidewalks and bike paths shall be maintained at 10 ft or more. 4. Vertical clearance over roadways and shoulders shall be maintained at 18 ft or more. 5. Clear horizontal distance behind guardrail shall be at least 5 ft for trees. 6. No dead trees shall remain on the roadside.	7 days

Table 3. Roadside Safety Performance Standards.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Guard Rails	1. Installations shall be free of missing posts, offset blocks, panels or connection hardware. 2. End sections shall not be damaged. 3. Rails shall not be penetrated. 4. Panels shall be lapped correctly. 5. No more than 10% of guard rail blocks in any continuous section shall be twisted. 6. No 25-foot continuous section shall be more than 3 inches above or 1 inch below the specified elevation. 7. No more than 10% of wooden posts or blocks in any continuous section shall be rotten or deteriorated.	3 days
Attenuators	1. Each device shall be maintained to function as designed. 2. Installations shall have no visually observable malfunctions (examples – split sand or water containers, compression dent of the device, misalignment, etc.) 3. Installations shall have no missing parts.	3 days
Chain Link Fences	1. Installations shall have no open gates. 2. Installations shall have no openings in the fence fabric greater than 1.0 square ft. 3. Installations shall have no openings in the fence fabric with a dimension greater than 1.0 ft.	14 days
Cable Median Barrier	1. Installations shall be free of missing or damaged post, cable, or connections 2. Installations shall be free of missing or damaged end sections 3. Installations shall be free of loose cable or cable with incorrect weave	3 days

Table 4. Drainage Performance Standards.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Ditches and Front Slopes	1. Ditches and front slopes shall be maintained free of eroded areas, washouts, or sediment buildup that adversely affects water flow. 2. Erosion shall not endanger stability of the front slope, creating an unsafe recovery area. 3. Front slopes shall not have washouts or ruts greater than 3 inches deep and 2 ft wide. 4. No part of the ditch can have sediment or blockage covering more than 10% of the depth and width of the ditch 5. Concrete ditches shall not be separated at the joints, misaligned, or undermined. 6. Front slopes shall not have holes or mounds greater than 6 inches in depth or height.	7 days
Culvert and Cross-Drain Pipes	1. A minimum of 75% of pipe cross sectional area shall be unobstructed and function as designed. There shall be no evidence of flooding if the pipe is obstructed to any degree. 2. Grates shall be of correct type and size, unbroken, and in place. 3. Installations shall not allow pavement or shoulder failures or settlement from water infiltration. 4. Culverts and cross-drain pipes shall not be cracked, have joint failures, or show erosion.	7 days
Drain Inlets	1. Grates shall be of correct size and unbroken. Manhole lids shall be properly fastened. 2. Installation shall not present a hazard from exposed steel or deformation. 3. Boxes shall show no erosion, settlement, or have sediment accumulation. 4. Outlets shall not be damaged and shall function properly. 5. Inlet opening areas shall be a minimum of 85% unobstructed. 6. Installations shall have no surface damage greater than 0.5 square ft.	7 days

Table 5. Roadside Cleanness Performance Standards.

Roadside Asset Type/Maintenance Activity	Performance Standards	Timeliness
Litter and Debris	1. No litter or debris that creates a hazard to motorists, bicyclists, or pedestrians is allowed. 2. No 0.1-mi roadway section shall have more than 50 pieces of fist-size or larger litter or debris on either side of the centerline of the highway. 3. Litter volume shall not exceed 3.0 cubic ft per 0.1-mi roadway section on both sides of the pavement. 4. In rural areas, traffic lanes shall be free of dead large animals. 5. In urban areas, traffic lanes and right of way shall be free of dead animals.	1. In rural areas, remove large dead animals from the traffic lanes within 24 hours. 2. In urban areas, remove dead animals from the right of way within 24 hours
Graffiti	1. No graffiti is allowed. 2. Surfaces and coatings shall not be damaged by graffiti removal. 3. Surfaces from which graffiti has been removed shall be restored to an appearance similar to adjoining surfaces.	1. Obscene, sexually or racially explicit, or "gang-related" graffiti shall be removed within 3 days. 2. Other graffiti shall be removed within 2 weeks.

7. **Contractor Non-Performance Notification and Timeliness Requirements.** The Department will notify the Contractor of performance standards, as shown in Section 6, "Scope of Work and Performance Standards Performance Standards," that has not been met. If Performance Standards are not met, the following measures will be taken:

   A. **Special Timeliness Requirements.** For the following Performance Standards, if the Performance Standard is not met within the specified number of days, the Contractor will be charged $3,000 per day (including Saturdays, Sunday and holidays), per item of work, per standard until the standard is met.

      1. Guard rail deficiencies shall be corrected by the Contractor within three days.

      2. Attenuator deficiencies shall be corrected by the Contractor within three days.

      3. Chain link fence deficiencies listed below shall be addressed by the Contractor within 14 days.

4. Cable median barrier missing or damaged post, cable, connections, or end sections shall be addressed by the contractor within three days

5. Loose cable, cable with incorrect weave, or installation shall be corrected in three days.

6. In rural areas, large dead animals shall be removed from the traffic lanes within 24 hours.

7. In urban areas, dead animals shall be removed from the right of way within 24 hours.

8. Obscene, sexually or racially explicit, or “gang-related” graffiti shall be removed within three days.

9. Other graffiti shall be removed within two weeks.

B. Seven-day Timeliness Requirements. For all other Performance Standards, if the Performance Standard is not met within seven days, the Contractor will be charged $3,000 per day (including Saturdays, Sunday and holidays), per item of work, per standard until the standard is met.

The costs associated with the measures shown in Sections 7.A and 7.B will be deducted from any monies due the Contractor.

In addition, the Department may take steps to have the work corrected. This may include the use of State Forces or Emergency Contracts. Once the Contractor is notified that the Department is taking corrective action, the Contractor shall refrain from performing work on the item in question unless approved by the Engineer. The costs associated with these measures will be deducted from any monies due the Contractor.

8. Formal Condition Assessment. The Department will perform a monthly condition assessment on randomly selected sample units. Sample units to be inspected will be selected randomly at random locations along the roadway and will be approximately 0.1-mi long. The sample unit will be inspected using the form shown in Figure 1 and will be assigned a Pass, Fail, or Not Applicable rating. No Fail grade should be assigned unless there is evidence that the timeliness requirements have been exceeded.

Inspector's Name:		Inspection Date:	
District:		Highway: Milepoint: Sample Unit No.: Urban/Rural:	
Roadside Asset Type/Maintena	**No.**	**Performance Standard**	**Grade (Pass, Fail, NA)**
Mowing and Roadside Grass	1	Obtained TxDOT approval of herbicides	
	2	Paved areas (shoulders, medians, islands, slope, and edge of pavement) shall be 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 shall be at least 85% free of noxious weeds (undesired vegetation)	
	5	In rural areas, roadside grass height shall be maintained below 24 inches and shall not be cut to below 7 inches	
	6	In urban areas, roadside grass height shall be maintained below 18 inches and shall not be cut to below 7 inches	
Landscaped Areas	7	Obtained TxDOT approval of herbicides	
	8	Landscaped areas shall be maintained to be 90 percent free of weeds and dead or dying plants	
	9	Grass height in landscaped areas shall be maintained at a maximum height of 12 inches .	
Trees, shrubs and Vines	10	No trees or other vegetation shall obscure the message of a roadway sign	
	11	No leaning trees presenting a hazard or dead tree shall remain on the roadside	
	12	Vertical clearance over sidewalks and bike paths shall be maintained at 10 feet or more	
	13	Vertical clearance over roadways and shoulders shall be maintained at 18 feet or more	
	14	Clear horizontal distance behind guardrail is at least 5 ft for trees	
Ditches and Front Slopes	15	Ditches and front slopes shall be maintained free of eroded areas, washouts, or sediment buildup that adversely affects water flow	
	16	Erosion shall not endanger stability of the front slope, creating an unsafe recovery area	
	17	Front slopes shall not have washouts or ruts greater than 3 inches deep and 2 feet wide	
	18	A minimum of 90% of the ditch length and depth shall function as designed	
	19	Concrete ditches shall not be separated at the joints, misaligned, or undermined	
	20	Front slopes shall not have holes or mounds greater than 6 inches in depth or height	
Culvert and Cross-Drain Pipes	21	At least 75% of the cross sectional area of each pipe shall be free of obstructions and functions as intended. There shall be no evidence of flooding if the pipe is obstructed to any degree	
	22	The grates shall be of correct type and size, unbroken, and in place	
	23	Installations shall not allow pavement or shoulder failures or settlement from water infiltration	
	24	Culverts and cross-drain pipes shall not be cracked, have joint failures, or show erosion	
Drain Inlets	25	Grates shall be correct size and unbroken. Manhole lids shall be properly fastened	
	26	Installation shall not present a hazard from exposed steel or deformation	
	27	Boxes shall show no erosion, settlement, or have sediment accumulation	
	28	Outlets shall not be damaged and shall function properly	
	29	Inlet opening areas shall be a minimum of 85% unobstructed	
	30	Installations shall have no surface damage greater than 0.5 square feet	
Chain Link Fence	31	Installations shall have no open gates; deficiency shall be addressed in 14 days	
	32	Installations shall have no openings in the fence fabric greater than 1.0 square feet; deficeincies shall be addressed in 14 days	
	33	Installations shall have no openings in the fence fabric with a dimension greater than 1.0 feet; deficiency shall be addressed in 14 days	
Guard Rails	34	Installations shall be free of missing posts, offset blocks, panels or connection hardware; deficeincies shall be addressed in 3 days	
	35	End sections shall not be damaged; deficiencies shall be addressed in 3 days	
	36	Rails shall not penetrated; deficiencies shall be addressed in 3 days	
	37	Panel shall be lapped correctly; deficiencies shall be addressed in 3 days	
	38	No more than 10% of the guardrail offset blocks in any continuous section shall be twisted, deficiencies should addressed in 3 days	
	39	No 25 continuous feet that is 3 inches above or 1 inch below the specified elevation shall be corrected in 3 days	
	40	No more than 10% of wooden posts or blocks in any continuous section shall be rotten or deteriorated; deficiencies shall be addressed in 3 days	
Cable Median Barrier	41	Missing or damaged post, cable, or connections shall be addressed by the contractor within 3 days	
	42	Damaged end sections shall be addressed in 3 days	
	43	Loose cable, cable with incorrect weave, or installation shall be corrected in 3 days	
Attenuators	44	Each device shall be maintained to function as designed; deficinecy shall be addressed in 3 days	
	45	Installations shall have no visually observable malfunctions (examples - split sand or water containers, compression dent of the device, misalignment, etc.) Deficiencies shall be addressed in 3 days	
	46	Installations shall have no missing parts; deficiency shall be addressed in 3 days	
Litter and Debris	47	No litter that creates a hazard to motorist, bicyclist, or pedestrian traffic is allowed	
	48	Less than 50 pieces of fist size or larger litter/debris within 0.1 miles	
	49	Litter volume shall not exceed 3.0 cubic feet per 0.1 mile roadway section on either side of the centerline of the highway	
	50	In Urban areas, remove dead animals from the right of way within 24 hours	
	51	In rural areas, remove large dead animals from the traffic lanes within 24 hours	
Graffiti	52	No damaged surface or coating due to graffiti removal	
	53	Obscene, sexually or racially explicit or "gang-related" graffiti shall be removed within 3 days	
	54	Surfaces from which graffiti has been removed shall be restored to an appearance similar to adjoining surfaces	
	55	Non-obscene graffiti shall be removed within two weeks	

Figure 1. Inspection Form.

The number of sample units to be inspected is determined using the following steps:

Step 1. The highway maintenance project is divided into N sample units (each is approximately 0.1-mi long).

Step 2. n sample units are selected randomly for field survey using the following equation:

$$n = \frac{z_{\alpha/2}^2 s^2}{e^2 + z_{\alpha/2}^2 * \frac{s^2}{N}}$$

where:
e = acceptable error in estimating the project LOS. It is recommended to set e= 4 LOS points,
s = standard deviation of the sample score from one sample unit to another. When performing the initial inspection, the standard deviation is assumed to be 6-11. For subsequent inspections the standard deviation from the preceding inspection should be used to determine n,
$z_{\alpha/2}$ = normal distribution z-statistic that corresponds to a desired confidence level. For a 95% confidence level, $z_{\alpha/2}$ = 1.96.
N = total number of sample units in the project.

The overall level of service (LOS) for the highway project under this contract is found from the samples unit scores, as follows:

Step 1. The randomly-selected sample units are inspected and rated on a “Pass/Fail/Not Applicable” basis using the performance standards shown in Figure 1.

Step 2. A 0-100 sample unit score (SUS) is computed as a weighted average score for all elements within the sample unit, as follows:

$$SUS = \frac{\sum_{i=1}^{k} \frac{PS_i}{AS_i} \times PM_i}{\sum_{i=1}^{k} 100 \times PM_i}$$

where:
PS = number of passing performance standards,
AS = number of applicable performance standards,
PM = a priority multiplier (or weight) for each roadside element (to be obtained from Table 5), and
k = total number of roadside elements within the sample unit.

Step 3. A roadside average level of service (LOS) for the highway maintenance project is computed, as follows

$$LOS = \overline{SUS} = \frac{\sum_{j=1}^{n} SUS_j}{n}$$

where:

SUS_j = sample score for sample unit j, and

n = total number of inspected sample units.

An example calculation of project LOS is shown in Figure 2.

Table 5. 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

Roadside Element	No. of Applicable Standards	No. of Passed Standards	Priority Multiplier	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 (SUS) = 727.83/1062.8 =	**68.5%**

Figure 2. Example Calculation of Sample Score.

9. **Pay Adjustment.** The contractor's monthly payment is adjusted based on the overall LOS using the following equation:

$$PA = a \cdot (LOS - T)$$

where
PA= pay adjustment, $
a = pay adjustment rate
T = target LOS specified by TxDOT
LOS = Average roadside level of service computed as described in Section 7 (Formal Condition Assessment) based on the field inspections.

10. **Measurement.** This Item will be measured by the "Lump Sum" as the work progresses.

11. **Payment.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for in partial payments in accordance with the schedule shown in Table 6, utilizing the contract's unit bid price.

    This price shall be full compensation for this work and for furnishing all labor, equipment, materials, fuel, tools, disposal of removed materials and incidentals necessary to complete the work for a 24 month period.

    Payment Schedule. Monthly payments shall be made by multiplying the "Lump Sum" bid price by the payment schedule percentage and deducting or adding any amounts as determined above under "Pay Adjustment."

Table 6. Payment Schedule.

Month	Payment Schedule Percent	Cumulative Payment Percent	Cumulative Time Percent
1	4.5%	4.5%	4.17%
2	4.5%	9.0%	8.33%
3	4.5%	13.5%	12.50%
4	4.5%	18.0%	16.67%
5	4.1%	22.1%	20.83%
6	4.1%	26.2%	25.00%
7	4.1%	30.3%	29.17%
8	4.1%	34.4%	33.33%
9	4.1%	38.5%	37.50%
10	4.1%	42.6%	41.67%
11	4.1%	46.7%	45.83%
12	4.1%	50.8%	50.00%
13	4.1%	54.9%	54.17%
14	4.1%	59.0%	58.33%
15	4.1%	63.1%	62.50%
16	4.1%	67.2%	66.67%
17	4.1%	71.3%	70.83%
18	4.1%	75.2%	75.00%

Month	Payment Schedule Percent	Cumulative Payment Percent	Cumulative Time Percent
19	4.1%	79.5%	79.17%
20	4.1%	83.6%	83.33%
21	4.1%	87.7%	87.50%
22	4.1%	91.8%	91.67%
23	4.1%	95.9%	95.83%
24	4.1%	100%	100%

12. **Contract Extension.** T If agreed upon in writing by both parties to the contract, the contract may be extended an up to an additional 24 months in accordance with the following payment schedule. Either party to this contract may request a revised pay schedule for the contract extension, and if executed by change order, will replace the following:

    Payment Schedule for Extended Contract. Monthly payments shall be made by multiplying the "Lump Sum" bid price by the payment schedule percentage and deducting or adding any amounts as determined above under "Pay Adjustment."

Table 7. Payment Schedule (If contract is extended to 48 months).

Month	Payment Schedule Percent	Cumulative Payment Percent	Cumulative Time Percent
25	4.5%	104.17%	104.17%
26	4.5%	108.33%	108.33%
27	4.5%	108.33%	108.33%
28	4.5%	116.67%	116.67%
29	4.1%	120.83%	120.83%
30	4.1%	125.00%	125.00%
31	4.1%	129.17%	129.17%
32	4.1%	133.33%	133.33%
33	4.1%	137.50%	137.50%
34	4.1%	141.67%	141.67%
35	4.1%	145.83%	145.83%
36	4.1%	150.00%	150.00%
37	4.1%	154.17%	154.17%
38	4.1%	158.33%	158.33%
39	4.1%	162.50%	162.50%
40	4.1%	166.67%	166.67%
41	4.1%	170.83%	170.83%
42	4.1%	175.00%	175.00%
43	4.1%	179.17%	179.17%
44	4.1%	183.33%	183.33%
45	4.1%	187.50%	187.50%
46	4.1%	191.67%	191.67%
47	4.1%	195.83%	195.83%
48	4.1%	200%	200.00%