A FRAMEWORK FOR MONITORING PERFORMANCE-BASED ROAD MAINTENANCE

by

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ABSTRACT

In the late 1980's and early 1990's few transportation agencies around the world considered performance-based specifications as an alternative to improve the efficiency of the services provided to the public. These initiatives are better known as Performance-Based Road Maintenance (PBRM). PBRM calls for performance-based work, in which a desired outcome is specified rather than a material or method. This type of specification promises to be an excellent tool to improve government efficiency in maintaining transportation networks; however, without proper monitoring, it could likely yield adverse outcomes. Since PBRM is relatively new, the availability of reliable and comprehensive sets of guidelines to evaluate the effectiveness and efficiency of this type of specifications in the roadway maintenance arena is limited. Transportation agencies currently rely on criteria and procedures they have had developed from their traditional methods used to evaluate performance. Unfortunately, some of these procedures cannot appropriately assess the benefits, if any, accrued by the government as a result of implementing performance-based specifications for the maintenance of the roadway system. This research presents the development of a framework for monitoring PBRM more comprehensively and accurately. The framework considers the assessment of five main areas -- Level of Service Effectiveness, Cost-Efficiency, Timeliness of Response, Safety Procedures, and Quality of Services -- in order to guarantee the comprehensiveness and reliability of the evaluation process. The major contribution of this framework is to provide transportation agencies with guidelines for evaluating the effectiveness and efficiency of PBRM as an alternative delivery method to maintain and preserve the roadway system.

DEDICATION

To my wife, Luz, and son, Christian, whose love and support made this dissertation possible.

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CONTENTS

LIST OF FIGURES

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 9

CHAPTER 10

LIST OF TABLES

CHAPTER 2

CHAPTER 4

CHAPTER 5

CHAPTER 10

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1. OVERVIEW

The challenge of maintaining the roadway infrastructure at the best possible condition by investing the minimum amount of money will always keep transportation agencies searching for innovative approaches that will provide the most of benefits to taxpayers. According to road administrators around the world, in the last two decades one initiative that has produced significant benefits has been the implementation of performance-based or outcome-based specifications in the maintenance of public roadway systems. These new initiatives are known as Performance-Based Road Maintenance (PBRM). PBRM calls for performance-based work in which a desired outcome is specified rather than a material or method. This approach differs significantly from the use of traditional maintenance specifications, which typically mandate the materials and techniques that must be used in the job. In the United States, transportation agencies within Virginia, Florida, Texas, and the District of Columbia were the first to implement performance-based road maintenance specifications. In the international arena, countries such as Argentina, Uruguay, Australia, New Zealand, Brazil, Chile, and Colombia are pioneering the implementation of this initiative as part of their strategies to preserve roadway systems (Zietlow 2001). If performance-based specifications are used, then road administrators must design and implement a comprehensive and reliable performance monitoring process to ensure the assets are maintained according to the performance standards. The use of performance-based specifications promise to be an excellent tool to improve government efficiency in maintaining the roadway system; however, without proper analysis, this approach could also yield adverse outcomes.

The purpose of this research is to develop a conceptual framework to assist road administrators in monitoring performance-based road maintenance. This framework will provide transportation agencies with guidelines based on statistically valid procedures to assess the overall performance in maintaining all the features (i.e., assets) located within the right of way of public roadways at the minimum acceptable performance level. The application of the proposed framework will be illustrated using the new public-private partnership enacted under the Public-Private Transportation Act 1995 (PPTA) between VMS, Inc. (private corporation) and the Virginia Department of Transportation (VDOT- public agency) for the maintenance of a portion of the interstate highway system in the Commonwealth of Virginia (VDOT 2000). However, it is envisioned that the proposed framework can be used to evaluate other performance-based road maintenance initiatives to assure a reliable and comprehensive assessment of the impact in the overall condition of the assets that form part of the roadway system and the cost benefits, if any, accrued by the government.

1.2. ROAD MAINTENANCE CONTRACTING

Over the years, numerous goods and services have been provided to the government by the private sector. According to Giglio and Ankner (1998), outsourcing through public/private partnerships is a very useful tool for improving the delivery of public services. Ignoring or prohibiting the use of outsourcing as an alternative of provision or production of services could result in missed opportunities to improve government efficiency. However, outsourcing government services without proper analysis could yield adverse outcomes (Finley 1989).

Despite the fact that numerous goods and services have been provided to the government by the private sector, most transportation agencies have been reluctant to release the private sector from the responsibility of maintaining and protecting the transportation infrastructure (Grimsey & Lewis 2002). Evidence of this philosophy can be seen in the traditional way public transportation agencies outsource road maintenance services. This philosophy started to change in the early 1990s when a new contracting scheme between the public and private sector was developed and implemented by several transportation agencies around the world. As a result of this initiative, public officials can choose between two main contracting approaches for the maintenance of the roadway system, the traditional or performance-based approach. This chapter presents an overview of these contracting schemes and proposes research to develop guidelines for assessing the benefits accrued by the government as a result of implementing a performance-based approach for public roads maintenance.

1.2.1. Traditional Road Maintenance

Transportation agencies normally indicate in their road maintenance specifications how work will be performed, the means and methods that will be used, and the sequence in which the job will be performed (Poister 1983, AASHTO 2002). According to some road administrators, this traditional contracting approach fails to meet the main goal of reducing maintenance expenditures and improving services to the traveling public (Poster 2001).

In the late 1980s and early 1990s, several transportation agencies around the world considered outsourcing as an alternative to improve their efficiency. As a result of this initiative, new partnerships between the public and private sector for maintaining and preserving public roadways were developed and implemented. This contracting relationship is referred to as Performance-Based Road Maintenance (PBRM). The idea behind PBRM is to use performance-based specifications instead of the traditional maintenance specifications as evaluative criteria for the condition at which roadway assets are maintained. A detailed description of this approach is presented in the next section.

1.2.2. Performance-Based Road Maintenance

Current best-practice techniques in outsourcing rely on performance-based specifications (Segal et al 2003). The most common form of how performance–based specifications are implemented in road maintenance is total asset management, or PBRM. PBRM calls for performance-based work in which a desired outcome is specified rather than a material or method. This approach differs significantly from traditional maintenance contracts, which typically mandate the materials and techniques that must be used (Poster 2001). Since PBRM focuses on the final product and not on how it is achieved, these approaches normally define minimum conditions of roads, bridges, and traffic assets that a contractor must meet, as well as other services such as the collection and management of asset inventory data, attendance to emergencies, and response to public requests. In comparison to the traditional contract arrangement, this new contracting scheme allocates higher risk to the contractor, but at the same time opens up opportunities to reduce the cost of achieving the specified standards as a result of implementing new technologies, materials, processes and innovative management strategies (Zietlow 2001).

1.2.2.1. Brief History

As previously stated, the development of performance-based contracts started in the late 1980s and early 1990s. In 1988, British Columbia in Canada made the first attempt in outsourcing its road maintenance activities. However, two major factors restricted this initiative from classification as PBRM. These factors are: (1) the contract still limited the contractor in the application of new technologies, and (2) the performance standards were still more oriented towards work procedures and materials to be used, rather than results (Zietlow 2001).

Shortly afterwards, Massachusetts, United States, signed a contract with a private contractor to provide routine highway maintenance services in Essex County (Hammond 1993). The contract assigned responsibility to the private contractor to perform routine maintenance activities with the exception of snow and ice removal, which constituted a big portion of the yearly expenses for highway maintenance in this county. Despite the fact that not all maintenance responsibilities for the portion of public roads included in the contract were released to the private contractor, this contract can certainly be considered a close attempt of a performance-based contract. However, the state Department of Transportation (DOT) still continued to specify for some activities how work should be done (i.e., limiting the contractor). According to DOT studies, the contractor was 21 percent more cost-effective than the state had been. This initiative went so well that in 1996, the DOT extended the initiative statewide.

In July 1995, the Commonwealth Legislation of Virginia enacted legislation to authorize public-private partnership to build, operate, and maintain transportation facilities, under the approval of the Department of Transportation (VDOT). This legislation is better known as the Public-Private Transportation Act (PPTA). When the PPTA was signed into law, Virginia became the first state to allow private contractors to submit unsolicited proposals for interstate maintenance and construction (VDOT 2000). In October 1995, VMS Inc., a maintenance contractor, submitted the first unsolicited proposal under PPTA regulations to implement a public-private partnership for the maintenance of a portion of the interstate highway system in the Commonwealth of Virginia. VMS's proposal was approved in December 1996. By establishing this new agreement, VMS became the first private firm to assume full responsibility for the comprehensive maintenance of significant portions of a state's interstate highway system. Since 1997, VMS has managed maintenance projects for 250 miles of highway, which constitute approximately 25% of the total interstate highway system of Virginia. In this new performance-based highway maintenance contract the private contractor, VMS, provided and/or procured all labor, materials, equipment, and services for a fixed price of $131.6 millions for a period of five and a half years (VDOT 1996). In 2000, Virginia Tech conducted an independent assessment for VDOT and reported a positive level of savings over the five-year contract duration (VDOT 2000, de la Garza & Vorster 2000). Based on the benefits and the satisfaction with the service provided by the contractor, VDOT extended the contract in 2002 for five additional years.

The contract between VDOT and VMS served as a model to other states in the United States and also other countries throughout the world. For instance, in 1998, the District of Columbia Department of Public Works (DC DPW/DDOT) and the Federal Highway Administration (FHWA) started a similar initiative for the maintenance of 344 lane-miles, 2950 catch basins, seven miles of drainage ditches, 450,000 feet of curb and gutter, 109 bridge structures, four tunnels, and traffic and weather control (Segal et al 2003). The contract was awarded in 2000 to VMS, Inc., which was already responsible for the maintenance and rehabilitation of 75 miles of federal roads in the district (Baker 1999). The District of Columbia DOT and the FHWA have reported major improvements in road quality since the contract began. Several other states such as Texas, Florida, and Oklahoma have implemented similar initiatives.

Other countries such as Australia, New Zealand, Uruguay, Argentina, Brazil, Chile, and Colombia have also implemented performance-based contracts for the maintenance of the roads and highways. Australia started its performance-based contracts in 1996 covering 285 miles of urban roads in Sydney, which constitute approximately 18% of Australian urban roads (Frost & Lithgow 1996). Since then, several new contracts have been implemented in other regions such as New South Wales, Tasmania, and Southern and Western Australia. In 1996, Uruguay started its first pilot performance-based contract on a small network of 223 miles, which represents approximately 4% of its national roads. According to Uruguay's Transportation Authority, this new contracting scheme proved to be so successful that now, only six years later, 50% of the national roads in Uruguay are being maintained through performance-based contracts. In 1998, New Zealand signed its first performance contract for the maintenance of 252 miles, or 4%, of national roads. Currently, 10% of New Zealand's national roads are maintained using this new contract scheme (Zietlow 2001).

1.2.2.2. Reasons for Implementation

Transportation agencies implemented performance-based road maintenance expecting to receive the following benefits (Finley 1989, Frost & Lithgow 1996, Baker 1999, Segal et al 2003):

1) Reduce maintenance costs through the application of more effective and efficient technologies and work procedures.
2) Provide transparency for road users, road administrators and contractors with regards to the conditions at which the roads must be maintained.
3) Improve overall road condition.
4) Improve control and enforcement of quality standards.

To determine if performance-based specifications in road can meet these goals, comprehensive guidelines and standards are needed.

1.3. NEED FOR RELIABLE AND COMPREHENSIVE GUIDELINES

Since performance-based road maintenance specifications are relatively new, the availability of reliable and comprehensive sets of guidelines to evaluate them are limited. Transportation agencies currently rely on criteria and procedures developed to evaluate the work under performance-based specifications based on the criteria and procedures used to evaluate performance when traditional maintenance specifications are used. These approaches are significantly different, and, for this reason, a special procedure must be defined to address all the factors for evaluating performance-based work. Some of the deficiencies identified in current evaluative procedures are: lack of reliable sampling procedures to assess the level of service at which the assets are maintained, lack of an appropriate inventory and frequency of data collection, need for a comprehensive methodology to assess the cost-efficiency, and the need for assessing similar work performed by the implementing agency for comparison. These deficiencies and the fact that transportation agencies are expanding the work under PBRM calls for an immediate revision of current performance evaluation procedures. Development of more comprehensive guidelines will assure the reliability of the overall performance evaluation.

1.4. RESEARCH OBJECTIVES

The main objectives of this research are:

1) To define a conceptual framework that can serve as a guideline for transportation agencies in the implementation and evaluation of Performance-Based Road Maintenance (PBRM).

2) To identify statistically valid procedures for each component included in the proposed framework to guarantee a reliable and comprehensive evaluation of PBRM.

3) To present an application of the proposed framework to an existing PBRM initiative and finally provide lessons learned from this experience.

1.5. TASKS REQUIRED TO FULFILL THE RESEARCH OBJECTIVES

The following steps are required in order to fulfill the objectives of this research:

1) Analyze the need of road administrations in terms of guidelines to monitor performance-based road maintenance. The previous section "Research Objectives" basically formulates the result of this analysis.

2) Analyze existing frameworks in the industry for measuring and monitoring performance as well as other areas related to the research topic. This review, in combination with Task 3 will identify general components that should to be considered when developing the proposed framework to monitor performance-based road maintenance.

3) Perform a review of the main elements considered by road administrations in the development and implementation of existing performance-based road maintenance initiatives throughout the world.

4) Identify the main components that constitute the proposed framework. The review and analysis of existing industry framework for evaluating performance and the detailed evaluation of key PBRM aspects will identify these components.

5) Define specific procedures based on statistically valid techniques that implementing agencies can use to evaluate each component of the framework. The implementation of these procedures will assure road administrators that final results from the performance assessment are reliable, comprehensive, and representative of the overall road population.

6) Apply the proposed framework to an existing performance-based road maintenance initiative. The current PBRM contract between the Virginia Department of Transportation and VMS, Inc., has been selected to illustrate the application of the framework. This application will serve two objectives: (1) illustrate how road administrations can implement the framework, and (2) validate the reliability and completeness of the proposed framework.

1.6. DISSERTATION OUTLINE

This dissertation is organized as follows:

- **Chapter one: Introduction.** This chapter provides an overview of performance-based road maintenance as well as the proposed research to develop guidelines for implementation and monitoring of this initiative in public road maintenance.

- **Chapter two: Literature Review.** This chapter discusses how the literature review was structured to provide the information and background required to define the proposed framework.

- **Chapter three: Proposed Framework for Monitoring Performance-Based Road Maintenance.** This chapter discusses the approach followed to develop the proposed framework. In addition, it introduces the main components of the proposed framework developed as part of this research for monitoring PBRM. A detailed discussion of the suggested methodologies within each framework component is presented in Chapters four through eight.

- **Chapter four: Evaluation of Level of Service Effectiveness.** A detailed methodology of how to perform a comprehensive evaluation of the condition and quality level at which highway assets must be maintained, according to performance-based specifications, is presented in this chapter.

- **Chapter five: Cost-Efficiency Evaluation.** This chapter discusses the suggested procedure to assess the cost-benefits, if any, accrued by the government as a result of implementing PBRM.

- **Chapter six: Timeliness of Response.** A detailed description of the proposed methodology to evaluate compliance with timeliness requirements in performance-based specifications is presented in this chapter.

- **Chapter seven: Safety Evaluation.** A detailed methodology to evaluate compliance with safety requirements in performance-based specifications is presented in this chapter.

- **Chapter eight: Quality Evaluation.** This chapter presents a detailed methodology to assess public satisfaction with the implementation of performance-based specifications in roadway and highway system maintenance.

- **Chapter nine: Application of the Framework.** To provide interested agencies with an actual implementation of the proposed framework, this chapter presents the application of the framework to the performance-based road maintenance contract between the Virginia Department of Transportation (VDOT) and VMS, Inc.

- **Chapter ten: Summary and Recommendations.** This chapter summarizes the contributions and achievements of this research and also addresses future research associated with the work presented in this study.

- **Appendix A: Example of Performance Indicators.** Examples of typical performance indicators used by the Virginia Department of Transportation in the maintenance of the highway system are presented in this appendix.

- **Appendix B: Flowcharts.** This appendix provides a series of graphical representations (i.e., Flowcharts) of the procedures adopted in the framework. The purpose of these flowcharts is to provide guidance to road administrators in the implementation of these procedures.

- **Appendix C: Review of Basic Cost Concepts.** This appendix provides an overview of the cost data required to conduct the methodologies proposed in Chapter five. Typical cost components for self-maintenance works as well as contract jobs are reviewed in this appendix.

- **Appendix D: Cost Study Records.** This appendix supports the Cost Study presented in Chapter nine. It includes a list of contract bid items from VMS's database for which distributions were generated using historical unit prices from traditional maintenance specifications.

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CHAPTER 2

LITERATURE REVIEW

This chapter presents a comprehensive review of elements to the development of the proposed framework for monitoring performance-based road maintenance. This review will define the proposed framework to be developed as part of this research.

2.1. STRUCTURE OF LITERATURE REVIEW

This literature review is organized into four main areas: (1) existing Performance-Based Road Maintenance initiatives, (2) frameworks in the public and private industry for measuring and monitoring performance, (3) statistically valid techniques for performance assessment, and (4) other areas related to the research topic. The main objectives of the literature review conducted as part of this research are: (1) to suggest ideas on the structure of the framework, (2) to identify concepts, criteria, and measures that must be considered when monitoring performance-based road maintenance work, and (3) to identify reliable techniques to evaluate performance.

Figure 2.1 depicts these objectives and the areas studied in the literature review. A detailed discussion regarding each of the four identified areas follows.

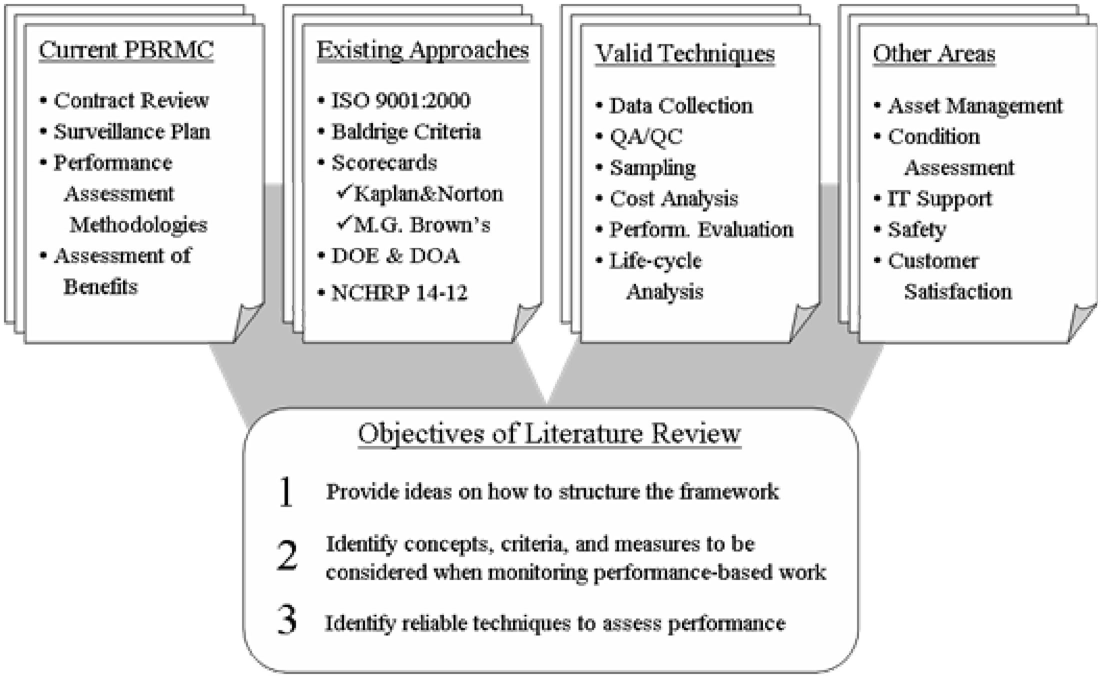

Figure 2.1. Focus and Objectives of the Literature Review

2.2. EXISTING PERFORMANCE-BASED ROAD MAINTENANCE CONTRACTS

As previously mentioned in Chapter one, a few number of performance-based road maintenance contracts exist around the world. In the United States, transportation agencies within Virginia (1996), Florida (1998), Texas (1999), and the District of Columbia (2000) were the first to implement performance-based contracts for the maintenance of public roadways. In the international arena, countries such as Argentina (1990), Uruguay (1995), Australia (1996), New Zealand (1998), Brazil, Chile, and Colombia pioneered this contracting scheme as part of their strategies to preserve the roadway and highway system. This section presents a comprehensive review of the main elements considered in the development and implementation of most of these performance-based road maintenance contracts throughout the world. This review will define crucial areas that must be considered when monitoring PBRM.

2.2.1. Development Stage: Initial Steps before the Implementation Phase

This section summarizes the most important aspects that transportation agencies must consider before the implementation of the PBRMC. According to this review, all countries that have introduced performance-based road maintenance contracts have done it gradually, starting with one or two pilot projects to gain experience with administering this new type of contract (Zietlow 2001, Poster 2001, Segal et al. 2003). According to Poster (2001), before these agencies embark on such contractual arrangement, they must consider several elements to ensure positive results. An overview of those elements is presented below.

i) *Financial and Legal Aspects.* Since PBRM contracts are normally fixed price contracts and have contract durations between four and ten years, it is important for transportation agencies to secure financing for the entire contract period before starting such contracts (Frost & Lithgow 1996, Baker 1999, Zietlow 2001, Poster 2001). For example, one pilot project in Brazil had to be abandoned after only one year of operation due to a shortage of funds. In addition, it is also very important to verify the maximum contract period allowed by law. For example, in most countries in Latin America, the maximum contract duration is restricted to either four or five years, making it necessary to change laws in order to accommodate long-term contracts.

ii) Geographic Scope. One of the first decisions road administrators interested in implementing PBRM contracts must make is to define the road network to be contracted out to the private sector. Normally, road administrations who implement this contracting scheme for the first time only select small networks as pilot projects. In addition to identifying the network to be outsourced to the private sector, several agencies also identify portions of the network that are still to be maintained by the road administration and that will be exposed to conditions similar to the roads maintained by the contractor (Baker 1999, VDOT 2000). By identifying these similar portions of the network, road administrators can perform a comprehensive comparison of the level of service at which each party maintains their assets. Some of the factors to consider in the identification of those similar portions of roads were: the geographical location, weather conditions, rural vs. urban settings, average traffic volumes, traffic mix, and types of assets in the routes.

iii) Inventory and Condition of Assets to be Maintained. Once the portions of the network to be contracted are identified, most agencies create a complete list with all the assets for which the contractor is responsible. Identifying these assets is only the first step of the process. The next step and the most time-consuming is to create an inventory and condition assessment of all assets to be maintained by the contractor. This information is extremely important for the contractor to understand the asset conditions of road portions included in the contract. Table 2.1 presents an example of a summary of assets and their conditions (Baker 1999, Segal et al. 2003).

Table 2.1. Example of a Summary of Assets and their Condition

Asset Type	Unit	Quantity	Condition		
			Good	Fair	Poor
Pavement	Lane Miles	344	299	25	20
Curb	Linear Feet	459,311	451,141	3,100	5,070
Retaining Walls	Square Feet	178,575	177,555	510	510
Sidewalks	Linear Feet	786,630	772,810	5,300	8,520

The approach to develop this type of inventory varies among road administrations. Normally, field inspections and/or existing agency records constitute the data collection process. The condition of the assets is assessed based on the same performance standards used to monitor the contractor's performance in maintaining the corresponding assets.

iv) <u>*Performance Measures and Response Times.*</u> Since PBRMC are outcome-based contracts, road administrators define performance measures that specify the standards by which the contractor's maintenance work will be evaluated. Implementing agencies consider this a very challenging process. Some of the variables considered when defining such performance measures were: the asset type, the roadway system, and the traffic volume (VDOT 1996, Frost & Lithgow 1996). Examples of some of the performance measures applied in different PBRM contracts in Latin America and in Sydney, Australia are presented in Tables 2.2 and 2.3, respectively (Gentili & Erbetta 1997, Zietlow 2001). Notice that while in the performance contracts in Latin America all performance measures have to be met at all times (i.e., performance targets equals 100%), contracts in Australia -- New Zealand and the United States (not presented in Tables 2.2 and 2.3)-- allow performance targets to be less than 100%. Other examples of typical performance measures for PBRMC are presented in Table A.1 (Appendix A). This table presents a list of some of the performance measures identified in the contract between VDOT and VMS, Inc (VDOT 1996). They are discussed as additional examples of typical performance measures; however, they will be used as part of the framework application example in Chapter nine of this dissertation. Until now, road administrators have developed their own performance measures by slightly modifying those previously used for self-performed jobs or subcontracts. The examples presented in this section give an idea of the wide variety of performance measures specified from one PBRMC to another. Defining appropriate performance measures is still in the early stages and is a subject of further analysis and debate.

In addition to delineating performance measures for the condition of the assets, road administrators also define acceptable response times and sometimes penalties for non-compliance. Defining proper response times for each type of service requested is extremely important to ensure public safety.

Table 2.2. Examples of Performance Measures Used in Different PBRMC in Latin America

Asset Group	Component	Performance Target	Performance Measure
Pavement	Potholes	100%	No potholes
	Roughness	100%	IRI<2.0 (Argentina), IRI <2.8 (Uruguay)
	Rutting	100%	<12 mm (Argentina), <10 mm (Uruguay, Chile)
	Cracks	100%	Sealed
Shoulders	Potholes	100%	No potholes
	Cracks	100%	Sealed
	Joints	100%	Vertical Alignment<1 cm (Chile, Uruguay)
Drainage	Obstructions	100%	No obstructions. Should allow for unhindered flow of water (Chile, Uruguay)
	Structures	100%	Without damage and deformation (Chile)
Road Signs and Markings	Road Signs	100%	Complete and clean (Argentine, Chile)
	Road Markings	100%	Complete and Visible (Argentine, Chile)
Right of Way	Vegetation	100%	<15 cm height (Argentine, Uruguay)
	Foreign Elements	100%	No foreign elements allowed

Table 2.3. Examples of Performance Measures Used in the PBRMC from Sydney, Australia

Asset Type	Outcome	Performance Target	Performance Measure
Cross Pipe < 36 ft sq.	Structurally Sound	95%	<10 % deteriorated barrel
	Open drains		> 90 % diameter open
	Joints Intact		Joints Intact
	Adequate Capacity		End Protection Intact
	No erosion		No dip in road over pipe
Paved Ditches	Aligned	95%	<1" settlement
	Structurally Sound		< 25% spalled
	Clean		No obstruction to flow of water
Sidewalks and Ramps	Smooth	90%	No settlement > ½"
	Safe		No unsealed cracks > ¼"
	Sound		<25 % spalled

v) *Maintenance Activities.* The main idea behind PBRMC is that the contractor will be responsible for identifying the best means to achieve the desired asset conditions contained within the contract. However, in most existing PBRMC, road administrators require that these specific procedures be submitted for approval before implementing them. Implementing agencies require that all maintenance activities used by the private contractor are consistent with current specifications and standards. If the contractor recommends new treatments with unavailable standards, then the contractor must submit evidence and proper documentation of the expected benefits based on proper testing. According to Poister 1983 and Poster 2001, road administrators carefully considered several factors when evaluating approval of maintenance treatments recommended by private contractor. These factors include:

- Assure that the proposed maintenance treatment meets the criteria specified in the contract.
- Certify that the proposed maintenance treatment conforms to applicable standards.
- Assure that the proposed maintenance treatment will improve the long-term performance of the asset.

The criteria listed above are very important, specially the last one. According to road administrators that currently manage PBRMC, when these contracts are shorter than five years, private contractors can be tempted to apply maintenance treatments that will improve the performance of the assets for a short period of time. This makes the contractor's performance look good throughout the length of the contract, but really affects the performance and increases the cost of maintenance in the long term. According to some of these agencies, a good incentive to promote the application of new technologies and procedures that will improve long-term performance of the assets is to increase the duration of the contract (i.e., ten years).

vi) *Contractor Qualification Requirements.* Existing performance-based contracts are essentially management contracts. According to implementing agencies, traditional road construction or maintenance contractors often do not have the required qualifications for this type of contract. Consulting firms with extensive experience in managing other contractors and experiences in pavement management systems that normally perform this kind of job. In Virginia, for example, the performance-based contract is managed by VMS, which was formed by two consulting partners (VDOT 1996). Most of the maintenance work is subcontracted, allowing for efficient resource allocation (i.e., just-in-time principle). Joint ventures between road construction firms and consultants seem also to work well.

Table 2.4. Summary of PBRMC Evaluation Criteria Used in Washington, D.C.

Area	Evaluation Criteria	Weight
Technical	Experience, knowledge and understanding of issues relating to preservation and maintenance of the assets covered by the contract. Soundness of technical approach for meeting the performance measures for all assets in the contract.	20%
Staffing, Quality Control/Quality Assurance, Management	Staffing Plan	5%
	Management Plan	5%
	Quality Control/Quality Assurance Plan	5%
Past Performance	The extent to which the Contractor's past performance on similar contracts demonstrates a likelihood of successfully performing all of the tasks required.	15%
Cost	The extent to which proposed costs are realistic and reflect the likely overall cost to the government over the term of the contract.	50%

The criteria considered by road administrations in awarding PBRMC vary among countries and states. However, road administrators agree in the fact that the selection of well-qualified contractors and inspectors are key elements in the success of PBRMC. Examples of some criteria considered in Washington, D.C. to award performance-based contract are presented in Table 2.4 (Baker 1999, Segal et al. 2003).

2.2.2. Implementation Stage

This section summarizes the most important aspects identified by most transportation agencies during PBRMC implementation. Two main areas are addressed: (1) bidding process, and (2) performance monitoring and payment procedure. A description of the issues related to these two areas follows.

i) *Bidding Process.* Since PBRMC are relatively new for road administrators and contractors alike, close cooperation between both parties is vital for success. Both sides must be comfortable with the contractual arrangement and understand the risks involved. In all existing PBRMC, road administrators and contractors work closely together to prepare bidding documents. Not considering the feedback from the private contractors can result in adverse outcomes. For example, in Uruguay, the road administration prepared the bidding documents without taking the feedback from private contractors into consideration. As a result, they had to adjust the contract because contractors were not interested in the new contracting scheme (Zietlow 2001). On the other hand, in the contract between VDOT and VMS, VMS actually initiated the process and presented an unsolicited proposal to VDOT to perform highway maintenance services (VDOT 1996). For the rest of the existing PBRMC, competitive bidding procedures were used after contractors were prequalify. With respect to the time given to the contractors to prepare their bids, road administrations have given much longer periods of time to potential bidders compared to the typical amount of time given for traditional maintenance contracts. This is reasonable considering that PBRMC shift most of the risk --which is normally assumed by the road administration-- to the contractor.

ii) *Performance Monitoring and Payment Procedure.* According to road administrators who have implemented PBRMC, the key factor in the success of this new contracting scheme is the performance monitoring process. These procedures must be well defined and implemented. They should evaluate not only maintenance conditions of the assets, but also other factors such as: (1) ensuring that the work has been performed in a timely manner and in accordance to the highest workmanship standards, (2) evaluating the contractor's compliance with applicable safety standards, and (3) verifying that all maintenance activities are conducted in a manner that minimizes the impact on the traveling public (Frost & Lithgow 1996, VDOT 2000, Baker 1999, Zietlow 2001, Poster 2001). Performance monitoring procedures vary from one contract to the other. For example, in Chile there are four kinds of inspections: (1) monthly random inspections which cover 10% of the roads under contract, (2) weekly inspections looking at 5% of randomly selected roads, (3) non-programmed inspections to respond to complaints by road users, and (4) follow-up inspections to verify that appropriate action has been taken by the contractor to rectify non-compliance. Contractor payments are based on the results of the monthly inspections. On the other hand, procedures implemented in contracts from Australia, New Zealand, and the United States are even more sophisticated to the procedures applied in Chile and other countries in Latin America. They not only perform inspections on a daily, monthly, and weekly basis, but they also implement comprehensive management and quality systems. Some of the components included in their maintenance management systems and incorporated in some of the PBRMC are listed below.

- Asset Inventory and Condition Assessment (e.g., updated annually)
- Pavement Management Program
- Bridge Management Program
- Snow and Ice Control Operations Plan
- Safety Management and Traffic Control Plan
- Emergency Response Plan
- Customer Response Plan
- Public Information Plan
- Annual work plan updated every 3 to 4 months
- Extensive reporting procedures

With respect to the monthly payments, the contractors are being paid a fixed fee as stipulated in the contract. No provisions for deduction in case of underperformance were included in the contracts from New Zealand and the United States. Instead, the road administrators have the right to terminate the contracts at any time if the private contractor does not meet contractual obligations

2.2.3. Previous Assessment of Existing PBRMC

Given the fact that existing PBRMC were implemented by transportation agencies as pilot projects, most of these agencies conducted studies after the contract started to assess the benefits accrued as a result of adopting and implementing this new contracting scheme. The approach taken to assess the efficiency and effectiveness of PBRMC varied from one implementing agency to the others, being some of them more comprehensive than others. In December 2000, the Virginia Department of Transportation (VDOT) published one of the most comprehensive evaluations of an existing PBRMC. The document reports the assessment of the efficiency and effectiveness of the performance-based highway maintenance contract between VDOT and VMS, Inc. This document was entitled "Report on Comprehensive Agreement for Interstate Highway Asset Management Services: VMS Operations for 1999/2000" (VDOT 2000). The purpose of this report was to present the results from the performance and cost-efficiency evaluation of the work done by VMS in managing VDOT's interstate assets from July 1998 through June 2000. This study presented the results from a series of parallel but independent studies that were performed during 1999 and 2000 to evaluate the overall performance of the private contractor. A brief summary of the sub-studies that formed part of this principal document is presented below.

1) *Level of Service Evaluation.* VDOT hired an independent consultant to perform an objective evaluation of four of the six asset groups specified in the agreement. These asset groups were: Shoulders, Roadside, Drainage, and Traffic. This study revealed a high level of service for each asset group.

2) *Condition of Pavement and Bridges.* The assessment of the two other asset groups specified in the contract, pavement and bridges, was performed by the agency through the use of their Pavement and Bridge Management Systems. Overall, the condition of the bridge structures maintained by VMS increased in comparison to the original condition of those structures at the beginning of the contract.

3) *Timeliness of Response Evaluation.* This study evaluated the effectiveness of VMS's response to emergency incidents by sending a questionnaire to the Virginia State Police (VSP), asking their opinion on VMS response to incidents that occurred during 1999 and 2000. Overall, the VSP gave a positive evaluation of VMS's response to incident requests and classified the company's performance as acceptable.

4) *Cost-Efficiency Study.* This study was performed by researchers from Virginia Polytechnic Institute and State University (de la Garza & Vorster 2000). The study assessed the cost-efficiency of the pilot PBRMC by comparing prices based on work done by VMS in 1999 with the price if the work was contracted or self-performed by VDOT. This study reported a positive level of savings.

In addition to the findings reported by VDOT with respect to their contract with VMS, other countries such as Australia and New Zealand have reported substantial cost savings and road condition improvements in comparison to the traditional form of contracting out road maintenance (Frost & Lithgow 1996). According to the Australian and New Zealand Transportation Authorities, these cost savings have been achieved mainly because of better resource allocation, the introduction of new technologies and work procedures, and the training of subcontractors. Countries such as Uruguay, Argentina, Chile, and Brazil have not been able to report cost savings from their performance contracts, since no studies have been undertaken to analyze this issue (Zietlow 2001). However, similar to the other countries, they have reported considerable improvements in their road conditions.

2.3. FRAMEWORKS FOR PERFORMANCE MEASUREMENT AND MONITORING

The use of performance-based specifications is considered relatively new in road maintenance; however, this approach has been used since the 1970s by other public agencies, such as the U.S. Department of Defense, as a new initiative to acquire services provided to the government (Tomanelli 2003). Several documents addressing the issues related to performance-based work and techniques to deal with this type of approach have been published by some of these agencies as well as other independent organizations. To gain knowledge from these experiences, the most comprehensive documents were reviewed that describe existing guidelines or frameworks commonly used in the public and private sector for measuring and monitoring performance. The following six frameworks were included in the review: (1) ISO 9001:2000 Criteria for Performance Excellence, (2) Malcolm Baldrige National Quality Program, (3) Kaplan and Norton's Balanced Scorecard Approach, (4) Mark Graham Brown's Scorecard Approach, (5) Department of Energy Performance Measurement Program, and (6) NCHRP 14-12: Highway Maintenance Quality Assurance Program. These frameworks provide information that can help organizations in two aspects: (1) determining what kind of measures can be used, and (2) providing guidance on what should be measured. The concepts adopted in these frameworks can be applied from the highest level of an organization down to the area where a specific task is accomplished. For these reasons they have been considered excellent sources to acquire knowledge about the topic. A detailed description and analysis of each one of these frameworks follows.

2.3.1. ISO 9001:2000 Criteria for Performance Excellence

In general, ISO 9000 is a written set of rules (i.e., standard) published by the International Organization for Standardization (ISO) that provides accepted quality practices to the industry in general (Johnson 1993). The first series of ISO 9000 Standards was published in 1987. The main goal of the ISO 9000 Standard is customer satisfaction by meeting customer requirements. In 1994, additional Standards were published to assist interested parties in the implementation and understanding of the 1987 version of ISO 9000 (Nee 1996, Peach 1999). The new incorporated Standards are described below.

1) ISO 9001 –Constitutes the minimal set of quality standards, and covers all of ISO 9002 including design, development and service.
2) ISO 9002 – Covers all of ISO 9003 including procurement and installation.
3) ISO 9003 – Covers production and activities relating to final inspection of goods.
4) ISO 9004 – Parallels ISO 9001/2/3, through which a company can audit itself.

In December 2000, a new version of the Standard was released (i.e., ISO 9001:2000). In this new version, the three Standards 9001, 9002, and 9003 were merged into a single Standard, ISO 9001:2000. Almost all requirements from the previous version were rewritten. However, the majority of the changes did not alter existing compliance status (Hoyle 2001). ISO 9001:2000 introduced a new emphasis on planning, continuous improvement and customer satisfaction. The new Standard is considered to be more "process oriented". In addition, the Standard reduced from twenty sections with requirements for procedures (e.g., 1994 version) to eight sections with requirements for procedures (e.g., 2000 version). A list of the sections included in ISO 9001:2000 is presented in Table 2.5.

As shown in Table 2.5, the major requirements of the ISO 9001:2000 Standard are organized into the following five sections:

- Quality Management System (Section 4)
- Management Responsibility (Section 5)
- Resource Management (Section 6)
- Product Realization (Section 7)
- Measurement, Analysis, and Improvement (Section 8)

A brief description of each section included in the ISO 9001 year 2000 version follows.

i) Quality Management System (Section 4). This section basically establishes that an organization must have a documented quality system (e.g., Quality Management System), which must be continually updated and improved. This documented quality system is the collection of processes, documents, resources, and monitoring systems that direct the work of an organization regarding product and service quality. In addition, the section emphasizes that organizations must define the procedures, plans and operations required to assure quality improvement in their products and services.

ii) Management Responsibility (Section 5). The ISO 9001:2000 Standard recognizes that in order to have success with implementing and maintaining an effective quality program, the involvement and commitment of the organization's top management is extremely important. For this reason, this section of the Standard establishes a minimum set of responsibilities that top manager's needs to follow in order to guarantee success. These responsibilities are the following:

a) Overseeing the creation of the Quality Management System (QMS).
b) Communicating the importance of meeting requirements, including customer, legal and regulatory requirements.
c) Establishing the quality policy (i.e., identify main goals of QMS) and the quality objectives (i.e., support quality policy).
d) Communicating with parties responsible for product and service quality.
e) Providing adequate resources for the operation of the QMS.
f) Reviewing the operation of the QMS.

iii) Resource Management (Section 6). This section basically establishes that the organization must provide the proper amount and quality of equipment, tools, people, and materials needed to meet the following goals: (1) build and maintain the QMS, (2) continually improve the effectiveness of the QMS, and (3) meet customer requirements.

iv) Product Realization Requirements (Section 7). In order to improve the efficiency of the QMS, the Standard emphasizes that the organization must describe the work required to develop, manufacture, and deliver the finished goods or services. This process is better known as "The Quality Plan". According to ISO 9001:2000, an efficient quality plan must include at least the following:

a) Product requirements and quality objectives
b) Creation of the processes, documents, and resources needed
c) Required verification, monitoring, inspection, and test activities
d) Records to be kept

v) Measurement, Analysis, and Improvement (Section 8). This section provides guidelines on how to plan and perform the inspection, test, measurement, analysis, and improvement of activities needed to assure the product meets specified requirements, and that the QMS works as planned and improves the operation. In addition, this section emphasizes the importance of defining what to do with non-conforming products (e.g., re-inspect, repair) and the monitoring of final customers' opinions of the product and service.

Table 2.5. Sections in ISO 9001: 2000 Standard

ISO 9001: 2000
1. Scope
2. Normative References
3. Definitions
4. Quality Management System
4.1 General Requirements
4.2 Documentation Requirements
5. Management Responsibilities
5.1 Management Commitment
5.2 Customer Focus
5.3 Quality Policy
5.4 Planning
5.5 Responsibility, Authority
5.6 Management Review
6. Resource Management
6.1 Provision of Resources
6.2 Human Resources
6.3 Infrastructure
6.4 Work Environment
7. Product Realization Requirements
7.1 Planning and Product Realization
7.2 Customer-related Processes
7.3 Design and Development
7.4 Purchasing
7.5 Production and Service Provision
7.6 Control of Monitoring and Measuring Devices
8. Measuring, Analysis & Improvement Requirement
8.1 General
8.2 Customer Satisfaction
8.3 Control of Nonconformity
8.4 Analysis of Data
8.5 Improvement

2.3.2. Malcolm Baldrige National Quality Program

Since 1988, the Malcolm Baldrige National Quality Award (MBNQA) has provided organizations with a valuable framework that can help them with their planning, monitoring, (i.e., performance assessment) and overall quality improvement (BNQP 2002). The U.S. Department of Commerce is responsible for the Baldrige National Quality Program and the Award (NPRG 1997). However, the National Institute of Standards and Technology (NIST) manages the Baldrige Program with the assistance of the American Society for Quality (ASQ). The Malcolm Baldrige Award criteria focus on the following three business factors:

- Approach - Definition of the processes used to run an organization
- Deployment - Execution of the approach
- Results - Analysis of the approach and the deployment outcome

Seven components have been defined in the Baldrige framework relative to these three business factors. The first six components pertain to the Approach/Deployment factors and the last component focuses on the Results factor. In addition, a point scale with a total score of 1000 has been assigned to every component in the framework to establish the relative importance of each. The seven components of the Baldrige framework for QA and their point values are listed below (BNQP 2002).

1) Leadership	120 points
2) Strategic Planning	85 points
3) Customer and Market Focus	85 points
4) Information and Analysis	90 points
5) Human Resource Focus	85 points
6) Process Management	85 points
7) Business Results	450 points

According to NIST and ASQ, the Baldrige standards call for a balance between customer satisfaction, employee satisfaction, and business results. In addition, they assure that these criteria have many benefits, such as providing:

1) An excellent framework for developing an integrated performance measurement system

2) An excellent roadmap for operating a better organization
3) A good tool for performing an organization's self-assessment (i.e., self-improvement)

In order to get a better understanding of what the seven categories emphasize in the MBNQA, a detailed description of each one follows.

1) <u>Leadership (120 points).</u> The Leadership category of the Baldrige framework takes into account the following two criteria:

   a) *Organizational Leadership (80 points)* - Describes how managers guide the organization and review organizational performance.

   b) *Public Responsibility and Citizenship (40 points)* - Describes how the organization addresses its responsibilities to the public.

2) <u>Strategic Planning (85 points).</u> The Strategic Planning category of the Baldrige framework is basically evaluated as follows:

   a) *Strategy Development (40 points)* - Describes the organization's strategic development process in order to improve organization's performance and competitive position.

   b) *Strategy Deployment (45 points)* - Describes the organization's strategic deployment process. It basically summarizes the action plans and related performance measures established by the organization.

3) <u>Customer and Market Focus (85 points)</u>. The Customer and Market Focus category of the Baldrige framework considers the following two criteria for performance excellence:

   a) *Customer and Market Knowledge (40 points)* - Describes how the organization determines short- and longer-term requirements, expectations, and preferences of customers and markets.

b) *Customer Relationship and Satisfaction (45 points)* - Describes how the organization determines customer satisfaction and builds new relationships.

4) Information and Analysis (90 points). The two criteria considered in the Information and Analysis category of the Baldrige framework are:

a) *Measurement of Organizational Performance (50 points)* - Describes how the organization provides an effective performance measurement.

b) *Information Management (40 points)* - Describes how the organization ensures the quality and availability of needed data and information to assess overall organizational performance.

5) Human Resource Focus (85 points). The following criteria are considered for evaluation in the Human Resource category of the Baldrige framework:

a) *Work Systems (35 points)* - Describes how the organization's work practices enable employees to achieve high performance in their operations.

b) *Employee Education, Training, and Development (25 points)* - Describes how the organization's education and training program contribute to the improvement of employee performance.

c) *Employee Well Being and Satisfaction (25 points)* - Describes how the organization maintains a work environment which contributes to the well-being, satisfaction, and motivation of all employees.

6) Process Management (85 points). The Process Management category takes into account the following criteria:

a) *Product and Service Processes (45 points)* - Describes how the organization manages the product design and delivery processes.

b) *Business Processes (25 points)* - Describes how the organization manages its growth and success.

c) *Support Processes (15 points)* - Describes how the organization manages its support processes.

7) Business Results (450 points). The Business Results category is the most important component of the of the Baldrige framework. This category is evaluated by considering the following criteria:

a) *Customer Focused Results (125 points)* - Summarizes the organization's customer focused results, including customer satisfaction and product and service performance results.

b) *Financial and Market Results (125 points)* - Summarizes the organization's financial performance results.

c) *Human Resource Results (80 points)* - Summarizes the organization's human resource results, including employee well-being, satisfaction, development, and work system performance.

d) *Organizational Effectiveness Results (120 points)* - Summarizes the organization's operational performance results that contribute to the achievement of organizational effectiveness.

2.3.3. Kaplan and Norton's Balance Scorecard Approach

The Balanced Scorecard Concept was introduced by Robert Kaplan and David Norton in 1992. According to Norton and Kaplan (1996), this concept is a tool for improving and measuring organization's performance. The Balanced Scorecard provides a way for management to look at the organization's well being from four different perspectives. These perspectives are:

1) *Financial.* - How does the organization look to its stakeholders?

2) *Customer*. - How well does the organization satisfy internal and external customers' needs?

3) *Internal Business Process*. - How well does the organization perform at key internal business processes?

4) *Learning and Growth.* - Is the organization able to sustain innovation, change, and continuous improvement?

Each one of these perspectives is directly tied to the organization's strategic plan. According to Kaplan and Norton (1996), this framework provides the components necessary to establish an integrated performance measurement system.

2.3.4. Mark Graham Brown's Scorecard Approach

In 1996, Mark Graham Brown, a consultant that has spent the past 18 years helping major corporations improve their performance, introduced a model similar to the one developed by Norton and Kaplan in 1992, but instead of four categories he identified a total of five categories that organizations may consider when implementing a reliable performance measurement system (PBM SIG 1995). The five categories considered in Brown's framework for performance excellence are listed and described below.

1) *Financial Performance.* Brown emphasizes that organizations should be able to determine the cost of providing their products and services as well as determine whether they are providing them at an optimal cost compared to their competitors or actual benchmarks.

2) *Process/Operational Performance.* According to Brown's Scorecard Approach, in order for an organization to improve its process and operational performance, it should always be able to predict the quality of the products or services it provides. Some of the most efficient measures that can be implemented by an organization to assure improvement in Process/Operational (O/P) performance are: productivity rates, cycle time, error rates, and safety.

3) *Customer Satisfaction.* This category basically emphasizes the importance of developing a good understanding of the organization's customers and their requirements. According to Brown, when evaluating customer satisfaction, the following should be considered with respect to the performance measures selected:

- Collect data frequently and with large sample sizes
- Use tools such as phone interviews and surveys to measure satisfaction
- Implement the usage of valid statistical techniques for measurement analysis
- Include measures to provide immediate feedback to drive improvement

4) *Employee Satisfaction.* According to Brown, a significant number of mature organizations have noticed that their overall performance is correlated to the health and satisfaction of their employees. For this reason, companies should develop good metrics to inform management of the health and well being of their employees. In addition, it is a good practice for organizations to compare employee satisfaction with other organizations in the industry, especially their competitors. Some of the most effective measures that organizations could use to assess employee satisfaction are listed below:

- Employee satisfaction survey
- Average hours worked per week
- Stress-related illness
- Transfer requests and turnover
- Complaints or grievances
- Absenteeism

5) *Community/Stakeholder Satisfaction.* This component basically emphasizes the importance of maintaining good relations with the community and other stakeholders to guarantee the overall success of the organization.

2.3.5. Department of Energy Performance Measurement Program

The next framework that will be considered in this evaluation will be the Performance Measurement Guidelines published by the U.S. Department of Energy (DOE) in 2001. To provide clear idea of the motivation behind these guidelines, a brief history follows.

In 1993, President William J. Clinton signed into law the Government Performance and Result Act (GPRA). The main objective of this new law was to require federal agencies to develop strategic plans for how they would deliver high-quality products and services to the American people (PBM SIG 2001). The strategic plans required each federal agency to address at least the following: (1) identification of the agency goals and objectives, (2) define how the agency intends to achieve those goals, and (3) demonstrate how the agency will measure performance when trying to achieve those goals.

In order to provide guidance on implementing GPRA and promote the use of performance-based management, the U.S. Department of Energy (DOE) and DOE contractors funded the Performance-Based Management Special Interest Group (PBM SIG). The PBM SIG has published several guidance documents. Among these documents, one of the most important is the Performance-Based Management Handbook, which is based on a model of the performance measurement process developed by this group. This handbook is a six-volume compilation of techniques and tools for implementing the GPRA. The handbook discusses and recommends several performance measurement approaches used by the industry to improve their services, but in general it emphasizes six main components that should be considered when developing a PM framework (PBM SIG 2001). These components are listed and described below.

a) Effectiveness – Indicates the degree to which the product or services conforms to requirements. Answers the question: Are we doing the right things?

b) Efficiency – Indicates the degree to which the process produces the required output at minimum resource cost. Answers the question: Are we doing things right?

c) Quality – Addresses the degree to which a product or service meets customer requirements and expectations.

d) Timeliness – Measures whether a unit was done correctly and on time according to customer requirements.

e) Productivity – Adds value from the process divided by the labor and capital consumed.

f) Safety – Measures the overall health of the organization and the working environment of its employees.

According to the PMB SIG, an effective performance measure system can provide the organization with the following information:

- How well the organization is doing
- If the organization is meeting their goals
- If the customers are satisfied
- If the processes are in statistical control
- If and where improvements are necessary

2.3.6. Highway Maintenance Quality Assurance Program

In 1997, the National Cooperative Highway Research Program (NCHRP) sponsored Project 14-12, better known as the Highway Maintenance Quality Assurance Project. The objective of this study was to research quality management concepts, evaluate existing maintenance quality programs, and to subsequently develop a state-of-the-art maintenance Quality Assurance (QA) program (Stivers et al., 1997). The product from Stivers et al.'s (1997) study was the development of a prototype QA program that interested government agencies could adopt to improve the efficiency of their highway maintenance programs. This prototype QA program was developed based on information gleaned from an extensive literature review and the documented maintenance practices of various highway agencies such as the British Columbia Ministry of Transportation and Highways (MTH), the Florida Department of Transportation (FDOT), the Maryland DOT, and the Oregon DOT-Region 4. The document is comprehensive and includes step-by-step instructions for agencies interested in developing, implementing, and routinely operating a customized version of the prototype QA program. The proposed QA program consists of two main phases: (1) preliminary work with a focus on developing a Level of Service (LOS) rating system, and (2) field implementation and closed-loop operational phase. Each phase contains several components that represent actions to be taken by an implementing agency. The main components of the QA program are briefly described below:

a) *Key Maintenance Activities* - Defining maintenance elements to evaluate system quality.

b) *Customer Expectations* - Collecting highway users' expectations concerning the LOS at which an agency should maintain its highway system.

c) *LOS Criteria* - Defining the conditions or requirements to be met in order to consider the existing LOS to be acceptable.

d) *Weighting Factors* - Establishing factors that reflect the relative importance between maintenance elements and between each maintenance item under each maintenance element.

e) *Maintenance Priorities* - Establishing the order in which maintenance activities will be conducted according to budget constraints.

f) *Baselining Existing LOS* - Assessing the existing maintenance condition of the agency's highway system.

g) *Workload Inventory* - Estimating workloads for maintenance activities using detailed information with respect to the type, location, and dimensions of key maintenance items.

h) *Activity Cost Data* - Reflecting the actual cost for performing specific maintenance activities using historic data.

i) *Zero-based Budget* - Determining the costs required to produce a specific LOS established from customer expectation.

j) *Formal LOS Inspections, Analysis and Reporting* - Evaluating periodic LOS based on random inspections of portions of an agency's highway system.

k) <u>Customer Satisfaction.</u> Assessing highway user satisfaction of the maintenance agency's LOS.

2.3.7. Comparison of Frameworks

From sections 2.3.1 through 2.3.6, a detailed discussion of six frameworks used in the industry to improve performance was presented. However, in order to promote a better understanding of the combined focus of these frameworks, the reader should consider the summary presented in Table 2.6.

In Table 2.6, the most important criteria of each framework are classified in one of the following performance categories: effectiveness, efficiency, quality, timeliness, productivity, and safety. Checkmarks have been used to specify the performance criteria included in each framework. According to the summary presented in Table 2.6, the Performance Measurement Handbook developed by the U.S. Department of Energy, the ISO 9001: 2000 Standards, and the Malcolm Baldrige Criteria are the most complete and comprehensive documents in that they provide guidelines for development, implementation, and monitoring of an integrated performance measurement system. If we compare the Stivers et al. (1997) framework which focuses on monitoring of highway maintenance activities with the other three most complete frameworks, (e.g., DOE, ISO & MB) it can be seen that Stivers et al. (1997) addresses the majority of the criteria covered in the other two frameworks. Some of the criteria not covered in Stivers et al. (1997) are irrelevant to the particular case of monitoring highway maintenance. However, there are good criteria from the other frameworks, such as the scoring among general components and the monitoring of employee satisfaction, that can be incorporated into the Stivers et al. (1997) framework to improve its general efficiency and completeness.

Table 2.6. Comparison of Frameworks for Performance Measurement and Monitoring

Performance Category	Measurement	Stivers et al. 1997	ISO 9001: 2000	Malcolm Baldrige	Kaplan and Norton	Mark Graham	DOE PM Program
Effectiveness	• Inventory of assets	√	√	√			√
	• Use existing condition as baseline for evaluation	√	√	√	√	√	√
	• Continuous condition assessment (inspection, analysis, and reporting)	√	√	√	√	√	√
	• Relative weights among components	√		√	√	√	
	• Emphasis on statistical techniques	√	√	√			√
Efficiency	• Define workload priorities	√	√	√	√	√	√
	• Resource management optimization	√	√	√	√	√	√
	• Financial performance monitoring	√	√	√	√	√	√
Quality	• Define customer requirements	√	√	√	√	√	√
	• Monitor customer satisfaction	√	√	√	√	√	√
	• Monitor employee satisfaction		√	√	√	√	√
	• Establish a document quality system		√				√
	• Overall quality monitoring (test and inspections)	√	√	√			√
Timeliness	• Assess if product or requirements where performed on time	√	√	√	√	√	√
Productivity	• Supplier management		√	√			√
	• Process and operational performance assessment	√	√	√	√	√	√
Safety	• Assess overall organization's health		√	√			√

Note: All the frameworks considered essential the involvement of the organization's top management in the development and implementation phases of a performance monitoring system.

2.4. ANALYTICAL TECHNIQUES RELATED TO THE RESEARCH TOPIC

Given the fact that the proposed framework covers many different areas relevant to the monitoring process of PBRM, a review of reliable techniques will be presented in Chapters four through eight of this document, which correspond to the detailed discussion of the methodologies adopted for each the component of the framework. Among the most important areas reviewed are concepts relevant to performance monitoring, such as: performance standards, quality control and assurance (QA/QC) in data collection, sampling statistics techniques, cost estimating and cost analysis, condition assessment of major roadway and highway assets, information technology support, safety standards related to roadway maintenance activities, survey design, and techniques for assessing user satisfaction.

2.5. OTHER AREAS OF RELEVANCE

There are many concepts that will be reviewed and discussed in Chapters four through eight when a detailed description of the evaluative procedures and techniques for each of the framework components will be presented. However, there are two areas closely related to the research topic presented in this document that will be reviewed in this section. These two areas are: (1) asset management in the transportation sector and (2) performance monitoring guidelines for infrastructure maintenance.

1) *Asset Management in the Transportation Sector*

In recognition of the significant investments made by the public in the construction, maintenance, and operation of the roadway and highway systems, many transportation agencies recognize that the public holds them accountable for the proper management of these assets. To meet these expectations, transportation agencies must turn to better business approaches such as the asset management concept. The asset management concept in the transportation sector basically emphasizes preserving, upgrading, and replacing in a timely manner roadway and highway assets through cost-effective planning and resource allocation decisions (OECD 2001). One of the technologies that has made the practice of asset management possible is the availability and continuous development of powerful computer systems. These computer systems not only allow transportation administrators to create and implement sophisticated analytical tools, but also allow agency officials to perform "what if" analyses that in turn facilitate discussions with other stakeholders (AASHTO 1998). Many transportation agencies around the world promote the use of asset management as an excellent business approach for managing the wide range of assets that form the roadway and highway system (Austroads 1994, TAC 1999TNZ 2000, OECD 2001, NAMSG 2000). For instance, in the US, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have played a major role in promoting asset management as a strategic approach to manage the assets within the transportation infrastructure (AASHTO 1998, NCHRP 2002). These agencies as well as many other transportation agencies and private organizations around the world have published numerous documents that define asset management and the techniques and procedures that comprise this approach (AASHTO 1998, FHA 1999, TAC 1999TNZ 2000, OECD 2001, NAMSG 2000, NCHRP 2002).

2) *Performance Monitoring Guidelines for Infrastructure Maintenance*

The topic of defining better practices for measuring performance on infrastructure maintenance has been of continuous research interest during the past two decades (Miller 2001). In most of the studies conducted so far in the United States, the federal government has been directly involved in the effort of defining standards and guidelines to evaluate how well the nation’s infrastructure serves the public (NRC 1995, NRC 1996). Despite the federal government’s substantial influence on monitoring infrastructure performance, the practices developed until the early 90s to measure and monitor performance were considered, largely, inadequate. As part of the intent to improve existing practices, the US federal government created a program known as the Federal Infrastructure Strategy (FIS) administered by the U.S. Army Corps of Engineers (USACE) with the objective to provide a substantial framework that defines policies on measuring and improving infrastructure performance. As part of this program, the USACE requested in 1993 that the National Research Council (NRC) undertake full responsibility for defining those policies.

In October 1993, the NRC appointed a committee to perform a study to define those policies (NRC 1995). The focus of the study was not only on transportation infrastructure, but also on water and waste systems within the urban regions. The appointed committee selected and visited three states in the United States (Maryland, Oregon, and Minnesota) to explore which performance concepts and measures were used by decision makers and how they were implemented. The main product of this study was a set of recommendations on measuring and improving infrastructure performance. The most important recommendations derived from this study are summarized below:

- Agencies with responsibilities for infrastructure management should explicitly define a comprehensive set of performance measures and set aside sufficient funds to sustain an adequate performance measurement process.

- The measures selected should reflect the concerns of stakeholders about the consequences of infrastructure systems and recognize interrelationships across infrastructure modes and jurisdictions. The committee suggested that the implementation of a framework that evaluates effectiveness, reliability, and cost is a useful tool for establishing these measures.

- All performance measures should be periodically reviewed and revised as needed to respond to changing objectives, budgetary constraints, and regulations.

Although the above study provided useful guidelines and suggested procedures for monitoring and improving infrastructure performance, a more specific study that defined methodologies to evaluate the performance of highway maintenance activities was needed. In 1997, the National Cooperative Highway Research Program (NCHRP) sponsored Project 14-12, better known as the Highway Maintenance Quality Assurance Program. The objective of this study was to research quality management concepts, evaluate existing maintenance quality programs and to subsequently develop a state-of-the-art maintenance Quality Assurance (QA) program (Stivers et al. 1997). This study was considered in the review presented in section 2.3.6 of this document. The HMQA Program is considered one of the most comprehensive studies conducted on the quality assurance of the performance evaluation of highway maintenance programs. The study led to new and more reliable procedures to develop, implement, and operate an appropriate QA program for highway maintenance.

2.6. SUMMARY

This literature review has provided the background on important issues that must be considered when dealing with performance-based specifications, especially when they are used for roadway system maintenance. The interest in implementing performance-based specifications has increased considerably in the last decade among road administrators worldwide. However, they all agree on the fact that assessing the benefits accrued as a result of implementing this contracting scheme for maintaining the roadway system is a very complex and challenging task. To help transportation agencies with this challenge, this research will provide them with guidelines to conduct a comprehensive and reliable evaluation of the effectiveness and efficiency of PBRM. It is envisioned that these guidelines (i.e., proposed framework) will provide road administrators with a valuable tool to properly assess the benefits of implementing this initiative as an alternative contracting mechanism to maintain and preserve the roadway system.

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CHAPTER 3

PROPOSED FRAMEWORK FOR MONITORING PERFORMANCE-BASED ROAD MAINTENANCE

This chapter introduces the main components of the proposed framework for monitoring Performance-Based Road Maintenance (PBRM). Only a general description of each component is presented in this chapter. A detailed description of the procedures adopted to quantitatively evaluate each one of the elements within each framework component is presented in Chapters four through eight of this document.

3.1. BUILDING THE FRAMEWORK

The framework to monitor PBRM was developed in two stages: (1) an extensive review of the literature relevant to the research topic, and (2) the definition of the main structure of the framework. A description of the approach for each stage follows.

3.1.1. Stage 1: Review of Relevant Literature

The literature review presented in Chapter two serves as the platform to define the proposed framework to monitor PBRM initiatives. The following three steps briefly summarize the most important concepts and areas studied in the literature review.

Step 1: The first step was to review where road administrations stand today in terms of procedures to monitor ongoing PBRM initiatives (Frost & Lithgow 1996, VDOT 1996, Gentili & Erbetta 1997, Zietlow 2001, Segal et al. 2002). The main benefit acquired from this review was to become familiar with the elements considered by implementing agencies throughout the world in the development and implementation stages of this contracting scheme. Other complementary tasks were performed as part of this step, such as the study of existing PBRM initiatives and informal interviews with various professionals involved in the management and evaluation of this type of initiative.

Step 2: A review of some of the most comprehensive documents that describe existing approaches commonly used in the public and private sector for measuring and monitoring performance was conducted. The following six approaches were included in the review:

1) ISO 9001:2000 Criteria for Performance Excellence (Johnson 1993, Nee 1996)
2) Malcolm Baldrige National Quality Program (BNQP 2002)
3) Kaplan and Norton's Balance Scorecard Approach (Kaplan & Norton 1996)
4) Mark Graham Brown's Scorecard Approach (PBMSIG 1995)
5) Department of Energy Performance Measurement Program (PBMSIG 1995)
6) NCHRP 14-12: Highway Maintenance Quality Assurance Program (Stivers et al. 1997)

The review of these frameworks helped to determine the general components or areas that should be considered when monitoring PBRM.

Step 3: Finally, a review of additional concepts relevant to performance monitoring of road maintenance activities was performed, as well. Among the most important additional concepts studied were: asset management, quality assurance and control (QA/QC) in data collection, sampling statistics techniques, cost estimating and cost analysis, condition assessment of major elements in the roadway system (e.g., pavement, bridges), safety standards related to roadway maintenance activities, and life-cycle analysis. Results from this review are presented in Chapters 5, 6, 7, and 8 of this document, which describes in detail the proposed methodologies to evaluate PBRM.

3.1.2. Stage 2: Definition of the Framework Structure

Once the comprehensive review described in Stage 1 was conducted, the following steps were followed as part of the strategy to define the proposed framework.

Step 4: The main components of the framework for monitoring PBRM were identified. Five main components were considered as part of the framework. A general description of each component is presented in section 3.2.

Step 5: A comprehensive structure that identifies statistically valid procedures and tools that implementing agencies can use to evaluate each one of the components of the framework were defined. The implementation of these techniques will guarantee road administrators that the final results from the performance assessment are reliable, comprehensive, and representative of the overall population.

3.2. FRAMEWORK COMPONENTS

As mentioned in the previous section, the review conducted as part of this research led to the identification of five key components that define the proposed framework to monitor PBRM. The five components are: **Level of Service Effectiveness (LOS), Cost-Efficiency (CE), Timeliness of Response (TOR), Safety Procedures (SP),** and **Quality of Service Provided: Agency and Users Satisfaction (QOS)**. Figure 3.1 presents these components.

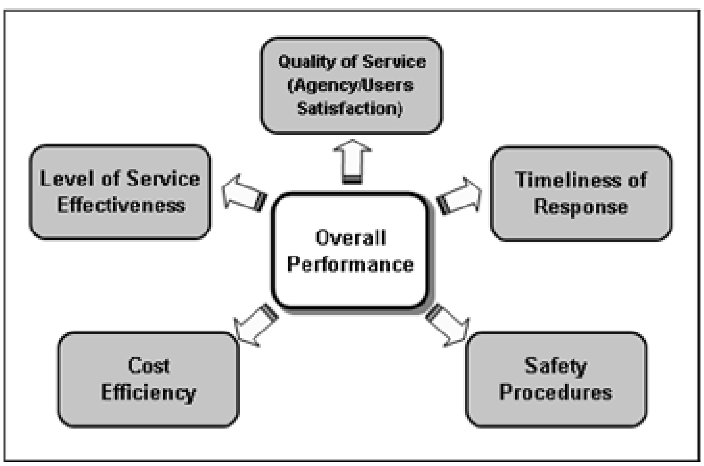

Figure 3.1. Key Components of the Proposed Framework to Monitor PBRM

For each of the five components of the framework, a specific structure that identifies the elements to be considered in the monitoring process was defined. The elements within each structure were organized in four sections: Input, Data Collection, Data Analysis, and Reporting.

Figure 3.2 illustrates a general representation of the structure defined for the components. The **Input** section identifies critical information to be defined by transportation agencies before implementing this type of initiative. In the second section, **Data Collection**, relevant areas to be considered in the data collection process are identified. This section provides guidance in the identification of data sources to support the monitoring program, information technology as a support to the data collection effort, the use of efficient sampling mechanisms, and the implementation of a proper QA/QC program, among others. The **Data Analysis** section provides specific methodologies to convert the raw data obtained from the data collection effort into meaningful information. Finally, the reporting section identifies mechanisms that will help transportation agencies communicate the results from the performance evaluation to all parties involved.

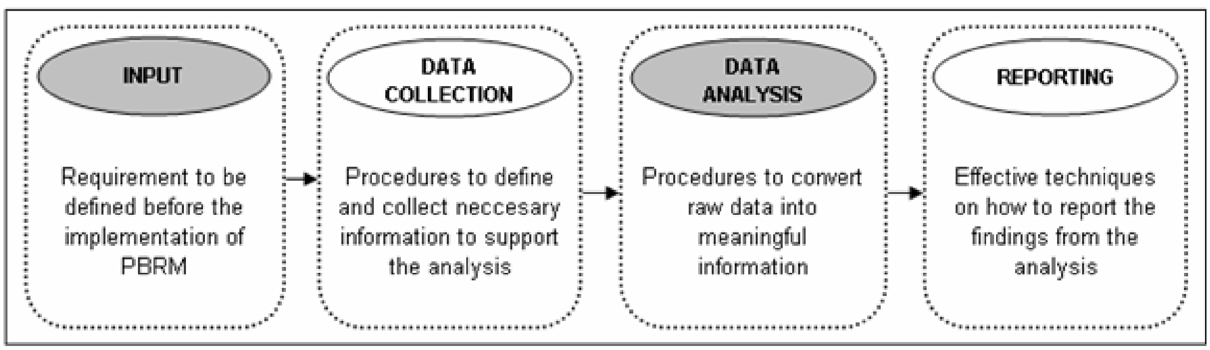

Figure 3.2. General Structure of the Components of the Proposed Framework to Monitor PBRM

A general and short description of each one of the framework components is presented in the following sections of this chapter. However, a comprehensive description of the proposed methodologies included within each component structure will be discussed in Chapters four through eight.

3.2.1. Level of Service Effectiveness

According to Poister (1983), the evaluation of Level of Service Effectiveness is considered one of the most important performance indicators of a monitoring system. The purpose of this evaluation is to indicate the extent to which each asset item has been preserved and the minimum acceptable quality levels specified by the implementing agency. The proposed methodology to evaluate this component of the framework provides guidance on aspects such as the creation and update of an asset inventory, the development of a data collection plan and sample selection process, the implementation of a quality control and assurance program (QA/QC), the conversion of raw data into performance information, and the implementation of reporting techniques to help communicate results. This research adopted some of the guidelines presented by Stivers et al. (1997) in their report on Quality Assurance in Highway Maintenance Programs to evaluate aspects related to this component, such as the calculation of the LOS ratings. Methodologies proposed for LOS have been defined so that they will help transportation agencies identify areas of concern. These areas includes: assets items that have been in continuous deterioration, the re-adjustment of unrealistic performance targets, and the evaluation and comparison of the long-term effectiveness of maintenance treatments used in roads under evaluation. A detailed description of the proposed methodology to evaluate the LOS component is presented in Chapter four.

3.2.2. Cost-Efficiency

The main objective of this component is to assess cost savings, if any, accrued by the government as a result of adopting outcome-based road maintenance specifications. The methodology to evaluate this component is comprised of two steps: (1) comparison between work costs of performance-based and traditional specifications and (2) the evaluation of the impact in LOS (i.e., condition of the roadway system) on changes in expenditure rate. A combination of cost-estimating techniques and probability analysis has been incorporated in this component to meet the evaluation objective. Regarding the first step of the study, two different approaches are recommended in the framework to execute such comparisons: the distribution and the regression approach. The distribution approach uses distributions to represent the behavior of unit prices, whereas the regression approach uses regressions to represent bid price behavior. Moreover, the framework proposes the implementation of the Monte Carlo Simulation approach to obtain a distribution that projects the total maintenance price if the agency uses traditional specifications for road maintenance instead of performance-based specifications. It is suggested that transportation agencies conduct the analysis by applying both approaches and then use the results obtained from each to conduct the comparison of LOS versus the expenditures rate (i.e., cost). Techniques such as the Bayes Theorem and Markov Chains (e.g., transition probabilities) were adopted in the framework to establish the relationship between these two parameters. By considering this technique, road administrators can analyze the impact in LOS by varying the rate in maintenance expenditures. The study results will serve as the basis to finally determine the cost-efficiency of the PBRM approach. A detailed description of the proposed methodology to evaluate the CE component is presented in Chapter five.

3.2.3. Timeliness of Response

Evaluating the timeliness of response of service requests related to events or deficient elements in the roadway is always extremely important (Poster 2002). If one does not address these requests in a prompt manner, then the safety of the traveling public can be placed at serious risk. For this reason, a component that evaluates a contractor's timeliness of response (TOR) when performing outcome-based highway maintenance activities was included in the framework. To conduct a proper evaluation of the TOR, road administrators must first define measures that establish acceptable response times for each asset type and/or service category. Timeliness requirements can be specified for services such as: response to incidents, lane closures, response to complaints, response to emergencies, and snow removal, among others. These requirements will serve as the basis to evaluate acceptability of actual response times. The framework proposes that the actual performance of these requirements should be evaluated by conducting at least the following: (1) a comparison of the actual response times versus timeliness requirements, and (2) an evaluation regarding the response and management of the contractor when unexpected events occur (e.g., storms and floods). Moreover, if a comparison of the actual compliance of the responsible party to timeliness requirements versus previous performance in this area is conducted, road administrators can assess the continuous commitment of the contractor in keeping a safer roadway system for the traveling public. A detailed description of the proposed methodology to evaluate the TOR component is presented in Chapter six.

3.2.4. Safety Procedures

Highway safety is often stated to be the most important goal of transportation agencies (ITE 1993). For this reason, agencies must continuously monitor and evaluate safety procedures implemented by personnel conducting road maintenance. This is the objective of considering this component as part of the framework. To comprehensively assess compliance with safety requirements, the framework proposes to evaluate feedback from personnel directly involved with the contractor in conducting regular maintenance activities and also responding to service requests that normally require the implementation of safety procedures such as emergencies, road kill removal, traffic control, accidents, and snow removal operations. Police Departments, Emergency Response Units, Sub-Contractors, and DOT Safety Coordinators are normally in direct contact with the contracting party conducting these activities. These individuals are excellent sources evaluators of the contractor's safety program. These evaluations can be conducted through the use of surveys. The framework emphasizes that the evaluative focus in those surveys must be in the following five areas:

1) Involvement of managers in the development and enforcement of a safety program
2) Implementation of a training program that increase the safety knowledge and safety skills
3) Implementation of safety related standards
4) Documentation of incident records and safety inspections
5) Innovation in the means and methods

The evaluations of the five areas from these parties will provide transportation agencies with an assessment of the overall commitment to safety within the performance-based approach. A detailed description of the proposed methodology to evaluate the SP component is presented in Chapter seven.

3.2.5. Quality of Services

Understanding the traveling public's (i.e., user) needs is essential for the success of any transportation program (NRC 1995). Users are the final evaluators of the services provided. Even more importantly they are the service payers. For this reason, it is very important that transportation agencies assess the customer (i.e., agency), users, and employee (i.e., sub-contractors) perceptions and satisfaction with respect to the condition at which the assets based on performance-based specifications are maintained by agency personnel or a private contractor. By considering their input, it will define performance measures that will finally guarantee their satisfaction. The methodology proposed in the framework to assess the quality of the services in PBRM consists of surveying individuals who worked with the responsible party. For example, when the scenario in which a private contractor was engaged to provide maintenance services, interviews were conducted with those impacted by the contractor's work. Traveling public, emergency response units, sub-contractors, and DOT contract administrators and supervisors are among the personnel identified as valuable sources of information. The surveys from each of these sources address different issues or areas of concern, such as: (1) Traveling Public Survey - examines user perspectives regarding the condition of the roadway system, (2) Emergency and Highway Patrol Unit Survey - examines the overall satisfaction of emergency and highway patrol personnel on the quality timeliness of emergency response, and the implementation of a strategic plan to address emergency events, (3) Sub-Contractor Survey - examines sub-contractor opinions about the fairness of the procurement process used to adjudicate maintenance contracts as well as their experiences with how contractors administer contracts (e.g., payment compliance, dispute resolution), (4) Road Administrator Survey - examines the satisfaction of road administrators regarding the general contractor performance conducting PBRM activities and the effectiveness of the performance-based approach. The findings from these surveys will be compared with the findings from the other components of the framework to verify if perceptions from the public and other agencies are in accordance with transportation agency reports. A detailed description of the proposed methodology to evaluate the QOS component is presented in Chapter eight.

3.3. SUMMARY

Interest in implementing performance-based specifications for roadway and highway system maintenance is increasing among road administrators worldwide. However, they all agree that assessing the benefits accrued as a result of implementing this type of approach is a very complex and challenging task. To help transportation agencies with this challenge, this chapter introduced a framework that was developed as part of this research to provide guidelines for conducting a comprehensive and reliable evaluation of the effectiveness and efficiency of PBRM. The proposed framework will provide road administrators with a valuable tool to properly assess the benefits, if any, of implementing PBRM as an alternative contracting mechanism to maintain and preserve the roadway system. Detailed descriptions of the methodologies adopted within each framework component are discussed in the next chapters.

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CHAPTER 4

LEVEL OF SERVICE EFFECTIVENESS

This chapter presents a detailed description of the proposed methodology to evaluate each element required to comprehensively assess the Level of Service effectiveness in performance-based road maintenance.

4.1. COMPONENT STRUCTURE

Figure 4.1 presents a graphical representation of the proposed methodology to evaluate the LOS effectiveness in PBRM. A detail description of the elements included in each of the sections follows.

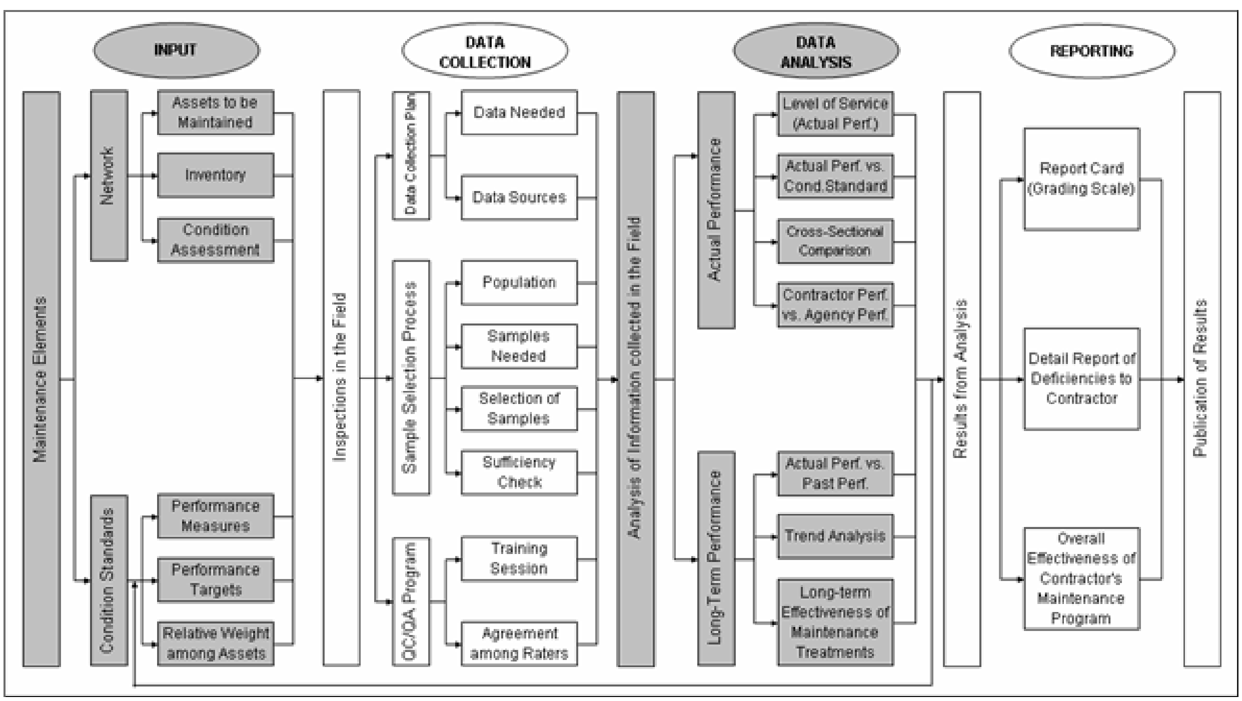

Figure 4.1. Methodology to Evaluate the Level of Service Effectiveness in PBRM

4.2. STAGE 1: INPUT FOR LOS EVALUATION

As previously stated, the Input section of the framework provides guidance to road administrators on the areas that must be defined and addressed before conducting performance-based work. In Figure 4.1, two main areas are identified as part of the Input section: (1) the Network Scope, and (2) the Condition Standards. A description of the elements within these two areas is presented in sections 4.2.1 and 4.2.2, respectively.

4.2.1. Network Scope

The Network Scope basically emphasizes the need to identify portions of roads as well as the assets to be maintained according to performance-based specifications. Road administrators must identify not only the type and quantity of assets to be maintained but also the existing condition of those assets throughout the road network under consideration. A description of these two elements follows.

i) Assets To Be Maintained. One of the first decisions road administrators interested in implementing PBRM must make is to define the road network to be subjected to performance-based specifications. Transportation agencies implementing this approach for the first time normally select small portions of their networks as pilot projects. In addition to identifying the network, administrators are encouraged to also identify portions of the network that will still be maintained with the traditional maintenance approach and that will be exposed to similar conditions as those roads that will be maintained with performance-based specifications. The important factors for identifying similar portions of roads for comparison are: the geographical location, weather conditions, rural vs. urban settings, average traffic volumes, traffic mix, and types of assets on the routes. These factors can also be used when deciding how to stratify the total population for the data collection process (discussed later). Identifying these similar portions of the network will allow road administrators to perform comprehensive comparison of the LOS at which the assets within each portion of the roadway system are maintained.

ii) Inventory and Condition of Assets To Be Maintained. Once the portion of the network is identified, a complete inventory and condition assessment is needed to describe all assets located within those portions of road. This information is extremely important to understand the condition of the assets located within the portions of roads to be maintained according to performance-based specifications. The approach to develop this inventory varies among road administrations. Normally, the data collection process is performed through field inspections and/or from existing agency records. This data collection effort can be very expensive and time consuming. In some instances, a sample (i.e., portion) of the total number of assets is inspected and the results are extrapolated to the whole population. Asset inventory and condition assessment are to be treated as on-going activities of the agency. That is, an asset inventory has a starting point but never ends. Therefore, a strategy that is rooted in the 80-20 philosophy should be adopted. In other words, one must collect 20% of the information that adds 80% of the value. Over the years, the 20 will increase. For example, an agency could start by geo-referencing the beginning and end of the sample units or sites (e.g., 0.1 mile in length). The agency will also determine if an asset item is present or not and can continue by geo-referencing the length (e.g., pipes length), then the diameter, etc. The main idea is to avoid the temptation of adopting an "all or nothing" philosophy which will invariably lead to failure.

In addition to the inventory of the assets and their condition, road administrations sometimes include activities such as snow removal in their PBRM. If performance-based specifications are applied to this type of activity, then statistics related to the average days of snowfalls by year and intensity must be provided to the contractor (Baker 1999). For some countries and states in the US, snow removal is one of the most expensive maintenance activities. For this reason, it is important to provide this kind of information before implementing performance-based specifications to this type of activity.

4.2.2. Condition Standards

The Condition Standards represents the performance measures and targets which will evaluate the contractor's performance. The appropriate definition of these elements is crucial to guarantee success in the implementation, execution, and proper evaluation of any performance-based road maintenance initiative. These elements are the heart of this approach. Guidance on defining these elements is provided below.

i) Performance Measures. Since PBRM is ruled by outcome-based specifications, road administrators need to define performance measures that specify the standards by which the maintenance work will be evaluated. Defining the "right" performance measures is a very challenging task. The main goals when defining these standards are: to ensure the safety and comfort of road users, and to ensure that each asset type will be preserved at a minimum acceptable level of service throughout the life of the asset. Performance measures have two components: (1) the performance indicator, which defines the asset item to be evaluated (e.g., pipes), and (2) the performance standard, which establishes the desired measurement (e.g., more than 90% of pipe diameter needs to be open). The performance measures should be based on the agency's prior experience with the performance level achieved in other works, as well as through market research.

ii) Performance Targets. In all performance-based work, there must be a tolerance or acceptable quality level, also known as a performance target. Performance targets vary depending on the importance of each individual asset item within the roadway system. It is important that transportation agencies define realistic targets for two main reasons: (1) the payment to the contractor will be based on his compliance to these minimum acceptable levels, and (2) the overall condition of the assets will be affected by the contractor's effort to meet or exceed the targets. The timetable to reach those performance targets needs to be explicitly defined, particularly at the inception of a performance-based contract when the current conditions on which the guaranteed maximum price is based are below target. In addition to specifying the timetable to reach the performance targets throughout the duration of the contract, road administrators must define the mechanisms to penalize the contractor for non-compliance on reaching the targets. The penalties can be monetary (e.g., reduction in contract price) or non-monetary (e.g., reduction in contract duration). Including penalties in PBRM is in accordance with the philosophy that payments must be made based on demonstrated results achieved by the contractor and not simply on the amount of cost incurred or work done.

iii) Relative Weights among Assets. It is understood that some asset items are more critical or important than others. For this reason, the framework suggests the use of two sets of relative weights, one set among the asset items within each asset group, and another set within the main asset groups. The purpose of defining these weights is to establish relative importance among asset items and asset groups (Stivers et al. 1997). For example, in the Roadside group, a very important item such as debris and road kill can receive a relative weight of 10, whereas a less important item such as sound barrier can receive a relative weight of 5 (2:1 relationship). On the other hand, with respect to the importance among asset groups, twice the importance can be given to the Traffic asset group in comparison to the Shoulder asset group. This means that the rating from the Traffic asset group will have more impact on the overall evaluation than the rating from the Shoulder asset group. These weights will be used in the overall calculation of the LOS ratings.

4.3. STAGE 2: DATA COLLECTION FOR LOS EVALUATION

In Figure 4.1, three main areas were identified as part of the data collection section: the Data Collection Plan, the Sample Selection Process, and the Quality Control and Quality Assurance Program. A detailed description of the elements within each one of these areas of the framework is presented in the following sections.

4.3.1. Data Collection Plan

A data collection plan is essential to ensure the collected data supports the overall objectives of the performance monitoring program (Atkinson 1990). The main objective of the data collection plan is to identify the information needed as well as the sources that can provide that information. For instance, in the case of road maintenance, one must first define the main asset groups (e.g., pavement, bridges, roadside) in which the asset items to be maintained by the contractor will be classified. Once the asset groups are defined, the next step is to identify the data sources that will aid in conducting performance evaluations for items such as pavement and bridge management systems, and/or field inspections. Close attention must be paid to collecting only what is needed, and not all that is available.

4.3.1.1. Information Technology Support

The data collection process can be very time-consuming and expensive. Like many other management decisions, cost plays a central role in deciding which data collection process to implement. Road administrators should balance the needs of the evaluation with the financial resources available (Grigg 1988, Hudson et al. 1997). Some low-cost data collection techniques limit the type of information that can be collected or the quality (i.e., the validity, reliability, and accuracy) of the data. Among the least-expensive data collection methods are program and agency records, file reviews, mail questionnaires, and telephone surveys. On the other hand, among the most expensive data collection methods are destructive testing and field inspections (Niebel 1985). In the current scenario, the most common and appropriate data collection method road administrators' use is field inspection. The data from the field inspections can be collected with pencil and paper forms or with portable electronic devices (i.e., information technology). The use of such information technology can play a major role in increasing the efficiency and effectiveness of the data collection process. Field crews can be equipped with portable notepads in which a smart computer-based form can be programmed to collect the condition of the different asset items within each portion of the road. Other technology such as Geographic Positioning Systems (GPS) and Geographic Information Systems (GIS) can be used as well to document the exact location of assets and represent and communicate the findings from the field inspections. Among the most significant advantages of implementing new technologies in the data collection effort is that errors from double entry of data are minimized, and the information is immediately available for verification, analysis, and posting on the Web and pocket-based computers, if desired.

4.3.2. Sample Selection Process

It is impractical to conduct a 100% inspection because doing as so will be very expensive. When collecting information for the whole population is not feasible, random inspections (or sampling) are useful for maximizing the benefits of the data collection effort (Thompson et al. 1996). The objective behind random inspections is to measure or survey only a portion of the whole population of interest. The results obtained from the sampled portion are then generalized to the whole population at a certain confidence level (Rao 2000). If the intent is to use sampling in the data collection process, as is mostly the case for road administrations (because of budget and timing constraints), then the sampling method to be used should be specified. The selection of the method and the complexity of the sampling process will depend on the characteristics of the population considered in the evaluation and the confidence at which the finding will be projected to the entire population.

When considering the use of sampling in the evaluation process, it is important to understand any bias that may exist with the sampled data. Sample bias refers to the likelihood that a population sample does not accurately reflect the whole population (Thompson 1992). Random inspections and the collection of large samples are efficient ways to decrease sample bias. However, one must keep in mind that there are also some disadvantages associated with sampling or random inspection. One of the most significant disadvantages is that sampling does not collect all cases and, although statistically unlikely, may result in misidentification of the general impact or opinion. Moreover, missing observations may lead to loss of unique perspectives, which affect data quality. For this reason, careful attention must be paid when defining and implementing sampling techniques. Regarding this study's specific scenario, defining a methodology that addresses all the sampling needs associated with performance-based road maintenance evaluation was a real challenge. This section provides a detailed description of the approach used to define such procedures.

The sampling procedure presented in this section was developed in three stages: (1) conducting a detailed analysis of the particular characteristics of outcome-based road maintenance evaluations, (2) reviewing and carefully studying potential sampling techniques that can be used to improve the effectiveness and efficiency of the sample selection process, and (3) defining a comprehensive methodology for the selection of sample units that will guarantee with a high confidence level that the sample results represent the entire population. A thorough description of each stage follows.

4.3.2.1. Characteristics of Performance-Based Road Maintenance Evaluations

The first step when defining any sampling application is to comprehensively study the particular properties of the population to be evaluated or analyzed. With respect to performance-based road maintenance evaluations, understanding the characteristics of factors such as overall population, sample units, assets within each sample unit, and acceptable quality levels for each asset type is crucial to guarantee the success of the sampling procedure to be defined. An evaluation of each factor follows.

i) Population. The population normally considered under road maintenance evaluations is defined by small segments of a specific length. These segments are better known as sampling units. The sampling units can be considered independently in each direction (e.g., North and South, East and West). For example, for a portion of a road that is 10 miles long running North and South and is divided in sample units of 0.1 mile long, the total population size will be 200 sample units (10 miles x 2 directions x 10 segments). Another important characteristic of the population is that portions of the road (population) can be exposed to very different conditions. In most of the cases, as in this study, it is interesting to evaluate areas with different characteristics separately. To address this need, the population should be divided into groups exposed to similar conditions, such as: same geographical location, weather variation, urban and rural settings, traffic volumes, and/or type of assets. For example, suppose that the first 5 miles of the 10 miles of road in the previous example are located in urban areas and the other 5 miles are located in rural areas. Then the 200 sample units will be divided in two groups with 100 units each. This concept of dividing the population in groups with similar characteristics is called stratification of the population.

ii) Sample Units. One important characteristic of each typical sample unit under consideration is that each one of them contains more than one element to be evaluated. These elements are asset items. Each sample unit may have a different number of asset items. Considering once again the example of the 10 mile road portion, consider that there are a total of five asset items that can be presented on a given sample unit (0.1 mile long). Obviously, not all units contain similar asset items. Thus, one can have 3 out of 5 asset items in one unit and 2 out of 5 asset items in another unit. This particular characteristic of each sample unit makes the development of an appropriate sample selection process a more complex one. The challenge is to significantly inspect each asset item to guarantee that the findings from the sampled population are representative, with high confidence, of the condition of the assets in the entire population. Sampling techniques such as stratification and sampling relative to the size of the unit are good alternatives to deal with this issue. These techniques were incorporated in this study's proposed sampling procedure and they will be discussed in the next section.

iii) *Performance Targets.* Since the methodologies presented in this document focus on performance-based evaluations, the acceptable quality (Performance Targets) must be considered in the development of the sampling procedure. Performance targets are normally different for each asset item within the roadway system. For example, a performance target can state that it will be considered acceptable that 90% of the pipes in a population are in good condition, where good condition is defined according to specific performance standards. The variability in performance targets among asset items is an important characteristic that can make a significant difference when determining the minimum number of samples required for inspection, which will end up affecting the confidence at which the findings from the sampled population are representative of the whole population.

Now that the characteristics and properties of the population under consideration are known, a review of sampling concepts will identify potential techniques to define the methodology that will better address this study's sampling needs.

4.3.2.2. Sampling Concepts and Techniques

The review of sampling theory is focused on the following four areas: (a) sampling mechanisms for drawing samples from the population, (b) basic sampling concepts, (c) formulas for sample size determination, and (d) issues related to the parameters used in sample size determination.

a) Sampling Mechanism. The most influential factor in any sampling scenario is the sampling mechanism that is used to randomly draw samples from the entire population. The sampling mechanism determines the statistical properties of the analytical procedures that are applied to the sample, and ultimately determines the variability of any inferences made on the population. There are four sampling strategies: simple random sampling, stratified sampling, systematic sampling, and cluster sampling (Scheaffer et al 1995). These are considered the simplest random sampling strategies. However, there can be cases in which a more complex sampling method than these simple variations should be used. If that is the case, then a combination of the simple methods can be used to address the specific sampling needs. Combining sampling methods is better known in sampling theory as multi-stage sampling (Cochran 1977). To understand which method or combination of methods will suit this study's needs a description of each alternative follows.

i) *Simple Random Sampling (SRS).* This is the simplest form of random sampling. Here, each sample from the population has an equal chance of been selected. This sampling method is not the most statistically efficient of all the methods, because one may not get good representation of subgroups in a population.

ii) *Stratified Sampling.* In stratified sampling, the population is divided into non-overlapping (i.e., mutually exclusive) sub-populations known as strata. Simple random sampling is then performed on each strata or subgroup. There are two major reasons for why one might prefer stratified sampling over simple random sampling. These are: (1) key subgroups of the population will be properly represented, especially small minority groups, and (2) better statistical precision is achieved (only true if groups or strata are homogeneous).

iii) *Systematic Sampling*. To achieve a systematic random sampling, a series of steps must be followed. First, numbers must be assigned to each sample unit in the population (1 to N). Then one must decide how many samples will be selected (n). With this information, an interval size should be computed as $k=N/n$. Once the interval is computed, a random number between 1 and k should be selected. This number will represent the first sample unit to be selected. From there, one must sample every k^{th} unit. This method is more precise and easy to apply than simple random sampling because samples selected are more evenly spread over the population.

iv) *Cluster Sampling*. In cluster sampling the population is divided into clusters (usually along geographic boundaries). Then, a random selection of these clusters is performed and for each cluster selected all units are measured. This sampling method is useful in situations where the population to be sampled is distributed across a wide geographic region. This approach is primarily done to improve the efficiency of the sampling administration.

Based on the previous description of the sampling mechanism available and the specific characteristics of this study's scenario, none of the individual sampling methods were suitable for the study's sampling needs. For this reason, a multi-stage sampling approach was adopted. A combination of two sampling mechanisms, simple and stratified random sampling, were considered in the proposed methodology. A general description of the sampling mechanisms adopted in the sample selection process follows.

Sampling Mechanisms Adopted. The main goal when defining the sampling procedure to be used in this study's scenario -- outcome-based road maintenance evaluations -- was to guarantee that enough assets on each category were evaluated. This will show with high confidence that the results were representative of the general condition of the different assets in the entire population. To meet this goal, it was necessary to combine several sampling techniques, such as simple random sampling (SRS), stratified random sampling, and random sampling proportional to the number of assets in each sample unit (i.e., Sampling Proportional to Size). In the first place, the adopted sampling approach considered the use of stratified sampling to allow dividing the population into sub-populations or strata to get a better representation of each group. The main reason for using this technique first is to allow independent evaluation of portions of the roadway system that are exposed to different conditions (e.g., rural and urban zones). Once stratified sampling is used to divide the population in each group of interest, then the second sampling mechanism -- Sampling Proportional to Size (PPS) -- is applied. In PPS sampling, unequal probabilities are assigned to each unit (site) based on the number of existing asset items in the sample unit (density of assets on the unit) (Brewer & Hanif 1983). The objective of assigning unequal probabilities is to allow more chances for the sample units that contain more assets of being selected with respect to the sample units containing the fewest assets. This approach leads to a more cost-effective procedure because the number of asset items inspected on each sampled unit is reduced (concept to be discussed later). Finally, the new sampling approach uses the concept of sampling without replacement (SWOR) to draw samples from the population as opposed to using the sampling with replacement (SWR) approach. Under SWOR, sample units are removed from the population once they are selected; thus, sample units can only be drawn once. In SWR, sample units can be drawn more than once; thus, they are not removed from the population once they are selected. It is therefore evident that SWOR is the most appropriate approach to be used in this study's scenario because the interest is in not inspecting the same sample unit twice.

b) Basic Sampling Concepts. Before a thorough discussion of the methodology to determine the required sample size, thistudy's basic sampling concepts should be reviewed. This discussion will help establish a better foundation for understanding the procedures presented later in this section. The review focuses on the following five concepts: population, target of inference (*p*), point estimator ($\hat{p}$), variability of $\hat{p}$, and confidence interval.

i) *Population* - In PPS sampling, the population is defined as the collection of N sampling units denoted by $Y_1, \ldots, Y_N$. Each unit is associated with a unit size a_i. In this scenario, the unit size is determined according to the number of assets. The PPS sampling mechanism will choose n units from the population (from each strata) denoted as $y_1, \ldots, y_n$ to make up the sample. Each sampling unit in the population is associated with a quantitative response measurement, denoted as X_i, that can only be observed if it is drawn and included in the sample. The x_i notation is used to represent the response measurement for a sampling unit included in the sample. When the response measurement can only take two values (for convenience $X_i = 0$ or 1) the population is classified as a binary population. For instance, this study's scenario has a binary population since each sample unit either meets its requirements ($X_i = 1$) or it does not ($X_i = 0$). From now on, the sampling concepts and theories presented in this section will focus on a binary population since the study deals with such a population type (Scheaffer et al. 1995).

ii) *Target of Inference* - The objective of most sampling procedures is to make inferences about the population mean or as in PPS refers to it the - population proportion -, defined by

$$p = \frac{\#\, population \quad sampling \quad units \quad with \quad X_i = 1}{\#\, units \quad in \quad the \quad population} = \mu \tag{4.1}$$

Since the entire population is never observed, the population proportion cannot be known exactly. Instead, inferences about *p* are derived from the observed sample.

iii) *Point Estimator* - The procedure used for inferencing about the population mean is known in sampling theory as the point estimator, and is denoted by $\hat{p}$. The most common point estimator is the sample mean or sample proportion. Under PPS, an unbiased estimator of the sample proportion is formed as the weighted average of the sample response measurement, defined by

$$\hat{p}_{PPS} = \frac{1}{n}\sum_{i=1}^{n} x_i \frac{1/N}{a_i/a_T} \tag{4.2}$$

where n is the number of sampled units, x_i is the response measurement for a given sampled unit, N is the total number of samples in the population, a_T is the unit sample size (i.e., number of assets in the unit), and $a_T = \sum_i a_i$.

iv) _Variability of point estimator_ - Because $\hat{p}_{PPS}$ is subject to uncertainty, it is often useful to provide an indication of the variability of the point estimator about its target of estimation (Thompson & Seber 1996). This assessment can be done by computing the variance of the sample proportion, which in PPS is defined by

$$\sigma_{\hat{p}}^2 = V_{[\hat{p}]} = \left(\frac{N-1}{N}\right)\frac{S_{PPS}^2}{n} \tag{4.3}$$

where S_{PPS}^2 represents the population variance weighted for PPS sampling. It is defined using the equation,

$$S_{PPS}^2 = \frac{1}{N-1}\sum_{i=1}^{N} \frac{a_i/a_T}{1/N}\left(X_i \frac{1/N}{a_i/a_T} - p\right)^2 \tag{4.4}$$

Notice that S_{PPS}^2 cannot be determined simply from knowledge of p (as is the case in SRS). However, it is possible to determine its upper and lower bounds, which will be illustrated in a later example.

v) _Confidence Interval_ - In most sampling scenarios, a detailed assessment of uncertainty is available in the form of a range of error, or interval estimate, which represents a region of high confidence where the population mean is thought to lie. Such assessments are called confidence intervals and are stated with a numerical level of confidence, usually a high percentage such as 90%, 95%, and even 99% in some cases. Under PPS, the confidence interval for the population proportion (p) is defined by the interval

$$[\hat{p}_{PPS} - z_{\alpha/2}\hat{\sigma}_{\hat{p}}, \hat{p}_{PPS} + z_{\alpha/2}\hat{\sigma}_{\hat{p}}] \tag{4.5}$$

where $Z_{\alpha/2}$ is the standard normal upper tale cut-off (its value depends on the desired confidence level), and $\hat{\sigma}_{\hat{p}}$ is the standard deviation of $\hat{p}_{PPS}$, defined by the following expression,

$$\hat{\sigma}_{\hat{p}} = \sqrt{\left(\frac{N-1}{N}\right)\frac{\hat{S}^2_{PPS}}{n}} \tag{4.6}$$

where the quantity

$$\hat{S}^2_{PPS} = \frac{1}{n-1}\sum_{i=1}^{N}\left(x_i \frac{1/N}{a_i/a_T} - \hat{p}_{PPS}\right)^2 \tag{4.7}$$

defines the unbiased estimate for S^2_{PPS}. The confidence interval formula is considered valid in binary sampling only if the following conditions are met,

$$\hat{p} - 3\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} > 0 \quad \text{and} \quad \hat{p} + 3\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} < 1 \tag{4.8}$$

c) Formulas for Sample Size Determination. One of the most important and difficult steps associated with a sampling procedure is the determination of the sample size (n) that will guarantee that the sampled population results represent entire population with high confidence. The selection of the sample size should be based on a clearly stated objective. For example, the interest might be to estimate the mean value of the actual condition (in numeric scale) of the bridge decks with a confidence level of at least 95% (α = 0.05). In this example, the specified level of accuracy will influence the sample size required (e.g., the higher the accuracy the higher the sample size). This section presents the formulas that should be used to compute a successful and meaningful sample size when conducting performance-based road maintenance evaluations.

To get a better understanding of the formulas to be used for sample size determination, the discussion will begin with the simplest scenario - simple random sampling (SRS). Under SRS, the sample size formula is defined by

$$n = \frac{z^2_{\alpha/2}\, S^2}{e^2 + z^2_{\alpha/2}\,\frac{S^2}{N}} \tag{4.9}$$

where the quantity

$$S^2 = \left(\frac{N}{N-1}\right)p(1-p) \tag{4.10}$$

defines the variance of the sample proportion, and *e* represents the tolerable sampling error. Remember that Eq.4.10 is valid only for SRS. If PPS is considered instead of SRS, then Eq.4.10 must be replaced by Eq.4.4 as previously introduced. Moreover, if in addition to PPS, stratification is considered in the methodology (this case), then some additional changes must be added to Eq.4.9. Under stratified sampling, the sample size determination is somewhat complicated since different strata (M) must be taken into consideration, resulting in different sample sizes. One approach to sample size determination under stratified sampling is to specify a fixed allocation of the stratum sample size as proportions of the overall sample size. For example, if the interest is in a population that is divided in two strata (M=2), one might decide in the planning stages that 60% (w_1=0.6) of the sample should come from stratum 1 (n_1=0.6n) and 40% (w_2=0.4) from stratum 2 (n_2=0.4n). To further illustrate how this concept is incorporated into Eq.4.9, Eq.4.9 can be considered in a slightly different way as in

$$e^2 = Z_{\alpha/2}^2 \sum_{k=1}^{M} \left(\frac{N_k - 1}{N_k}\right) S_{PPS}^2 / n_k \tag{4.11}$$

where N_k is the stratum size, n_k is the stratum sampled size, and M is the number of strata. If we the previous example is considered (in which sample units from two strata are drawn using PPS), then the following expression can be derived from Eq.4.11 to determine the sample size

$$n = \frac{Z_{\alpha/2}^2 \left\{ \left(\frac{N_1}{N}\right)^2 \frac{S_{PPS,1}^2}{w_1} + \left(\frac{N_2}{N}\right)^2 \frac{S_{PPS,2}^2}{w_2} \right\}}{e^2} \tag{4.12}$$

where

$$S_{PPS,1}^2 = \frac{1}{N_1 - 1} \sum_{i=1}^{N_1} \frac{a_i / a_T}{1/N_1} \left(Yi \frac{1/N_1}{a_i / a_T} - \mu_1 \right)^2 \tag{4.13}$$

$$S_{PPS,2}^2 = \frac{1}{N_2 - 1}\sum_{i=1}^{N_2}\frac{a_i/a_T}{1/N_2}\left(Yi\frac{1/N_2}{a_i/a_T} - \mu_2\right)^2 \quad (4.14)$$

For simplicity, the factors $(N_1 - 1)/N_1$ and $(N_2 - 1)/N_2$ were set to 1, which is a fair assumption for large strata.

d) <u>Issues Related to the Parameters Used in Sample Size Determination</u>. The issues related to the values of the parameters used in Eq.4.9 and Eq.4.12 to compute the sample size must be addressed before discussing the step-by-step instructions on how to apply the proposed sampling procedure. The issues to be discussed are related to the tolerable sampling error (*e*), the population proportion (*p*), and the estimate of the population variance weighted for PPS (S_{PPS}^2).

i) <u>*Tolerable Sampling Error*</u> - The objective of the tolerable sampling error is to give some idea of the precision of the statistical estimate. This error is related to the sample size. *How?* The greater the sample size, the smaller the sampling error. *Why?* Because the greater the sample size, the closer the sample is to the actual population itself. For instance, if a sample is taken that consists of the entire population, there actually is no sampling error since the whole population was sampled. Under binary sampling, sometimes the value of *e* is not straightforward, since its practical relevance may change drastically depending on the particular value of the population proportion. One approach to deal with this issue is to state the error bound (*e*) relative to the population's coefficient of variation (COV) (Scheaffer et al. 1995). In this scenario, the COV can be expressed in terms of the population proportion as stated in

$$COV = \sqrt{\frac{(1-p)}{p}} \quad (4.15)$$

To better illustrate how this approach works, consider the following example. Suppose in planning a binary sampling experiment it is determined that a suitable error bound when p=0.80 is e=0.06. However, the interest is in estimating the value of e when p=0.94. To compute this value, the relative proportion (p_R) must be computed with respect to COV for p=0.80 first. The following expression depicts this step

$$e = p_R \ COV \quad (4.16)$$

$$0.06 = p_R \sqrt{\frac{1-0.8}{0.8}}$$

$$p_R = 0.12$$

Thus, the error bound of *e*=0.06 is exactly 12% of the COV when *p*=0.80. The next step is to compute the adjusted value of *e* when *p*=0.94 and the relative proportion is 12%. By substituting these values into Eq.4.16, an error bound of 0.03 is obtained when *p*=0.94. The main benefit of adopting the procedure presented above is that the final estimation of the sample size will be more realistic given the fact that the tolerable sampling errors will now be adjusted according to the actual proportion of the population.

ii) Population Proportion – In the proposed methodology, the following values are recommended for use as an estimate for p minimum: the historic performance rate and the performance target. In addition, the minimum of these two values must be at least 0.5, which represents where the maximum sample size n is obtained. By considering the minimum value among these alternatives as an input, the probability of obtaining an actual value of p (based on performance rate) lower than the one used as an input is reduced.

Now that the known value of *p* must be any number between 0.5 and 1, the issue of what happens when *p* very close to 1 must be addressed. When this happens, the equations previously defined to determine the sample size are considered invalid unless a very large number of sampling units are drawn. To deal with this issue, a probabilistic tool known as binomial distribution is incorporated into the proposed sampling approach. The use of a binomial distribution as an alternative approach allows performance of a more accurate assessment of the uncertainty even for small samples. This is especially easy to accomplish in extreme cases, such as the one in consideration where $p \approx 1$. The exact derivation of the binomial distribution arises from the case when sampling with replacement is applied; however, it is reasonably accurate to use this procedure for sampling without replacement if the binary population is large. The binomial distribution is defined by the following equation

$$Pr(K_1 \leq k \leq K_2 \text{ units with } x_i = 1, \text{ in } n) = \sum_{k=k1}^{k2} {}_nC_k \, p^k (1-p)^{n-k} \qquad (4.17)$$

where Pr represents the probability of observing a given number k of sampling units within the lower bound K_1 and the upper bound K_2, and the component ${}_nC_k$ represents the combination operator (Milton & Arnold 1995). The intent is to use this binomial distribution to determine a suitable sample size for inferring with high confidence wether the population is completely uniform with a performance of 1 (based on p=1). Of course, it is impossible to make such an assessment without observing the entire population. However, if it is true that the population is uniform with a performance of 1, then it will be true that every observed sampled unit would have a value of p equal to 1, and one's confidence that p is near to 1 would increase as more samples are drawn. According to sampling theory, one approach to determine the sample size for this specific scenario is to specify a tolerable lower bound for p near 1 (e.g., p=0.99), then assume that every sampled unit will be observed with a value of p equal to 1 and finally use the binomial distribution to calculate the number of samples required. This will require a sample size large enough so the binomial probability will become

$$Pr(n\ units\ with\ x_i = 1,\ in\ n) = p^n \tag{4.18}$$

For instance, assume that every unit within a sample will be observed with x_i=1. What sample size would be required to state with 95% confidence that p is larger than 0.99? This sample size can be obtained by solving Eq.4.18 with respect to n ($0.05=0.99^n$). By doing this, a sample size of 299 sampling units is required to state with 95% confidence p will be larger than 0.99.

iii) <u>*Estimate of Population Variance for PPS*</u> - For a binary population, a preliminary assessment of the weighted population variance is particularly more complicated compared to its unweighted counterpart, for S^2_{PPS} cannot be determined from knowledge of p alone. Yet, it is possible to obtain upper and lower bounds for S^2_{PPS} from such knowledge by considering the extreme configurations of the population with respect to the unit sizes. At one extreme, the largest sampling units (those with the largest a_i) will have X_i=1, and in this configuration S^2_{PPS} will achieve its lower bound for any fixed p. At the other extreme, the smallest sampling units have X_i=1 and S^2_{PPS} will achieve its upper bound. Given the fact that the present interest is to compute the minimum sample size required to infer for the entire population with high confidence, only the upper bound for S^2_{PPS} is really needed (will generate a higher sample size). A concrete example will help to illustrate this approach. Consider a population of size N = 30 and p=0.8 with sampling units of the size (i.e., number of asset) depicted in Table 4.1 (column 2). The sample units presented in Table 4.1 have already been arranged in descending order with respect to the unit size, which is the first step in computing the upper bound for S^2_{PPS}. As previously stated, in order to obtain the upper bound for S^2_{PPS} it is assumed that the smallest units have X_i = 1 (in this case the 24 smallest units - 80% of 30). The calculation for the upper bound for S^2_{PPS} is presented in Table 4.1. As shown at the end of Table 4.1, the final value for the upper bound of the population variance is 0.2805. This value can then be used as an input in Eq.4.12 to obtain the minimum sample size required from the entire population.

4.3.2.3. Proposed Sampling Methodology

This section provides a detailed description of the steps required to implement the proposed sampling procedure for conducting outcome-based road maintenance evaluations. The methodology is summarized in ten steps in which the sampling theories and concepts introduced in the previous section were combined to provide comprehensive guidance on how to determine the appropriate sample size and finally select sample units for evaluation. A description of each step follows. Refer to Flowchart B.1 (Appendix B) for a graphical representation of these steps.

Step 1: Stratify the Population. The first step in the proposed sampling approach is to stratify (divide) the population into different areas (strata) of interest. The number of strata depends on the information needed and the different parameters to be incorporated in the analysis. Some of the criteria that can be considered when determining how to stratify the population were previously discussed.

Step 2: Define Sample Units. Once the strata have been identified, the next step is to divide each stratum into sample units. The same sample length for all units should be specified. For instance, in this study's scenario one can specify a sample unit length of 0.1 mile long, which divides each mile into 10 equal sample units in one direction and 10 units in the other direction (if two directions are considered separately).

Table 4.1. Example to Compute the Upper Bound for S^2_{PPS}

Sample Unit (1)	Unit Size (2)	a_i/a_T (3)	Upper bound for S^2_{PPS} X_i (4)	Σ portion of Eq.(4) (5)
1	9	0.045	0	0.864000
2	9	0.045	0	0.864000
3	9	0.045	0	0.864000
4	8	0.040	0	0.768000
5	8	0.040	0	0.768000
6	8	0.040	0	0.768000
7	8	0.040	1	0.001333
8	8	0.040	1	0.001333
9	8	0.040	1	0.001333
10	8	0.040	1	0.001333
11	7	0.035	1	0.024381
12	7	0.035	1	0.024381
13	7	0.035	1	0.024381
14	7	0.035	1	0.024381
15	7	0.035	1	0.024381
16	7	0.035	1	0.024381
17	7	0.035	1	0.024381
18	6	0.030	1	0.087111
19	6	0.030	1	0.087111
20	6	0.030	1	0.087111
21	6	0.030	1	0.087111
22	6	0.030	1	0.087111
23	6	0.030	1	0.087111
24	6	0.030	1	0.087111
25	5	0.025	1	0.213333
26	5	0.025	1	0.213333
27	5	0.025	1	0.213333
28	4	0.020	1	0.450667
29	4	0.020	1	0.450667
30	3	0.015	1	0.910222
a_T =	**200**	**Upper S^2_{PPS} =**		**0.2805**

Step 3: Identify Assets on each Sample Unit. Once the sampling units have been defined, a density of all the asset items located within each sample unit should be created. What is important in this asset density study is not the exact quantity of a particular asset item on a given unit, but to establish if the asset item truly exists. For instance, a given unit may have ten pipes. The information that must be provided in the asset density is only that pipes exist on that particular unit as opposed to specifying the exact quantity (in this case 10). Table 4.2 presents a more comprehensive example of the kind of information needed from the asset density to properly implement the proposed procedure. As depicted in this example, the population in Table 4.2 contains N=95 sample units (column 1), for which the existing asset items have been identified (columns 2 through 5). The total existing asset items on each unit are added in column 6. Notice that in addition to the column with the total number of assets on each unit, an additional column (column 7) with the cumulative number of assets was included. The purpose of having the cumulative number of assets is to use them to define the intervals (column 8) that will be used to determine the sites selected for inspection. This procedure is discussed in detail in Step 8.

Table 4.2: Example of Asset Density for each Sample Unit

Sample Unit (1)	Assets that exist on each site (E = Exist, NE= Not Exist)						
	Signal (2)	Slope (3)	Guardrail (4)	Sidewalk (5)	Total (a) (6)	Cum.(ΣN) (7)	Interval (8)
1	E	E	E	E	4	4	0-4
2	NE	E	NE	E	2	6	5-6
3	E	NE	E	NE	2	8	7-8
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
95	E	NE	E	E	3	ΣE_{95}	ΣE_{94}- ΣE_{95}
Total(N)	Σ E’s	Σ E’s	Σ E’s	Σ E’s	Σ E’s		

Step 4: Create a Database with the Sample Units Containing each Asset Item. Before starting with the calculations to determine the sample size, one additional task must be performed. This is the creation of complementary databases which identify the sample units containing each asset item within each stratum. These databases are essential for the success of the random selection process to be discussed in Step 8. The information needed to create these databases can be

derived from the asset density study conducted in Step 3. Table 4.3 provides an example of how these databases look based on the information provided in Table 4.2. For instance, notice in column 3 that database number 1 (for Signals) only contains sample units 1, 3, …, and 95. Sample unit number 2 was not included in database 1 because, according to the information in Table 4.2, that segment does not have signals (NE).

Table 4.3: Databases for each Asset Item

Database (1)	Main Asset Included (2)	Sites Included in database (3)
1	Signals	1, 3,…, 95
2	Slopes	1, 2, …
3	Guardrail	1, 3,…, 95
4	Sidewalks	1, 2,…, 95

<u>*Step 5: Define Values of Parameters to be Used in Sample Size Formulas.*</u> The next step in the procedure is to define the values for the parameters to be used in the formulas to determine the sample size. According to Eqs.4.9 and 4.12, the parameters that need to be defined are: the population size (N), each sample unit size (a_i), the standard normal deviate ($Z_{\alpha/2}$), the performance rate (p), the sampling tolerable error (e), the number of strata (M), and the strata proportions (w_i). As shown in Step 3, the values for N (total number of sampled units) and a_i, (column 6 in Table 4.2), are already defined. With respect to the standard normal deviate $Z_{\alpha/2}$, the value will depend on the desired confidence level (CL). This value can be obtained from statistics tables. Among the most commonly used values for $Z_{\alpha/2}$ are 1.96 for a 95% CL (α=0.05) and 1.65 for a 90% CL (α=0.10). Alternative values for p and e were previously discussed. One must remember that the value of p must be defined as the minimum between the historic performance rate and the performance target (but not lower than 0.5) and the sampling error must be adjusted relative to the value of p, as stated in Eqs.4.15 and 4.16. Finally, the values for M and w_i must be defined according to the stratification strategy adopted.

<u>*Step 6: Compute the Required Sample Size for each Asset Item.*</u> The proposed methodology for sample size determination was divided in two stages: (1) a sample size determination for each

asset item considering SRS, and (2) a sample size determination for each stratum considering stratification and PPS. The main purpose of the first stage is to compute a sample size that will guarantee that each asset item is sufficiently inspected. In other words, one must be sure that enough assets on each category are evaluated to guarantee with high confidence that the results represent the general condition of the different assets in the entire population. The only way in which sufficiency can be guaranteed for each asset item is to compute a sample size for each asset type. To accomplish this, Eq.4.9 and 4.10, should be used which correspond to SRS for a binary population. The idea is to use the databases created in Step 4 as an input to compute the minimum sample size required for each asset item. For example, database 1 in Table 4.3 may identify a total of 85 sample units that contain signals. This value represents the total population for the signals asset item (*N*=85). Now, assuming that the value of $p, Z_{\alpha/2}$, and e have been estimated, then one can compute the required sample size (n) for signals by using Eqs.4.9 and 4.10. The SRS approach was adopted in this stage because the impetus is to give the same evaluative chance to all the sample units within each database created in Step 4. This procedure must be repeated for each asset item within each stratum. Once this procedure is repeated for each asset item within each stratum, the second stage can take place. A detailed discussion of the procedure adopted in the second stage is presented in Step 7.

Step 7: Compute the Required Sample Size for each Strata. In Step 6, simple random sampling was used to compute the sample size for each asset item. However, one must remember that two additional sampling techniques were adopted in our proposed methodology - stratification and PPS sampling. By considering these techniques, Eq.4.12 was derived. The output from Eq.4.12 provides a value that corresponds to the minimum sample size required to properly represent each defined strata. The values computed with Eq.4.12 must be used as minimum targets. This means that if the values computed with Eq.4.12 are lower than the total number of units to be sampled in Step 8 (next step), then no more additional units need to be sampled. Otherwise, the remaining number of samples required to match the values computed with Eq.4.12 must be sampled from the population. A better understanding of this procedure will be acquired in the application example to be presented in Chapter nine by considering the performance-based road maintenance contract between the Virginia Department of Transportation (VDOT) and VMS, Inc. (private contractor).

<u>*Step 8: Perform Random Selection of Sample Units and Check Sufficiency.*</u> The first step in the process of selecting sites for inspection is to generate random numbers. The random number must be generated from an interval of 1 through the total number of assets on each stratum (a_T). The purpose of using this interval is to introduce the concept of sampling proportional to the sample size to the random selection process, in which the number generated will be used to determine which interval (column 8 of Table 4.2) applies. Depending on the interval in which the random number is located, the sample unit associated with that particular interval will be selected. For example, according to Table 4.2, if a value of 5 is randomly generated, then the sample unit that will be selected for inspection is unit 2. The remaining steps of the procedure to be followed, once a sample unit is selected, are illustrated in Table 4.4. As shown in Table 4.4, units will be randomly selected from all the databases created in Step 4 until a particular asset type is sufficiently inspected. Then, the databases used for the selection of samples are narrowed to only those databases that contain the main asset type that has not been sufficiently inspected. To better illustrate this process, consider the procedure presented in Table 4.4. For the first 35 sample units selected for inspection (order of selection no. 35), all the databases were considered. However, after 35 sample units were selected, the slopes met sufficiency (according to column 6 in which 22 sites were needed and 22 sites were selected). However, since the cumulative number of selected sample units (n_A) containing signals, guardrails, and sidewalks are lower than the number of sample units required (n_R), more sample units need to be selected for inspection. For the selection of the next sample units, only databases 1, 3, and 4 need to be used. Once again, notice that after 50 sites were selected, the sidewalks met sufficiency, which required another reduction in the databases considered for the selection of the next sample units (only databases 1 and 3 are used at this stage). This process is repeated until all the different assets are sufficiently inspected, as shown on the last row in Table 4.4 (82 sites were required to sufficiently inspect all asset items). Once the total number of sample units required to meet sufficiency for each asset item is known, then this number should be compared with the number computed in Step 7, which represents the minimum sample size required to satisfy all the conditions related to stratification and PPS sampling.

Before describing the last step, one last concept needs to be highlighted regarding the proposed sample selection process. Notice in Table 4.4 that every time sufficiency is met for a given asset item, the cumulative number of assets selected for inspection (n_A) remains the same as the number of assets required to be inspected (n_R). This means that only the asset items that have not yet met sufficiency yet will be considered for inspection in the subsequent sample units selected. For example, consider in Table 4.4 that the order of selection number 75 corresponds to the selection of unit number 22. At this stage in the example, three out of the four asset items have meet sufficiency (slopes, sidewalks, and guardrail). However, two of these asset items, slopes and sidewalks, met sufficiency in selection order number 35 and 50, respectively. With respect to slopes, if any sample unit selected for inspection contains slopes after slopes meets sufficiency (occurs at selection order no. 35), then this asset item will not be inspected in those additional units, even if slopes exist. This approach makes the process more cost-effective since only the asset items that will make a contribution to the sufficiency of assets inspected will be included in the evaluation.

Table 4.4: Selection of Sites and Check for Sufficiency of Asset Inspected

Route (1)	Order of Selection[1] (2)	Unit Selected (3)	Database Used (4)	Statistics of Asset Inspected							
				Signals (5)		Slopes (6)		Guardrail (7)		Sidewalks (8)	
				n_R[2]	n_A[3]	n_R[2]	n_A[3]	n_R[2]	n_A[3]	n_R[2]	n_A[3]
	1	3	1,2,3,4	70	1	22	0	66	1	14	0
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	35	67	1,2,3,4	70	35	22	22	66	35	14	9
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
A	50	5	1,3,4	70	48	22	22	66	50	14	14
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	75	22	1,3	70	67	22	22	66	66	14	14
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	82	10	1	70	70	22	22	66	66	14	14

Represent assets sufficiently inspected

[1] Represents the cumulative number of sites selected for inspection.

[2] Represents the minimum number of sites required for inspection to meet sufficiency.

[3] Represents the actual number of assets selected for inspection.

Step 9: Perform Inspections. Once sufficiency is met for all the different type of assets, then inspections in the field can be performed on the sites selected in Step 8. Since sufficiency was met for all asset items in Step 8, the confidence at which the results can be generalized to the entire population will be at least the confidence associated with the selected Z value. For instance, if the value used for the Z value is equal to 1.96, then a 95% confidence level is achieved. However, if less than the required number of samples selected for inspection in Step 8 is actually inspected in the field, then the confidence level must be adjusted according to the actual number of sites inspected. The adjusted confidence level can be computed by using Eqs. 4.9 and 4.10. Step 10 addresses this scenario in detail.

Step 10: Adjusting Confidence Levels. If for some reason not all the required samples are inspected, then the confidence at which the findings are generalized to the whole population must be adjusted to reflect the real scenario (lower confidence level). Since simple random sampling was used to compute the minimum number of samples required for inspection, then Eqs.4.9 and 4.10 must be used to re-compute the confidence levels, if necessary. Remember from Step 6 that a value for the Z parameter was assumed. This parameter is estimated based on the desired level of confidence at which results were projected to the entire population. This means that if sufficiency is met in Step 8, then the findings from the sampled population will be representative of the condition in the entire population with at least the confidence level assumed for the value of Z. However, if sufficiency is not met in Step 8 for a given asset item, then the confidence level must be adjusted according to the actual number of assets inspected. The values of the original parameters (N, p, and e) and the actual value of n (actual number of samples inspected for each asset item) are used in Eqs.4.9 and 4.10 to obtain the actual value of Z. With the actual computed value of Z, statistics tables must be used to obtain the actual confidence level.

4.3.3. Quality Control and Quality Assurance Process

To ensure that the data collection and analysis is representative of the actual conditions or performance, it is important to verify and validate the data. In order to increase the reliability of the data collected, errors of measurement must be minimized (Anderson et al. 2001, London 2001). Some of the most difficult errors to assess are the ones that deal with changes in individuals responding to the measure (e.g. fatigue, anxiety), or the result of changes in physical conditions (e.g. noise, poor lighting). These errors negatively influence (i.e, lack of consistency and/or agreement among raters) the measurement of true scores and force the examiner to rely on obtained scores as estimates of true condition (Landy & Farr 1983). Two elements have been included in the proposed methodology to reduce as much as possible the variability of ratings among raters. These two elements are: (1) a training session, and (2) the use of reliable indices to assess the level of agreement.

i) Raters' Training Session. The main purpose of the training session is to discuss the performance measures (i.e., condition standards) specified by the transportation agency with the raters who will collect field data and to ensure that each rater interprets all measures in the correct manner. As part of the training session, the teams are sent to the field to collect data on real segments of the population (samples). All teams are required to inspect the same segments or samples. This will allow performing the agreement evaluation among the raters.

ii) Agreement among Raters. Several indices have been developed by different researchers to assess the agreement among raters (James et al. 1984, Kozlowski & Hattrup 1992, James et al. 1993, Lindell et al. 1999). These alternatives have been reviewed and finally two approaches have been selected that meet the study's specific need. The two methodologies are: (1) James, Demaree and Wolf's (1984, 1993) r_{wg} index, and (2) the methodology suggested by Stivers et al. (1997) to evaluate the difference in LOS ratings from multiple teams. Both approaches have been adopted because one will be applied to assess agreement at the asset group level (Stivers et al.1997 approach) and the other will be used to assess agreement at the asset item level (James et al.1984 r_{wg} index). The combination of these two approaches will provide road administrators with good information to determine which asset items (the ones with low level of agreement) require a revision of the criteria for evaluation before the actual inspections take place. A detailed description of each approach follows. Refer to Flowchart B.2 (Appendix B) for a graphical representation of the steps associated to the application of these approaches.

a) James, Demaree and Wolf's (1984, 1993) r_{wg} Index. The r_{wg} index basically compares the observed variance in the raters' responses to the variance that would be expected if the ratings were characterized by uniform distributed random responses. As previously mentioned, this approach should be used to assess agreement at the asset item level. The index is defined by the following expression,

$$r_{wg} = \frac{J\left(1-\frac{\overline{S_x^2}}{\sigma_{EU}^2}\right)}{J\left(1-\frac{\overline{S_x^2}}{\sigma_{EU}^2}\right)+\left(\frac{\overline{S_x^2}}{\sigma_{EU}^2}\right)} \tag{4.19}$$

where J is the number of raters, $\overline{S_x^2}$ is the variance of the ratings, $\sigma_{EU}^2 = (A^2-1)/12$ is the variance of the uniform distribution and A is the number of alternatives in the response scale (discrete scale). The closer the value of the r_{wg} index is to 1, the higher the level of agreement among the raters. The following steps summarize the procedure required to implement Eq.4.19.

<u>*Step 1.*</u> To properly compute the r_{wg} index, it is necessary to first define the value of J, which corresponds to the number of independent raters that will conduct the field inspections. For instance, if four raters will conduct the evaluations, then the value of $J = 4$.

<u>*Step 2.*</u> The next step is to identify the number of alternatives (A) that are available in the response scale for each asset item. These alternatives refer to the number of performance standards that have been specified for each asset item. For example, if the agency identified three conditions that will be used to evaluate pipes, then the value of A=3. These conditions are the ones that the raters will use in the field to determine if the asset item (e.g., pipes) fails or meets expectations. The value of A can vary depending on the asset item.

<u>*Step 3.*</u> With the value of A assigned for each asset item, then the variance of the uniform distribution can be computed as follows: $\sigma_{EU}^2 = (A^2-1)/12$. For instance, if the value of A=3 then $\sigma_{EU}^2 = 0.75$.

<u>*Step 4.*</u> The next step is to compute the last parameter needed to estimate the value of the r_{wg} index. This parameter is the variance of the ratings, $\overline{S_x^2}$. To better illustrate how to compute this variance, consider the following example. Assume that four raters (J=4) evaluate the same asset item in four different sample units, and that there are six criteria or performance standards to be

considered in the evaluation of each asset item (A=6) . Table 4.5 summarizes the criteria specified by each rater that meet the standards. For instance, in sample 1, raters 1 and 2 specify that 5 out of the 6 criteria have been met, whereas raters 3 and 4 specify that 4 out of the 6 criteria have been met. These differences in ratings obviously reveal a lack of agreement among the raters conducting the evaluations, but to evaluate the degree of severity, the $\overline{S_x^2}$ parameter must to be computed, which will allow estimation of the r_{wg} index. According to column 7 in Table 4.5, the $\overline{S_x^2}$ is equal to 0.229. This value was obtained by taking the average of all the variances computed for each sample unit (0.91÷4).

Table 4.5. Example of Methodology to Calculate $\overline{S_x^2}$

Sample	**Team (J=4)**				**Mean (M)**	**Sx_j^2**
	***J*=1**	***J*=2**	***J*=3**	***J*=4**		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	5	5	4	4	4.5	0.33
2	6	6	6	6	6	0.00
3	5	6	5	5	5.25	0.25
4	6	6	5	5	5.5	0.33
Mean						**0.229**

<u>*Step 5.*</u> Finally, all the values of the parameters defined and computed in Steps 1 through 4 must be used as an input in Eq.4.19 to obtain the value of the r_{wg} index for each asset item. For instance, an r_{wg} index equal to 0.979 is obtained if the values of the example presented in Step 4 are applied. There is no defined standard related to the acceptance criteria for this index. The evaluator must define what constitutes an acceptable level of agreement for the specific scenario under consideration. However, it is obvious that the higher the required value of the index, the higher the agreement among raters and the better the expected quality of the actual evaluations.

b) <u>Stivers et al. 1997 approach.</u> Stivers et al. (1997) proposed a methodology to determine if the differences between ratings produced by different rating teams are statistically significant. In contrast to the r_{wg} index, this approach should be used to assess agreement at the asset group level. The following steps describe the statistical analysis required to determine difference in statistical significance between two ratings.

Step 1. Compute the LOS ratings for each asset group on each site inspected.

Step 2. For each inspected site, compute the difference between the two LOS ratings using the following expression

$$\Delta LOS_i = LOS_{i,1} - LOS_{i,2} \tag{4.20}$$

where ΔLOS_i represents the difference in LOS ratings for a given sample unit, $LOS_{i,1}$ correspond to the LOS rating from team 1, and $LOS_{i,2}$ correspond to the site LOS rating from team 2.

Step 3. The mean value of the LOS differences for each asset group is then calculated. The mean value is obtained by adding the ΔLOS_i and then dividing by the total number of sites inspected.

$$\overline{\Delta LOS} = \frac{\sum \Delta LOS_i}{n} \tag{4.21}$$

where $\overline{\Delta LOS}$ represents the mean value of the LOS differences, ΔLOS_i corresponds to the difference in LOS ratings for a given sample unit, and n corresponds to the number of sites inspected.

Step 4. Once the differences between the LOS ratings are obtained, the variance of those differences is computed with the following equation

$$s^2 = \frac{\sum (\Delta LOS_i - \overline{\Delta LOS})^2}{n-1} \tag{4.22}$$

where s^2 represents the variance of the LOS differences, and $\overline{\Delta LOS}$ corresponds to the mean value of the LOS differences.

Step 5. With the variance calculated in Step 4, the standard deviation of those differences is computed as follows

$$s = \sqrt{s^2} \tag{4.23}$$

where s represents the standard deviation of the LOS differences, and s^2 is the variance of the LOS differences.

Step 6. The parameter *z* is used to determine statistically significant differences between the ratings performed by the two raters on the same sample unit. The final step in the process is to compute the z-statistic using the following equation

$$z = \frac{\overline{\Delta LOS} \times \sqrt{n}}{s} \tag{4.24}$$

where *z* represents the z-statistics, $\overline{\Delta LOS}$ corresponds to the mean value of the LOS differences, n is the total number of samples inspected , and *s* corresponds to the standard deviation of the LOS differences. Three conclusions can be reached with the calculated *z*-statistics. If *z* is greater than 1.96 (*z* corresponds to a 95% confidence level), then team 2 is producing significantly higher ratings than those of team 1. However, if z is lower than -1.96, then team 2 is producing ratings that are significantly lower than those of team 1. Otherwise, it can be concluded that no significant difference between team ratings is observed.

4.4. STAGE 3: DATA ANALYSIS FOR LOS EVALUATION

Data analysis is one of the most important steps in performance monitoring. The analysis converts raw data into performance information. Two main groups of performance indicators are included in the framework to serve this purpose: Actual and Long-Term Performance Evaluation.

4.4.1. Actual Performance

The elements defined in the framework to evaluate actual performance are the following: (a) calculation of actual ratings, (b) comparison of the actual ratings versus the performance targets, (c) comparison among different sections (strata) considered in the evaluation, and finally (d) comparison between the contractor performance and the agency performance in maintaining their similar road portions. A detailed description of each element follows.

i) <u>*Calculation of Actual Ratings.*</u> The main objective in the analysis process is to transform the data collected in the field into meaningful information. To fulfill this objective, it is necessary to define a procedure to process such data. In our scenario, the calculation of actual ratings for each asset item within each stratum will serve this purpose. The framework adopts some of the guidelines presented by Stivers et al. (1997) in their report on Quality Assurance in Highway Maintenance Programs to compute the actual ratings. The procedure is illustrated in Table 4.6.

Table 4.6. Example of Methodology to Calculate Actual Weighted Ratings

Asset Group (1)	Asset Item (2)	Required to be Inspected (3)	Inspected (4)	Passed (5)	Weight (6)	Total Score (7)	Actual Score (8)	Actual Rating (9)	Target (10)	Score Req. (11)	Actual Rating (12)	Req. Rating (13)	Confidence Level (14)
Roadside	Landscaping	5	5	4	3.2	16	12.8	80%	80%	12.8			95%
	Fence	20	20	17	4.5	90	76.5	85%	98%	88.2			95%
	Total				**0.52**	106	89.3			101	**84.2%**	**95.3%**	**95%**
Drainage	Box Culv.	3	3	3	7.0	21	21	100%	95%	20			**95%**
	Pipes	26	25	24	8.5	212.5	204	96%	95%	201.9			**91%**
	Total				**0.48**	233.5	225			221.9	**96.4%**	**95%**	**93%**
All	All										**90.1%**	**95.2%**	**94%**

The procedure presented in Table 4.6 to obtain the ratings for a particular section or strata is fairly simple and can be summarized with the following steps. Refer to Flowchart B.3 (Appendix B) for a graphical representation of these steps.

<u>*Step 1.*</u> The first step to compute actual and required ratings is to process the statistics associated with field data. An example of this information is presented in columns 4 and 5 of Table 4.6. As shown in these columns, the number of samples inspected (column 4) is recorded for each asset item as well as the number of samples that meet the conditional criteria specified in the contract (column 5). For example, in the Roadside group, of the 20 fences inspected, 17 met the requirements.

Step 2. Once the statistics for each asset item are collected, the next step in the process is to apply the relative weightings (column 6) to each asset item within each asset group. As previously mentioned, the purpose of these weights is to establish relative importance among asset items in a particular asset group. For example, in the Roadside group, the fence asset item (which serves to restrain the access to the right of way) received a weighting of 4.5, whereas the landscaping asset item, which is considered less important since it is only present for aesthetic purposes, received a weighting of 3.2. Each weight (column 6) is multiplied by the number of samples inspected (column 4) and the number of passing samples (column 5), generating a total possible score (column 7) and an actual score (column 8) for each asset item, respectively.

Step 3. Once the actual scores and total possible scores are obtained, an asset group score is calculated by adding all asset item scores on each asset group. As shown in columns 12 and 13, the actual and required LOS ratings were obtained by dividing the actual or required asset group score by the total possible asset group score.

Step 4. The next step in the process is to define and apply a second set of weights to establish relative importance among asset groups. Column 6 on Table 4.6 presents the weights assigned to each asset group (0.52 for Roadside and 0.48 for Drainage). As shown at the end of columns 12 and 13, by multiplying the weights previously defined with the actual and required LOS ratings for each asset group and adding them together, the final overall LOS ratings for this particular section or strata are obtained (Actual = 90.1% and Required = 95.2%).

Step 5. The procedure defined in Steps 1 through 4 is repeated for each section or strata considered in the monitoring process.

ii) Comparison of the Actual Ratings versus Performance Targets.

Step 6. The most important step in the evaluation of the compliance with the performance standards is to compare the actual ratings computed in the previous step with the performance targets defined by the agency for each asset item within each asset group. This comparison is crucial to determine if each asset item has been preserved at a minimum acceptable level of service throughout the life of the asset. For instance, if the actual rating (90.1%) computed for the strata in Table 4.6 is compared with the computed requirement (95.2%), it can be concluded that the contractor performing outcome-based maintenance activities failed to meet the targets specified by the agency at the strata level. However, notice that if the actual rating is compared with the requirements at the asset group level, the drainage asset group meets the targets (96.4% vs. 95%) whereas the roadside asset group failed to meet the target (84.2% vs. 95.3%). Conducting a bottom-up comparisons from the asset item level to the strata level of the actual rating versus the performance requirements will provide both the agency and the contractor a good overview of the areas of concern or the areas that need improvement.

Step 7. Once the ratings are obtained, the next step is to determine the confidence at which those ratings can be generalized to the entire population. As previously mentioned, if all the samples required for inspection which have been specified from the random selection process are actually inspected, then the confidence level will be at least the one used for the sample selection process, which is 95% or equivalent to Z=1.96. However, if not all the samples specified for inspections were actually inspected, then the confidence level will need to be adjusted to reflect the actual conditions. Since the number of samples inspected is lower than the number required, then one can expect a lower confidence level at which the results can be generalized to the entire population. Column 14 in Table 4.6 illustrates this issue.

iii) Cross-Sectional Comparison. As previously discussed, it is very common to have a population that has been divided in different sections or strata to account for the exposure to different conditions. If this is the case, then the bottom-up comparison of the actual performance versus the requirements must be performed for each stratum separately. This comprehensive comparison, also known as cross-sectional comparison, will help identify common areas of concern (e.g., common assets in continuous deterioration) among the different strata or sections of the population.

iv) Comparison of Contractor's and Agency's Performance. As previously stated, in addition to identifying the network to be maintained according to performance-based specifications, portions of the network should be identified that will still be maintained traditionally with similar conditions as those maintained by performance-based standards. This allows road administrators to perform a comprehensive comparison of the actual level of service accrued as a result of implementing both approaches. One must be careful to consider all the factors applicable to each approach to guarantee the reliability of the findings from such comparisons. If the comparison is conducted properly, it will provide a valuable insight regarding effective implementation of the performance-based specifications.

4.4.2. Long-Term Performance

The evaluation of the long-term effectiveness and efficiency of the contractor's maintenance program is crucial in assuring transportation agencies that the infrastructure is preserved properly throughout the years. For this reason, two elements were included in the framework to evaluate long-term performance. These elements are: (a) Trend Analysis, and (b) Maintenance Treatment Effectiveness. A detailed description of these elements follows.

(a) Trend Analysis. The importance of performing a comparison of the actual performance versus past performance in previous years (trend analysis) is to identify areas of concern such as the identification of assets in continuous deterioration and the re-adjustment of performance targets.

(b) Maintenance Treatment Effectiveness. The focus of this element is to perform an evaluation and comparison of the long-term effectiveness of maintenance treatments normally used by the contractor on portions of road that correspond with those used by the implementing agency. By conducting these evaluations, road administrators will truly assess if the contractor is applying maintenance treatments that will extend the life of the assets, which is one of the main goals of transportation agencies.

4.5. STAGE 4: REPORTING FOR LOS EVALUATION

One of the major challenges when conducting any evaluation is to find a simple, effective and meaningful way to communicate the findings obtained from the analysis. This section provides suggestions on: (a) the kind of information that needs to be reported to all the parties involved in the process (e.g., contract administrators, contractors, DOT executives, and taxpayers), and (b) how the findings can be efficiently and effectively reported.

4.5.1. Performance Reports

The main goal of this component is to report the condition at which the assets have been maintained and the compliance to the performance standards specified by the agency. The findings from this analysis must be summarized in a series of reports. The following are some suggestions on the type of report that must be submitted to the contractor and the parties involved.

i) *Report of Overall Effectiveness of Contractor's Maintenance Program*. This report will basically summarize the performance of the private contractor in maintaining its portion of public roads. The report not only should detail the contractor's performance but also should compare it with the agency's performance. Results from trend analysis and evaluation of the effectiveness of maintenance treatments should be included in this report as well. This report is like a document that will become available to the public.

ii) *Report of Deficiencies to Contractor*. A more detailed report with the deficient asset items per sampling unit should be provided to the contractor. This report will provide the contractor with a comprehensive list of which asset items failed to meet the performance targets, their location, and the applicable penalties, if any, for non-compliance or immediate improvement of the deficient and unacceptable condition of the assets. This information should be used by the contractor to re-adjust the maintenance work schedule to improve the condition of the deficient items as soon as possible. This report is an internal document since it provides details that may be irrelevant to the public.

4.5.2. Effective Reporting Techniques

When reporting technical information to a diverse audience (e.g., agency technical personnel, the public), it is crucial to describe and illustrate the findings from complex procedures in a way that will be meaningful to the audience. One excellent approach to do that is to use illustrations via photographs, sketches, charts, and any combination of these. This gives the report life. In the current scenario, there are an infinite number of techniques that can be used to present analytical findings graphically. Following are some techniques adopted in the framework to serve this purpose.

i) Report Card. The motivation behind this technique was the report card prepared by the American Society of Civil Engineers (ASCE) for the Nation's Infrastructure (ASCE 2001). The report card is basically the representation of quantitative results with a grading scale. The grading scale is based on the performance requirements specified in the contract. The main purpose of developing a report card is to help communicate and compare the actual condition of the assets maintained with performance-based standards with those maintained with the traditional specifications. For example, the contractor can receive a grade of A if the actual rating for a given asset group is greater than the performance target specified in the contract. However, if the actual rating is between 95% and 100% of the performance target specified in the contract, then the contractor receives a grade of B for that asset group and if the actual rating is between 90% and 95% of the performance target then the contractor receives a grade of C. Otherwise, the contractor receives an F. If this grading scale is applied to the previous example in Table 3.7, then a grade of C must be assigned at the strata level since the actual overall rating obtained ranged between 90% to 95% of the calculated performance requirement (0.9x95.2=85.7<90.1<0.95x 95.2= 90.4). An example of a report card is presented in Figure 4.2. In addition, Flowchart B.4 (Appendix B) presents a graphical representation of the steps required to generate a Report Card. Notice in Figure 4.2 that the confidence at which the results can be generalized to the whole population has also been included in the report card. This technique can be used to report the condition of the assets for several years (trend analysis) as depicted in the example presented in Figure 4.3. It is easy is to identify the areas of concerns in these figures by studying the trends in the grades assigned.

REPORT CARD *for Maintenance Performance*										
Sections	Roadside		Pavement		Drainage		Traffic		All Groups	
	Grade	CL	Grade	CL	Grade	CL	Grade	CL	Grade	CL
Section A	*F*	*95%*	*A*	*95%*	*A*	*95%*	*A*	*95%*	*B*	*95%*
Section B	*A*	*95%*	*A*	*95%*	*C*	*90%*	*A*	*95%*	*A*	*94%*
Section C	*F*	*94%*	*A*	*93%*	*A*	*95%*	*A*	*87%*	*B*	*91%*
Section D	*B*	*93%*	*A*	*94%*	*C*	*88%*	*A*	*94%*	*A*	*92%*
Section E	*A*	*95%*	*A*	*95%*	*A*	*95%*	*A*	*95%*	*A*	*95%*
All Sections	*C*	*94%*	*A*	*94%*	*B*	*90%*	*A*	*94%*	*B*	*93%*

Figure 4.2. Example of a Report Card Considering the Findings from One Year

TREND ANALYSIS *for Maintenance Performance*															
Sections	Roadside			Pavement			Drainage			Traffic			All Groups		
	2002	2003	2004	2002	2003	2004	2002	2003	2004	2002	2003	2004	2002	2003	2004
Section A	A	F	F	A	A	C	A	A	C	F	A	A	C	B	C
Section B	A	A	A	A	A	A	A	C	A	A	A	A	A	A	A
Section C	A	F	B	A	A	A	A	A	C	F	A	A	B	B	A
Section D	B	B	B	A	A	A	A	C	C	B	A	B	A	A	B
Section E	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
All Sections	A	C	B	A	A	A	A	B	B	B	A	B	A	B	B

Figure 4.3. Example of a Report Card Considering Multiple Years

ii) Geographic Information System. The use of Geographic Information Systems (GIS) is an excellent tool to support reporting the findings from the condition assessment, because it allows organizing and presenting the information for each sample unit in a very graphic way. GIS stores information about the condition of the assets located in the roadway system as a collection of thematic layers and displays this information as maps. Geography is the glue that binds these layers together and GIS is the tool that allows one to see relationships between them. To properly implement GIS technology, GPS coordinates such as latitude and longitude must be collected to locate the corresponding sample units and even asset items within each sample unit. In this study, one major asset that GIS has is that it can display information stored in spreadsheets or databases as a map. This feature is extremely helpful for presenting the condition assessment in a more graphic, meaningful way. One additional benefit is that GIS allows selective combination of data, which greatly helps to identify relationships, patterns, and trends that are otherwise difficult to see. The bottom line is that GIS provides new and exciting tools to help visualize the end result, in this case the overall condition of the assets present in the roadway network under consideration. Figure 4.4 presents an example of how GIS can be used to perform a trend analysis for a specific asset item for a particular period of time (e.g., three years). Figure 4.4 aids understanding of the condition performance of this specific asset item during the three-year period. In addition, different colors identify failing and passing units. Even more importantly that each sample unit (represented by the dots in the figure) can be selected, which provides detailed information of the condition history of the assets present within each unit. The benefits that can be obtained as a result of using GIS to analyze results are unlimited.

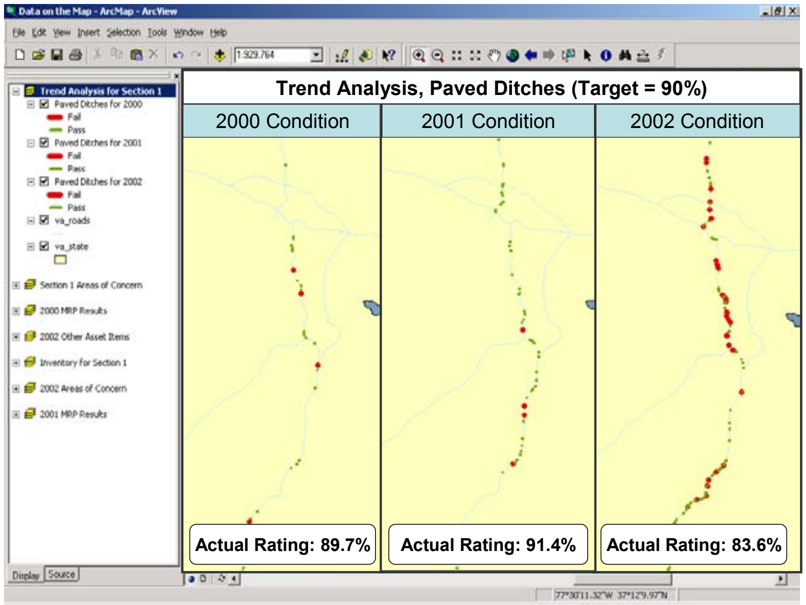

Figure 4.4. Example of the Use of GIS to Perform a Trend Analysis

iv) <u>*Other Reporting Techniques*</u>. As previously mentioned, a very effective way to report findings from the analysis is by combining photographs, charts, sketches, and text. To illustrate the impact of using a more graphical way to illustrate results, consider the example presented in Table 4.7 and Figure 4.5. The information reported in both of them is exactly the same. Which is easier to understand? Notice from Figure 4.5 that a combination of a pie chart, column charts, and text comments were used to more efficiently represent the information provided in Table 4.7. The combination of techniques that can be used is unlimited; but the challenge is to present the information clearly to the reader.

Table 4.7. Example of Tabular Format to Represent Typical Performance Information

Asset Item	Code	Description	% of Failing Comments	% of Non-Failing Comments
Grass	201	5% of vegetation > 12 ins	69.6 %	
	202	Sight Dist.-120 FT clear vision	0.4 %	
Road & Kill	205	Dead animal	0.7 %	
Brush & Tree	212	Non-regul. sign		12.5 %
Concrete Barr.	214	Misalignment>1 in at joints	0.4 %	
	215	Settement>1 in at joints	0.0 %	
Slopes	221	Excessive erosion>6 in deep	5.2 %	
Fence	222	> 10% need repair >50 LF L/S	4.8 %	
	223	Opening allow access	18.5 %	
	224	>10% vegetation over fence		87.5%
Total			100.0 %	100.0 %

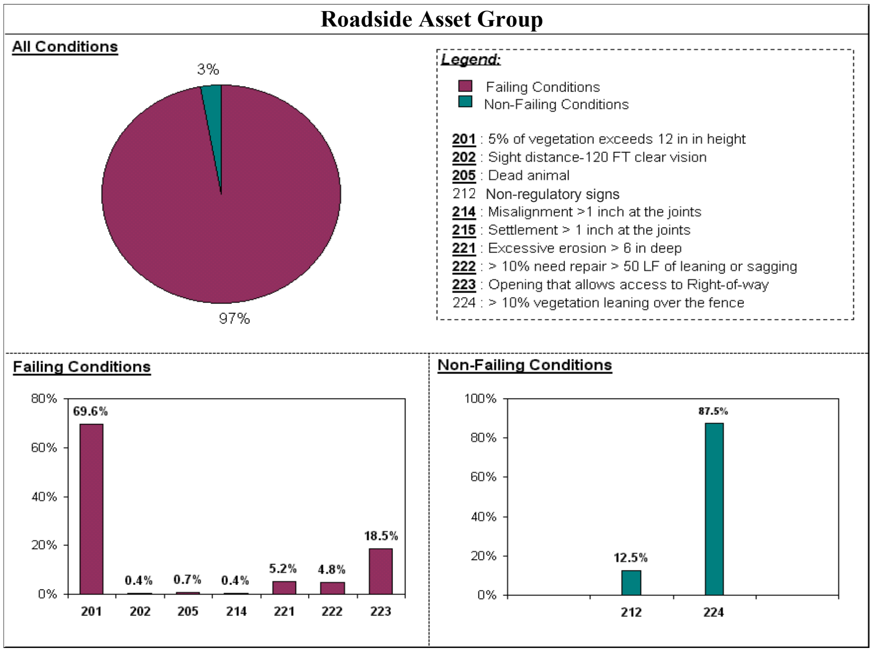

Figure 4.5. Example of Graphic Format to Represent Typical Performance Information

4.6. SUMMARY

The main goal when conducting an evaluation of the condition at which the assets are maintained (according to performance-based specifications) is to report with high confidence whether the minimum acceptable quality levels specified by the implementing agency were met. The implementation of the proposed methodology presented in this chapter will allow road administrators to achieve this goal. All the issues and techniques that can be used in the monitoring process, from the planning stage through the reporting of results from the analysis, were discussed in detail. An application of the techniques and procedures proposed in this chapter to monitor the level of service effectiveness is presented in Chapter nine.

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CHAPTER 5

COST-EFFICIENCY EVALUATION

This chapter presents a detailed description of the techniques and procedures adopted in the framework to comprehensively assess the Cost Efficiency (CE) of Performance-Based Road Maintenance (PBRM) initiatives. The cost-efficiency evaluation of the framework is probably the most difficult component to understand and calculate. For this reason, a comprehensive review of basic cost concepts have been included in Appendix C to support the concepts and methodologies presented in this chapter. The Cost-Efficiency component has two main objectives, as depicted in Figure 5.1.

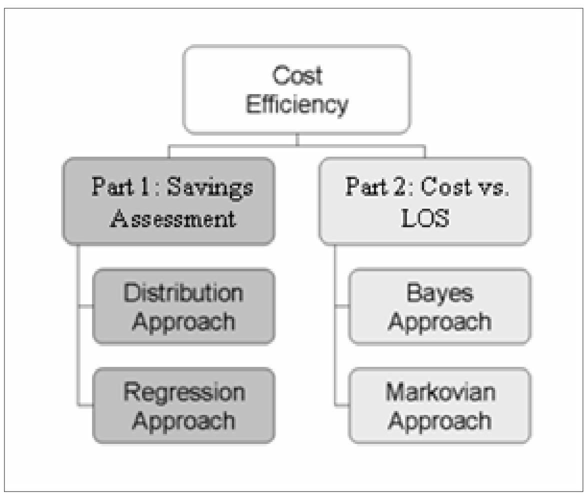


Figure 5.1. Objectives of the Cost-Efficiency Evaluation in PBRM

The first objective of this component (Part 1) is to assess the cost benefits, if any, accrued by the government as a result of adopting outcome-based road maintenance specifications. The second objective (Part 2) is to determine if the agency can achieve similar benefits in traditional maintenance at least at the same rate of expenditure as under performance-based specifications. A combination of cost-estimating techniques and probability analysis were incorporated into the structure of this component to meet these objectives.

5.1. COMPONENT STRUCTURE

Before describing the proposed methodology to evaluate the cost efficiency of PBRM, it is important to first review the two main goals of this component. The first goal is to quantify or estimate as accurately as possible the cost benefits accrued as a result of implementing performance-based specifications in road maintenance. This goal corresponds to Part 1 of the study, as shown in Figure 5.1. The methodology adopted in the framework to meet this goal is to carefully compare the total maintenance expenditures incurred by the agency if outcome-based specifications for road maintenance are implemented as opposed to traditional maintenance specifications. There are a number of issues that were considered when defining the procedures to make such comparisons, including: the accuracy of the data used in the comparison (e.g., unit prices), the applicability of cost components, and the adjustment of data for consistency (e.g., inflation/deflation, geographical location), among others. Figure 5.2 presents a graphic representation of the general methodology developed as part of this research to evaluate the first part of the cost-efficiency study.

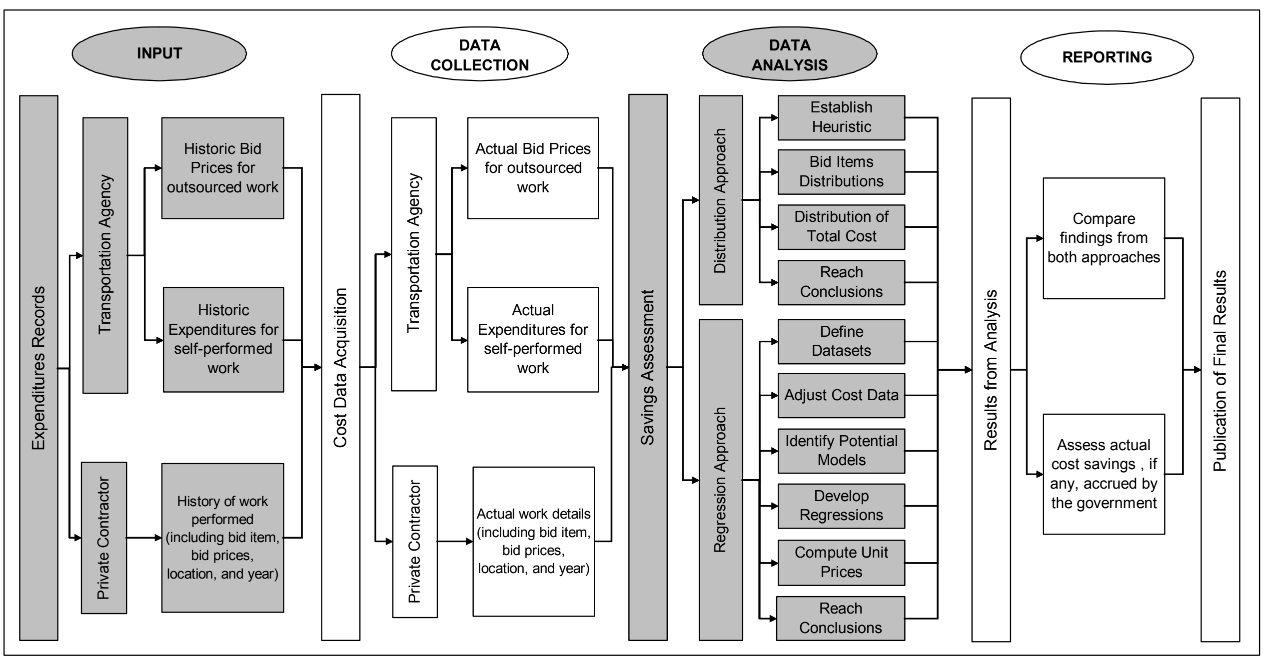


Figure 5.2. Methodology to Evaluate Part 1 of the Cost-Efficiency Evaluation in PBRM

The second goal of the study, which corresponds to Part 2 in Figure 5.1, is to assess the impact in Level of Service (LOS) if the same rate of expenditure under performance-based specifications is used when traditional maintenance specifications are applied. Figure 5.3 presents a graphic representation of the general methodology developed as part of this research to meet the goal of the second part of the cost-efficiency study.

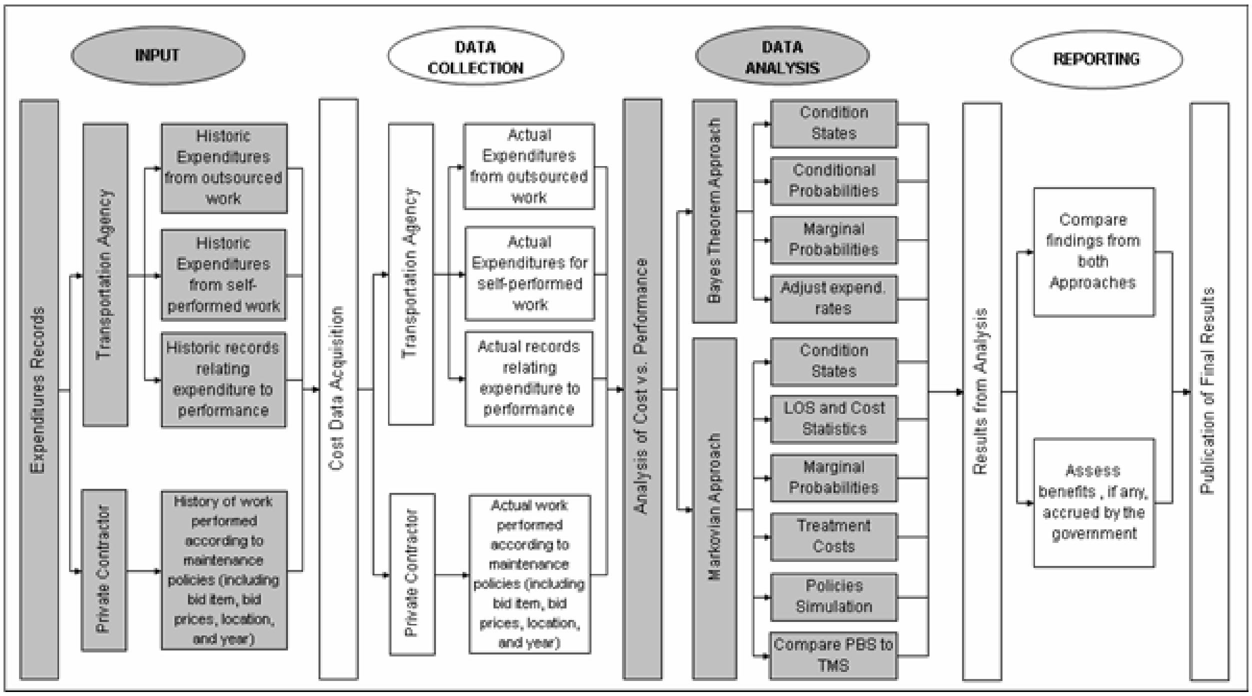


Figure 5.3. Methodology to Evaluate Part 2 of the Cost-Efficiency Evaluation in PBRM

A detailed description of the elements included in each section of the Cost-Efficiency component follows.

5.2. STAGE 1 AND 2: INPUT AND DATA COLLECTION FOR CE EVALUATION

One of the most essential elements required to guarantee the reliability of the estimate of cost benefits, if any, is the quality and management of the data used to perform the analysis (Clark & Lorenzoni 1997). The type of data needed is that which provides the cost information required to make possible the proposed comparison. Transportation agencies normally keep track of all the expenses incurred in the maintenance of the roadway system; however, the format and mechanisms used to record and classify all the expenditures (e.g., direct and indirect costs) by the different types of maintenance treatments applied varies significantly from one agency to the other (Kleywegt & Sinha 1994, CSI 2001). Some agencies may have very well-structured and detailed systems for collecting and classifying expenses. These can provide the necessary information to conduct a good and reliable assessment of the cost benefits, whereas other agencies may not have a system that can provide such information to support the analysis. For this reason, this section will first review several basic concepts related to capturing historical cost data and the development of unit prices for typical road maintenance activities. Such prices are the most important data inputs for evaluating the cost efficiency of PBRM. This review will serve two purposes: (1) provide a clear understanding of the cost components considered in historical unit costs and unit prices, and (2) make sure that evaluators understand all the issues that must be taken into consideration before conducting any cost evaluation. A detailed discussion of these concepts is presented in the next section.

5.2.1. Cost Data

Any cost evaluation requires the data to be credible and representative of the corresponding maintenance activities before they can be used effectively. To meet these criteria, it is necessary to efficiently coordinate and manage the collection and maintenance of such data. Two main elements, Cost Components and Capturing of Cost Data, related to the type of data required to conduct the proposed cost evaluations are addressed below.

i) *Cost Components.* Before conducting any cost evaluation one must clearly understand all the factors that affect the unit prices associated with maintenance activities (Halpin 1985, Patrascu 1988, Perifoy & Oberlender 1989). To assure that the evaluators understand the characteristics (e.g., consistency, accuracy, and proper format) of the data required to conduct the methodologies proposed in this chapter, a review of the basic concepts associated with the generation of unit prices is presented in Appendix C. This review addresses the scenario when agencies maintain the roadway system as well as the scenario in which the job is contracted out.

ii) *Capturing Cost Data.* There are many formats that can be used to capture cost data; however only a few techniques are considered very efficient (Simpson & William 1996). This section provides a description of several techniques that ensure the data collected and maintained by the agency will support not only the agency's managerial needs but also the methodology adopted in the proposed framework. A detailed discussion of these techniques follows.

a) Data Collection Techniques. There are many techniques that can be used to avoid inconsistencies in the collection of cost information. One format or technique that is considered very effective and efficient for the collection of cost data is the use of the Work Breakdown Structure (WBS). The major advantage of using WBS is that it provides a uniform approach for classifying and collecting cost data, which is essential to guarantee the consistency of the data collected (Miller et al. 1999). The WBS approach consists of subdividing the job into work packages or cost accounts that will be used to collect actual cost information while the job is in progress. These cost accounts can be set in such a way that the information collected will be representative of the items typically defined when performing road maintenance activities. There are other cost data collection methods that are also considered appropriate to meet the needs of the proposed methodology. These are Activity Based Costing (ABC) and Service Based Costing (SBC). These approaches are very similar. The most significant difference between these two approaches is the hierarchy level used for the collection of cost information. ABC works at a more detailed level than SBC, but the concept is the same (Simpson & William 1996).

Regardless of the approach used, the collecting point for cost data in transportation agencies is the Accounting Management System (AMS) and Maintenance Management System (MMS). These systems contain a general ledger and other accounting data. For these systems to provide more detailed and useful information to conduct studies such as the one proposed in this chapter, a system of subsidiary ledger accounts should be established that are subordinate to the general ledger accounts. Each one of these subsidiary accounts can be established to gain better detail regarding expense or work activities within each job (activity-based costing concept). The number of subsidiary accounts can be seen as a hierarchy of multiple levels that breaks the total costs of projects down to the specific cost components associated with a given job line item. To better illustrate this concept, Figure 5.4 presents a general accounting ledger at the top level, which represents the overall accumulation of all projects expenses. A second level is then used to divide the cost for each job. Figure 5.4 defines four additional levels to break down costs associated with a given job into each cost component and, in some cases, into different parties involved in the job, such as the subcontractors which have been considered in separate accounts as shown in Level Six. Cost are recorded in a format similar to the one presented in Figure 5.4, which allows the cost evaluators to more accurately combine all the costs associated to a given activity or item and from there perform a more realistic cost evaluation.

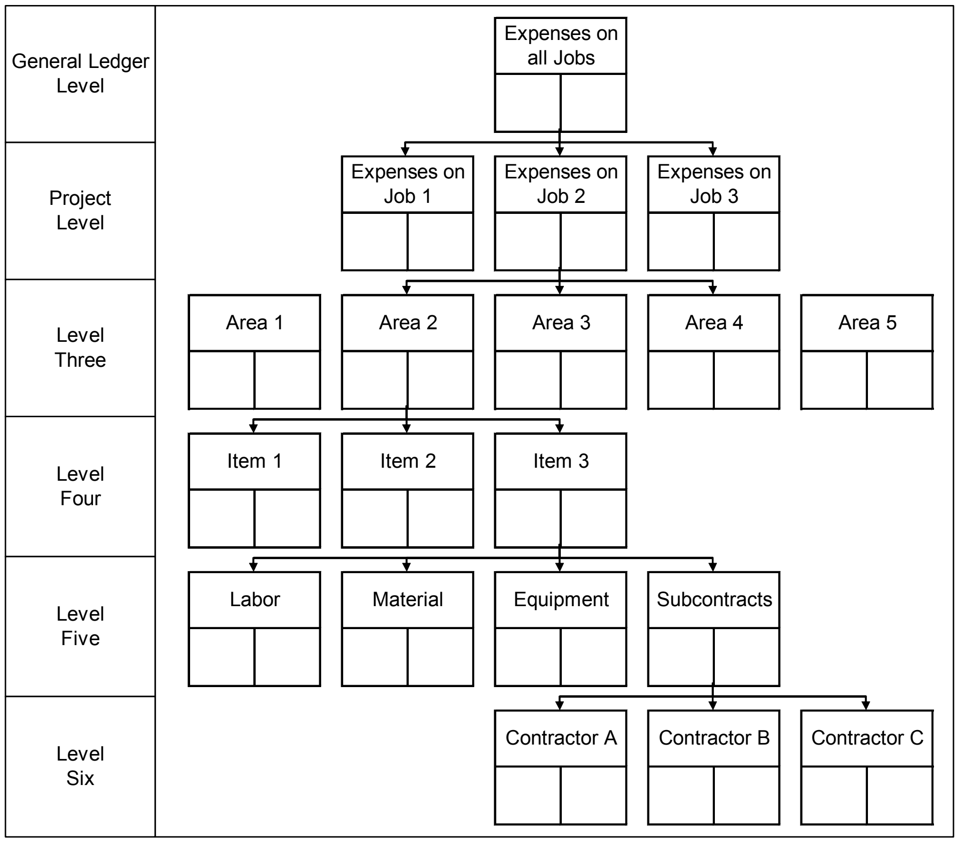


Figure 5.4. Example of the Concept of Subsidiary Ledger Accounts

b) <u>*Data Sources.*</u> There are many sources from which cost data can be obtained; however one must be clear in the limitations, quality, and usefulness of the information provided within each data source before considering the usage of such information in the analysis. Some of the most common sources that have been used in cost evaluations are: accounting records, cost reports, contracts, cost proposals, and other information systems. Cost data can be obtained from internal and/or external sources. For instance, in the United States, a private organization publishes a database every month that contains historical bid tabulation data from transportation projects for over 30 different states. This database provides bid information for the three lowest bidders that submitted bids to each state Department of Transportation project from 1993 to the present. This database provides very valuable information that can also be used as a supplement in case proper in-house cost records are not available or are limited in size. With this information in hand, specific queries can be performed for a given bid item by specifying a particular location, a period of time, and even a quantity range. The data obtained from these queries can be adjusted to meet the criteria for a particular scenario. It is evident that the selection of data sources will totally depend on the type of study to be performed as well as the quality, format, and completeness of the data available within each of the data sources.

5.2.2. Data Required to Implement Proposed Methodology

Now that the structure and the properties of typical cost data have been reviewed, specific cost information must be defined to implement the suggested approaches that will assess the cost benefits, if any, from PBRM. As shown in the data collection sections in Figures 5.2 and 5.3, to properly implement the proposed methodology for the cost evaluation, the following cost information must be obtained from the agency and private contractor records:

(1) Agency Historic and Actual Bid Prices from Outsourced Work - Transportation agencies must identify bid price tabulations for each maintenance activity that is specified in the performance-based contractual agreements. Different sources such as agencies' historic bid tabulations as well as private institutions that record bid tabs from DOT jobs can be used to get this information. The goal is to use this data as the input to estimate cost if the work done through the performance-based contractual agreement was outsourced to companies that normally bid for jobs administered by the transportation agency.

(2) Agency Historic and Actual Expenditures from Self-Performed Work – Similar to the identification of bid price tabulations, records of the agency maintenance expenditures for self-performed or self-administered work are required. Sources such as the Accounting Management System (AMS) and Maintenance Management System (MMS) are normally available in transportation agencies to obtain this information. These systems keep track of detailed data related to the costs or expenditures associated with self-performed and self-managed work. However, one must be careful when using the information from these systems because sometimes this information has not been captured in the proper format to support the proposed analytical procedure in this framework. As discussed in the previous section, to perform a

reliable and valid comparison, it is crucial for the unit prices and unit costs used in the study to be consistent and composed of the appropriate cost components.

(3) Contractor's Maintenance Work Done in the PBRMC - A database with all the bid tabs of all the work performed through performance-based contracts is required to implement the cost analysis approaches adopted in the framework. This database must provide at least information related to the bid date, contract location, bid item or activity description, bid quantities, bid prices, and total cost. This information is essential for the implementation of the proposed approaches to evaluate the cost benefits.

(4) Agency and Contractor's Records Relating Expenditures to Performance – Records containing the relationship between historic and actual expenditures with the performance levels are required to support the methodologies adopted as part of the second part of the Cost-Efficiency Study. For instance, a record for a specific asset item must contain information about the type of work performed, the amount of money spent, and the condition level accrued according to yearly inspections.

A better understanding of how this information will be used to support the cost evaluation will be acquired in the next section when a detailed discussion of the proposed methodology is presented.

5.3. STAGE 3: DATA ANALYSIS FOR COST-EFFICIENCY EVALUATION

This section describes the proposed methodology developed as part of this research to evaluate the cost efficiency of PBRM. In addition, before describing in detail the proposed procedure, the section first addresses several issues and introduces some concepts that were considered necessary to improve understanding of the cost analysis process.

5.3.1. Cost Analysis Concepts

It was necessary to first review several concepts and issues that must be addressed in the analysis stage of any cost evaluation to properly define an approach to evaluate the cost benefits, if any, accrued by the government as a result of implementing performance-based specification in the maintenance of the roadway system. The review focused on the following three areas: (1)

methodologies to estimate expected costs, (2) data considerations, and (3) potential analytical tools.

5.3.1.1. Methodologies to Estimate Expected Costs

It is understandable that the adopted methodology for any cost evaluation will totally depend on the particular characteristic of the scenario under consideration, the properties of the cost data available, and the evaluation needs. When defining such methodologies it is common to use one of four approaches for estimating expected cost or even a combination of some of them as the baseline to define the approach that will best fulfill the evaluation needs. These four approaches are: (1) expert opinion, (2) analogous, (3) engineering, and (4) parametric (Clark & Lorenzi 1997, DOD 1999, Ostwald 2001). A general review of each approach is presented next to provide an idea of their potential use in this study.

a) Expert Opinion Approach. The expert opinion approach basically uses the subjective judgment of an experienced individual or group of individuals to come up with an estimate of the expected costs. In general, the estimates generated with this approach usually lack a detailed rationale and analysis. While estimates developed with this approach are commonly used in the conceptual stage of the development process, they are normally highly uncertain and have a low confidence rating.

b) Analogous Approach. The analogous approach is very similar to the expert judgment approach described above, but it relies on the degree of similarity of work activities to some existing or past work activities. The major disadvantage of this approach is that it is a judgment process and requires much experience and expertise. The effectiveness of this approach relies on the ability to correctly identify differences between the cases in hand and those deemed to be comparable.

c) Engineering Approach. The engineering approach is considered a bottom-up approach that involves identifying the separate tasks that define the job, estimate the cost of each task, and then combine all the costs for the total cost of the job. The methodology is very similar to the approach presented in Figure C.1 (Appendix C) where all the cost components are estimated and then a total cost is obtained. An engineering approach requires many resources to obtain the final assessment of the job's expected cost. This method is very time consuming, but it provides a very accurate estimate of the expected cost.

d) Parametric Approach. The parametric estimating approach promotes the use of statistical relationships between historical costs and other variables such as physical and performance characteristics. It involves not only the collection of historical costs and technical information, but also an analysis using mathematical and statistical techniques. This approach focuses heavily on historical data to minimize the time and effort required to produce reliable estimates.

Based on the description presented above, the two approaches that better suit the study's needs are the engineering and parametric approaches. The ideal scenario would be a combination of these approaches. For instance, if historical data is not available to support the implementation of the parametric approach, then the engineering approach can be used to estimate the work activities under consideration. However, evaluators must keep in mind that the engineering approach will require a significant amount of additional resources (more costly and time consuming) in comparison to the parametric approach. If the resources (e.g., budget, time, and personnel) are limited, then the use of the parametric approach seems to be the most appropriate approach (if historical data is available) for developing the methodology that will best suits the study.

5.3.1.2. Data Considerations

The first step before conducting any cost evaluation is to perform a review and analysis of the data to be used (DOD 1999, DOA 2001). In many cases it will be necessary to perform several adjustments and manipulations of the data in order to guarantee the reliability of the final results. Some of the factors that should be considered as part of this review are the following:

i) Data Availability. The evaluator must be sure that the type of data needed to conduct the evaluation is available. If the data required for a specific approach are unavailable, then that methodology cannot be used effectively.

ii) Sufficiency. Having data available is not enough. One must be sure that sufficient data are available to adequately implement the techniques adopted in the cost evaluation. It is understandable that reliable conclusions cannot be reached from a small amount of data points. The quantity of the data required will totally depend on the type of analysis required.

iii) Consistency. The evaluator must be sure that the data used for the analysis were collected in a consistent format and on a routine basis. In addition, the evaluator needs to be sure that the data considered for the analysis were accumulated consistent with the format and detail required for the evaluation procedures to be used.

iv) Anomalies. One of the most difficult issues to identify and examine is the presence of anomalies in the data collected. Anomalies refer to the addition of unusual costs during a certain period of time that affected the recorded cost, making it unrepresentative of the common scenario. Analysts have two options if the data are biased as a result of any anomalies. These are: (1) avoid using the data for the analysis (strongly recommended), or (2) perform the necessary adjustments and use judgment in preparing the data for the analysis, but if this is done then the analyst must fully document the process.

v) Adjustments. Once the data to be used in the analysis are identified, that data may require some adjustments in order to make them homogeneous or consistent. This process is also known as the normalization process, in which data are adjusted for items such as inflation or deflation, geographic location, and other factors such as production rate. This process is crucial to guarantee that the data are free of any effects that may bias the results. A general description of some of the items considered in the adjustment process follows.

1) Inflation/Deflation. If data for multiple years are considered in the evaluation, then the effect of inflation or deflation must be considered in the adjustment process. Inflation and deflation refer to the rise and drop in the general level of prices, without changing the amount or quantity of units. The key when performing this kind of adjustment is to be consistent (DOD 1999). In other words, if a particular factor is used to escalate prices forward to a specific date, then the same factor should be used to escalate the prices backward from the reference date. There are many sources that can be used to define the factor to be used for the adjustment. For example, many government agencies publish indices (for different type of sectors in the industry) that can be used as a reference. Evaluators must be aware that this process will always require the use of good judgment. Table 5.1 illustrates this process. The table presents five unit prices collected for the same item from 1999 through 2003 (*column 2*). According to published government indices, the inflation rate from 1999 through 2003 remained constant at a rate of 3%. If the interest is to consider these unit prices for a study in which 2003 should be considered as the base year, then Eq.5.1 is used to compute the inflation factor in 2003.

$$IF_f = \left(1 + r/c\right)^n \tag{5.1}$$

where IF_f represents the inflation factor to adjust quantities to the future, r is the annual rate of inflation, c is the number of times (compounds) the inflation rate vary in one year, and n refers to the number of times the rate changes over the entire time period considered in the analysis. If the ratio of r/c remains constant during a year period, then the ratio will be equivalent to the annual inflation rate, normally represented by the symbol i. By applying this equation to the scenario just mentioned, the factors in column 3 of Table 5.1 are obtained. The final adjusted unit prices are computed by multiplying the factors from column 3 with the recorded unit prices listed in column 2. These adjusted unit prices must be used in the analysis with emphasis on 2003 conditions. Another scenario would be if 1999 is considered as the base year for the evaluation. If this is the case, then the unit prices need to be adjusted backwards. To be able to perform such a calculation, the reciprocal of Eq.5.2 must be used to compute the factors to be multiplied by the original unit prices. The equation will look as follows:

$$IF_p = \frac{1}{(1 + r/c)^n} \tag{5.2}$$

where IF_p represents the inflation factor to adjust quantities to the past. By applying Eq.5.2 the factor listed in column 5 is obtained, which is used to compute the adjusted unit prices (column 6) for 1999 conditions.

Table 5.1. Example of the Adjustment for Inflation

Year	Recorded Unit Price	Adjusted to 2003		Adjusted to 1999	
		Inflation Factor	Adjusted Unit Price	Inflation Factor	Adjusted Unit Price
(1)	(2)	(3)	(4)	(5)	(6)
1999	2.75	1.126	$ 3.10	1.000	$ 2.75
2000	2.85	1.093	$ 3.11	0.971	$ 2.77
2001	2.88	1.061	$ 3.06	0.943	$ 2.71
2002	2.91	1.030	$ 3.00	0.915	$ 2.66
2003	3.12	1.000	$ 3.12	0.888	$ 2.77

2) Geographic Location. In addition to the variation in costs because of the changing value of money over time, the costs may vary depending on the geographic location. There may be cases in which data from multiple locations is used in the analysis. When this happens, the evaluator must adjust the data to a desired common location to maintain the consistency and homogeneity desired. The key when conducting this analysis is to use reliable sources of information to define the adjustments factors. There are many reliable sources that can be used, such as in-house records, government and private publications that provide adjustment factors by different location such as the R.S. Means Collection of Cost Indexes, Engineering News Record Construction Cost Indexes, and the Federal Highway Maintenance and Cost Indexes. However, the evaluator must perform a comprehensive study of how the indexes were developed and defined regarding each potential source before selecting a particular index. This assures the evaluator that the one selected is compatible with the needs of the study.

3) Others. Many other factors can be considered in the adjustment of cost data, such as quantity differences, rate of production, and learning curve effects. Evaluators must remember that no matter which criteria are used in the adjustment process the main goal is to improve and guarantee consistency of the data used in the analysis.

vi) *Definition of Categories*. This issue emphasizes once again the consistency of the data. Many problems occur when the data used in the analysis fails to account for the same cost elements as those considered in the work activities under evaluation. It is crucial for the evaluator to be sure, that when using different sources of data for comparison, the data within each must be subjected to the same conditions and same categories included. This issue requires a lot of good judgment and documentation from the analyst.

vii) *Uncertainty.* Given that there are many uncertainties associated with the estimating process, all cost data are uncertain. Considering the uncertainty of cost data in the analysis can help provide more realistic results, but it requires the implementation of more technical procedures and knowledge of probability theory. Approaches such as the Monte Carlo Simulation and the use of distributions (instead of using a single values) to represent the behavior of cost data are excellent techniques to incorporate uncertainties into the analysis.

5.3.1.3. Analytical Tools

There are three primary analytical tools commonly used when performing costs and performance evaluations. These tools are: (1) variance analysis, (2) probability analysis, and (3) sensitivity analysis (Ang &Tang 1975). Readers should be aware that other tools are available, but the focus of this section is on these three. Each tool provides different information to the evaluator. A description of each analytical tool is presented next to provide the reader with a better understanding of their objectives.

a) *Variance Analysis*. The main reason for performing a variance analysis is to compare actual performance with established standards or requirements. This tool is normally used to identify unexpected costs and performance; however, it does not provide insight on why the process did not work properly. For instance, if a performance level is outside an acceptable range, then an evaluation of several ratios can help explain the deviation. Some of the ratios commonly used to serve this purpose are:

i) *Ratio of Actual to Expected Outcome.* This ratio helps an evaluator indicate the relative success of the service in accomplishing its requirement.

ii) *Ratio of Actual Costs to Outcomes.* This ratio indicates the relative cost effectiveness of the program.

iii) *Ratio of Actual Obligations to Funding Levels.* This ratio evaluates the efficiency of budget execution.

iv) ***Ratio to Measure Relative Efficiency.*** The relative efficiency of the process can be measured by evaluating the ratio between the actual cost per unit to the standard cost per unit.

v) ***Ratios to Measure Relative Effectiveness.*** Other ratios are commonly used to measure the relative effectiveness of the process such as: actual to standard quality, actual to standard quantity, and actual to expected customer satisfaction.

It is important to understand that variance analysis does not quantify the cause and effect relationship between costs and performance. One must also know that this type of analysis cannot be used when discrete variables are used to measure the outcome.

b) ***Probability Analysis***. The idea behind probability analysis is to minimize the difference between estimated costs and actual costs by considering the probability of occurrence of events. This analytical tool is supported by concepts in probability theory, statistics, and decision theory. There are two general approaches to probability analysis. These are:

i) ***Inductive Logic.*** This approach refers to the use of logic that is based on proven experience or accepted axioms to derive statistical inference (e.g., coin toss). The most important characteristic of this approach is that it depends on an assumed probability distribution to predict an outcome.

ii) ***Deductive Logic***. This type of logic is considered as the opposite of inductive logic. With this approach the outcome is the beginning point, and the probability of occurrence is inferred from the outcome. One example of deductive logic is Bayes Theorem.

Using probability analysis to infer outcomes can be complicated because of the required development of probabilities and understanding and application of several probability and statistical concepts. However, the incorporation of this tool as part of the analysis process is worthwhile it because it provides a reliable methodology to assess the likelihood that a given estimate will result in actual costs.

c) <u>Sensitivity Analysis</u>. Sensitivity analysis assesses the extent to which costs and benefits are sensitive to changes. The general objective of a sensitivity analysis is to examine the sensitivity of the dependent variable to changes in the independent variables. For instance, if the change in values for a given variable causes a large change in the output of the analysis, then the analysis is sensitive to changes in that variable. Factors that may warrant sensitivity analysis are: economic effects, geographic effects, production rate effects, organizational change effects, and effects caused by information technology changes. All cost evaluations may include a sensitivity analysis. Figure 5.5 illustrates how this analytical tool works. In this study, four independent variables were considered. The methodology consists of changing each variable one at a time. Therefore, while one of the variables changes, the others remain at a fixed value. The figure shows the values of the dependent variable plotted against the normalized values of the independent variables. From the results presented in Figure 5.5, one can conclude that the dependent variable is very sensitive to changes in the values of variable 2 and variable 1. Variables 3 and 4 did not seem affected by changes in values of the dependent variable. This kind of study helps identify variables that need special consideration.

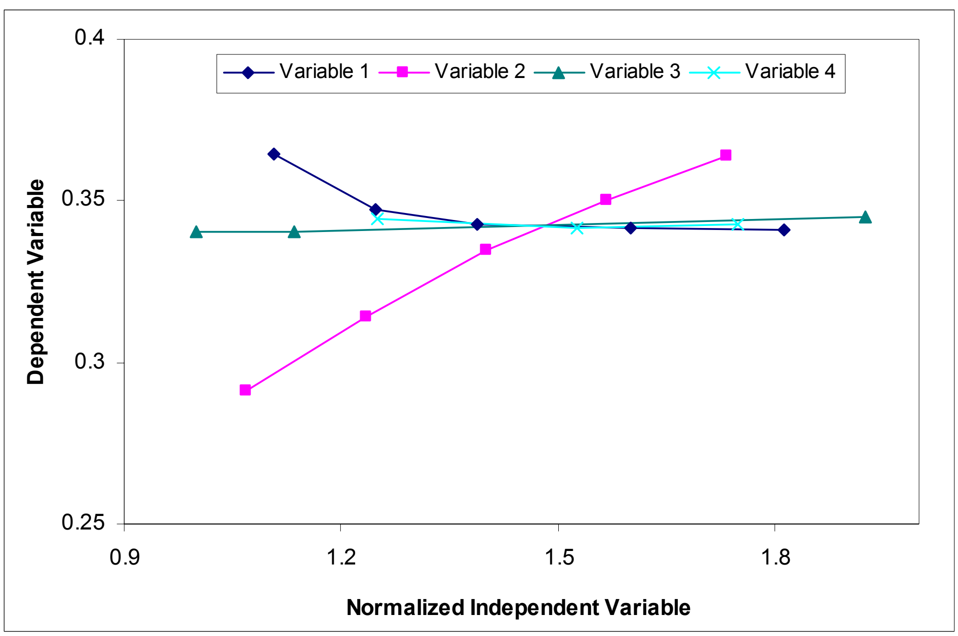


Figure 5.5. Example of a Sensitivity Analysis

5.3.2. Proposed Methodology to Evaluate Cost-Efficiency

All the concepts reviewed and discussed in the previous sections of this chapter define the proposed methodology presented in this section. As previously mentioned, the proposed analysis to evaluate the cost-efficiency is divided into two parts: (1) assessment of agency costs if the work would have been done according to traditional maintenance specifications, and (2) study of the level of service or performance versus expenditure rate. A description of the procedures adopted within each area is presented in sections 5.3.2.1 and 5.3.2.2, respectively.

5.3.2.1. Part 1: Assessment of Costs if the Work Would Have Been Done According to Traditional Maintenance Specifications

The main objective of this study is to compare the cost of the work if performance-based specifications are used to maintain the roadway system with the cost of the work if traditional specifications would have been used. The assumption is that the cost of the specific work performed under performance-based specification is known. This information is basically the schedule of bid prices submitted by the contractor performing performance-based work and approved by the agency in establishing a contractual agreement. Therefore information that is missing or needs to be estimated is the cost of the work if the same work conducted under performance-based specification was instead performed by the contractor according to traditional maintenance specifications. Figure 5.6 presents a graphical representation of the scope of part 1 of the cost study.

Two different approaches are proposed in the framework to perform this assessment: the distribution approach and the regression approach. It is recommended that transportation agencies conduct the analysis by applying both approaches and then reach conclusions by comparing the results obtained from both. A description of each approach follows.

Bid Date	Contract Number	Maintenance Activity	Unit	Bid Quantity	Performance Based		Traditional	
					Bid Price	Total Cost	Bid Price	Total Cost
18-Aug-99	11B00002	Fence (FE-CL)	LF	1000	$25.00	$25,000.00		
		Line Brace Unit (FE-CL)	EA	5	$50.00	$250.00		
		Corner Brace Unit (FE-CL)	EA	5	$75.00	$375.00		
13-Sep-00	11B419	Mobilization	LS	1	$10,000.00	$10,000.00		
		Traffic Control	LS	1	$50,000.00	$50,000.00		
		Stone Rip Rap Class 1	TN	2030	$3.50	$7,105.00		
21-Feb-01	11B489	Substructure Repair	SY	2562	$2.50	$6,405.00		
		Epoxy Sealant, Type EP-3	SY	280	$1.50	$420.00		
					Total =	$99,555.00		

Compare

Bid Prices to be obtained from historic cost records corresponding to work performed under Traditional Maintenance Spec.

Figure 5.6. Scope of Part 1 of the Cost Study

(a) Distribution Approach. This approach estimates the costs if the performance-based work had been done according to traditional maintenance specifications by replacing the contract bid prices with unit-price distributions developed from the agency's historic bid prices for traditional maintenance specifications. The final goal is to obtain a distribution that represents what would have been the total maintenance cost if the work had been performed with the traditional maintenance approach. Using distributions instead of a single value to represent the behavior of unit prices addresses the need to model or capture uncertainty in the process, which will result in a more realistic estimate. The uncertainty represents the variability that is associated with the costs. For instance, the cost of repairing a pipe is never a unique value, like $300. Instead, the cost for repairing the pipe can range between $200 and $400. Trying to use a single value can be unrealistic and lead to wrong conclusions. The concept of employing probabilistic distributions fitted to the available historical cost data is depicted in Figure 5.7.

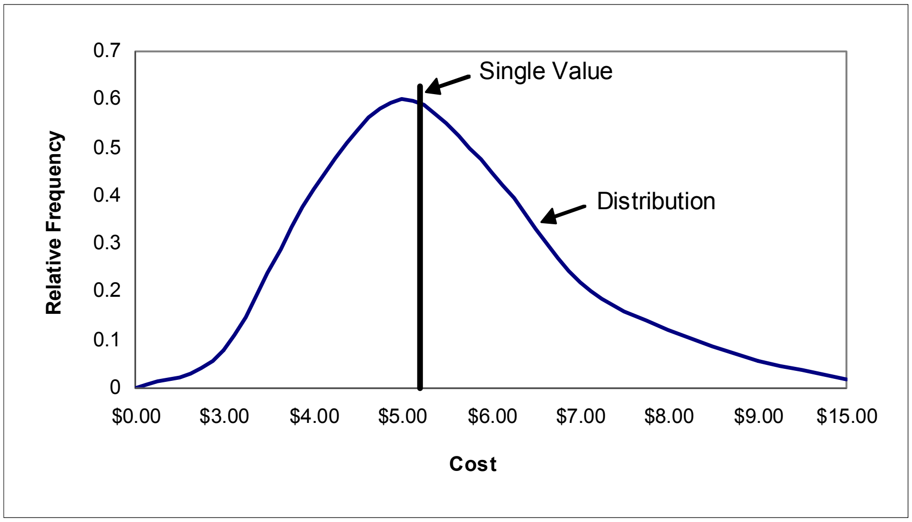


Figure 5.7. Use of a Distribution to Represent the Behavior of Unit Prices instead of a Single Value

The following steps summarize the procedure for using the distribution approach. Refer to Flowchart B.5 (Appendix B) for a graphical representation of these steps.

<u>Step 1. Develop Datasets.</u> The first step is to identify the data to be used in the analysis and classify them per bid item, resulting in an individual set of data for each bid item. Each one of these datasets must contain information relevant to each data point, such as the item ID, location, contract number, date, bidder's position, and bid quantity. For example, Figure 5.6 presents the number of datasets that must be identified from hypothetical contract records (work done under performance-based specifications). A dataset with historical records associated to work under traditional maintenance specifications can be created using a total of eight different items (e.g., Fence, Line Brace Unit, etc.).

<u>Step 2. Establish heuristic to query data.</u> The general philosophy adopted in this approach is that each dataset will be queried to extract a reasonable (statistically speaking) number of data points that will provide enough points to develop a distribution representative of the typical prices (using traditional maintenance specifications) of each bid item within the contracted work under performance-based specifications. Once the number of data points required to develop a distribution that will closely represent the behavior of the unit prices is obtained, several adjustments will be made to the data in order to account for variations in location and period of time (discussed in Step 3). Figure 5.8 illustrates this approach.

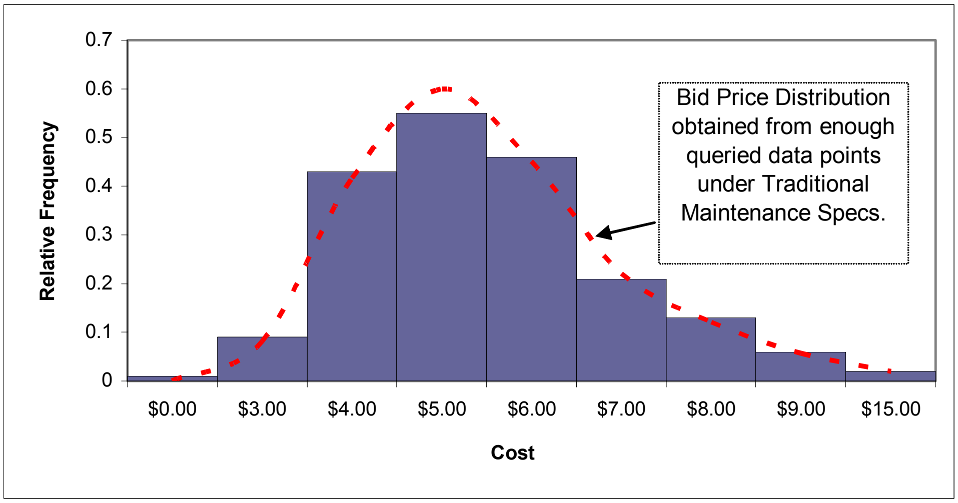


Figure 5.8. Historic Traditional Maintenance Cost Data that Closely Represents the Characteristics of a Contract Item under Performance-based Work

Since the objective is to estimate a distribution of unit prices that represents the unit prices for a given contract item, a valid and systematic process needs to be established in case not enough data are found in the records that match each specific contract item criteria (e.g., specific year, location, and quantity). Valid statistic techniques are recommended, such as the variance among data groups to establish the heuristic to be used. In general, the methodology consists of dividing each variable (e.g., location, year, and quantity) considered in the study into different groups with the same properties (i.e., data from year1996 considered in one group and data from year 1997 considered in an other group). Once the different groups have been identified, the statistical variance between the groups can be calculated (Hamburg 1983). Arranging the variances calculated for each variable in ascending order can be used as the heuristic to search for additional data points to represent a given contract item. The following steps summarize this process.

i) Define groups for each variable. The first step is to classify the data points into different groups for each variable considered in the study. For instance, let's assume the following three variables are used: location, year, and quantity. An example of this procedure is shown in Figure 5.9. The groups that have been defined in this figure are exclusively for a specific bid item (activity) and for the variable Years. Each group includes the bid prices found in the dataset for each specific year. Similar graphs and group definitions should be developed for the other two variables: location and quantity.

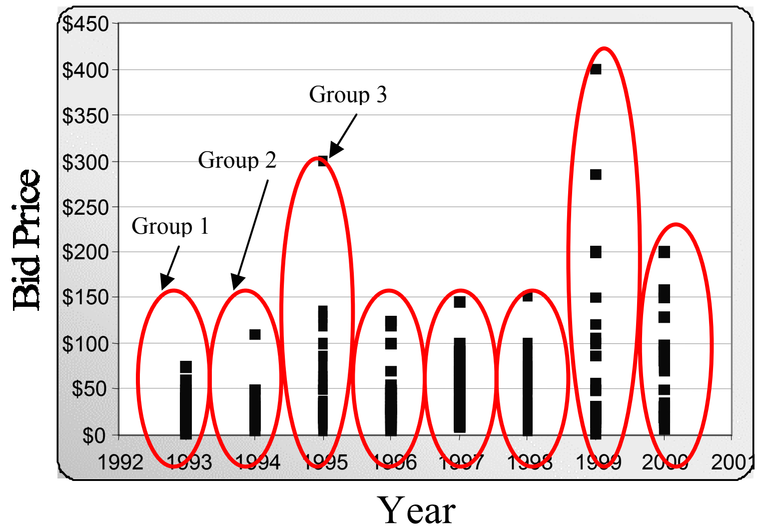


Figure 5.9. Example of Defining Groups to Compute Variances in Distribution Approach

ii) *Calculate the variance between groups.* Once the different groups have been identified, the statistical variance between the groups can be calculated with the following equation (Hamburg 1983):

$$\sigma^2 = \frac{\sum n_j (\overline{X}_j - \overline{\overline{X}})^2}{k-1} \qquad (5.3)$$

where:

σ^2 = variance between groups

n_j = number of data points on each group

$\overline{X}_j$ = average unit price for each group

$\overline{\overline{X}}$ = average unit price for the whole population

k = number of groups

For instance, if Eq.5.3 is applied to the data groups identified by years in Figure 5.9, one gets a variance equal to $45.50. An illustration of how this variance was obtained is presented in Table 5.2.

Table 5.2. Example of How to Compute the Variance between Groups

Group No. k (1)	Year (2)	Number of data points n (3)	Average Yearly Unit Price $\overline{X}$ (4)
1	1993	10	$41.52
2	1994	8	$38.15
3	1995	25	$54.22
4	1996	80	$57.36
5	1997	100	$59.05
6	1998	95	$60.69
7	1999	12	$77.49
8	2000	14	$73.14
All	All Years	344	$\overline{\overline{X}}$ = $58.98
		Variance =	**$45.50**

By comparing the variances calculated for each variable, one can establish a heuristic (specific order) that can be used to search for additional data points for a given contract item if enough points are available to generate a distribution. Table 5.3 presents an example of how this process is implemented. In this example, the Location variable is represented by different districts. The idea is to find enough points from the database that will match the characteristics of the contract item in consideration, which in this example corresponds to a bid item from a contract that was performed in District 1 in year 1998 and for a quantity of 500 units. A database that included all the records available for this asset item was created. The data was then divided in different groups for each of the following three variables: Districts, Years, and Quantity. For instance, for the Year Variable all the data points associated with work performed in 1993 (first year recorded) were combined in one group. The data points from work done in 1994 were combined in a second group, and so on. A total of eight groups (one for each Year) were identified. Once these groups were defined, the variance for the variable Year was calculated as previously shown in Table 5.2. The variance obtained for the variable Year was $45.50. The same procedure was performed to obtain the variance for the other two variables, Districts and Quantity. The results are shown in Table 5.3. The lower variance was obtained for the District variable and the upper variance was obtained for the Quantity variable. This means that the heuristic to be used to search for additional data points is to first obtain additional data from other Districts, then from other Years, and finally by increasing the Quantity range. A discussion of how the heuristic was used in the example presented in Table 5.3 follows.

As shown on the example presented in Table 5.3, the first query was performed considering the specific information provided for this particular bid item (District 1, 1998, and 500 units). It can be seen in column 8 that the number of points obtained with these conditions was zero (0), thus the specified conditions must be expanded to obtain more data points. The search for more data points was performed in a systematic way by using the heuristic obtained from the variance calculated for each variable. In this example, the following heuristic was used according to the variance calculated for each variable (sorted from lower variance to higher variance): (1) first include additional districts, (2) add more data points from additional years, and, finally, (3) increase the quantity range used in the search. The idea is that if not enough data points are found by specifying the original conditions of the contract for a given bid item, then the constraints in the database will be released following the heuristic. In Table 5.3, for instance to get data points (13 in this example) that can be used to develop a distribution (in this case it was assumed that the minimum quantity of data points needed was 10) it was necessary to specify in the query all the districts, all the years, and a quantity range that includes values within 10% of the base quantity (equal to 500 in this example).

Table 5.3. Example of expanding search of data points based on heuristic

INITIAL CONDITIONS OF BID ITEM

DISTRICT:	**1**	**DISTRICTS VARIANCE=**	**$22.34**
YEAR:	**1998**	**YEARS VARIANCE =**	**$45.50**
QUANTITY:	**500**	**QUANTITY VARIANCE =**	**$99.87**

Heuristic:

Districts → Years → Quantity

QUERY (1)	DISTRICT (2)	YEAR (3)	QUANTITY: BASE (4)	QUANTITY: VARIANCE (5)	QUANTITY: LOWER RANGE (6)	QUANTITY: UPPER RANGE (7)	OUTPUT: DATA POINTS (8)	OUTPUT: AVERAGE (9)
1	**1**	**1998**	500	**5%**	$ 475.00	$ 525.00	0	$ -
2	**1,2**	**1998**	500	**5%**	$ 475.00	$ 525.00	0	$ -
3	**1,2,3,8**	**1998**	500	**5%**	$ 475.00	$ 525.00	1	$ 1,120.00
4	**1,2,3,4,7,9**	**1998**	500	**5%**	$ 475.00	$ 525.00	2	$ 1,036.00
5	**All Districts**	**1998**	500	**5%**	$ 475.00	$ 525.00	4	$ 1,096.00
6	**All Districts**	**1997-1999**	500	**5%**	$ 475.00	$ 525.00	5	$ 1,125.00
7	**All Districts**	**1996-2000**	500	**5%**	$ 475.00	$ 525.00	7	$ 1,102.00
8	**All Districts**	**1995-2001**	500	**5%**	$ 475.00	$ 525.00	7	$ 1,102.00
9	**All Districts**	**1994-2001**	500	**5%**	$ 475.00	$ 525.00	8	$ 1,112.00
10	**All Districts**	**All Years**	500	**5%**	$ 475.00	$ 525.00	9	$ 1,105.00
11	**All Districts**	**All Years**	500	**10%**	$ 450.00	$ 550.00	13	$ 1,109.00

Step 3. Adjust Data. Once the number of data points required to develop a distribution are obtained for each bid item, then these points must be adjusted for factors such as the variation of money over time (inflation/deflation), variations based on the geographic location, and any other factor that is considered important in a particular study. A detailed discussion of this issue was presented previously in this chapter.

Step 4. Develop Distributions for Unit Prices. Once all data points have been adjusted by the corresponding factors to guarantee consistency and homogeneity of the distribution data, the next step is develop distributions for the bid items that define the work performed under performance-based specifications by using the adjusted data queried from the bid tabulations. Statistical software can be used to more easily generate the distributions that best fit the data points for each bid item. However, careful attention is required when selecting the statistical software to be used to generate those distributions. The software must perform a detailed comparison and provide final recommendations among alternative distributions that can fit the data specified based on reliability and validity fit tests such as Chi Squared, Kolmogorov Smirnov, and Anderson Darling (Milton & Arnorld 1995, Law & Kelton 2000). The software must report for each potential distribution considered as an alternative several key statistical parameters that must be considered when searching for the best distribution that fits the data. A list and a short description of the objective of those parameters is presented below.

1) F-Stat. Tests whether the entire distribution is valid.

2) t-Stat. Tests whether the individual X variable (unit price in our case) is valid.

3) Standard Error (SE). Assess the size and proportion of the average estimating error when the distribution is used as the estimating rule.

4) Coefficient of Variation (CV). Like the SE, this coefficient represents a relative measure of estimating error.

5) Coefficient of Determination (R^2). Measures the percentage of variation in the dependent variable explained by the independent variable(s).

6) *Adjusted R^2.* This basically represents the adjusted value of R^2 to explain the variation of the independent variable(s) as a result of the variation of the dependent variable.

7) *Outliers.* Represents the observations or data points the distribution predicts poorly. This is a reference that can be used to discard data, but should not be considered as the only reason for doing so.

8) *P-Value.* Represents the probability level at which the statistical test would fail, suggesting the distribution is not valid. P-values less than 0.10 are generally preferred (i.e., only a 10% chance or les, that the model is not valid).

Step 5. Implement Monte Carlo Simulation Approach. Once the unit price distributions have been developed for each bid item on the different contracts provided by the contractor, a methodology based on the Monte Carlo Simulation approach was adopted to obtain a final distribution that represents what would have been the total cost if the work performed under performance-based specification was performed using traditional maintenance specifications instead. In this procedure, the distributions were randomly sampled for a high number of repetitions (e.g., 1000, 10000) until convergence was obtained (Law & Kelton 2000). Then, with these data points, a distribution that represents the total cost was then developed. As previously discussed in this chapter, this distribution must be adjusted to consider the overhead of the agency, since the costs included in the unit prices represent only the costs for the contracted work. Figure 5.10 demonstrates this procedure.

Step 6. Reach Conclusions from the Distribution of the Total Cost. Finally, the distribution of the total cost can be used to reach conclusions on cost savings, if any, accrued by the government based on the methodology used on this approach. A cumulative normal distribution can also serve this purpose. Figure 5.11 illustrates how the cumulative normal distribution can be used to reach conclusions. In this particular hypothetical example, which is not representative of the final assessment, it was assumed that convergence was reached after conducting 1000 repetitions of the sampling process. The mean value of the total cost if traditional maintenance specifications were used was equivalent to $525,000 with a standard deviation of $93,658. A cumulative normal distribution from these parameters was then obtained. If the actual total cost when using performance-based specifications was $595,000, then Figure 5.11 suggest that there is a 70% probability that the agency can perform the same job at less cost with traditional maintenance specifications.

BID DATE	CONTRACT NUMBER	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	BID PRICE	TOTAL COST
18-Aug-99	11B00002	Fence (FE-CL)	LF	1000		
		Line Brace Unit (FE-CL)	EA	5		
		Corner Brace Unit (FE-CL)	EA	5		
					Sub-Total=	
13-Sep-00	11B419	Mobilization	LS	1		Monte Carlo Approach
		Traffic Control	LS	1		
		Stone Rip Rap, Class I	TN	2030		
					Sub-Total=	
21-Feb-01	11B489	Substructure Repair	SY	2562		
		Epoxy Sealant, Type EP-3	SY	280		
					Sub-Total=	
					TOTAL COST=	

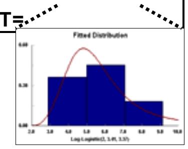


Figure 5.10. Graphical Representation of the Procedure to Obtain the Distribution for Total Cost

(b) *Regression Approach*. The goal of this approach is the same as for the Distribution Approach; however, the methodology is slightly different from the one adopted in the Distribution Approach. The main objective here is to use regression analysis to develop functions for each bid item that represent cost behavior. Figure 5.12 presents a graphic representation of this approach. As shown in the figure, the objective is to develop a regression curve that will better represent the behavior of historical cost data for each bid item separately under traditional maintenance specifications. The general idea is to use the regression curves based on historic costs from traditional maintenance specifications generated for each item

within the performance-based contract to calculate a total maintenance cost corresponding to the scenario in which the work done with performance-based specifications would have been done with traditional maintenance specifications. A comparison of the total cost under performance-based specifications with the estimated total cost under traditional maintenance specifications will serve as the basis for assessing the savings, if any, accrued by the government.

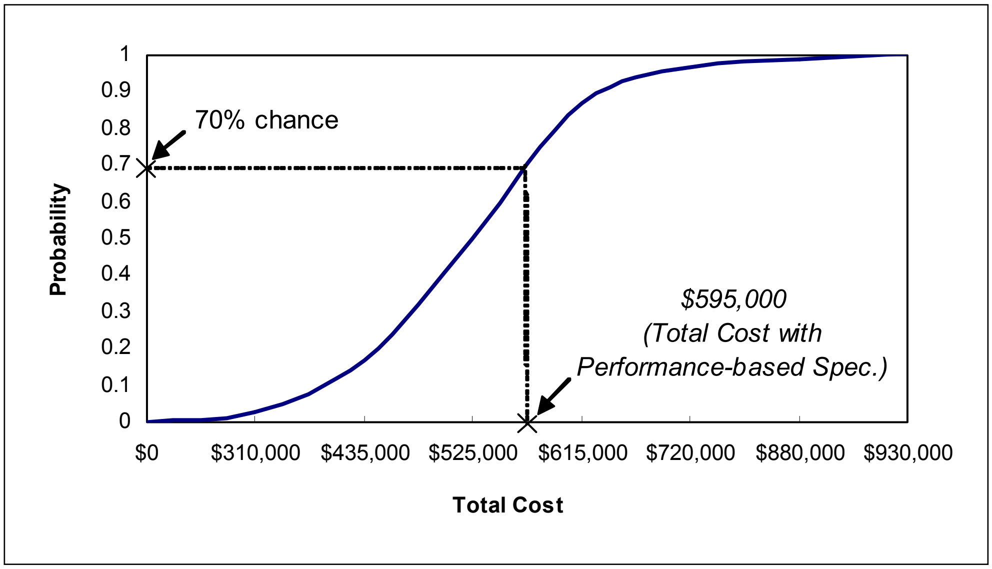


Figure 5.11. Example of How the Cumulative Distribution is Used to Reach Conclusion

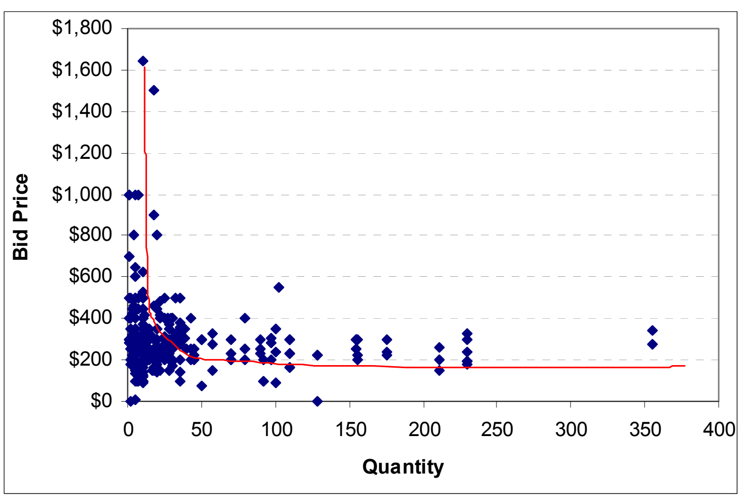


Figure 5.12. Example of a Regression Curve used as the Input in the Regression Approach

The following steps detail the methodology that has been defined as part of this approach. Refer to Flowchart B.6 (Appendix B) for a graphical representation of these steps.

Step 1. Develop Datasets. Similar to the distribution approach, a set of databases that contain the cost information for each individual item to be considered in the evaluation must be created.

Step 2. Normalize Data. As opposed to the distribution approach, in which a heuristic is used to query the data to develop bid item distributions, in this approach all the historical cost data for a given item will be combined and then adjusted (or normalized) to a common baseline, such as specific location and time. This will allow for the development of only one representative function for each bid item. The idea is to use these functions to obtain the distributions that will represent the cost behavior of each bid item within a particular contract. The main benefit from this approach is that all the data are used to develop the regression functions that define the cost behavior of each bid item. Table 5.4 illustrates this concept by presenting a list of historical cost records associated with maintenance work done (with traditional maintenance specifications) on the asset item Fences. Notice from columns 1 and 3 that the records correspond to work done from 2000 to 2003 and to Fences located in different places (Districts 1 through 4). This step requires adjustment of the bid prices associated with each scenario for the asset item Fences to a common baseline. In this example, it was assumed that the baseline was the year 2003 and District 1. This means that all bid prices will be adjusted to this year and location by applying the corresponding adjustment factors listed in columns 8 and 9. The factors applicable to the years can be computed with Eq.5.1. In this example a yearly 4% inflation rate was used. With respect to the adjustment factors for location, multiple sources can be used to estimate cost variations between different locations. The location factors used in this example are hypothetical.

Table 5.4. Data Normalization Example

Bid Date (1)	Contract Number (2)	Location (3)	Maintenance Item (4)	Unit (5)	Bid Quantity (6)	Original Bid Price (7)	Normalizing to 2003 and to District 1		
							Adjustment Factor for Time (8)	Adjustment Factor for Location (9)	Normalized Bid Price (10)
28-Sep-00	A	District 1	Fence	LF	600	$45.00	1.125	1	$50.63
6-Feb-00	B	District 2	Fence	LF	1000	$20.00	1.125	0.85	$19.13
19-Oct-01	C	District 3	Fence	LF	2500	$18.00	1.082	1.16	$22.59
7-Jul-02	D	District 2	Fence	LF	4000	$18.00	1.04	0.85	$15.91
8-Apr-02	E	District 3	Fence	LF	75	$125.00	1.04	1.16	$150.80
1-May-03	F	District 4	Fence	LF	5280	$13.00	1	1.08	$14.04

By applying the factors in columns 8 and 9 to the original bid prices in column 7, the normalized bid prices in column 10 were obtained. A comparison of the original prices with the normalized prices is shown in Figure 5.13. For this scenario, the normalized values in column 10 will then be used to generate a regression curve (function) that will represent the general behavior of bid prices associated with maintenance work done on Fences.

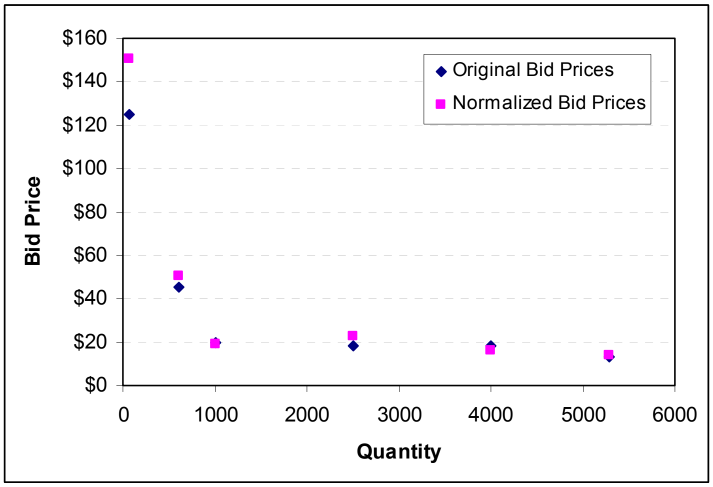


Figure 5.13. Comparison of Original and Normalized Bid Prices

Step 3. Identify Relevant Variables. Before developing regressions for each bid item, it is necessary to first identify the variables to be considered, study and test the relationship among them, and also identify potential models that will better fit the behavior of the cost data. These issues are addressed in Steps 3, 4, and 5, respectively. Regarding the identification of variables, the analyst must define the variables that must be considered in the development process to generate regression curves. For instance, one may be interested in defining the behavior of the bid prices based only on the variation of the number or quantity of units (similar to the scenario presented in Figure 5.13). If this is the case, then the bid prices will be considered as a dependent variable and the quantity as an independent variable. The analyst will need to study the relationship between these two variables to determine which model will better represent the behavior of the bid prices based on variations in the quantity of units. A detailed description of this type of study is presented in Step 4.

Step 4. Study of Relationship among Variables. For the development of any regression curve, it is crucial to first study the relationship among the variables identified in the study to ensure that sound logical concepts and relationships were considered when generating the curves or models. The study of variables can be summarized in the following three steps:

(a) Study the relationship between the dependent variable (e.g., unit price) and the independent variable(s) (e.g., location, year) separately. These variables are also known as cost drivers.

(b) Study the relationship of ratios between independent variables and the dependent variable.

(c) Eliminate the variables and factors that appear to have little or no correlation with the dependent variable.

Statistical tools such as scatter plots and parameters such as the correlation coefficient can be used to support these studies (Milton & Arnold 1995). Figure 5.14 presents an example of the use of scatter plots to study the relationship between variables. Four scenarios are shown in this figure to illustrate some of the multiple variations that can be seen when conducting this kind of study.

Other techniques that can be used to accept or reject the variables and factors derived from the ratio of multiple variables is the step-wise regression approach. The step-wise regression approach can be performed in two ways: the step-wise forward regression and step-wise backward regression. The step-wise forward regression approach consists of introducing the independent variables to the regression model one at a time (Atkinson 1985). The decision to add or drop the variable is usually made on the basis of the contribution of the variable to the error sum of squares, which is judged by the F-Stat. In the step-wise backward regression approach a similar procedure is followed, but in the opposite direction by considering multiple regression. All the variables are introduced in the first trial and then they are rejected one at a time. No matter which technique is used, understanding the variables is always requiered before they are introduced in the model.

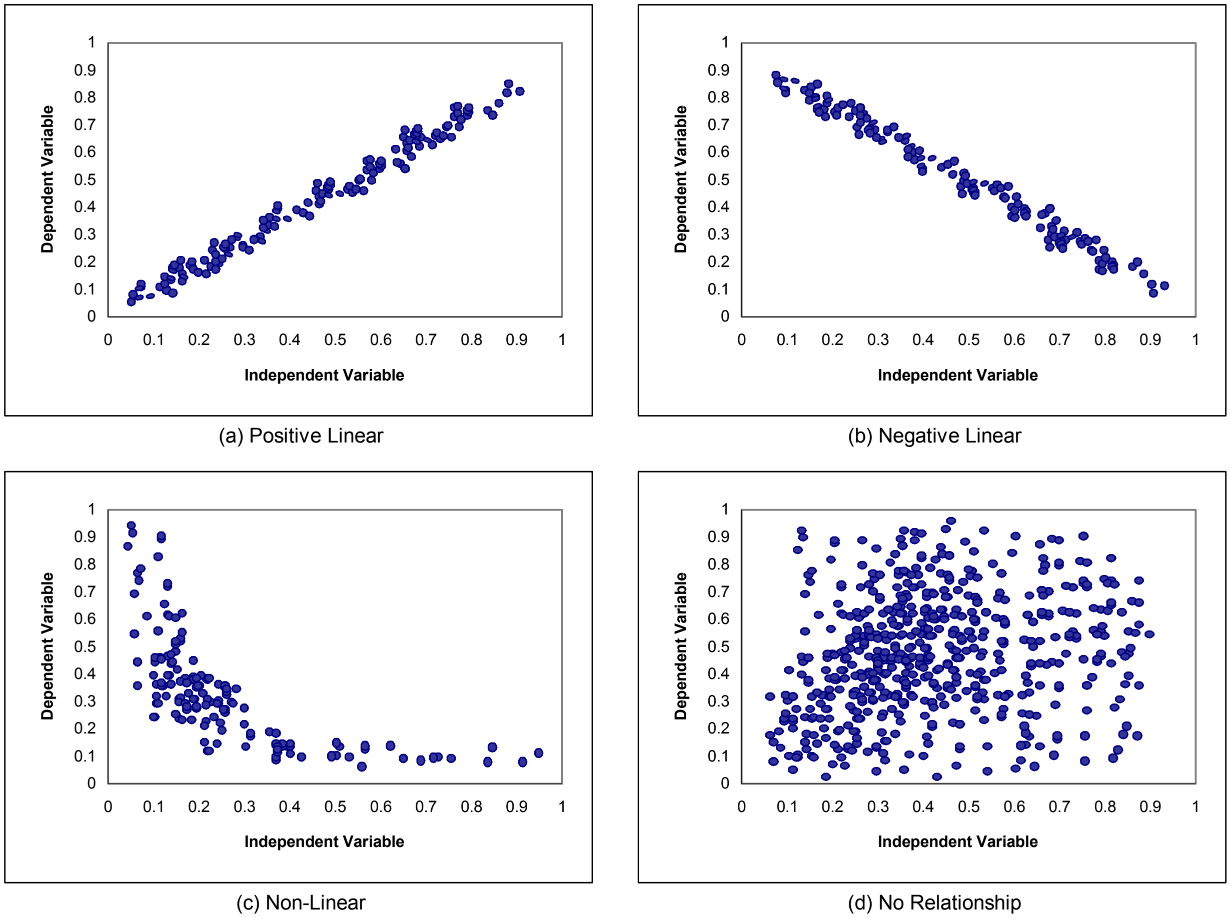


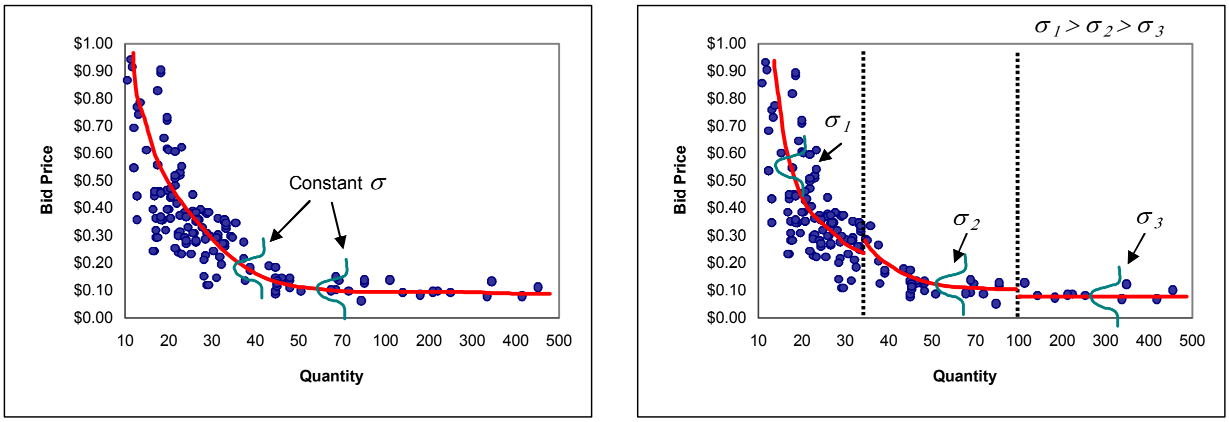
Figure 5.14. Use of Scatterplots to Study the Relationship between Variables

Step 5. Identify Potential Regression Models. Cost regression models are basically mathematical expressions that express cost (dependent variable) as a function of one or more cost-driving variables (independent variables). These mathematical expressions will totally depend on the behavior of the data (Atkinson 1985). Given the fact that the behavior of the data was studied in detail in the previous step, alternatives for the regression models can be identified. There are many different models that can be used to represent the behavior of the data. Some of them are characterized by linear expressions, others by curvilinear and even non-linear expressions. Each alternative considered as a potential model to represent data behavior under consideration must be carefully evaluated with all the curves fitting criteria and the statistical parameters previously mentioned, such as the F-Stat, t-stat, CV, R^2, etc. Among the most common models used in previous studies to fit roadway maintenance cost data are the following four non-linear models: (1) Exponential Decay Model ($Y=b_1X+b_2exp(-X/b_3)$), (2) Inverse Power Model

($Y=b_1+b_2X+b_3/X^{b4}$), (3) Hyperbolic Model ($Y=b_1X+(b_2+b_3X)/(1+b_4X)$), and (4) Logarithmic Model ($Y=b_1+b_2X-b_3log_{10}(X)$) (Weyers et al. 1992). These models have been included here only as a reference for potential candidates. However, it is the analyst's responsibility to identify and consider as many related models as possible in the evaluation to minimize the introduction of any bias in the results due to focusing only on a few models.

Step 6. Develop Regression Curves. The next step in the process is to develop regression curves that better fit the data for each bid item. These regressions can be generated with statistical software. If statistical software is used, then the same parameters (F-Stat, t-Stat, SE, CV, R^2, P-Value) considered in the selection of distributions that best fits the cost behavior of bid items applies here for the selection of the regression curve that best fits the cost behavior. The regression model that must be selected is the one that better fits the data according to the values obtained for these parameters (Atkinson 1985, Law & Kelton 2000). In addition to considering these criteria for the selection of the curve that better fits the data, there is one additional concept that the analyst must consider when developing these curves. This concept relates to the use of multiple curves instead of only one curve to represent the behavior of the cost data for a given asset item. Let's consider the scenarios presented in Figure 5.15 to better illustrate this concept. Notice from Figure 5.15 (a) that only one curve was developed to fit the data. In this single curve, the normal distribution remains constant throughout the entire curve. However, in Figure 5.15 the dispersion of the data points is higher for small quantities than for large quantities. This evident difference in the dispersion of values, depending on the quantity range, will affect the precision at which the bid prices are estimated with the regression curve. If this scenario is observed in the development of the regression curves, one can consider an alternative approach in order to improve the precision of the estimate. The approach consists in generating multiple curves instead of only one curve to represent the bid price behavior for a given asset item. Figure 5.15 (b) illustrates this concept. In the example presented in this figure, the data were divided in three sections and for each section a regression curve was generated. There are several alternatives to define these sections. One of them is to use judgment based on the visual dispersion of the data points. This approach was used to define the sections in Figure 5.15. However, a more precise and sophisticated statistical approach can be used to establish how the data set should be divided more reliably. The technique is known as the *Box-Cox*

Transformation. A detailed discussion of this approach is out of the scope of this chapter; however, the reader can refer to Atkinson (1985) for a comprehensive description of how to implement this approach.



(a) One Curve (b) Multiple Curves

Figure 5.15. Alternative Approaches for the Generation of Regression Models

<u>*Step 7. Develop Normal Distributions for Unit Prices.*</u> The regression curves obtained in the previous step are then used to generate a distribution of the unit price if the work would have been performed with traditional specifications based on the specific parameters of each contract item considered in the study. Table 5.5 presents an example of how this step is implemented. In this table, two contracts for the same activity or item are listed. The difference between these two performance-based contracts is basically the year in which the work was done, the location where it took place, and the quantity of work performed. The format of the records presented in this table is typical of the information needed to perform this part of the cost study.

Table 5.5. Development of Formulas for each Contract Item

Contract (1)	Activity (2)	Unit (3)	Year (4)	District (5)	Quantity (6)	Bid Price from Performance-Based (7)	Formula for Traditional Price (8)
A	Fence Repair	LF	2002	1	30	$0.27	N (μ_A, σ_A)
B	Fence Repair	LF	2003	2	70	$0.11	N (μ_B, σ_B)

Assuming historical cost records based on work performed according to traditional maintenance specifications are available for the Fence Repair Activity, then a regression curve similar to the one presented in Figure 5.16 can be developed.

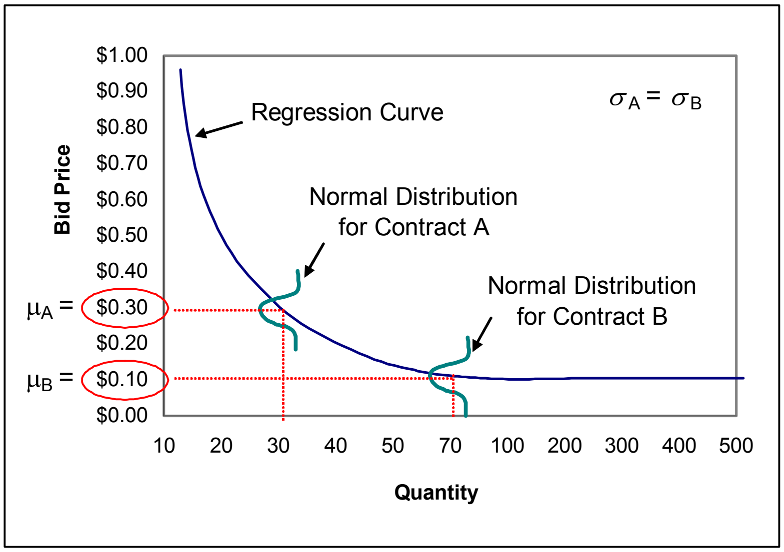


Figure 5.16. Development of Bid Price Distributions for each Contract Item

The objective is to use the regression curve to generate a distribution that represents the particular characteristic of each contract. For example, if the quantity (equal to 30 LF) specified for Contract A is used as an input in the regression curve, then a mean unit price equal to $0.30 is obtained. Since a regression model is used to estimate the mean unit price for each specific contract, one can use the combination of the mean bid prices with the standard deviation of the curve to generate a normal distribution for each contract item. For instance, the corresponding normal distribution for Fence repair in Contract A will be N (μ_A=$0.30, σ_A). However, this formula still needs to be adjusted to account for the specific location and year of this particular contract, which is year 2002 and District 1. This procedure is discussed in Step 8.

Step 8. Re-adjust Distributions for Unit Prices. The normal distributions obtained in the previous step must be re-adjusted to account for other factors such as the location at which each contract took place and any escalation based on the year the work was performed. These re-adjusted distributions will then be used to estimate the costs of the work if traditional maintenance specifications had been used to perform the same work done with performance based specifications. Thus, the parameters (μ, σ) that define the distributions listed in Table 5.4 (column 8) need to be adjusted to account for location and year. The following expression is used to adjust these parameters based on the properties of a Normal Distribution,

$$\textit{Adjusted Unit-Price Distribution}_i = N\,(F^*\mu_i\,,\ F^*\sigma_i) \qquad (5.4)$$

where the factor F is computed according to Eq.5.5,

$$F = F_L \text{ x } F_T \qquad (5.5)$$

where F_L represents the adjustment factor for location and F_T refers to the adjustment factor to account for time differences. For example, assuming that the data used to generate the distribution presented in Figure 5.16 was normalized using District 2 and Year 2003 as the baseline, the parameters of the distribution formula for Contract B will remain the same, since the conditions of that contract are exactly the same as the ones used to normalize the data ($F_L = F_T = 1$). On the other hand, both parameters for Contract A (μ_A, σ_A) must be adjusted to account for the difference in location (factor corresponding to District 1 with respect to District 2) and year (inflated from 2002 to 2003) with respect to the normalized data.

<u>*Step 9. Implement Mont -Carlo Simulation Approach.*</u> Once the distributions of the unit prices are obtained, the same Monte Carlo Simulation technique used in the distribution approach is then used in the regression approach. As previously stated, the product from implementing this technique will be a distribution that represents what would have been the total cost if the work performed under performance-based specification was done using traditional maintenance specifications.

<u>*Step 10. Reach Conclusions Based on the Comparison of Total Cost.*</u> Finally, conclusions on the cost savings, if any, accrued by the government can be reached by comparing the total costs of the work when performance-based specifications are used with the distribution of the cost of the work if traditional maintenance specifications were used instead. As for the distribution approach, the cumulative distribution of the total cost under traditional specifications is used to reach conclusions.

5.3.2.2. Part 2: Study of LOS versus Expenditures

The main objective of this study is to be able to relate cost to performance by evaluating the impact in level of service (i.e., condition of the assets) if the implementing agency spent in traditional maintenance at least the same amount as under performance-based work. Figure 5.17 illustrates this concept.

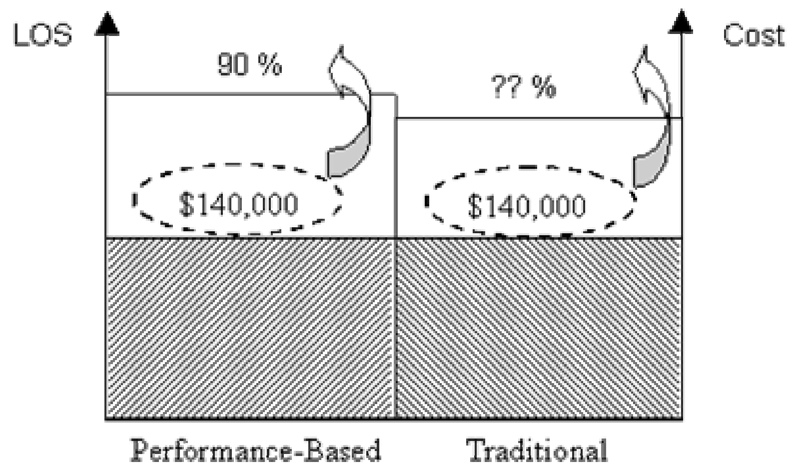


Figure 5.17. Scenario Comparing Cost and Performance

As presented in the figure above, the goal is to assess the impact in LOS if the same rate of expenditure under performance-based specifications is used when traditional maintenance specifications are applied. The main issue here is how to relate cost to level of service. To address this issue, the framework proposes the use of two approaches (as previously shown in Figure 5.3): (1) Bayes Theorem Approach and (2) Markov Chains or Transition Matrices Approach. The Bayes Approach is considered easier to implement than the Markovian Approach. The input required to implement the Bayes Approach can be obtained from the combination of the cost expenditures (i.e., detailed accounting records) and the condition evaluations performed in the field. On the other hand, the Markovian Approach requires the implementing agency to define transition matrices (to be discussed later) for each asset item as well as the cost information related to maintenance policies. The Markovian Approach requires more effort from the agency, but the results obtained by implementing this approach can be more realistic. A detailed description of how these techniques were incorporated in the framework to address our needs regarding the relationship between cost and performance is presented next.

1) *Bayes Theorem*. Bayes Theorem uses the concept of reverse probability or an inverse deductive logic (Ang & Tang 1975, Milton & Arnold 1995). This means that a hypothesis can be made regarding the potential output based on known facts. From subsequent knowledge based on actual experience a new hypothesis is established for the output. How can this approach be helpful in relating cost to level of service? The idea is to provide insight on how changes in funding levels from the facts on which the first hypothesis is based can change the probability of realizing an LOS rating (condition state).

To better understand how Bayes Theorem can be used to relate cost to performance, review a of few probability concepts associated with Bayes Theorem is necessary. Bayes Theorem is based on the Total Probability Theorem (TPT) (Milton & Arnold 1995). TPT states that the case of the occurrence of an event, A, is always accompanied by the occurrence of other events, E_i, the probability of event A will be an average probability weighted by those of events E_i. In the Venn diagram in Figure 5.18, the sample space was divided in four mutually exclusive and collectively exhaustive events. The union of these events represent the whole sample space. Moreover, an additional event, A, was also defined in the sample space. Given the condition presented in Figure 5.18, the probability of occurrence of event A will be (according to the TPT),

$$P(A) = P(A/E_1)*P(E_1)+P(A/E_2)*P(E_2)+P(A/E_3)*P(E_3)+P(A/E_4)*P(E_4) \quad (5.4)$$

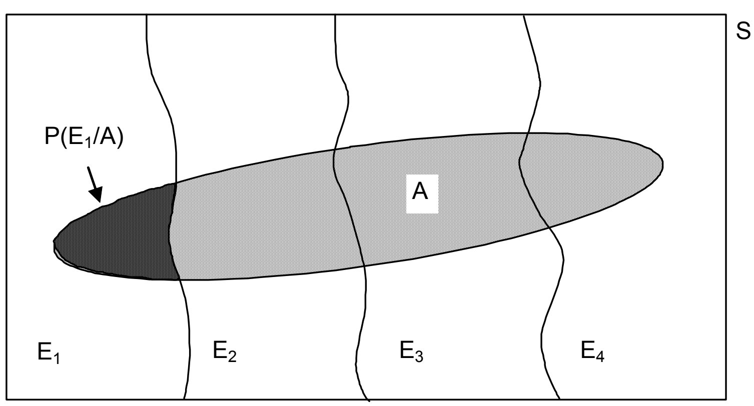


Figure 5.18. Graphical Interpretation of TPT and Bayes Theorem

The interest is in obtaining the probability of occurrence of events E_i given that event A occurred (e.g., P(E_1 / A)). This is considered a reverse probability and can be obtained with the Bayes Theorem defined by the following expression (Ang & Tang 1975),

$$P(E_i / A) = \frac{P(A / E_i)P(E_i)}{P(A)} = \frac{P(A / E_i)P(E_i)}{\sum_{j=1}^{n} P(A / E_j)P(E_j)} \quad (5.5)$$

This concept can be applied to the current scenario. For instance, the Venn diagram depicted in Figure 5.19 illustrates a typical scenario where cost is related to performance. Notice from Figure 5.19 that the sample space is divided into five mutually exclusive and collectively exhaustive events (State 1, State 2, State 3, State 4, and State 5) that represent the performance condition categories (e.g., excellent, good, fair, poor, and very poor condition). Moreover, four additional events (E_1, E_2, E_3, and E_4) were also defined in the sample space. These events represent four cost categories that define the expenditure rate to obtain a given performance level. For example, the union between event E_2 (expenditure range from \$195 to \$205) and State 3 will provide the probability that the performance condition will be in State 3 given that the expenditure rate is between \$195 and \$205. By generalizing this concept, one can see the potential of this approach to assess the LOS distribution as a result of changes in the expenditure rate.

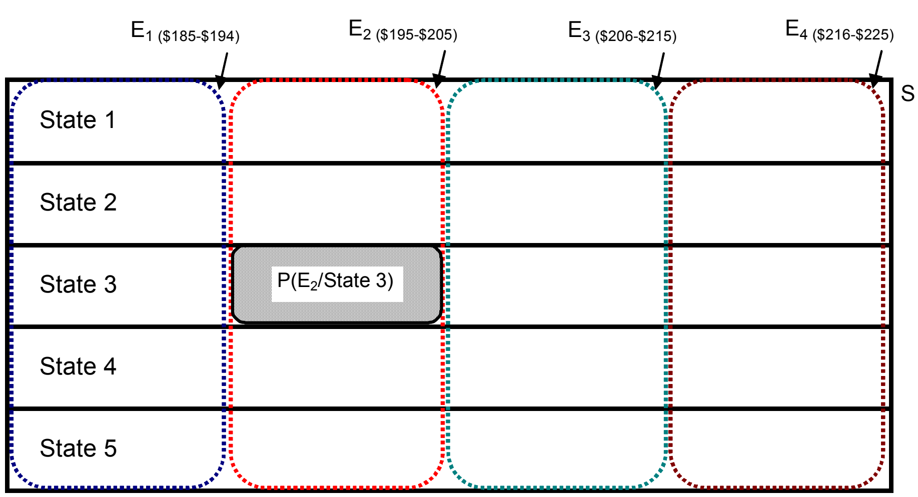


Figure 5.19. Graphical Representation of the Bayes Theorem to relate cost to Performance

To properly implement this approach, the agency must collect cost and performance information associated with the use of traditional maintenance specifications. Table 5.6 presents an example of this type of record. From these records, statistics can then be collected similar to the ones presented in Table 5.7 (expenditure rates and condition states). The following steps have been defined to provide instructions and explanations of how Bayes Theorem is used to meet the need of relating cost to performance. Refer to Flowchart B.7 (Appendix B) for a graphical representation of these steps.

Table 5.6. Example of Input Needed for Bayes Theorem Approach

Segment		Cost and Performance Information			
Number (1)	Location (2)	Asset Type (3)	Unit (4)	Unit Price (5)	LOS Rating (condition) (6)
1	I-295, MP 2.0 to 2.1, North	Pipes	LF	$200	92
2	I-295, MP 2.1 to 2.2, North	Fence	LF	$50	89
3	I-295, MP 3.5 to 3.4, South	Luminaries	EA	$150	98
4	I-295, MP 3.4 to 3.3, South	Signs	EA	$400	82

Table 5.7. Format Used to Collect Statistics from Cost and Performance Records

Condition	Frequency of Actual Maintenance Cost Rate				
	Cost Range 1	Cost Range 2	Cost Range 3	Cost Range 4	Total
State 1					
State 2					
State 3					
State 4					
State 5					
Total					

<u>*Step 1. Define the Number of ConditionSstates.*</u> The first step of the process is to define a finite set of events. In this case those events will represent condition states or level of service condition. For instance, it is recommended that the states to be defined by using the grading scale used in the condition evaluation discussed in Chapter four of this document (section 4.5.2). For example, if five grades (*e.g., A, B, C, D and F*) are defined based on compliance to performance standards, then those categories can be taken as the condition states to be used in this analysis. An example of how condition states are defined relative to a grading scale is depicted in Table 5.8.

Table 5.8. Example of a Condition State Transition Matrix

State	Grade	Description of Condition State
State 1	A	Actual condition ≥ Performance Target
State 2	B	95% of Requirement ≤ Actual condition < Performance Target
State 3	C	90% of Performance Target ≤ Actual condition < 95% of Performance Target
State 4	D	85% of Performance Target ≤ Actual condition < 90% of Performance Target
State 5	F	Actual condition < 85% of Performance Target

Step 2. Collect Statistics regarding LOS and AssociatedEexpenditure Rate. Once the condition states have been defined, the next step will be to collect statistics regarding the condition state of each asset item throughout the network with respect to pre-defined ranges of actual expenditures (e.g., $185-$194, $195-$205), which will vary depending on the asset item under consideration. Table 5.9 presents an example of information required. Notice that to collect the statistics presented in Table 5.9, the agency must have good records that associate the condition of the assets with the actual expenditures incurred from the maintenance of those assets. As previously stated, this is one of the main reasons why the agency must implement an efficient methodology for capturing cost and performance data.

In addition, it is important to re-emphasize that cost data and condition frequency required at this stage corresponds to the information from portions of the network maintained with traditional specifications and subjected to similar conditions as those portions of the network maintained under performance-based specifications. The suggestion about identifying sections in the roadway system exposed to similar conditions to those portions of the network under performance-based specifications was discussed in Chapter four. The main objective of identifying those sections was for comparison purposes, such as the one presented in this study. The reason why the information must to come from these portions of the network maintained with traditional specifications will be addressed in the following steps.

Table 5.9. Example of How to Collect Condition Frequencies by Category of Actual Costs

Condition	Asset Item Actual Maintenance Cost Rate				
	$185-$194	$195-$205	$206-$215	$216-$225	Total
State 1	3	7	8	16	34
State 2	5	7	11	14	37
State 3	7	5	6	10	28
State 4	4	2	1	1	8
State 5	3	2	1	1	7
Total	22	23	27	42	

<u>*Step 3. Define Conditional Probabilities.*</u> Once the statistics from Step 2 are collected, the next step will be to express those frequencies in terms of percentage (relative frequencies). These percentages are known as conditional probabilities. Conditional probabilities are computed by dividing the frequency on each category by the sum of the frequencies from each condition state. Table 5.10 presents the conditional probabilities obtained by using the hypothetical data depicted in Table 5.9.

Table 5.10. Example of Matrix with Conditional Probabilities

Condition	Asset Item Actual Maintenance Cost Rate				
	$185-$194	$195-$205	$206-$215	$216-$225	Total
State 1	0.088	0.206	0.235	0.471	1.00
State 2	0.135	0.189	0.297	0.378	1.00
State 3	0.250	0.179	0.214	0.357	1.00
State 4	0.500	0.250	0.125	0.125	1.00
State 5	0.429	0.286	0.143	0.143	1.00

<u>*Step 4. Define Marginal Probabilities.*</u> The next step in the process is to define marginal probabilities for the condition states. Marginal probabilities represent the distribution of the actual condition of the asset items throughout the network (within the portions of the network subjected to traditional maintenance specifications) which is believed to be the proposed budget for maintenance activities for the coming year. In other words, they represent the agency-expected distribution in performance conditions if the proposed schedule of maintenance work is performed. In the example presented in Table 5.11, it is stated that the agency foresees that 28% of the network will be in condition 1 at the end of the fiscal year (as a result of the maintenance activities conducted throughout the year), 33% in condition 2, 25% in condition 3, 8% in condition 4, and 6% in condition 5. These marginal probabilities as well as the frequencies in

Step 2 can be obtained from the condition assessments performed by the agency throughout the year.

Table 5.11. Example of Marginal Probabilities

Condition	Marginal Probability
State 1	28 %
State 2	33 %
State 3	25 %
State 4	8 %
State 5	6 %

<u>*Step 5. Combined Conditional and Marginal Probabilities for each Asset Item.*</u> This step combines all the values estimated from Steps 2 through 4 into a single source. Table 5.12 is a typical example of the kind of table and type of information that is needed to support the analysis proposed in this section, which will discern the relationship between cost and performance. This type of table should be prepared for each asset item identified in the network (analysis to be performed at the asset item level).

Table 5.12. Example of a Typical Matrix to be Used in Bayes Approach

Condition	Asset Item Actual Maintenance Cost Rate				Marginal Probability
	$185-$194	$195-$205	$206-$215	$216-$225	
State 1	0.088	0.206	0.235	0.471	0.28
State 2	0.135	0.189	0.297	0.378	0.33
State 3	0.250	0.179	0.214	0.357	0.25
State 4	0.500	0.250	0.125	0.125	0.08
State 5	0.429	0.286	0.143	0.143	0.06

<u>*Step 6. Compute the Probability of Executing at each Cost Rate.*</u> The next step before applying Bayes Theorem to analyze the relationship between cost and performance is to compute the probability of execution at each expenditure range. That is, the probability that the expenditure rate for this particular asset item (Table 5.12) will be in the range of $185-$194 (*P($185-$194)*), $195-$205 (*P($195-$205)*), must be recalculated. This probability can be obtained by computing the joint probability of a given cost rate, which is calculated by multiplying the conditional probability with the corresponding marginal probability (Total Probability Theorem). For example, P($185-$194) is calculated using Eq.5.4 as a reference,

P($185-$194) = P(($185-$194)|State 1)*P(State 1)+ P(($185-$194)|State 2)*P(State 2)+ P(($185-$194)|State 3)*P(State 3)+ P(($185-$194)|State 4)*P(State 4)

P($185-$194) = 0.088*0.28+ 0.135*0.33+ 0.25*0.25+ 0.50*0.08+ 0.429*0.06

P($185-$194) = 0.1975

The calculated values for the four corresponding probabilities are summarized in Table 5.13.

Table 5.13. Calculation of the Probability of Executing at each Cost Rate

Asset Item Actual Maintenance Cost Rate			
P($185-$194)	P($195-$205)	P($206-$215)	P($216-$225)
0.1975	0.2019	0.2361	0.3645

Step 6. Apply Bayes Theorem to Derive the Relationship between Cost and Performance. In this step, Bayes Theorem is used to derive the causal relationships between the actual cost and performance. As illustrated in Eq.5.5, the probabilities are computed by dividing each joint probability ($P(E_i/State_j)*P(State_j)$) by its actual cost probability ($P(E_i)$). For example, the probability of State 3 with an expenditure rate between $195 and $205 is computed as follows:

$$P[State3/(\$195-\$205)] = \frac{P[(\$195-\$205)/State3]P(State3)}{P(\$195-\$205)}$$

$$P(State3/\$195-\$205) = \frac{0.179*0.25}{0.2019}$$

$$P(State3/\$195-\$205) = 0.221$$

Table 5.14 summarizes the calculations for all the combinations of performance conditions and expenditures. The information in this table provides valuable information for road administrators which they can use to assess the impact in performance condition by spending on traditional maintenance at least at the same rate as under performance-based specifications. For example, the average maintenance expenditure rate when traditional specifications are used is between $185 and $194 (column 2). In this case, there is a probability of 12.5% that this type of asset item will be in State 1, 22.6% in State 2, 31.6% in State 3, 20.3% in State 4, and 13% in State 5. Moreover, the average maintenance expenditure rate for this asset item when performance-based specifications are implemented is between $195 and $205 and an average LOS rating equal to 87.53% was obtained by spending at this rate. If that is the case, then Table 5.14 can be used to assess the impact in performance if this expenditure rate is applied when traditional maintenance specifications are used (for traditional specifications the expenditure rate increases). Notice in column 3 that if the expenditure rate is increased, then it is expected that the probability of having the asset item in State 1 will increase from 12.5% to 28.6%, State 2 will increase from 22.6% to 30.9%, State 3 will decrease from 31.6% to 22.1%, State 4 will decrease from 20.3% to 9.9%, and finally, State 5 will decrease from 13% to 8.5%. If it is desirable to assess the impact by comparing the differences in LOS, then these percentages can be used in combination with the average performance ratings (LOS rating) per condition state to obtain an overall average LOS rating from the new distributions. For example, the average LOS ratings for the original distributions (marginal probabilities) are 97% for condition state 1 (represents 28 % of the assets), 90% for state 2 (represents 33 % of the assets), 85% for state 3 (represents 25 % of the assets), 80% for state 4 (represents 8 % of the assets), and 75% for state 5 (represents 6 % of the assets). With these values, an average LOS rating equal to 85.32% was obtained for the expenditure rate of $185-$195 (*97*0.125+90*0.226+85*0.316+80*0.203+75*0.130*). With the new distributions obtained for an expenditure rate of $195-$205 (28.6% for state 1, 30.9% for state 2, 22.1% for state 3, 9.9% for state 4, and 8.5% for state 5) the original LOS ratings can be multiplied by each percentage and from there the overall average LOS rating can be obtained for the asset item. By doing this, an LOS rating equal to 88.63% (*97*0.286+90*0.309+85*0.221+80*0.099+75*0.085*) was obtained. In this example, the average LOS rating for work under traditional specifications is expected to increase from 85.32% to 88.63%. If the 88.63% is compared to the average LOS rating obtained under performance-based work (87.53%) as well as the distributions in column 2 (cost rates under traditional specifications) with the new distributions listed in column 3 (cost rates under traditional specifications), it can be concluded that if the agency spent in traditional maintenance at least at the same rate as under performance-based specifications, it will end up improving the overall performance condition of the asset item under consideration.

Table 5.14. Example of Relationship of Cost and Performance by Using Bayes Theorem

Condition	Asset Item Actual Maintenance Cost Rate			
	$185-$194	$195-$205	$206-$215	$216-$225
(1)	(2)	(3)	(4)	(5)
State 1	0.125	0.286	0.279	0.362
State 2	0.226	0.309	0.415	0.343
State 3	0.316	0.221	0.227	0.245
State 4	0.203	0.099	0.042	0.027
State 5	0.130	0.085	0.036	0.024
Sum	1	1	1	1

2) *Markov Chains*. As previously mentioned, the second approach consists of using Markovian Chains or condition state transition probabilities to relate cost to performance. The motivation behind this approach is the successful application of this theory in the prediction of bridge element condition and maintenance estimates (Kleywegt and Sinha 1994). Two nationwide projects in the United States, PONTIS and BRIDGIT, implemented the Markovian Approach to model the impact in the condition of bridge elements as a result of implementing different maintenance policies (CSI 2001). The successful implementation of the Markovian Approach in these bridge management systems inspired for the methodology presented in this section and is applicable to each asset item within the other asset groups in the roadway system. A detailed description of how this approach has been adapted to this study follows.

A Markov Chain is basically a square matrix that has a set of mutually exclusive states (Schrer and Glagola 1994). The objective of this matrix is to predict the future condition or future state of the system based on the current condition or current state. To apply this approach, simulation is necessary, since the analysis is based on the implementation of maintenance policies for a given period of time usually more than 10 years. The following steps describe in detail how transition matrices can be used in our scenario to relate cost to performance. Refer to Flowchart B.8 (Appendix B) for a graphical representation of these steps.

Step 1. Define the Number of Condition States. Similar to the Bayes Theorem approach, the first step in constructing transition matrices is to define a finite set of condition states (Gopal & Majidzadeh 1991). The same approach of using the grading scale as rule of thumb is recommended here. In addition, it will also be necessary to consider the initial average LOS rating by condition state as part of the input. These values will be used in the simulation process to estimate the new LOS ratings after each simulation cycle takes place.

Step 2. Define Transition Matrix for each Asset Item. Transition matrices have two basic components: (1) the condition states (n) and (2) the transition probabilities (p_{ij}). The condition states were defined in the previous step, whereas the transition probabilities still need to be defined for a matrix of size nxn. Table 5.15 depicts a transition matrix and its definition. The transition matrix presented in this table is representative of a typical transition matrix which represents a scenario in which no maintenance treatment or maintenance activity takes place because there is no probability of improvement to a higher state. This type of matrix is also known as a deterioration matrix. It can be observed from Table 5.15 that if the asset item is in condition 2, there is a 90 % chance the item will remain in condition 2 and a 10% chance of dropping to condition 3 if no maintenance activities are performed. Notice that the sum of the transition probabilities on each row must be equal to 1.

Table 5.15. Example of a condition State Transition Matrix when no Maintenance is Performed

From Condition State	To Condition State				
	State 1	State 2	State 3	State 4	State 5
State 1	0.2	0.7	0.1	0	0
State 2	0	0.9	0.1	0	0
State 3	0	0	0.75	0.2	0.05
State 4	0	0	0	0.7	0.3
State 5	0	0	0	0	1.0

The other scenario for a transition matrix occurs when maintenance activities take place. Table 5.16 presents an example of how the transition matrix looks if this is the case. In this example, if the asset item is in condition 5 and the corresponding maintenance treatment is performed, there is a 70% chance the item will improve to condition 1, 10% chance it will improve to condition 2, 15% chance it will improve to condition 3, and 5% chance it will improve to condition 4. This type of matrix is also referred to as a condition prediction matrix.

Table 5.16. Example of a Condition State Transition Matrix when Maintenance is Performed

From Condition State	To Condition State				
	State 1	State 2	State 3	State 4	State 5
State 1	0.2	0.7	0.1	0	0
State 2	0	1	0	0	0
State 3	0	0	0.9	0.1	0
State 4	0	0	0.05	0.95	0
State 5	0.70	0.10	0.15	0.05	0

Road Administrators must basically define at least two matrices for each asset item. These are: (1) a transition matrix for the scenario in which no maintenance activities take place, and (2) a transition matrix when maintenance activities take place. More than two matrices may be required for the second scenario if there is more than one maintenance activity that needs to be characterized by different transition probabilities. If this is the case, the one that applies to each particular situation will be selected for the analysis. The definition of the transition probabilities within each matrix can be defined based on historical records, agency policies, and/or expert opinion.

Step 3. Define Marginal Probabilities for each Asset Item. The next step in the process is to define marginal probabilities for the condition states. The marginal probabilities represent the distribution of the actual condition of the asset item throughout the network under performance-based work. In our study, an estimated value must be assigned to these probabilities to perform a trial and error process. However, the main objective of the study is to find the values of the marginal probabilities if the same expenditure rates accrue as a result of the implementation of performance-based specifications. This approach will be discussed in a later step.

Step 4. Identify Treatment Costs for each Maintenance Action. Since the objective is to relate cost to performance, it is necessary to include an input of the estimated costs of each maintenance action considered to improve the condition of each asset item. Table 5.17 presents a set of hypothetical costs for a maintenance action to be used for the particular asset item under consideration.

Table 5.17. Example of Maintenance Activity Costs

Condition State	Treatment Cost
State 1	$0.00
State 2	$60.00
State 3	$65.00
State 4	$63.00
State 5	$115.00

Step 5. Simulation Process. Steps 1 through 4 describe the characteristics of the input required for the implementation of this approach. Now that the input has been defined for each asset item, the next step is to perform the simulation process. The objective of the simulation process is to model the impact on the condition level and total expenditure for each asset item if the policies related to traditional maintenance specifications and the ones related to performance-based specifications are applied. To get a better understanding of the simulation process, let's consider the example presented in Figure 5.20.

Notice Figure 5.20 is divided into three sections: (1) Input, (2) Simulation Process, and (3) Output. The input contains the same transition matrices defined in Steps 1 through 4. Those matrices are used in the simulation process to assess the impact on the condition level and the costs incurred as a result of implementing the corresponding policies. In the simulation shown in the figure, it is assumed that the input matrices correspond to the scenario in which traditional maintenance specifications were used. In addition, the adopted policy stated that maintenance action 1 would be applied for two consecutive years, while in the third year no maintenance would be performed. These three years constitute a cycle. Since no maintenance activities took place in Year 1, the initial performance condition (*Matrix D*) was multiplied by each of the columns in the deterioration matrix (*Matrix A*). The result from this multiplication was Matrix Y1, which provides a new distribution of performance conditions at the end of Year 1. To get a better idea of how the vectors Y and E and the average LOS were obtained in Figure 5.20, step-by-step calculations are presented below for Years 0, 1, and 2.

STEPS 1,2,3,4: INPUT

Matrix A: Deterioration Matrix

	State 1	State 2	State 3	State 4	State 5
State 1	0.2	0.7	0.1	0	0
State 2	0	0.9	0.1	0	0
State 3	0	0	0.75	0.2	0.05
State 4	0	0	0	0.7	0.3
State 5	0	0	0	0	1

Matrix B: Condition Prediction Matrix for Maintenance Activity 1

From Cond.	To Condition State				
	State 1	State 2	State 3	State 4	State 5
State 1	0.2	0.7	0.1	0	0
State 2	0	1	0	0	0
State 3	0	0	0.9	0.1	0
State 4	0	0	0.05	0.95	0
State 5	0.7	0.1	0.15	0.05	0

Matrix C: Costs for Activity 1

Cond. State	Maintenace Cost
State 1	$0.00
State 2	$60.00
State 3	$65.00
State 4	$63.00
State 5	$115.00

Matrix D: Initial Condition of the asset

Cond. State	Marginal Probability	Aver. LOS
State 1	15%	97
State 2	27%	90.5
State 3	38%	84.5
State 4	12%	77.5
State 5	8%	71
	Average =	**86.1**

STEP 5: SIMULATION PROCESS

Iterations

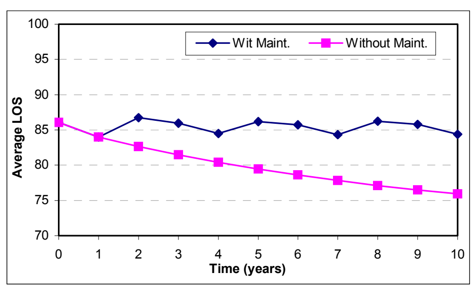
Year	Maintenance Performed	Input Matrices	Output Condition Matrix	Ave.LOS	Maintenance Expenditures	Total
0	None	D & A	Y_0 = 0.150 | 0.270 | 0.380 | 0.120 | 0.080	= 86.1	$E_0=Y_0*C$ = $0.00 | $0.00 | $0.00 | $0.00 | $0.00	= $0.00
1	None	Y_0 & A	Y_1 = 0.030 | 0.348 | 0.327 | 0.160 | 0.135	= 84.0	$E_1=Y_1*C$ = $0.00 | $0.00 | $0.00 | $0.00 | $0.00	= $0.00
2	Maint.Act. 1	Y_1 & B	Y_2 = 0.101 | 0.383 | 0.326 | 0.191 | 0.000	= 86.7	E_2 = $0.00 | $22.95 | $21.16 | $12.06 | $0.00	= $56.17
3	Maint.Act. 1	Y_2 & B	Y_3 = 0.020 | 0.453 | 0.313 | 0.214 | 0.000	= 86.0	E_3 = $0.00 | $27.17 | $20.32 | $13.51 | $0.00	= $61.00
4	None					
5	Maint.Act. 1					
6	Maint.Act. 1					
7	None					
8	Maint.Act. 1					
9	Maint.Act. 1					
10	None	Y_9 & A	Y_{10} = 0.002 | 0.447 | 0.231 | 0.229 | 0.090	= 84.4	E_{10} = $0.00 | $0.00 | $0.00 | $0.00 | $0.00	= $0.00
In Average (considering all years)			0.030 | 0.432 | 0.276 | 0.223 | 0.039	= 85.4	$0.00 | $16.02 | $10.86 | $8.79 | $0.00	= $35.67

STEP 6: OUTPUT

Summary

Time	With Maint.		Without Maint.	
	Aver. LOS	Total Cost	Aver. LOS	Total Cost
0	86.1	$0.00	86.1	$0.00
1	84.0	$0.00	84.0	$0.00
2	86.7	$56.17	82.6	$0.00
3	86.0	$61.00	81.5	$0.00
4	84.5	$0.00	80.4	$0.00
5	86.2	$58.68	79.5	$0.00
6	85.7	$61.40	78.6	$0.00
7	84.3	$0.00	77.8	$0.00
8	86.2	$58.24	77.1	$0.00
9	85.8	$61.24	76.5	$0.00
10	84.4	$0.00	75.9	$0.00

Variation in LOS



Variation in Total Cost

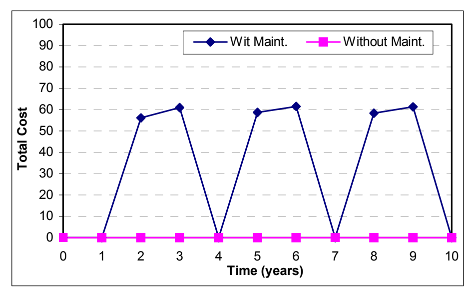


Figure 5.20. Example of How to use Markovian Chains to Relate Cost to Performance

i) <u>*Year 0.*</u> The values for vectors Y and E at Year 0 are basically the initial conditions specified in Matrices C and D. These are depicted in Figure 5.21 for convenience. With respect to the average level of service, this value is obtained by multiplying vector Y_0 times the initial distribution of the level of service presented in Matrix D of Figure 5.20. By performing this multiplication, an average LOS equal to 86.1 was obtained for Year 0 as shown in Figure 5.21.

Y_0	=	0.15	0.27	0.38	0.12	0.08				
LOS_0	=	97	90.5	84.5	77.5	71	=	(97*0.15+90.5*0.27+84.5*0.38+77.5*0.12+71*0.08)	=	**<u>Average LOS</u>** **86.1**
E_0	=	$0.00	$0.00	$0.00	$0.00	$0.00			=	**<u>Average Unit Cost</u>** **$0.00**

Figure 5.21. Values of Y, E, and LOS for Year 0

ii) <u>*Year 1.*</u> As shown in Figure 5.22, vector Y_1 was obtained by multiplying Matrix Y_0 by Matrix A, since no maintenance activity should take place according to the hypothetical policies. For instance, the first value for vector Y_1 was obtained as follows:

$$Y_{1,1} = 0.03 = 0.\ 2*\ 0.15+0*0.27+0*0.38+0*0.12+0*0.08$$

On the other hand, by multiplying the distribution Matrix Y_1 times the average condition ratings (LOS ratings) listed in Matrix D, then a new average overall LOS rating equal to 84.0 was obtained. Finally, notice in Figure 5.22 that vector E_1 was obtained by multiplying each element of vector Y_1 times the corresponding expenditure rate, which in this year is equal to zero since no maintenance was performed.

iii) <u>*Year 2.*</u> The scenario in Year 2 is slightly different, since maintenance action 1 took place. Notice from Figure 5.23 that for year two the new conditional matrix is obtained by multiplying matrix Y_1 (condition from Year 1) times Conditional Prediction Matrix B (associated with maintenance action 1). Once vector Y_2 is obtained, then the average LOS as well as vector E_2 is computed in the same way as in Year 1. These calculations are presented in Figure 5.23.

$Y_1 = Y_0 \times A$

Y_0 = [0.150, 0.270, 0.380, 0.120, 0.080]

A:

0.2	0.7	0.1	0	0
0	0.9	0.1	0	0
0	0	0.75	0.2	0.05
0	0	0	0.7	0.3
0	0	0	0	1

Y_1 = [0.030, 0.348, 0.327, 0.160, 0.135]

=0.15*0.2 ; =0.15*0.7+0.27*0.9

LOS_1 = (97*0.03+90.5*0.348+84.5*0.327+77.5*0.16+71*0.135) = **84.0**

E_1 = [$0.00, $0.00, $0.00, $0.00, $0.00] = **Average Unit Cost** **$0.00**

$=C_1 * Y_{1,1}$ =$0.00*0.03 ; $=C_2 * Y_{1,2}$ =$0.00*0.348

Figure 5.22. Values of Y, E, and LOS for Year 1

$Y_2 = Y_1 \times B$

Y_1 = [0.030, 0.348, 0.327, 0.160, 0.135]

B:

0.2	0.7	0.1	0	0
0	1	0	0	0
0	0	0.9	0.1	0
0	0	0.05	0.95	0
0.7	0.1	0.15	0.05	0

Y_2 = [0.101, 0.383, 0.326, 0.191, 0.000]

=0.03*0.2+0.135*0.7 ; =0.03*0.7+0.348*1+0.135*0.1

LOS_2 = (97*0.101+90.5*0.383+84.5*0.326+77.5*0.191+71*0) = **86.7**

E_2 = [$0.00, $22.95, $21.16, $12.06, $0.00] = **Average Unit Cost** **$56.17**

$=C_1 * Y_{2,1}$ =$0.00*0.101 ; $=C_2 * Y_{2,2}$ =$60.00*0.383

Figure 5.23. Values of Y, E, and LOS for Year 2

In this example the simulation ran up to year 10. At the end of the simulation process, a distribution of the average condition of the assets throughout the ten-year period was obtained. According to this average distribution, an average of 3% of the asset item in the entire population was in state condition 1, 43% in state condition 2, 28% in state condition 3, 22% in state condition 4, and 4% in state condition 5. The same average distribution is provided for the costs incurred.

<u>Step 6. Output from Simulation.</u> Finally, the output section provides a summary of the results both in tabular and graphical format. A graphical representation of the results from each year is presented in the two graphs shown at the bottom of Figure 5.20. The simulation shown in Figure 5.20 constitutes half of the simulation process, since the process must be repeated with the maintenance actions adopted under performance-based work. A description of the comparisons that can be performed with both simulated results is addressed in Step 7.

<u>Step 7. Comparison.</u> To illustrate the comparisons that can be made, let's perform the second half of the simulation process, in which the policies adopted under performance-based work are applied. Table 5.18 summarizes the conditional prediction matrix applicable to the same asset item considered in the example presented in Figure 5.20, but related to performance-based specifications.

Table 5.18. Example of a Condition Prediction Matrix under Performance-based Specifications

From Condition State	To Condition State				
	State 1	State 2	State 3	State 4	State 5
State 1	0.2	0.7	0.1	0	0
State 2	0	1	0	0	0
State 3	0	0.2	0.8	0	0
State 4	0.5	0.1	0.25	0.15	0
State 5	0.80	0.15	0.03	0.02	0

The costs associated to this maintenance action are listed in Table 5.19.

Table 5.19. Example of Maintenance Activity Costs under Performance-based Specifications

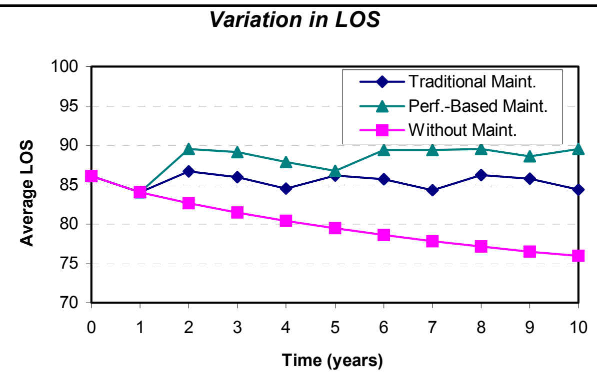
Condition State	Treatment Cost
State 1	$0.00
State 2	$65.00
State 3	$78.00
State 4	$93.00
State 5	$125.00

The matrices presented in Tables 5.18 and 5.19 were substituted in the format presented in Figure 5.20 to tabulate the final results when performance-based policies are used. Figure 5.24

presents a graphic representation of the final results obtained from the simulation of both scenarios. Based on the hypothetical data used in this example, the performance level under performance-based specifications tends to be higher than the performance level obtained by implementing the policies associated with traditional maintenance specifications throughout the 10-year period. However, the costs associated with performance-based specifications are relatively higher than the ones associated to traditional maintenance specifications. The next step in the analysis is to run the simulation once again for the traditional maintenance scenario, but this time adjust the policies in such a way that the agency will end up expending at a rate close to the one used under performance-based work. After performing this analysis, conclusions can be reached regarding the efficiency of the PBRM initiative. For instance, if, after increasing the expenditure rate similar to the one in performance-based work, the performance levels are still lower than the ones obtained by applying performance-based specifications, then the agency accrued positive level of savings. On the other hand, if the condition levels end up being higher than the ones obtained under performance-based work, then it can be concluded that if the implementing agency spent in traditional maintenance at least at the same rate as under performance-based work it will get higher performance levels, which will make the use of traditional maintenance specifications more effective.

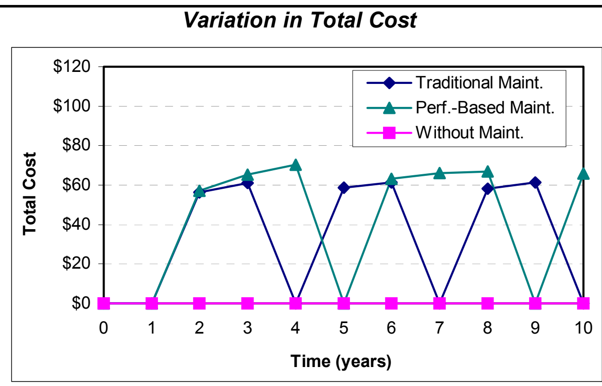
5.4. STAGE 4: REPORTING FOR CE EVALUATION

The reporting section for this component basically consists of presenting a comparison of the findings obtained from both approaches, specially the findings from the study of the level of service versus the expenditures discussed in the previous sections. The reporting techniques discussed in chapter 4 as well as similar graphs and tables to the ones presented in the examples of this chapter can be used to support this report.



In Average:

	State 1	State 2	State 3	State 4	State 5
TMS	3%	43%	28%	22%	4%
PBS	4%	65%	25%	4%	2%



In Average:

	State 1	State 2	State 3	State 4	State 5
TMS	$0.00	$16.02	$10.86	$8.79	$0.00
PBS	$0.00	$31.34	$12.91	$1.03	$0.19

Figure 5.24. Comparison between Performance-Based and Traditional Specifications using Markovian Chains

5.5. SUMMARY

Transportation agencies are always searching for innovative approaches that will help them maintain the infrastructure system at the best possible condition by investing the minimum amount of money. The implementation of performance-based specifications in the roadway maintenance arena is a good example of this initiative. However, once the approach has been implemented, reliable and comprehensive studies must be done to certify that indeed the new approach is cost-efficient. It was the intent in this chapter to define methodologies that that can be used by transportation agencies to assess the cost savings, if any, accrued as a result of adopting performance-based road maintenance specifications. A combination of cost-estimating techniques and probability analysis were incorporated in these methodologies to serve the purpose of the evaluation.

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CHAPTER 6

TIMELINESS OF RESPONSE EVALUATION

Evaluating the timeliness of response to service requests is extremely important because if the contractor does not address service requests in a prompt manner, then the safety of the traveling public can be placed at serious risk. Road administrators must define, in addition to the technical condition indicators presented in Chapter four, performance measures that establish acceptable response times by asset type and/or service category. These criteria are normally referred to as timeliness requirements and have been considered in this component of the framework. This chapter presents a detailed description of the proposed methodology to evaluate the timeliness of response in PBRM.

6.1. COMPONENT STRUCTURE

A graphic representation of the proposed methodology to evaluate the timeliness of response (TOR) in PBRM is presented in Figure 6.1. A detailed description of the elements included within each section follows.

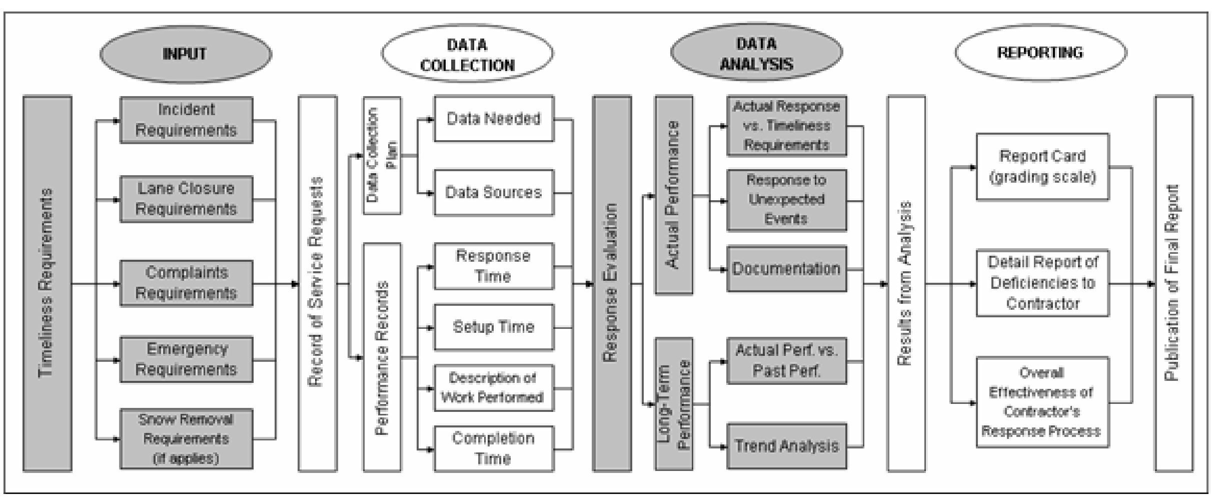


Figure 6.1. Methodology to Evaluate Timeliness of Response (TOR) in PBRM

6.2. STAGE 1: INPUT FOR TOR EVALUATION

The input that is required by transportation agencies to properly evaluate the contractor's timeliness of response to service request is basically the definition of acceptable performance standards addressing timeliness requirements. Defining appropriate timeliness requirements is a great challenge. The main goal when defining these requirements is to assure the traveling public has minimum exposure to hazardous environments at all times (Poister 1983, PBMSIG 1995, FHWA 1999, Segal et al. 2002). Timeliness requirements can be specified for categories such as:

1) *Services.* This category relates to the events associated to the contractor's response to service request. Some of these requests required the removal of debris and road kill, the installation of temporary electronic signs to alert the traveling public of any events or delays, installation of temporary signs, and trimming of any tree, among others. Timeliness requirement may vary by service type.

2) *Incidents.* This category includes incidents of minor severity in which minor assistance from the contractor's personnel is required. Agencies may specify the contractor to respond to these requests in a maximum acceptable time frame (i.e., it may depend on the working shift). Some examples of events considered as part of this category are: vehicles and truck break downs, minor accidents or collisions, and other events requiring minor intervention from the contractor.

3) *Lane Closures*. In many instances the closure of roadway lanes to traffic is necessary in order to properly address an event (e.g., incidents, emergencies, repairs, and special events). Depending on the type of event, agencies may require a maximum time frame for the closure of these lanes to traffic. For instance, when an incident occur, an agency may required the contractor to close a lane to the traffic and setup all the traffic control devices in less than 20 minutes after notification of the event.

4) *Emergencies.* This category includes incidents of major severity in which the response from several emergency units is required. These types of incidents may require lane closures to traffic, the use of temporary electronic sings to alert traffic of possible delays, and good

coordination from the contractor with the emergency personnel responding to the event. Agencies may define timeliness requirements associated to the maximum acceptable arrival time to the site (after notification), time requirements for the notification of traffic delays, and special time frames for the setup of traffic control devices, among others.

5) *Repairs.* In many cases, the repair of several deficiencies in elements of the roadway system must be performed in a timely manner, since they may become hazards for the traveling public. Different timeliness requirements can be specified depending on the severity of the damage. For instance, two different requirements can be specified for the repair of guardrails. If the guardrail is damaged, but it is still functional, then the contractor is required to fix the guardrail in 7 days. However, if the guardrail is badly damaged, then the contractor may be required to fix the guardrail in only 2 days. This scenario applies to many other assets in the roadway system, such as: regulatory signs, potholes, and impact attenuators, among others.

6) *Snow Removal.* This category is one of the most important, since proper coordination and response is required from the contractor to maintain the roadway network in acceptable traveling conditions. Different timeliness requirements may be adopted depending on many aspects, such as: the road type (e.g., interstate, primary roads, secondary roads), storm severity, and lane type (e.g., main lane, shoulders).

All timeliness requirements (time related performance standards) to be defined by the agency for each service category must contain two criteria: (1) performance measure, and (2) performance target (Frost & Lithgow 1996, VDOT 1996, Baker 1999, Gentili & Erbetta 1997, Tomanelli 2003). A description of these criteria follows.

a) *Performance Measure*. The performance measure refers to the maximum acceptable time frame required to the contractor when responding to service requests. For instance, an agency may specify that the contractor should respond within twenty minutes (20 min.) for any incident requests during working hours, and within forty five minutes (45 min.) for any incident requests during non-working hours. Table 6.1 presents other examples of time related performance measures applicable to performance-based road maintenance initiatives (columns 3, 4, 6, and 8).

Notice from Table 6.1 timeliness requirements were specified for the following three types of responses:

i) *Arriving Time.* The arriving time refers to the maximum acceptable elapsed time between the request notification (call received by the contractor) and the arriving of the contractor's personnel to the site.

ii) *Lane Closure.* The lane closure criteria basically refers to the maximum acceptable time frame between the arriving of the contractor's personnel to the site and the setup of traffic control devices and closure of lanes to traffic, if necessary.

iii) *Completion of Work.* This criteria refers to the maximum allowed time to finish the work required as part of a given service request. These requirements are mostly related to service requests for the repair of assets in non-acceptable condition that can become hazards to the traveling public.

b) *Performance Target*. In addition to performance measures, it is required the implementing agency defines performance targets that specify acceptable levels of compliance regarding the timeliness of response. These requirements will serve as the basis to evaluate if the actual response times from the contractor are acceptable or not. For instance, the agency may specify 90% of the time the contractor has to meet the twenty minutes requirement for incident requests during both working and non-working hours. Additional examples of these performance targets are presented in columns 5, 7, and 9 of Table 6.1.

.

Table 6.1. Example of Time Related Performance Standards

(a) Services, Incidents, Emergencies, and Repairs

Category	Type	Arrival Time			Lane Closure Time		Time to Finish Work	
		Performance Measure		Target	Performance Measure	Target	Performance Measure	Target
		During Working Hours	During Non-Working Hours					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Services	Temporary Electronic Sign	20 Min.	45 Min.	90%	N/A	N/A	N/A	N/A
	Road Kill Removal	15 Min.	30 Min.	90%	19 Min.	90%	45 Min.	98%
Incidents	Regular	20 Min.	45 Min.	90%	20 Min.	90%	N/A	N/A
	Immediate Attention	15 Min.	30 Min.	95%	20 Min.	90%	N/A	N/A
Emergencies	Any	15 Min.	30 Min.	95%	20 Min.	90%	N/A	N/A
Repairs	Fix Regulatory Signs-Badly Damaged	20 Min.	45 Min.	95%	20 Min.	90%	24 hours	98%
	Fix Guardrail-Damaged but Functional	N/A	N/A	N/A	N/A	N/A	7 days	95%
	Fix Luminaries	N/A	N/A	N/A	N/A	N/A	7 days	95%
	Fix Truck Ramp	N/A	N/A	N/A	N/A	N/A	2 days	95%
	Fix Impact Attenuators	N/A	N/A	N/A	N/A	N/A	7 days	95%
	Fix Potholes	N/A	N/A	N/A	N/A	N/A	2 days	95%

(b) Snow Removal

Category	Type	Performance Measures		Target
Snow Removal	Interstate	During Storm	At least 1 lane of travel must be operating in each direction of traffic	99%
		After Storm Cessation	All traffic lanes must be open within 24 hours of storm cessation or termination	99%
			All shoulders lanes must be open within 48 hours of storm cessation or termination	99%

6.3. STAGE 2: DATA COLLECTION FOR TOR EVALUATION

On of the most important aspect, which needs to be taken in consideration to guarantee the success of the Timeliness of Response (TOR) evaluation, is the definition and implementation of a very systematic and well-documented process to collect timely, accurate, and reliable information related to the contractors response to service requests (PBMSIG 1995, Zietlow 2001, Tomanelli 2003). When defining the data collection process, transportation agencies must address issues such as: who is responsible for keeping the response time's records and what type of information must be collected in order to assure the proper implementation of proposed procedure for timeliness performance evaluation (e.g., Time Sheets). Each one of these issues is addressed below.

i) *Responsibility of Records.* Implementing agencies should determine who will be responsible within the agency for collecting and maintaining information regarding contractor's response. The individual(s) conducting this task must certify that all necessary information is accurately collected for every single service request. This job can be done with the help of a Time Sheet, which is discussed next.

ii) *Time Sheets.* The Time Sheet is basically an efficient mechanism to record all the necessary information required to effectively conduct the timeliness performance evaluation. The Time Sheet must be carefully design to guarantee the completeness of the records. The information collected in the Time Sheet for each service request should include at least the following: (1) time when service was requested, (2) time of arrival, (3) time when setup of traffic control devices was finished (if required), (4) description of work performed (e.g., location and type of service), (5) personnel involved, and (6) completion time. This information will allow the agency to compute and compare the contractor response times to the corresponding timeliness requirements. Table 6.2 presents an example of a Time Sheet that can be used by implementing agencies to collect the necessary information to support the proposed evaluation methodology. Notice that several hypothetical records have been included in the table to provide a better understanding of the type of information needed. These hypothetical records will be used in the Data Analysis Section to better illustrate how to finally assess the compliance of the contractor to timeliness requirements.

Table 6.2. Example of Time Sheet Used to Keep Response Time Related Records

Service Request						Timeliness Performance Measure				Contractor's Actual Response				
Number	Date	Call Received From	Time Call Received	Location	Description of Request	Category	Arrival Time	Lane Closure Time	Time to Finish Work	Time Arrived	Time Lane Closure Finished	Type of Traffic Control Required	Date Work Finished	Time Cleared
(2)	(1)	(3)	(4)	(5)	(6)	(7)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	11/3/2003	Vickie Bright	12:27 PM	MP 41 NB	Repair work zone sign damaged by incident	Repair, During Working Hours	20 Min.	20 Min.	24 hours	12:45 PM	N/A	None	11/3/2003	1:27 PM
2	11/7/2003	Thomas Ford	11:10 AM	MP 4.5 NB	Assist 2 car in accident on left shoulder	Incident requiring lane closure, During Working Hours	20 Min.	20 Min.	N/A	11:31 AM	11:55 AM	Left lane closure	11/7/2003	12:30 PM
3	11/8/2003	Diane Williams	5:45 PM	MP 74 SB	Assist in trailer break down	Incident, During Non-working Hours	45 Min.	20 Min.	N/A	5:55 PM	N/A	None	11/8/2003	6:50 PM
4	11/8/2003	Peter Mills	6:45 AM	MP 2 EB	Guardrail Repair - damaged but functional	Repair, During Non-working Hours	N/A	N/A	7 days	N/A	N/A	None	11/10/2003	1:50 PM
5	11/9/2003	Lisa Hunt	10:45 PM	MP 112 SB	Gas Truck Spill	Emergency, During Non-working Hours	30 Min.	20 Min.	N/A	11:12 PM	11:27 PM	Right lane & shoulder closure	11/10/2003	2:50 AM
6	11/10/2003	John Tomas	3:45 PM	MP 32 NB	Install Temporary electronic sign advising traffic delays	Service, During Working Hours	20 Min.	20 Min.	N/A	3:57 PM	N/A	None	11/10/2003	6:50 PM
7	11/12/2003	Daniel Cook	1:05 PM	MP 81 WB	Road Kill Removal	Service - Immediate attention, During Working Hours	15 Min.	20 Min.	45 Min.	1:13 PM	N/A	None	11/12/2003	1:23 PM

6.4. STAGE 3: DATA ANALYSIS FOR TOR EVALUATION

The main objective when analyzing the response times is to be able to assess the compliance of the contractor to timeliness requirements (Frost & Lithgow 1996, VDOT 1996, Baker 1999, Gentili & Erbetta 1997). The compliance of the contractor to timeliness requirements should be evaluated by conducting at least the following: (a) a comparison of the actual response times versus timeliness standards established in the contractual agreement for each service request, (b) the long-term performance or commitment of the contractor, and (c) a response evaluation of the contractor's performance during unexpected events (e.g., storms, and floods). The recommended procedures to evaluate each one of these areas are discussed in Sections 6.4.1, 6.4.2, and 6.4.3, respectively.

6.4.1. Actual Response Times versus Timeliness Requirements

As previously stated, the main objective of the timeliness evaluation is to actually compare the contractors response times to service requests with the performance standards or timeliness requirements specified by the agency in the contractual agreement. The information needed to conduct this comparison was described in the previous section. Assuming this information was properly collected by the agency, the next step will be to process the recorded data in such a way it will allow the agency to perform such comparison. The following steps summarize the data analysis process required to assess the compliance of the contractor to timeliness performance standards. Refer to Flowchart B.9 (Appendix B) for a graphical representation of these steps.

Step 1. Calculation of Response Times for each Response Category. The first step of the analysis process is to calculate the response times of the contractor to each service request. For instance, if the contractual agreement specifies the contractor must arrive to the site within twenty minutes of receiving the request, then the arrival response time will be calculated by obtaining the difference between the time when the contractor received the call and the time when the contractor personnel arrived to the site. To better illustrate this step, let's consider the hypothetical service requests presented in Table 6.2. Seven records are depicted in this table. Each record may contain information regarding three response types: (1) arriving time, (2) lane closure time, and (3) time to complete the job. When applicable, timeliness requirements have been specified for each one of these response types. Notice that information such as the time at which the request was made, the time when lane closures where finished, and the time when the work was finished will allow the agency to compute the response time of the contractor to each category and later on compare those responses with the corresponding performance measures. Table 6.3 presents a summary of the calculated response times for each service request. For instance, for service request number two (2), incident during working hours, the contractor was required to close the left lane due to an accident between two vehicles. The request call was received at 11:10 a.m. and the contractor personnel arrived to the site at 11:31 a.m. Thus, it took the contractor 21 minutes to arrive to the site. In addition, it took the contractor personnel 24 minutes to setup the necessary traffic control devices to close the lane, since they arrived to the site at 11:31 a.m. and finished the lane closure setup at 11:55 a.m. In this particular request, no work completion requirements applied.

Table 6.3. Example of Response Times Calculations

Request		Response Time					
		Arrival		Lane Closure		Finish Work	
Number (1)	Category (2)	Time (3)	Met PM? (4)	Time (5)	Met PM? (6)	Time (7)	Met PM? (8)
1	Repair, During Working Hours	18 Min.	Yes	N/A	N/A	42 Min.	Yes
2	Incident requiring lane closure, During Working Hours	21 Min.	No	24 Min.	No	N/A	N/A
3	Incident, During Non-working Hours	10 Min.	Yes	N/A	N/A	N/A	N/A
4	Repair, During Non-working Hours	N/A	N/A	N/A	N/A	2 days	Yes
5	Emergency, During Non-working Hours	27 Min.	Yes	15 Min.	Yes	N/A	N/A
6	Service, During Working Hours	12 Min.	Yes	N/A	N/A	N/A	N/A
7	Service -Immediate attention, During Working Hours	8 Min.	Yes	N/A	N/A	10 Min.	Yes

Step 2. Comparison of Response Times with Performance Measures. Once the response times are computed, the next step will be to compare those responses with their corresponding timeliness performance measures. Let's consider the response times computed for hypothetical service request number 2 (refer to Table 6.3). Since it took the contractor 21 minutes to arrive to the site, the contractor failed to meet the 20 minutes timeliness requirement established by the agency for this particular service category. In addition, it took the contractor personnel 24 minutes to setup the necessary traffic control devices to close the left lane to the traveling public, which lead to a failure of the 20 minutes requirement for lane closure. Columns 4, 6, and 8 in Table 6.3 summarizes the compliance of the contractor (based on the response times computed in Table 6.3) to the timeliness performance measures specified for each hypothetical service request presented in Table 6.2.

Step 3. Collection of Response Time Statistics for each Request Category. The next step of the process is to collect the statistics to be used to evaluate the compliance of the contractor to time related performance targets. The objective of the statistics is to report the frequency of passing and failing events with respect to the performance measures. This statistics can be reported by request category and even for different periods of time (e.g., quarterly reports), as shown in Tables 6.4 through 6.6. The statistics presented in the fourth quarter on these tables are based on the response times summarized in Table 6.3. Table 6.4 summarizes the frequencies related to the arriving times, whereas Tables 6.5 and 6.6 summarizes the frequencies associated to lane closure and completion of work, respectively. For instance, let's consider the first record presented in Table 6.4. This record correspond to service request number six (6), in which a temporary electronic sign was required by the agency to the contractor in order to alert the traveling public of possible delays due to an accident a couple of miles ahead. Since the contractor responded within the time frame required by the agency, the arriving response time for this event was counted as one event passing and zero failing, which lead to a 100% passing rate. By performing this type of analysis for each one of the hypothetical service requests considered in this example, one could obtained the statistics presented in Tables 6.4 through 6.6.

Table 6.4. Example of Response Times Statistics for Arriving Time

Request Number	Category	Performance Measure	Performance Target	Status	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		Overall		
					Qty	%	Qty	%	Qty	%	Qty	% Meeting PM	Qty	% Meeting PM	Met Target?
6	Service-During Working Hours	20 Min.	90%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
7	Immediate Service-During Working Hours	15 Min.	95%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
2	Incidents-During Working Hours	20 Min.	90%	Met PM							0	0%	0	**0%**	**No**
				Failed PM							1		1		
3	Incidents-During Non-Working Hours	45 Min.	90%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
5	Emergency-During Non-Working Hours	30 Min.	95%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
1	Sign Repair-During Working Hours	20 Min.	95%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		

Table 6.5. Example of Response Times Statistics for Lane Closure

Request Number	Category	Performance Measure	Performance Target	Status	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		Overall		
					Qty	%	Qty	%	Qty	%	Qty	% Meeting PM	Qty	% Meeting PM	Met Target?
2	Incidents-During Working Hours	20 Min.	90%	Met PM							0	0%	0	**0%**	**No**
				Failed PM							1		1		
5	Emergency-During Non-Working Hours	20 Min.	90%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		

Table 6.6. Example of Response times Statistics for Completion of Work

Request Number	Category	Performance Measure	Performance Target	Status	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		Overall		
					Qty	%	Qty	%	Qty	%	Qty	% Meeting PM	Qty	% Meeting PM	Met Target?
7	Immediate Service-During Working Hours	45 Min.	98%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
1	Repairs-During Working Hours	24 hours	98%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		
4	Repairs-During Non-Working Hours	7 days	95%	Met PM							1	100%	1	**100%**	**Yes**
				Failed PM							0		0		

<u>*Step 4. Comparison of Response Time Statistics with Performance Targets.*</u> Once the statistics in Step 3 are obtained, the remaining step will be to compare those statistics, specifically the passing rates, with the corresponding performance targets associated to each service category. Once again, let's take a look of service request number 6 (i.e., arriving time) considered in the example presented in the previous step. For this particular request, the specified performance target was 98%. This means the contractor must met the performance targets related to the arriving time in 98% of the service request received. In particular example, the contractor met the target specified by the agency because an actual passing rate equal to 100% was obtained (Actual=100%, Target=98%). When this procedure is done for all corresponding service request categories, then an overall evaluation of the actual compliance of the contractor to timeliness requirements can be reported by the agency. A graphical representation of the comparison of actual passing rates versus the performance targets is presented in Figure 6.2. According to the information depicted in the figure, it can be concluded the contractor failed to meet the targets only for the arriving time (Actual=50%, Target=90%) and lane closure time (Actual=0%, Target=90%) requirements associated to the incident request category.

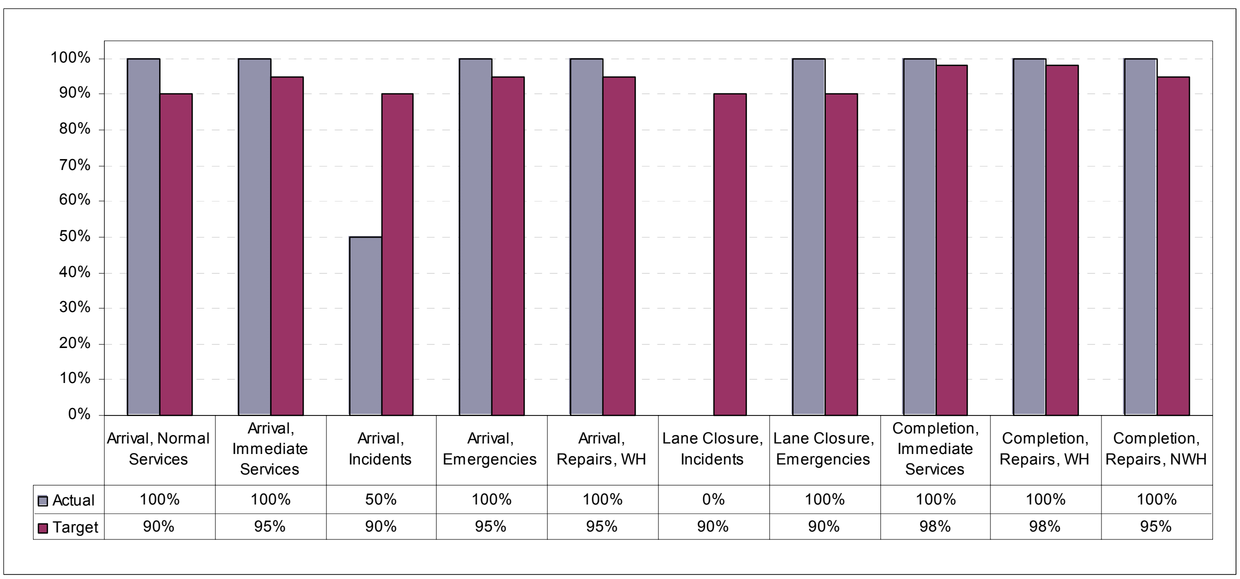
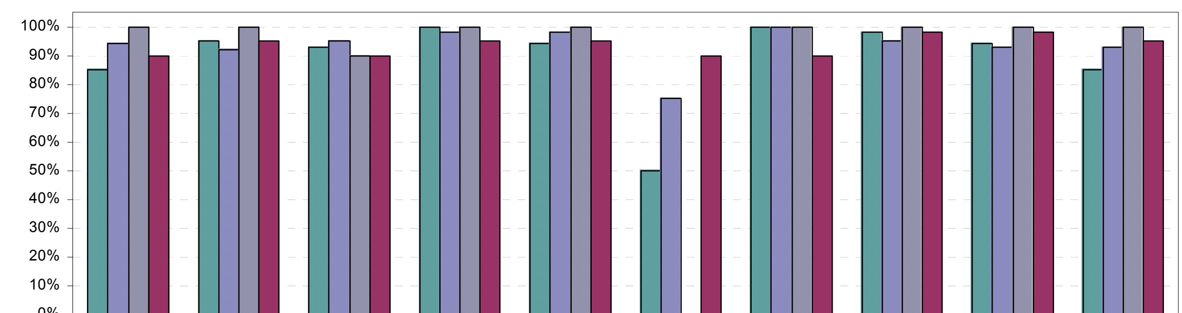


Figure 6.2. Graphical Representation of the Compliance to Timeliness Performance Targets

6.4.2. Long-Term Performance

It is important transportation agencies not only evaluate the actual performance of the contractor to timeliness requirement, but also perform a long-term response evaluation in order to assess the continuous commitment of the contractor in keeping a safer roadway system for the traveling public. In order to make a reliable long-term evaluation it is important the implementing agencies maintain a consistent and accurate record keeping of the contractor's response to service requests, as previously stated. If these records are collected and the analysis previously discussed is conducted for several periods of times, then long-term evaluations such as the one presented in Figure 6.3 can be performed. The example presented in Figure 6.3 is a continuation of the example used in the previous steps. Notice the results from the analysis conducted in the previous step are depicted in the year 2003 and the target category. The hypothetical data included for years 2001 and 2002 were created to better illustrate the long-term performance example. From this hypothetical scenario, it can be concluded the contractor is having problems on meeting the performance targets specified for lane closures on the incident request category.



	Arrival, Normal Services	Arrival, Immediate Services	Arrival, Incidents	Arrival, Emergencies	Arrival, Repairs, WH	Lane Closure, Incidents	Lane Closure, Emergencies	Completion, Immediate Services	Completion, Repairs, WH	Completion, Repairs, NWH
2001	85%	95%	93%	100%	94%	50%	100%	98%	94%	85%
2002	94%	92%	95%	98%	98%	75%	100%	95%	93%	93%
2003	100%	100%	90%	100%	100%	0%	100%	100%	100%	100%
Target	90%	95%	90%	95%	95%	90%	90%	98%	98%	95%

Figure 6.3. Example of a Graphic Representation of a Long-term Timeliness Performance Evaluation

6.4.3. Response to Unexpected Events

In addition to respond to daily events associated to the maintenance of the roadway system, the contractor may have to deal also with some other events which are less probable to occur, such as hurricanes, tornados, and floods, among others. These types of events may cause serious damages to many of the asset items within the roadway system, requiring the contractor to make a significant effort and investment in putting the system back to at least the condition at which the system was before the event took place. Moreover, this type of events will required from the contractor a lot of coordination with emergency response and disaster response teams dealing with the incident.

Since the respond and coordination of the contractor in these types of events is crucial to maintain the safety of the traveling public, it is important agencies monitor and evaluate the performance of the contractor in areas such as: (1) proper use of people, materials, and equipment to restore the condition of the assets, (2) proper timely response to service requests, (3) efficient management of temporary traffic control devices and lane closures (if necessary), (4) proper coordination with emergency units and parties involve in the management of the incident, and (5) effective notification to the traveling public of areas of concern related to the traffic, among others. It is evident agencies must paid close attention to the performance of the contractor during and after the occurrence of these types of events, since the contractor will be conducting under irregular conditions. Feedback from personnel and other agencies (e.g., Police Departments, Emergency Management Units, Fire Departments) directly involve with the contractor must be considered in this evaluation.

6.5. STAGE 4: REPORTING FOR TOR EVALUATION

Similar reports to the ones previously discussed for the LOS evaluation should be produced at this stage (e.g., Report Card, Deficiencies to Contractor, and Effectiveness of Contractor's Response Process). However, the focus of these reports has to be on the overall compliance of the contractor to timeliness requirements. Figures and tables similar to the ones presented in the previous section can be used to report the findings from the analysis. For example, a report card such as the one shown in Figure 6.4 can be incorporated in the performance report as a tool to better illustrate the findings from the long-term performance evaluation presented in Figure 6.3. In this report card, an A grade was assigned if the actual passing rate was greater or equal to the performance target, a B grade was assigned if the actual passing rate was greater or equal to 95% of the performance target and lower than the target, a C grade was assigned if the actual passing rate was greater or equal to 90% of the performance target and lower than 95% of the performance target, a D grade was assigned if the actual passing rate was greater or equal to 85%

of the performance target and lower than 90% of the performance target, and finally, an F grade was assigned if the actual passing rate was lower that 85% of performance target.

Category	Grade		
	2001	2002	2003
Arrival, Normal Services	*C*	*A*	*A*
Arrival, Immediate Services	*A*	*B*	*A*
Arrival, Incidents	*A*	*A*	*A*
Arrival, Emergencies	*A*	*A*	*A*
Arrival, Repairs, WH	*B*	*A*	*A*
Lane Closure, Incidents	*F*	*F*	*F*
Lane Closure, Emergencies	*A*	*A*	*A*
Completion, Immediate Services	*A*	*B*	*A*
Completion, Repairs, WH	*B*	*C*	*A*
Completion, Repairs, NWH	*D*	*B*	*A*

Figure 6.4. Example of a Report Card for a Timeliness of Response Long-Term Evaluation

6.6. SUMMARY

The prompt response of the contractor to service request is crucial to control potential hazards. In order for transportation agencies to be able to properly monitor the performance of the contractor in this area, timeliness requirements must be define and included as part of the contractual specifications under performance-based work. This chapter provided examples on of typical time related standards. Moreover, valid techniques and procedures that agencies can use to evaluate the contractor's compliance to timeliness requirements were defined.

6.7. REFERENCES

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CHAPTER 7

SAFETY PROCEDURES EVALUATION

Highway safety is often stated to be the most important goal by transportation agencies (ITE 1993). For this reason, it is required to continuously monitor and evaluate the safety procedures implemented by personnel conducting highway related works, which in our case are outcome-based highway maintenance activities. This chapter presents a detailed description of the proposed methodology to evaluate Safety Procedures (*SP*) in PBRM.

7.1. COMPONENT STRUCTURE

Figure 7.1 presents a graphical representation of the proposed methodology to evaluate safety procedures in PBRM. A detail description of the elements included in each section of Figure 7.1 follows.

7.2. STAGE 1: INPUT FOR SP EVALUATION

Since safety is the major priority for transportation agencies, they must establish, improve, and clearly communicate the organization's safety policies and safety goals to potential contractors conducting road maintenance activities in order to assure an effective implementation of a safety program (ITE 1993, FHWA 2000, RIP 2002). In order to achieve this goal in PBRM, it is strongly recommended that before transportation agencies establish any contractual agreement for performance-based road maintenance services, they must appoint a safety committee who will be responsible to establish or revise the agency safety goals, revise and improve agency safety requirements, define performance safety measures to be used to evaluate the contractor's performance, and define additional criteria to evaluate the contractor's safety program (ITE 1993, Hinze & Piepho 1995, Jaselskis et al. 1996, FHA 2000). These criteria will serve as the input to the proposed methodology for assessing the compliance to safety requirement in PBRM. A detailed description of these criteria follows.

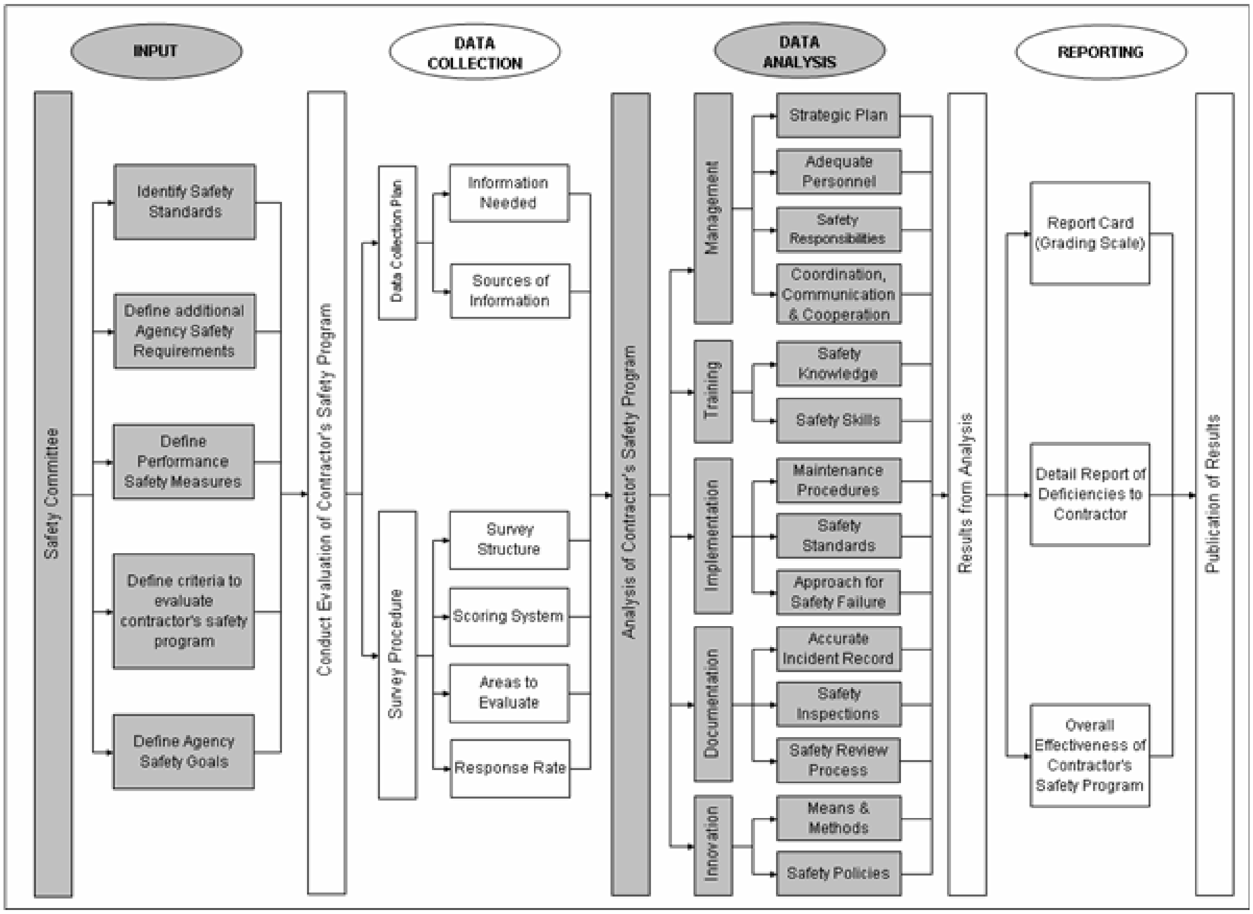


Figure 7.1. Methodology to Evaluate the Safety Procedures (SP) in PBRM

If transportation agencies maintain a high-profile and proactive role in the PBRM safety program development and monitoring, contractors will receive a clear message that safety indeed is a priority for the agency. It is understood that the appointment of a safety committee to be responsible for the review and identification of safety policies, goals, expectations, performance measures and other safety requirements will be the first step to assure that the deployment of the safety program will be a success. Some of the responsibilities of the safety committee in the development phase (i.e., input) are listed below:

1) *Definition of Agency Safety Policies, Goals, and Expectations.* In order to be able to assess the performance of the contractor there has to be a clear definition of what are the agency safety expectations. The agency safety expectations must be clearly stated and explained by the safety committee. The written policies must define the goals of the agency regarding safety and the

expectations with respect to the contractor's safety behavior and attitude towards the safety of employees and the traveling public. Making all these points clear to the contractor is only the first step toward the success of the safety program. The agency must continue enforcing these policies throughout the whole contract period in order to be sure that the contractor keeps the level of safety desired at all times.

2) *Identify Applicable Safety Regulations and Standards.* In addition to clearly state the agency policies and expectations, it is necessary the safety committee also specify the applicable safety standards and regulations that will provide guidelines and minimum legal requirements as to what constitute good safety operational practices. Standards such as the ones promulgated by the Occupational Safety and Health Administration (OSHA) are normally included as part of the requirements specified by the agency in any contractual agreement. Moreover, agencies may have additional safety requirements applicable to the maintenance of the roadway system. The purpose of these standards is to control hazards and prevent the occurrence of accidents by promoting the use of minimum acceptable safety practices that will lead to a sound maintenance safety program.

3) *Define Performance Safety Standards.* Since the contracting scheme considered in this research (*PBRM*) is based on outcome-based specifications, the agency must define performance measures to establish minimum acceptable safety levels required to the contractor when providing performance-based maintenance related activities in the roadway system. These performance safety standards will be used to determine the level of compliance of the contractor to the safety requirements and the agency safety goals and expectations. For instance, an agency may specify a performance measure stating the contractor must implement traffic control devices in accordance to the standards defined by the Federal Highway Administration (FHWA). In addition, the agency establishes a performance target which requires the contractor to meet the performance measure 95% of the time in which traffic control devices were required. Performance standards such as the one previously mentioned must be defined by the agency for all maintenance related activities that may promote a hazardous and un-safety environment. These performance standards should focus on the presence, rather than on the absence, of safety. However, penalties for non-compliance to minimum safety requirements can also be specified to

promote the implementation of safety practices and to prevent the contractor from becoming less committed to safety.

4) *Define criteria to evaluate Contractor's Safety Program.* It is evident, that in order for the contractor to meet the requirements established by the agency, it must create a plan that will address all the safety issues. However, the question the agency should ask is how good and comprehensive is the contractor's safety plan. In order to answer this question, let's consider the results from a research conducted by the Lincoln Nebraska Safety Council in 1981 (Reese & Eidson 1999). The objective of the study was to assess the effect of not having a viable safety program in place. The conclusions from the study were based on a comparison of responses from a survey of 143 companies in the United States. The level of confidence at which the conclusions are representative of the general opinion of the population exceeds 95 percent. The most important findings from this study are summarized in Table 7.1.

Table 7.1. Summary of Conclusions from LNSC Study

Conclusion	Statement	Findings
1	Do not have separate budget for safety	43% more accidents
2	No training for new hires	52% more accidents
3	No outside sources for safety training	59% more accidents
4	No specific training for supervisors	62% more accidents
5	Do not conduct safety inspections	40% more accidents
6	No written safety program	130% more accidents
7	No employee safety committees	74% more accidents
8	No membership in professional safety organizations	64% more accidents
9	No established system to recognize safety accomplishments	81% more accidents
10	Did not document/review accident reports	122% more accidents
11	Top management did not actively promote safety awareness	470% more accidents

It is evident, based on the findings from the LNSC Study, that in order to have an effective and comprehensive safety program, the agency must be sure the contractor addresses the following areas in their safety plan:

a) *Previous Commitment to Job Safety and Health*. It is understood that considering the contractor's past safety performance as part of the evaluation criteria for selecting prospective contractors to perform outcome-based road maintenance activities improves the probability that overall on-site safety performance will be good. There are several means by which transportation agencies can evaluate the contractor past performance. Some of them are: (1) Experience Modification Rate (EMR), (2) Recordable Incident Rate (RIR), (3) Cost Time Incident Rate (CTIR), and (4) on-site audits of contractor safety attitudes and practices.

b) *Personnel Training (New Employees and Supervisors).* According to Reese and Eidson 1999, previous experience shows a good safety program is based on a well planned and on-going training program. For this reason, it is considered as a crucial component as part of the contractor's safety program. A good training program at least should include the following: (1) meetings and talks focusing on safety awareness and hazard control, (2) trainings to improve job skills, and (3) orientations with respect to safety conduct, proper tools operation, use of protective equipment, emergency evacuation procedures, and first aid training.

c) *Written Safety and Health Program.* It is important the safety program be formalized in writing, since it will provide the foundation and guidelines to the contractor to remain consistent and well oriented regarding safety and health. This document must be submitted by the contractor to the agency as part of the documents to be included in any proposal package. The evaluation of this document should play a major role in the qualification of contractors to perform outcome-based road maintenance activities.

d) *Accident Investigation and Documentation.* A proactive program is based on good information. For this reason, transportation agencies must required the contractor to include as part of their safety program the reporting and investigation of all accidents and near misses in a timely manner. These reports will provide the contractor and the agency with the information required to identify areas for which immediate corrective actions must take place to avoid a repeated accidents. It is suggested that the agency required the submission of these reports at least in a monthly basis. They must include summary statistical results with information on near-misses, personal injuries, equipment related accidents, among others. In a study done for the Construction Industry Institute (CII) (de la Garza et al. 1998) it was found that those contractors who keep records and analyze accidents systematically had half the RIR and CTIR of those contractors who did not – what gets measured, gets improved.

e) *Safety Inspections and Audits.* In order to enable prompt feedback to the contractor and the agency of identified shortcomings, it is a good practice to perform daily inspections and audits by agency safety representatives and contractors supervisory personnel. For this reason, it is recommended transportation agencies evaluate the contractor's proposed approach with respect to safety inspections and audits.

Finally, it is extremely important transportation agencies clearly explain all safety requirement and performance standards to potential contractors before engaging in a contractual relationship with them. A good habit is to conduct an orientation meeting for interested contractors in which the agency asserts safety is a priority in the PBRM initiative. This meeting offers an excellent opportunity to reinforce safety requirements and highlight the areas to be evaluated regarding the Contractor's Safety Plan (to be submitted as part of final proposals to perform work under performance-based specifications). It is the agency responsibility, to evaluate the comprehensiveness and effectiveness of the Contractor Safety Plan with respect to at least the criteria previously mentioned.

7.3. STAGE 2: DATA COLLECTION FOR SP EVALUATION

The main objective of the safety procedures evaluation is to assess the level of effectiveness of the contractors safety program by collecting information (*receive* feedback or opinions) from people who are directly involved with the contractor in conducting daily maintenance activities for which the implementation of safety procedures is a requirement. Many methods are available for obtaining people's opinion. A survey is one of the most commonly used methods. It relies on directly asking people questions to get information. When surveys are properly contracted and administered on a statistical basis, it provides very reliable and representative feedback about the population's opinion. The intent is to use surveys, in our scenario, to assess the satisfaction and perspective of personnel that is working in a day-to-day basis with the contractor, in one way or the other, with respect to the compliance of the contractor to agency safety goals and regulations. Moreover, these evaluations will provide transportation agencies with an overall assessment of the contractor's commitment to safety.

When surveys are used as the mechanism to evaluate the effectiveness of a program, many factors needs to be taken in consideration in order to guarantee the reliability of the results. Many concerns should be addressed, such as:

- What type of survey type will be used (*questionnaires or interviews*)?
- How the survey will be administrated (*mail, telephone, or computer*)?
- What kind of structure the survey will have (*design*)?
- Who and how many will be asked questions (*sampling*)?
- When and how often the survey will be conducted (*frequency*)?
- How the survey will be tested before its deployment (*testing*)?
- How the information received from the survey will be analyzed (*data analysis*)?

Guidelines for addressing each one of these areas, which are extremely important for the success of the survey deployment, are provided in the following sections.

7.3.1. Survey Types

There are several techniques for conducting surveys, such as questionnaires, personal interviews, public hearings, focus groups, and informal conversations. Among these alternatives, questionnaires and personal interviews are deemed appropriate since they produce very useful and reliable results. However, even if personal interviews generally yield useful and reliable results, the use of questionnaires is normally preferred since they are cheaper to administer. With respect to public hearings, focus groups, and informal conversations, they are considered inefficient to serve our purpose since they usually introduce considerable bias to the results and input is mostly considered inadequate. In general, here is a brief description of the criteria that can be used for selecting the most appropriate survey type (Fink & Kosecoff 1998).

i) *<u>Reliability and Validity.</u>* The selection of the most reliable (i.e., consistent) and valid (i.e., accurate) method will depend on the specific purpose of the survey. For instance, if the intent is to improve consistency or homogeneity by promoting the use of a common scale to rate performance, then questionnaires may be considered as the optimum choice. The key factor is to perform a good job in designing the survey and making it user-friendly. These characteristics in a survey will always lead to a good reliability and validity.

ii) *Usefulness or Credibility of Results.* Usefulness and credibility is measure by the acceptance that respondents have towards the method used in the survey. For this reason, it is recommended to find out before administering the survey, which method will be more accepted by the respondents. Some times respondents have strong preferences (e.g., short telephone interview).

iii) *Costs and Time Frame.* Cost usually plays a major role in the selection of the survey type. The cost of conducting a survey will be affected depending on the factors such as: the technology used to deploy the survey, the required time to complete the study, the confidence at which the results wanted to be representative of the whole population (affects the percentage of the population to be sampled), the implementation of any special technology, among others. A comprehensive comparison, considering the factors previously mentioned, must be made among the different alternatives before finally selecting the most appropriate one.

iv) *Confidentiality.* People normally like to be sure that their point of view remains confidential. For this reason, survey administrators must emphasize that interviewers assure to the respondents that their opinions will remain confidential.

7.3.2. Survey Administration

Surveys can be administered in many ways. The most common are the use of mail (paper and pencil), telephone interviews, and computer based (through the web). The decision on what method to use will mostly depend on the costs and availability of resources to conduct the survey. A general rule of thumb is that if sufficient staff and supplies are available, then an in-house mail-in survey may be the ideal alternative. One additional option will be use an external consultant to perform the survey, but it is likely the cost will be higher in comparison to conducting the survey with in-house resources. If an external consultant is used to conduct the survey and in addition, the results from the survey must be available in a short period of time, then a telephone survey may be the best option. Such external consultants, specialized in telephone interviewing, may use a good number of well-trained interviewers to conduct the survey in a quick but reliable and valid manner. In addition, those firms normally provide the results from the survey in computer format, which facilitate and accelerate the analysis process.

Regardless of the type of survey chosen to evaluate the safety performance in roadway maintenance related activities, survey administrators must take in consideration also the following criteria when administering the survey (Stivers et al. 1997).

- *Select an Appropriate Time for Conducting the Survey.* Surveys must be conducted in periods of time in which the results cannot be biased, such as times when un-expected events took place.

- *State the Purpose and Importance of the Survey.* A statement describing the purpose and importance of the survey must be included or explained at the beginning of all surveys. For instance, if a mail-in survey is used, then the statement must be included in a cover letter to the respondent and even in the first page of the survey itself. On the other hand, if a survey is conducted through the telephone, the interviewer must clearly explain to the respondent the purpose and objective of the survey at the beginning of the conversation.

- *Assure Confidentiality and Appreciation for Survey Participation.* As previously stated, survey administrators must assure interviewers that their opinions and feedback will remain confidential. Equally important is to clearly appreciate the respondent for participating in the survey.

- *Provide Clear Instruction for Responding the Survey.* In addition to clearly stating the purpose and importance of the survey, it is extremely important each survey includes an explanation of how to respond to the forthcoming questions. This will minimize any bias introduced as a result of a misinterpretation in the way the survey should be answered.

7.3.3. Guidelines for Survey Design

When surveys are used as the mechanism to collect information, the survey must be designed in such a way the response from the person answering the survey is not biased by how the questions were structured and how the survey looks (Peterson 1998, Reese 1999, FHWA 2000, Peterson 2000). It is the responsibility of the survey designer to clearly specify the objective of the survey, the different areas to be evaluated, and the scoring system to be used to evaluate each area. A detail discussion on how to design efficient surveys and determining acceptable response rates follows.

7.3.3.1. Survey Structure

All surveys consist of (1) questions and (2) instructions focusing in different areas of interest. There are many ways in which the questions included as part of a survey can be written; however, there are only few techniques recommended to be used that helps minimize the introduction of any bias as a result of the way in which the question was structured and presented as well as the length of the question. Brief guidance on how these issues should be addressed in an effective and efficient way is provided below.

a) *Length.* The key is to keep the survey as short and concise as possible. However, the reality is the length of the survey will totally depend on the information needed and the respondents. Surveys designers must keep in mind that the length or the difficulty the questionnaire, the higher the probability respondents will get tired, which will lead to answer to last questions carelessly or not answer them at all. There are several techniques that can be use to keep the attention of the respondent in case that a long survey needs to be used. Among the most effective ones are: (1) grouping the questions in categories providing transitions between them, (2) avoiding the use of items that look alike, (3) placing short questions at the end because they can be answered quickly, and (4) using rating scales (e.g., discrete alternatives) that will facilitate the response.

b) *Format and Aesthetics.* The appearance and format of the questionnaire (in case of mail-in surveys) is crucial to minimize the chance to confuse or irritate respondents. For example, a questionnaire that does not provide sufficient space for recording answers will definitely reduce the efficiency rate at which the questions will be answered. This is critical since this creates a chain reaction starting by requiring more time to the respondent to answer the questionnaire, which may lead to the scenarios previously mentioned (e.g., responding to last questions carelessly or not responding them at all). For this reason, careful attention must be paid when deciding on the appearance and format of the questionnaire. Guidance regarding techniques that improve the appearance and format, such as the use of rating scales and the definition of specific areas to evaluate (i.e., grouping), are discussed in the following sections.

7.3.3.2. Areas to Evaluate

As previously stated, the data required to perform the Safety Procedure (SP) evaluation will be provided from the response of surveys submitted to the parties involved with the contractor (in one way or the other) when performing safety related activities. It is proposed as part of this framework that those surveys should focus at least on the evaluation of performance and compliance by the contractor with respect to the following five different areas:

(a) *Management Involvement* – In general, this area examines the commitment and involvement of the contractor's managers in the development and enforcement of a safety program. This evaluation has three objectives: (1) determines if the contractor defines strategic and action plans to address safety issues, (2) evaluates if adequate personnel was designated and empowered to coordinate and monitor the safety management process, and (3) if proper coordination, communication, and cooperation is provided by the contractor's safety personnel (Mohamed 2003).

(b) *Training Program* – The main objective of this area is to evaluate if the contractor provides an effective safety orientation and training program to in-house crews and also to sub-contractors with the objective to increase safety knowledge and consciousness (e.g., potential hazards, and safer work practices), and safety skills (e.g., proper handling of equipment) (Reese 1999).

(c) *Implementation (Operational Procedures)* - This area examines if the contractor and sub-contractors perform road maintenance procedures (including winter maintenance) according to national and statewide safety related standards, and according to the safety strategic plan (ITE 1993, FHWA 2000, Mohamed 2003).

(d) *Documentation* – This area examines the contractor's capabilities in collecting accurate incident records and safety inspections as part of an ongoing safety review process (Hilsop 1991).

(e) *Innovation* – This area examines the initiative of the contractor on searching for improved means and methods to ensure more effective safety practices, such as: better traffic control devices and techniques, better management of work zone operations, and reduction of work durations (promotes less exposure of traveling public to hazardous environments), among others (Budworth 1997, Cooper 2000, Flinn et al. 2000).

The respondent's assessment of the elements of concern within each one of these areas will provide transportation agencies with a general overview of the compliance of the contractor to safety requirements and the overall commitment of the contractor to safety.

7.3.3.3. Rating Scale

The implementation of a rating scale to quantitatively evaluate the performance of the contractor regarding the areas listed in the previous section was included as part of the proposed methodology to evaluate this component of the framework. The use of a rating scale is considered an appropriate way to measure the importance of various safety related issues associated to the maintenance of the roadway system. There are many techniques that can be used to effectively measure the perception of the respondent with respect to safety issues. Those techniques can be generalized in four categories: nominal, ordinal, interval, and ratio scales. It is up to the survey designer to determine which approach or combination of approaches will better suit the needs of the study. As a reference, a description and example of each one of these techniques follows.

a) *Nominal.* Nominal scales are also known as category response scales, since they are used to obtain answers from people regarding specific groups to which they belong: such as gender, affiliations, etc. An example of this type of scaling approach is presented in Figure 7.2.

Which agency do you represent?	
	Circle one
Department of Transportation	1
Police Department	2
Emergency Response Unit	3
Sub-contractor	4

Fugure 7.2. Example of a Nominal Scale

b) *Ordinal.* Ordinal scales basically require respondents to place alternatives in rank order. A measure of whether a respondent strongly agrees, disagrees, or strongly disagrees with the statement is considered an ordinal measure. Figure 7.3 presents an example of the use of an ordinal scale to assess the level of compliance to several safety requirements.

Please review the following list of activities and specify the the contractor's level of compliance, with respect to each activity, using the following scale:

Category	Code (Level Achieved)
Always	1
Most of the Time	2
Rarely	3
Never	4

Activity	Level Achived (circle one)
1) Written Safety Program	1 2 3 4
2) Comprehensive Incident Reports	1 2 3 4
3) Daily Safety Meetings	1 2 3 4
4) Participation of Sub-contractors personnel in safety training sessions	1 2 3 4

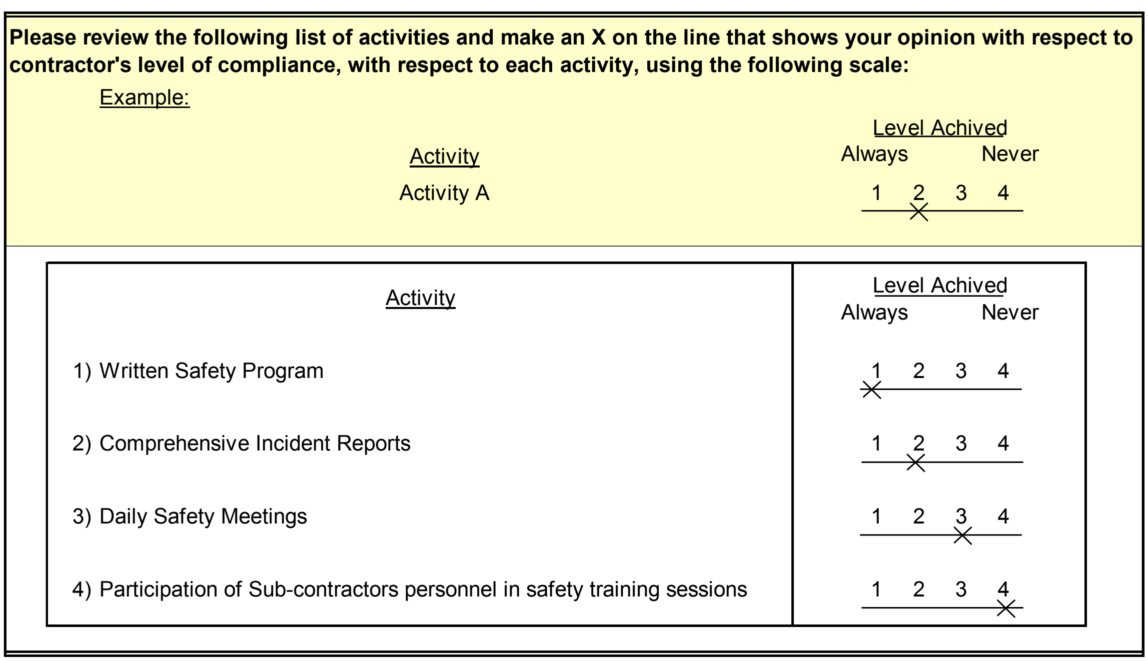
Fugure 7.3. Example of an Ordinal Scale

Both the Nominal and Ordinal rating scales are strongly recommended to be used in the surveys to evaluate the compliance and commitment of the contractor to safety in PBRM initiatives. The next two rating techniques will rarely be used in the surveys applicable to our scenario.

c) *Interval.* In this technique, alternatives are defined in terms of ranges or intervals. For example, the respondents may be required to choose between several expenditure ranges (e.g., $1,000-$2,000, $2,000-$3,000, $3,000-$4,000). In this technique, the difference between $1,000 and $2,000 means the same as the difference between $3,000 and $4,000. However, having an expenditure of $4,000 does not represent twice the amount of an expenditure of $2,000. If the desire is to make such a comparison, then ratio scales should be used.

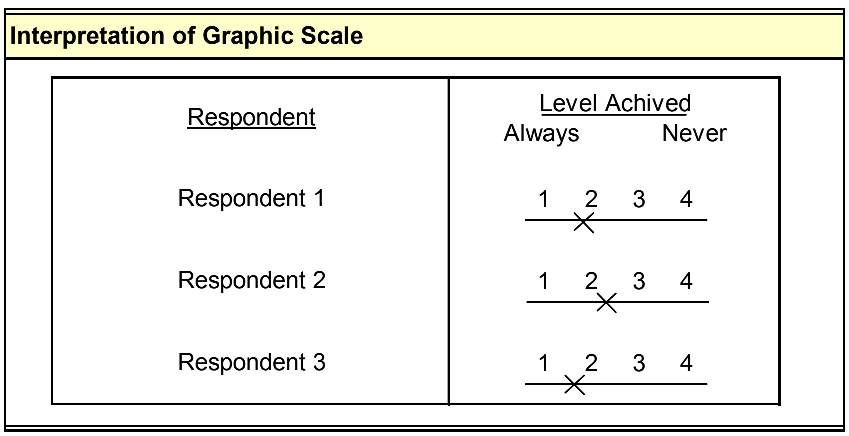
d) *Ratio.* In ratio scales units are equidistance from each other. Thus, an expenditure of $4,000 will represent twice the amount of an expenditure of $2,000. Ratio scales are rarely founded in surveys.

It is important to mention that in addition to the four techniques previously described, there is a technique known as graphical rating scales, which is normally used by survey designers in scenarios in which the interest is not to specify all the points on the scale. Figure 7.4 presents an illustration of this technique considering the example presented in Figure 7.3.



Fugure 7.4. Example of a Graphic Rating Scale

Graphic rating scales are basically a visual representation of the continuum of responses. This type of scale is relatively easy to use; however, there is one major disadvantage on using this technique as a rating alternative. The disadvantage is that in some cases this scale is difficult to interpret. This issue is illustrated in Figure 7.5. Notice that Respondent 1 clearly selected alternative 2 (most of the time). However, which are the actual ratings of Respondents 1 and 2? Is it 1, 2, or 3. Two assumptions can be made: (1) all ratings will be the ones closer to the nearest alternative or point, and (2) the rating line can be interpreted as a continuous rating scale, in which a value of 2.25 can be assigned to Respondent 2 and a value of 1.75 can be interpreted as the response from Respondent 3. The message here is that survey response evaluators must be aware of this problem in interpretation and should define a consistent approach to decide on the meaning of respondent's ratings.



Fugure 7.5. Illustration of Potential Problems with Graphic Rating Scales

7.3.4. Sampling Considerations

As it was done in the LOS evaluation, agencies should determine if the entire population will be surveyed or if only a portion of it (sample) will be considered in the evaluation, instead. As previously stated in Chapter four, sampling is normally considered as an alternative when assessing the response from the entire population will be costly and time consuming. If sampling is considered as the alternative approach, then several factors must be defined and taken into consideration. A description of those factors follows. The reader can refer to section 4.3.2.2 for a more detailed description of some basic sampling concepts not described in detailed in this section.

a) *Target Population (Sources of Information)*. As previously stated, the main purpose of this evaluation is to receive feedback from the personnel that is directly involved with the contractor in conducting daily maintenance activities that required safety procedures to be implemented. Activities that normally required the implementation of safety procedures are emergencies, road kill removal, traffic control, accidents, and snow removal operations, among others (ITE 1993, AASHTO 1999). The personnel that is normally in direct contact with the contractor when conducting these activities are Police Departments, Emergency Response Units, Sub-Contractors, and DOT Safety Coordinators. For this reason, it is proposed as part of the methodology adopted in this component to consider the personnel within these agencies as the sources of information to assess the compliance and commitment of the contractor to safety. The idea is to identify the individuals within each agency that have been in contact with the contractor, in one way or the other, in events in which the implementation of any area of the contractor's safety program have been required. The total number of people identified will constitute the whole population of respondents. Survey Administrators must keep in mind that if the total population of respondent is very small, then practically the response from all these individuals will be required in order to be able to report with high confidence that the results or the opinion form the respondents are representative of the point of view of the entire population. Guidance on how to determine the minimum number of responses required to be sampled is provided in point (c) (Sample Size Determination).

b) *Sampling Mechanism.* As previously discussed in Chapter four, there are four general sampling mechanisms available. The following two of those mechanisms, simple random sampling and stratified random sampling, are considered the most appropriate when conducting this type of survey. As a reminder, simple random sampling refers to the scenario in which the same probability of selection is assigned to each sample unit (in this case, each respondent) and in stratified random sampling the population is divided into strata and then simple random sampling is used for randomly selecting units within each strata. It is up to the survey administrator to determine the sampling mechanism to be used based on the particular interests of the evaluators.

c) *Sample Size Determination.* As it is known, the sample size is dependent on several factors, such as the tolerance error, the desired confidence level, and the desired precision (variance). Stivers et al. (1997) recommended the use of a specific formula to determine the optimum sample size that not only is dependant on these factors but also considers the rating scale used by the respondents to answer the survey questions. This formula was adopted as part of our proposed methodology and is defined by the following expression,

$$n = \frac{[0.25 \times (b-a)^2 \times z^2 \times N]}{[d^2 \times (N-1) + 0.25 \times z^2 \times (b-a)^2]} \quad (7.1)$$

where:	n	=	sample size
	a,b	=	lower and upper bounds of rating scale
			(*e.g., for 1-100 rating scale, a=1, b=100*)
	d	=	precision (*e.g., for precision of* $\pm$ *0.5 on a 1-10 scale, use 0.5*)
	N	=	survey population size
	z	=	z-statistics, standard normal upper tale cut-off

Application Example: To better illustrate the applicability of Eq.7.1, consider the following example. If there is a population of 500 respondents (N=500), a rating scale from 1 to 100 will be used by the respondents to answer the questions, and a precision of $\pm$5 points and a confidence level of 95% is desired, then the required sample size (number of respondents) will be equal to 215, as shown in the following expression,

$$n = \frac{[0.25 \times (100-1)^2 \times 1.96^2 \times 500]}{[5^2 \times (500-1) + 0.25 \times 1.96^2 \times (100-1)^2]} = 215$$

d) *Response Rate.* The response rate is basically the percentage of persons who responded to the survey. This rate is calculated by dividing the number of respondents (actual sample size) by the total eligible number of respondents (required sample size). For instance, if from the 215 people required to respond the survey (previous example), only 172 actually completed the survey, then the response rate obtained is 80% (172/215=0.80). The goal in any survey is to obtain the highest response rate possible; however, that may not always be the case. Is this an acceptable response rate? The answer is that it will depend on each particular scenario (objective of the study and the evaluator's interests). In some instances, a response rate of 70% will be considered acceptable whereas in other cases a response rate higher than 90% may be required. No matter what the actual value of the response rate is, since it affects the reliability of the results, the evaluator must consider the expected response rate when determining the required sample size. For example, if for the population of 500 respondents (previous example) it was expected to obtain a response rate of 75%, then the originally computed sample size (215) needed to be adjusted by multiplying it by the reciprocal of the response rate in order to account for this expected deficiency. If this approach is applied to this hypothetical example, the final sample size required will be 287 respondents instead of 215 (215/0.75=287). Survey Administrators must keep track of the actual response rate in order to determine if more people needs to be surveyed. Monitoring the actual response rate is really important because if the response rate decreases, the degree of non-response bias (distortion of results due to un-representation) will increase. As a reference, mail-in surveys normally has a higher non-response bias than telephone surveys. This fact should be taken in consideration when deciding on which survey type to use.

7.3.5. Survey Testing

No matter how careful survey administrators have been in designing the survey, it should not be assumed that the survey will work according to the plan until it has been tested. The objective of the test is to see if it can be administered and that accurate data can be obtained. This is done by testing the logistics of the survey, length, interpretation, clarity, and also the format of the survey itself. It is recommended to consider people from the actual population to participate in the testing phase (representative of the actual population), but the responses from these people should not be included as part of the analysis. Some questions that should be answered after conducting this testing are (Fink & Kosecoff 1998):

- Are the questions appropriate for the people who will be surveyed?
- Will the respondents be able to use the survey form properly?
- Will the survey provide the needed information?
- How consistent is the information collected?
- Are certain words or questions redundant or misleading?

7.4. STAGE 3: DATA ANALYSIS FOR SP EVALUATION

The purpose of the analysis is to produce meaningful performance information by processing the ratings assigned by the respondents in the surveys. Similar to the analysis stage in other components of the framework, two main groups of performance indicators were included to serve the purpose of this stage: (1) actual performance evaluation and (2) long-term performance evaluation.

7.4.1. Actual Performance Evaluation

Once an acceptable response rate is obtained, the actual performance evaluation can take place. This evaluation consist of first collecting statistics based on the ratings assigned by the respondents and then comparing those statistics, which provide information regarding the actual performance of the contractor, with the safety performance standards specified by the agency as part of the performance-based specifications included in the contractual agreement. A description of some of the methods that can be used to analyze the survey responses are described next (Fink & Kosecoff 1998).

a) *Descriptive Statistics.* This technique is the most commonly used. This technique basically promotes the use of counts or frequencies, proportions or percentages, measures of central tendency (e.g., mean, median, and mode), and measures of variation (e.g., range, standard deviation) to analyze the survey responses.

b) *Correlations.* This technique basically shows relationships. The level of correlation between two variables of interest can provide valuable information with respect to patterns in the survey responses.

c) *Differences.* This methodology focus on the analysis of differences in outcomes. Statistical methods such as the chi-square test and of variance (ANOVA) are normally used to conduct this type of study.

d) *Changes.* This technique can be used if the interest is to measure change over time. Special forms of t-tests and ANOVA are normally used to support this type of analysis.

The techniques presented in the data analysis section in Chapter six can also be used to summarize the results from this evaluation, but obviously with a focus on the safety issues (questions) addressed in the surveys and the comparison of them to the safety performance standards.

7.4.2. Long-term Performance Evaluation

The evaluation of the long-term performance of the contractor's safety program is extremely important to be conducted in order to provide insight to the transportation agency about the contractor commitment to provide a safety environment not only to the traveling public, but also to the employees and sub-contractors performing outcome-based road maintenance activities. Continuous enforcement of sound safety practices, improvement in safety performance, and reduction in accidents rates are some of elements that can be considered in the long-term performance evaluation of the contractor safety program. Techniques such as the ones described in previous chapters can also be used here, but obviously, with a focus on safety.

7.5. STAGE 4: REPORTING FOR SP EVALUATION

Similar reports to the ones for the Level of Service and Timeliness of Response but with a focus on the overall effectiveness of the contractor in implementing an acceptable Safety Program should be produced. Among the recommended reports are the Report Card, Deficiencies to Contractor, and Effectiveness of Contractor's Safety Program.

7.6. SUMMARY

The assessment of the contractor's compliance to safety requirements is one of the most important evaluations that should be performed by transportations agencies involved in performance-based road maintenance initiatives. If these evaluations are taken seriously, the agency will send a very clear message to the contractor, "SAFETY COMES FIRST". The methodologies and techniques presented in this chapter provide guidance to transportation agencies on how to conduct these areas in a reliable and comprehensive way. Suggestions on what areas should be evaluated, which statistically valid techniques that can be used to collect data, and what kind of procedures can be used to convert the data collected into meaningful information where addressed.

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CHAPTER 8

QUALITY OF SERVICES EVALUATION: CUSTOMER, USERS, AND EMPLOYEE SATISFACTION

To guarantee the success of any transportation program is essential to understand of the traveling public and customer needs (Atkinson 1990, Grigg 1988, Hudson et al. 1997). They are the final evaluators of the services provided and even more important they are service payers. For this reason, this component was included as part of the framework. The goal of this evaluation is to assess the user's (i.e, traveling public), customer's (i.e., agency), and third-parties' (i.e., sub-contractors) perceptions and satisfaction with respect to the condition of the assets and the performance of the contractor conducting outcome-based road maintenance activities. This chapter presents a description of the proposed methodology to evaluate the Quality of Services (QOS) in PBRM.

8.1. COMPONENT STRUCTURE

Figure 8.1 presents a graphical representation of the methodology adopted as part of the framework to evaluate the perception of the quality of the services in PBRM. A description of the elements included in each section follows.

8.2. STAGE 1: INPUT FOR QUALITY OF SERVICES EVALUATION

The most important element as part of the input of this component is the definition of performance standards that will finally guarantee customer satisfaction (Kaplan & Norton 1996, Peach 1997, PBMSIG 2001, BNQP 2002). Unfortunately, not always transportation agencies consider the input from the public. That is the reason why there is sometimes significant difference when comparing the perspective of the traveling public with the condition reported by road administrators (NRC 1995, Miller 2001). In order to address this issue, transportation agencies must spent more time in the development phase to understand the public needs and expectations about the work to be done for the maintenance of the highway system. The input from the public will provide transportation agencies with feedback on what are the areas of higher and lesser importance to the traveling public. This feedback will help transportation agencies when prioritizing among maintenance needs and defining performance standards to be included in the contractual agreements with private corporations to perform work under performance-based specifications. The objective of the methodology presented in this chapter is to assess the level of satisfaction of the traveling public, agency, and third parties that were directly impacted by the implementation of the PBRMC. In order to be able to measure the level of satisfaction of these parties, it is crucial that the agency defines a target that can be used to compare the findings. These targets should be defined based on the public expectations. The concepts and guidelines provided in this chapter focus on assessing the level of satisfaction. However, they can be used also by transportation agencies to assess the customer and users expectations before implementing PBRM initiatives.

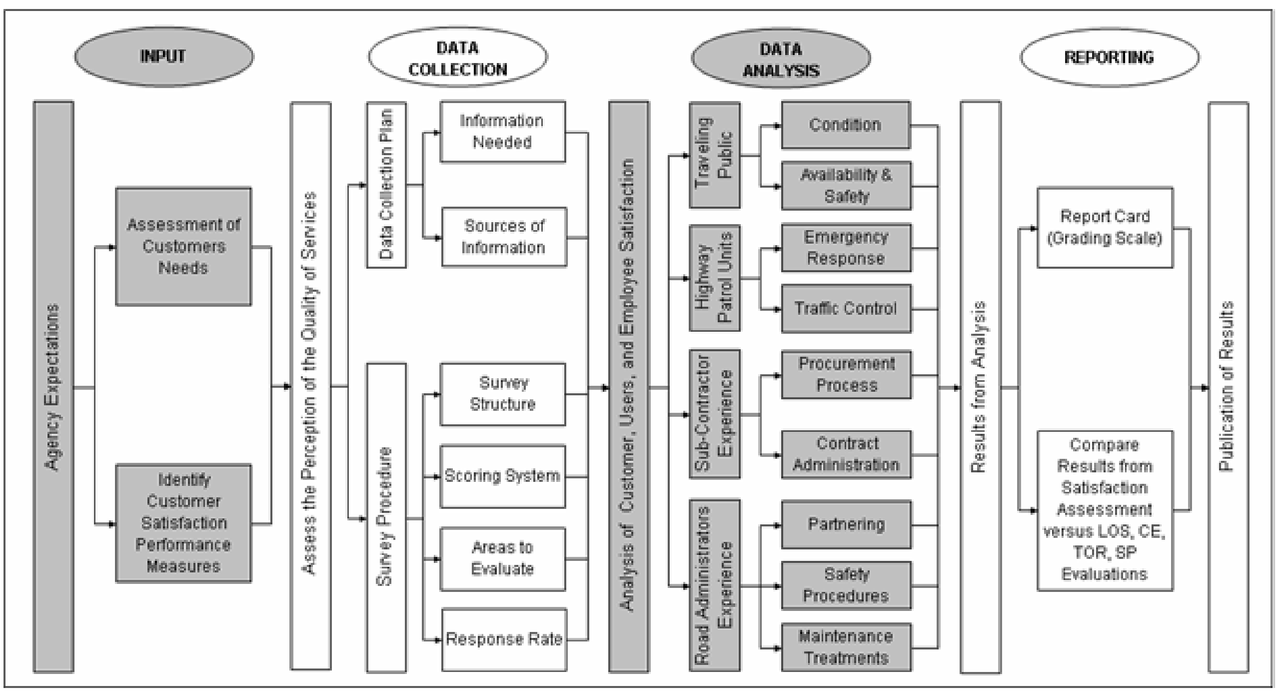

Figure 8.1. Methodology to Evaluate the Quality of Services (QOS) in PBRM

8.3. STAGE 2: DATA COLLECTION FOR QUALITY OF SERVICES EVALUATION

As previously stated, the main purpose of this component is to assess the satisfaction of individuals that have been impacted by the contractor’s work under performance-based specifications. Among the personnel identified as valuable sources of information to serve this purpose are: (1) Traveling Public, (2) Emergency Response Units, (3) Sub-Contractors of the Main Contractor conducting the job, and (4) Contract Administrators and Supervisors from the Department of Transportation. Similar to the Safety Procedures evaluation discussed in Chapter seven, the intent in this component is to use Surveys as the data collection mechanism to assess the level of satisfaction of the individual from these agencies or institutions. Given the fact that the same mechanism (i.e., Surveys) used in the safety evaluation was adopted in this component, most of the concepts discussed in Chapter seven regarding to the development and deployment of Surveys applies also to this component. Some of these concepts will be reviewed in this chapter, but obviously focusing on assessing the quality of the services provided by the contractor.

8.3.1. Survey Type and Administration

As previously stated, there are many techniques that can be used to assess the feedback from individuals. However, it was stated that the most appropriate and reliable survey techniques applicable to our scenario were self-completion questionnaires and personal or telephone interviews. In order to get a better understanding about the advantages and disadvantages of each one of these techniques, let's consider the information presented in Table 8.1. According to the information presented in this table, it is understood that there are actually only two out of the three alternatives that are considered more appropriate and feasible (i.e., cost-efficient) to serve the purpose of the Quality of Services evaluation. These alternatives are: (1) self-completion questionnaire and (2) telephone interview. Many factors need to be considered by road administrators when they have to decide on which one of these two alternatives to apply. For instance, let's assume a telephone questionnaire will cost the agency \$22 per respondent and it will take three (3) weeks to achieve an acceptable response rate. On the other hand, if the agency deploys a self-completion questionnaire, it will cost them \$14 per respondent but it will take two (2) months to achieve an acceptable response rate. The dilemma now is if the agency is willing to wait practically double the time to get the responses back from the survey at a cheaper cost (i.e., if self-completion questionnaire is selected) or to get the responses quicker at a more expensive cost (i.e., if telephone questionnaire is selected). The answer totally depends on the needs of the agency for the particular scenario under consideration. However, no matter which type of survey is selected, the agency must be sure that the survey is conducted in the most appropriate time, clearly state the purpose of the survey, and provide clear instruction on how to answer the questions. The survey should be tested before using it to collect the real information in order to assure bias is not introduced in the response of the interviewers as a result of the inappropriate structure and format of the questionnaire.

Table 8.1. Advantages and Disadvantages of several Survey Techniques

Survey Type	Advantages	Disadvantages
Self-completion Questionnaire	• Usually the cheapest method of data collection • Most respondents see this type of survey as the least intrusive and most anonymous way of being surveyed • No risk of interviewer bias	• Usually take long time • Suffer from low response rate • Questionnaire must be short and simple • Lack of control over who fills it in and how it is filled in
Personal Interviews	• Easy to achieve respondent understanding • Visual aids can be used as a rating scale • Complex questions can be easily explain • More qualitative information can be gather • Longer interviews are feasible	• Normally very costly • Tendency from interviewers to be less frank
Telephone Interviews	• Quickest way to gathering survey data • They are relatively low-cost • Interviewer can explain things and minimize the risk of misunderstanding • No distance constraints	• Interviews have to be short (e.g., less than 15 minutes) • Questions have to be straightforward • Require good interviewers

8.3.2. Survey Design

As stated in Chapter seven, survey administrators must be careful when designing the structure and questions used in survey. The fact is that a well prepared survey can provide the agency very valuable information, whereas a badly designed survey not only will give a hard time to the interviewers (Hayes 1998). Moreover, a badly designed survey will provide the wrong insight regarding the perception on the quality of the services provided by the contractor, which may lead to serious consequences. According to Hill et al (1999), asking the right questions to the right people are the two factors that will determine the accuracy of the results from the survey.

In order to avoid defining questions that will bias the response of the interviewers, survey designers must implement techniques such as the ones discussed in Section 7.3.3.1 of Chapter seven. As a remainder, these techniques are summarized below.

- Clearly specify the objective of the survey
- Provide clear instructions on how to answer the survey
- Keep the survey as short and concise as possible
- Group questions in categories
- Place short questions at the end of the Survey
- Define a scoring system to quantitatively evaluate respondents opinion
- Avoid the use of items that look alike
- Acknowledge the respondents for their input and contribution

Refer to Section 7.3.3.1 for a more detail description of each of the techniques listed above. Figure 8.2 presents a graphical representation of how some of these techniques can be incorporated in the general structure of the questionnaire.

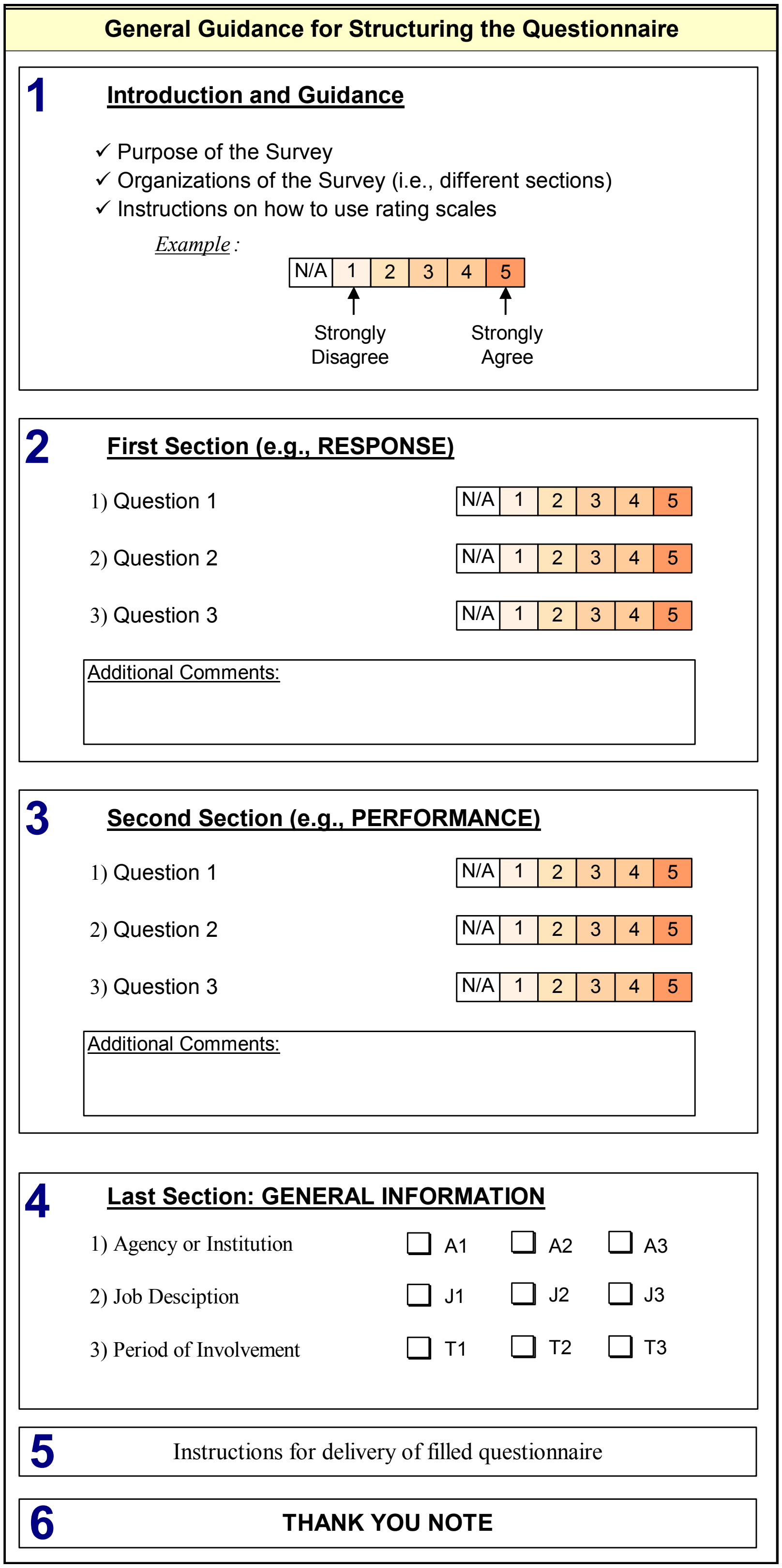

Figure 8.2. General Guidance on How to Structure the Questionnaires

8.3.3. Survey Focus

As previously mentioned, four sources of information (i.e., traveling public, emergency response units, sub-contractors, and DOT contract administrators and supervisors) were identified to assess the quality of the service provided by the contractor in PBRM. It is proposed as part of the framework that the surveys submitted to these parties focus on different issues or areas of concern. A description of the focus of each survey follows.

(1) Traveling Public Survey – The objective of this survey is to evaluate the satisfaction of the traveling public with respect to the condition at which the assets are maintained in portions of the roadway system under performance-based specifications. This type of surveys should be conducted by transportation agencies every two to three years (NRC 1995, Hudson et al. 1997).

(2) Emergency and Highway Patrol Units Survey - The main objective of this survey is to examine the overall satisfaction of the emergency and highway patrol personnel with respect to the quality of the job done by the contractor in maintaining the portions of the roadway system under its responsibility. Some of the areas that should be addressed in this survey are the contractor's collaboration and coordination when addressing emergencies and the compliance of the contractor to any regulation associated to the occurrence of an emergency (VDOT 2000).

(3) Sub-Contractors Survey – The purpose of this survey is to evaluate the perception and opinion of the sub-contractors performing work for the General Contractor with respect to the fairness of the procurement process used by the General Contractor to adjudicate contracts under performance-based standards (i.e., opportunity to bid on the works in a fair and competitive manner, and proper discussion of the nature of the work in the contract). In addition, the survey also examines the sub-contractors experiences on how the contractor administers the contracts (e.g., supervision, dispute avoidance, and payment compliance).

(4) Road Administrators Survey – The objective of this survey is to assess the satisfaction of road administrators with respect to the general performance of the contractor conducting performance-based work. These individuals normally work with the contractor on a daily basis, which categorize them as excellent resources to provide feedback on the commitment of the

contractor to provide an excellent service to the public (Stivers et al. 1997, VDOT 2000, Zietlow 2001).

The combination of feedback from all the parties will provide transportation agencies with an overall assessment of the satisfaction of the people affected, in one way or the other, with the work done by the contractor under performance-based specifications.

8.3.4. Sampling Considerations

Since it will be very costly and time consuming, if not impossible, to assess the feedback from all the users affected by the work done by the contractor under performance-based specifications, sampling of the population is considered one more time as an excellent alternative to minimize the time and expenses associated to the assessment process. The reader can refer to Section 4.3.2.2 for a detailed review of several basic sampling concepts as well as the most important factors that must be taken into consideration when sampling the population is considered as an alternative. This section highlights the most important characteristics that must be taken in consideration when sampling is adopted to support the assessment of the perspective of the users and other parties with respect to the quality of the service provided by the contractor in PBRM. A description of the three most important aspects considered as part of the sampling approach applicable to this evaluation follows.

1) *Target Population (Sources of Information)*. Since the main purpose of this evaluation is to receive feedback from four different parties (i.e., Traveling Public, Emergency Response Units, Sub-Contractors, and DOT Contract Administrators and Supervisors), it is recommended to consider each party as an independent population to help simplify the calculations and get a better understanding of the each party's independent perception of the quality of services provided by the contractor. The sampling frame, which is the source from which a sample of individuals is selected, will vary depending on each party's population size. For instance, the size of the population to be used to survey the Emergency Response Units, Sub-Contractors, and DOT Contract Administrators and Supervisors will be based on the number of individuals within each party that were identified as having been impacted in one way or the other by the contractor's performance. The total number of people identified will constitute the whole population of respondents for each party. These populations can be

well identified. However, define the population for the traveling public is a major challenge. The ideal scenario would be if the agency can assess the perception of all the traveling public using the portions of the roadway system under performance-based work. However, the reality is that to define the population for this scenario would be unrealistic, since there may be many users from outside the area (e.g., tourists). As suggested by Stivers et al. (1997), the correct approach to define the population of interest will be to consider only the people that live within the jurisdiction of the portions of the roadway system under evaluation. For instance, in the United States, the following two sources of information can be used to identify these individuals: (1) records from the Department of Motor Vehicles (DMV) or Driver's Licensing Bureau (DLB) containing the names and addresses of individuals licensed to drive within the geographic scope of the study and (2) telephone listings with licensed drivers in the region. It is strongly recommended to use the records from the Department of Motor Vehicles as opposed to the telephone listings, since the second one normally can lead to more biased results because of the potential of excluding a telephone number in the list.

2) *Sampling Mechanism.* Similar to the sampling scenario in the Safety Procedures, survey administrator must determine the sampling mechanism to be used in the deployment of the survey. Any of the four sampling mechanism or even a combination of them can be used in this evaluation, as it was also the case in the Level of Service and Safety Procedures evaluations.

3) *Sample Size Determination.* Since similar type of surveys to the ones in Chapter seven have been proposed to be used in this chapter to evaluate the perception of the quality of services, it is propose to use the formula recommended by Stivers et al (1997) (i.e., Eq.7.1) to compute the required sample size for each independent population.

8.3.5. Maximizing the Response Rates

The issue of the response rate was previously addressed in Chapter seven. As it was stated in this chapter, the main goal for a survey administrator is to obtain the highest response rate possible. According to Vavra (1997), to provide an accurate measure of customer and users satisfaction a response rate below 50 percent cannot be relied on. It will be preferable to get a response rate higher than 65 percent; however, in many cases to achieve this target will be very difficult. Since the response rate influences the reliability of the findings (e.g., non-response bias), high level of attention must be given to the issue of maximizing the response rates. Some of the most effective techniques used by practitioners to boost the response rates are described below. These techniques were grouped in the following three categories: (1) Essentials, (2) Advisables, and (3) Avoidables (Hill et al. 1999).

1) *Essentials.* This category refers to things or techniques considered essentials to achieve an adequate response rate. Some of the elements that are considered essentials are: (a) keep a reliable and accurate database with all the candidates that can be selected to participate in the survey, (b) include a postage-paid reply envelope when mail-in surveys are used, (c) include an introductory letter accompanying self-completion questionnaires, and (d) implement a follow-up strategy.

2) *Advisables.* This category focuses on strategies that are considered helpful to boost the response rates, although it may be a lower margin. The most important strategies within this category are: (a) pre-notification of the survey, (b) careful design of the survey (i.e., aesthetics, format), and (c) monetary awards as an incentive to participate in the survey.

3) *Avoidables.* The Avoidables category refers to the techniques that should be avoided since no evidence has been found that prove that those techniques improve response rates. Some of these techniques are: (a) incentives or future monetary rewards, and (b) use of new media as tools to answer surveys.

8.3.6. Survey Testing

As it was previously stated, all surveys must be piloted before they are used to perform the actual assessment. Some of the factors that must be taken in consideration when testing surveys were listed in the pervious chapter. All of these factors are applicable when testing the type of surveys proposed in this chapter. Some of the factors are listed below as a reference.

- Check if questions included in the survey are approapriate to the people who will be surveyed
- Evaluate if the respondents will be able to use the survey form properly
- Analyze if the responses from the survey will provide the needed information

- Check the consistency of the information to be collected
- Check if there is any redundant or misleading word or question in the survey

Once the survey is tested according to each one of these criteria and the results from the test are positive, then the survey can be deployed to the actual sampled population.

8.4. STAGE 3: DATA ANALYSIS FOR QUALITY OF SERVICES EVALUATION

Once acceptable response rates are obtained, the analytical procedures suggested in Chapter seven to convert the raw data or responses into meaningful information can be implemented in this evaluation as well. As it was discussed in the previous chapter, the first step in the analysis is to collect the statistics (e.g., descriptive statistics, correlations, differences, and changes) based on the ratings assigned by the respondents. These statistics are then compared with the performance standards in order to get information regarding the satisfaction of the parties involved in the evaluation regarding the performance of the contractor (Hayes 1998).

As it was proposed in Chapter seven, the guidelines with the techniques presented in the data analysis section in Chapter six can be used to summarize the results from this evaluation, but obviously with a focus on the perception on the quality of services.

8.5. STAGE 4: REPORTING FOR QUALITY OF SERVICES EVALUATION

Similar to previous components, a Report Card must be produced to help communicate the results from the analysis. In addition to the Report Card, a report that compares the results from the quality of service satisfaction with the results from the analysis of the other components of the framework is recommended. The main objective of this last report is to verify if the perception from the traveling public is in accordance to the reported condition by the agency.

8.6. SUMMARY

For a project to be considered as a success it must satisfy the specific needs of the users, customers, and employees related to it. For this reason, it is crucial to consider the feedback from these individuals when assessing the overall success of a given initiative. This chapter provided directions to transportation agencies on how assess the perceptions and satisfaction of user's (i.e, traveling public), customer's (i.e., agency), and third-parties' (i.e., sub-contractors) with respect to the quality of services provided by the contractor.

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CHAPTER 9

APPLICATION OF THE FRAMEWORK

This chapter presents the application of the framework described in chapters 3 through 8 to the Performance-Based Road Maintenance Contract (PBRMC) between the Virginia Department of Transportation (VDOT) and VMS, Inc. (i.e., private contractor) for the maintenance of portions of the highway system in the Commonwealth of Virginia. This contract started in 1996 and it is considered the first PBRMC in the United States (VDOT 2000). The main purpose of this application is to provide the reader with a better understanding of how the methodologies adopted in the framework can be applied to a real scenario in order to assess the actual performance of the private contractor (e.g., VMS) in maintaining the assets under their responsibility. The framework was partially applied to this PBRMC. The proposed methodologies to evaluate the Level of Service Effectiveness and Timeliness of Response were comprehensively applied to this PBRMC. Regarding the Cost-Efficiency evaluation, only Part 1 of the proposed methodology was applied using the Distribution Approach. An application of the Safety Procedures and Quality of Services components was not conducted. However, several examples on typical surveys that can be used by transportation agencies to evaluate these areas are provided in this chapter.

9.1. CONTRACT OVERVIEW

The relationship between VDOT and VMS started in October 1995. It began when VMS submitted an unsolicited proposal under the Public-Private Transportation Act to implement a public-private partnership for the maintenance of a portion of the interstate highway system in the Commonwealth of Virginia. In December 1996, VDOT approved VMS's proposal and from then, VMS has been fully responsible for the maintenance of approximately 250 miles of highway on portions of I-81, I-95, I-77, and I-381. These portions constitute approximately 25% of the total interstate highway system in Virginia. VMS provided and/or procured all labor, materials, equipment, and services for a fixed price of $131.6 millions for a period of 5-1/2 years (VDOT 1996).

As part of the effort to evaluate VMS's performance, in 2000, VDOT turned to Virginia Tech and Wilbur Smith and Assoc. (i.e., private consultant) to perform an independent assessment of VMS's performance and a cost-efficiency evaluation of their contract with VDOT. The main objective of the study conducted by Virginia Tech researchers was to assess the cost-efficiency of the pilot VMS contract by comparing the price based on work done by VMS in 1999 with the price if the work was contracted or self performed by VDOT. This study reported positive level of savings (de la Garza & Vorster 2000, VDOT 2000). On the other hand, the objective of the study conducted by Wilbur Smith was to perform an independent and objective evaluation of the following four maintenance asset groups: traffic, drainage, roadsides, and shoulders. This other study also reported a high level of service (VDOT 2000). As a result of the benefits reported in these studies and VDOT's satisfaction with the service provided by VMS, VDOT extended in 2001 the contract for five additional years. In August 2001, VDOT created a partnership with Virginia Tech to assist the agency in the development and implementation of comprehensive and reliable procedures to monitor the cost-efficiency and level of service effectiveness of this contracting scheme. The framework presented in this document is one of the deliverables from this partnership. A detailed discussion of the application of the framework to the VDOT-VMS Performance-Based Road Maintenance Contract follows.

9.2. LEVEL OF SERVICE (LOS) EVALUATION

The proposed methodologies presented in Chapter four were implemented to evaluate the LOS effectiveness in the VDOT-VMS contract. A discussion of the implementation is presented in this section for each of the elements associated to this component.

9.2.1. Input

Before engaging the services of VMS to perform outcome-based road maintenance activities, VDOT identified the portions of the highway system network for which VMS was going to be fully responsible. They also defined the performance standards to be used by the agency to assess the performance of VMS in maintaining the assets located within the right of way of the portions of highway included in the contract. A detailed description of the scope of the contract and the performance standards specified by VDOT is presented in sections 9.2.1.1 and 9.2.1.2, respectively.

9.2.1.1. Network Scope

The portion of the interstate system for which VMS have full responsibility is summarized in Table 9.1. As shown in column 4 of this table, VMS is responsible for a total of 257.6 miles of interstate. As depicted in Table 9.1, the 257.6 miles were divided in four sections. In addition, notice This table presents that VDOT have full responsibility of a total of 217.85 miles of interstate (i.e., sections 5 through 12). The purpose of defining these sections was to use them to compare the benefits accrued as a result of the implementation of performance-based specifications (VMS Sections) with the benefits if the work is done under traditional maintenance specifications (VDOT Sections). Sections 5 through 12 are referred to as the Control Sections. These control sections are located in portions of the remaining 75% of the interstate system in Virginia. The VDOT Control Sections are exposed to similar conditions to those sections maintained by VMS. These sections were carefully selected. Conditions such as similar geographical characteristics, weather conditions, rural and urban settings, average traffic volumes, traffic mix, and types of assets on the routes were considered in the selection process. A graphical representation of the location of the twelve sections in the state of Virginia is presented in Figure 9.1.

Table 9.1. Summary of VMS Sections and VDOT Control Sections

Party Responsible (1)	Section (2)	Interstate (3)	No. of Miles (4)
VMS	Section 1	I-95	101.24
	Section 2	I-81	87.3
	Section 3	I-77	67.4
	Section 4	I-381	1.65
	All VMS Sections	**All Routes**	**257.6**
VDOT (Control Sections)	Section 5	I-95	23.55
	Section 6	I-66	21.95
	Section 7,8 & 9	I-64	117.35
	Section 10 & 12	I-81	48.35
	Section 11	I-581	6.65
	All VDOT Sections	**All Routes**	**217.85**

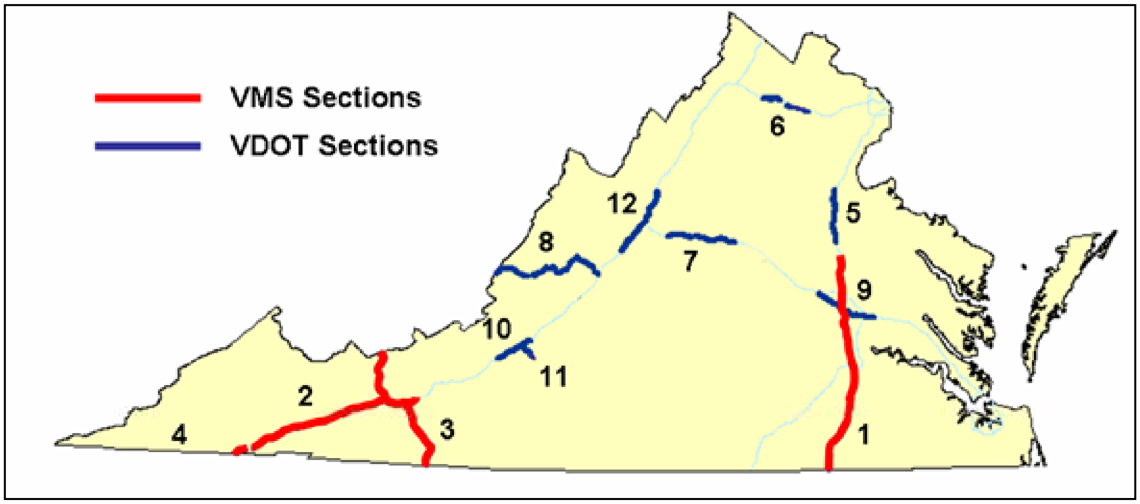


Figure 9.1. Location of VMS Sections and VDOT Control Sections

i) ***Assets to be Maintained.*** Within each section, VDOT specified in the contract that VMS must be responsible for the maintenance of all the assets within the right of way of the interstate. The assets were classified in six groups, which are listed below.

- *Pavement* - includes pavement conditions such as joints, bumps, and potholes.
- *Bridges* - includes condition of bridges superstructure, substructure, deck, and slope protection.
- *Shoulders* - includes general condition of shoulders (*paved or unpaved*).
- *Roadside* - includes fence condition, mowing, landscaping, and liter removal, among others.
- *Drainage* - includes ditches, culverts, and other drainage components.
- *Traffic* - includes pavement markers, guardrails, signs, and other others traffic components.

Specific asset items were identified within each asset group. The list of asset items identified within each asset group is listed in Table 9.2, excluding pavement and bridges. VDOT defined specific performance standards for each of these asset items. It is obvious that not all the asset items are present in each section. Although, VMS is responsible for the maintenance of the asset items that exist within each section.

Table 9.2. Asset Items Identified in VDOT-VMS PBRMC (Excluding Pavement and Bridges)

Unpaved Shoulders	Paved Shoulders	Roadside	Drainage	Traffic
Drop Off	Surface Defects	Grass	Ditches Paved	Signals
Drainage	Drop Off	Debris & Road Kill	Ditches Unpaved	Pavement Message
	Separation	Litter	Pipes	Pavement Stripping
	Drainage	Landscaping	Box Culverts	Pavement Markers
		Brush and Tree Control	Under/Edge Drain	Delineators/Obj marker
		Concrete Barrier	Storm D/D Inlets	Glare Foils
		Sound Barrier	Curb & Gutter	Signs-Regulatory
		Slopes	Sidewalks	Signs-Other
		Fence	SW Management Ponds	Luminaries
				Guardrail
				Impact Attenuators
				Truck Ramps
				Cross Overs
				Rumble Strips

ii) ***Inventory and Condition of Assets.*** In addition to the list of items to be maintained, VDOT provided VMS with a summary of the overall condition of the assets located within Sections 1 through 4. This information was used as one of the factors to negotiate the final contract price.

9.2.1.2. Performance Standards

The Virginia Department of Transportation (VDOT) specified in the contractual agreement with VMS the performance standards to be used to assess the level at which VMS maintained the assets under its responsibility. Performance standards were defined for the six asset groups. A description of these standards is presented next.

i) ***Performance Standards for Shoulders, Roadside, Drainage, and Traffic.*** The performance standards specified by VDOT for the asset items identified within these four asset groups are listed in Table A.1, located in Appendix A. The two components of the performance standards, Performance Measure and Performance Target, were included in this table. For example, notice in Table A.1 that only one performance measure was specified to evaluate the condition at which landscaping areas must be maintained by VMS. The performance measure for landscaping establishes that if more that 20% of the landscaped area is unhealthy or contain weeds, then the condition is not acceptable (i.e., landscaping fails). VDOT required that the performance measure must meet 80% of the time (i.e., performance target equals to 80%). As depicted in Table A.1, for some of the asset items VDOT specified up to nine (9) performance standards (e.g., pipes and box culverts).

ii) ***Performance Standards for Pavement Structures.*** The performance standards for Pavement Structures included in VDOT-VMS contract are summarized in Table A.2 located in Appendix A. A discussion of some limitations related to these standards will be presented in Section 9.2.3.2.

iii) ***Performance Standards for Bridge Structures.*** Similar to the other five asset groups (i.e., Pavement, Shoulders, Roadside, Drainage, Traffic), VDOT specified in their contractual agreement with VMS a set of performance standards used to assess the condition at which the assets are maintained. A summary of the performance standards applicable to Bridge Structures is presented in Table A.3. The application of these standards will be presented in Section 9.2.3.3.

iv) ***Relative Weights among Assets.*** A set of weights was adopted to establish relative importance among asset items and asset groups. The weights are listed in Table 9.3. Notice that the same set of weights was defined for the assets located in urban and rural zones. For instance, in the Traffic group, a very important item such as debris and road kill received a relative weight of 8.5, whereas a less important item such as sound barrier received a relative weight of 4.83 (i.e., 2:1 relationship). On the other hand, with respect to the importance among asset groups, twice the importance was given to the Traffic asset group in comparison to the Shoulder asset group (i.e., 37% versus 15%). This means that the rating from the Traffic asset group will have more impact on the overall evaluation than the rating from the Shoulders asset group. These weights were used in the overall calculation of the LOS ratings to be discussed later.

9.2.2. Data Collection

This section describes the data collection process adopted by VDOT in 2002 to evaluate the condition assessment of each asset group and asset item under consideration. As stated in Chapter four, the data collection focuses basically in three areas: (1) Data Collection Plan, (2) Sampling Procedures, and (3) QA/QC Process. A detailed discussion of these three areas applicable to each one of the six asset groups is presented next.

Table 9.3. Relative Weighting among Asset Groups and Asset Items

Asset Group	Asset Item	Rural Zones			Urban Zones		
		Group	Sub-Group	Item	Group	Sub-Group	Item
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shoulders		**0.1560**			**0.1560**		
Paved	Surface Defects		**7.17**	5.33		**7.17**	5.33
	Drop-off			5.83			5.83
	Separation			5.66			5.66
	Drainage			5.50			5.50
Unpaved	Drop-off		**1.00**	5.83		**1.00**	5.83
	Drainage			5.50			5.50
Roadside		**0.2350**			**0.2350**		
	Grass			5.67			5.67
	Debris and Road Kill			8.50			8.50
	Litter			4.67			4.67
	Landscaping			4.83			4.83
	Brush and Tree Control			5.33			5.33
	Concrete Barrier			8.17			8.17
	Sound Barrier			4.83			4.83
	Slopes			5.83			5.83
	Fence			5.00			5.00
Drainage		**0.2370**			**0.2370**		
	Ditches, Paved			6.67			6.67
	Ditches, Unpaved			6.33			6.33
	Pipes (ea.)			8.50			8.50
	Box Culverts			8.00			8.00
	Under/Edge Drains			8.33			8.33
	Storm Drains/ Drop Inlets			8.67			8.67
	Curb and Gutter			4.00			4.00
	Sidewalks			3.17			3.17
	SW Management Ponds			5.33			5.33
Traffic		**0.3720**			**0.3720**		
	Signals			9.17			9.17
	Pavement Messages			6.33			6.33
	Pavement Striping			8.67			8.67
	Pavement Markers			8.00			8.00
	Delineators/Obj. Markers			4.83			4.83
	Glare Foils			5.50			5.50
	Signs-Regulatory			8.00			8.00
	Signs Other			8.00			8.00
	Luminaires			6.50			6.50
	Guardrail			8.50			8.50
	Impact Attenuators			9.33			9.33
	Truck Ramps			6.00			6.00
	Cross Overs			5.00			5.00
	Rumble Strips			5.00			5.00

9.2.2.1. Data Collection Plan

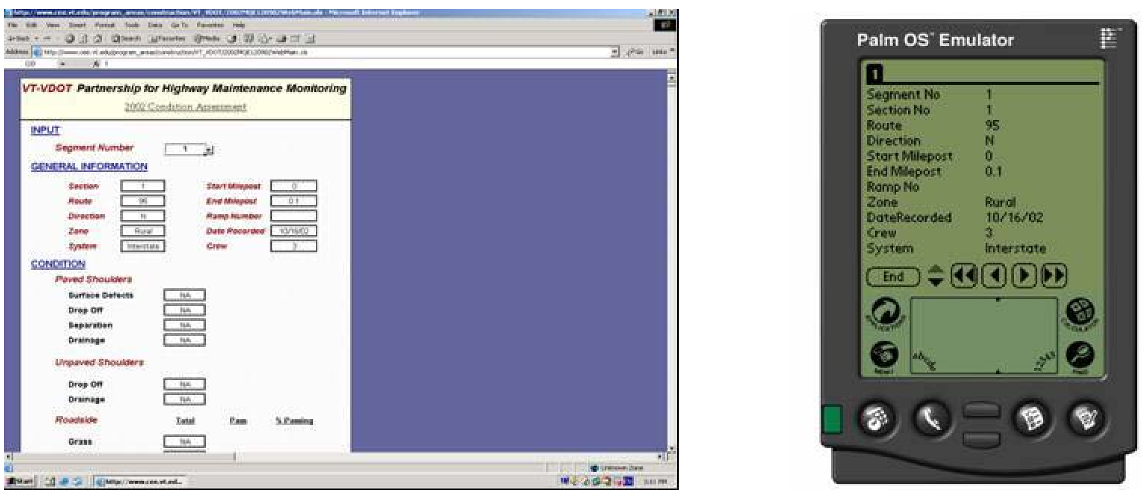
The data collection plan varied depending on the asset group. For instance, the condition assessment for Shoulders, Roadside, Drainage and Traffic was performed through Field Inspections conducted by an Independent Consultant. On the other hand, the condition assessment of Pavement and Bridges was performed by VDOT Personnel from the Pavement and Bridge Management Divisions, respectively. A detailed description of the data collection plan for each of the asset groups follows.

i) ***Data for the evaluation of Shoulders, Roadside, Drainage, and Traffic.*** As previously stated, the condition assessment of these four asset groups was performed through Field Inspections. In these inspections, crews from an independent consultant were sent to the field to assess the condition of the assets in the twelve sections under VMS and VDOT responsibility. The crews used the performance standards specified in the contract for these four asset groups (i.e., Table A.1 in Appendix A) to assess the condition of the assets within each section. In 2002, crews were equipped with portable computers to collect the information directly from the field. This technology improved the data collection process, which was previously done using pencil and paper forms. In other words, the information in 2002 was recorded by field crews in a smart computer-based form generated in Microsoft Access. An illustration of this technology is presented in Figure 9.2.

(a) (b)

Figure 9.2. Illustration of the Information Technology used by VDOT since 2002 to Collect field data

The electronic collection of the data in the field increased considerably the efficiency and effectiveness of the condition assessment process by minimizing errors associated to double entry of data. In addition, the information collected was immediately available for verification, analysis, and posting on the web and pocket-based computers. This promoted the immediate verification and audit of the filed inspections records by all the parties involved in the condition evaluation. All parties involved in the condition assessment process were able to receive reliable information in a short period of time. This was one of the main goals of VDOT and Virginia Tech as part of the effort to provide a very transparent procedure. Figure 9.3 presents a screen shot of how the information collected electronically in the field was presented in the Web and Palm computer devices.



(a) Web (b) Palm Devices

Figure 9.3. Illustration of How the Condition Information was Depicted in the Web and Palm Devices

In addition to portable computers, field crews were also equipped with GPS receivers used to locate the starting and ending point of each sampling site within each of the twelve sections under evaluation. The idea behind the implementation of this technology was to increase the precision at which the segments were located by the crews and allow the implementation of Geographic Information Systems (GIS) to help communicate the findings from the analysis. A discussion of the application of GIS technology will be presented in Section 9.2.4.

ii) ***Data for the evaluation of Pavement Structures***. Pavement structures were evaluated by VDOT personnel from the Pavement Management Division. The evaluations were conducted throughout the year in each of the twelve sections. The condition of the Pavement was assessed by combining the results from subjective windshield type surveys with the results of an objective video imaging data collection process. The data was collected automatically through the use of computers carried in rating vans. The focus of these evaluations was in the assessment of pavement distresses and the roughness of the riding surface which were evaluated in terms of several pavement condition indices defined by VDOT. Many different indices have been used by VDOT throughout the years to assess the condition of the pavement. The problems is that in some years, as it was the case in 2002, the indices used to evaluate the condition of the pavement in sections maintained by VMS were not exactly the ones specified in their contractual agreement. For this reason, it was impossible to determine if VMS met the standards for pavement specified in the contract. However, the indices were still used to get a sense of how VMS was maintaining the pavement structures under their responsibility and how those results compared with the condition of the pavement in VDOT Control Sections. For the evaluation of the level of distresses in the pavement, the following two indices were used by VDOT to serve this purpose: (1) Load Related Distress Rating (LDR) and (2) Non-Load Related Distress Rating (NDR). These indices were estimated from data collected automatically by videotape or by laser sensors mounted on a vehicle carrying the video recorders. To provide a better understanding of what the values from these two indices represent, a description of each one of them follows.

a) *Load Related Distress Rating (LDR)*. This index reflects the condition of the pavement from the perspective of damage due to wheel loads applied to the pavement. The values for this index range from 0 to 100. A pavement with an LDR in the range of 80 to 100 is considered slightly distressed. If the LDR is between 50 and 80, then the pavement can be considered to have moderate distress. However, if the LDR index is below 50, the pavement is considered heavily or excessively distressed. A pavement that is categorized as heavily or excessively distressed is considered to be a deficient pavement.

b) *Non Load Related Distress Rating (NDR)*. The NDR index reflects the condition of the pavement with respect to distresses related to temperature, moisture changes in the pavement over time and also to oxidation of asphalt concrete. This index also ranges from 0 to 100 and pavements are classified using the same scale defined for the LDR index.

In general, the distressed condition of the pavement is classified based on the lower value between LDR and NDR, which corresponds to an overall distress index known as the Combined Condition Index (CCI). On the other hand, the roughness of the riding surface was measured by VDOT personnel based on the International Roughness Index (IRI). The IRI was developed by the World Bank in the 1980s and is used to define the characteristic of the longitudinal profile of a surface. The index is considered as a standardized roughness measurement. This index was included in the 2002 evaluation and the results will be presented in Section 9.2.3.

iii) ***Data for the Evaluation of Bridge Structures.*** As previously stated, Bridge Structures were inspected by the personnel of VDOT's Bridge Management Division. The condition of the bridges was assessed for four main components: *Deck, Superstructure, Substructure* and *Slope Protection.* Table A.3, located in Appendix A, listed the performance criteria specified in the contractual agreement to assess the condition of the bridge components maintained by VMS (VDOT 1996). Each bridge components were rated according to the guidelines provided by VDOT's "Element Data Collection Manual", published in 1996. The Manual promotes the use of a rating scale that goes from zero (0) to nine (9) to evaluate the elements within each bridge component. A rating of zero (0) corresponds to the worst condition and a rating of nine (9) corresponds to the best condition.

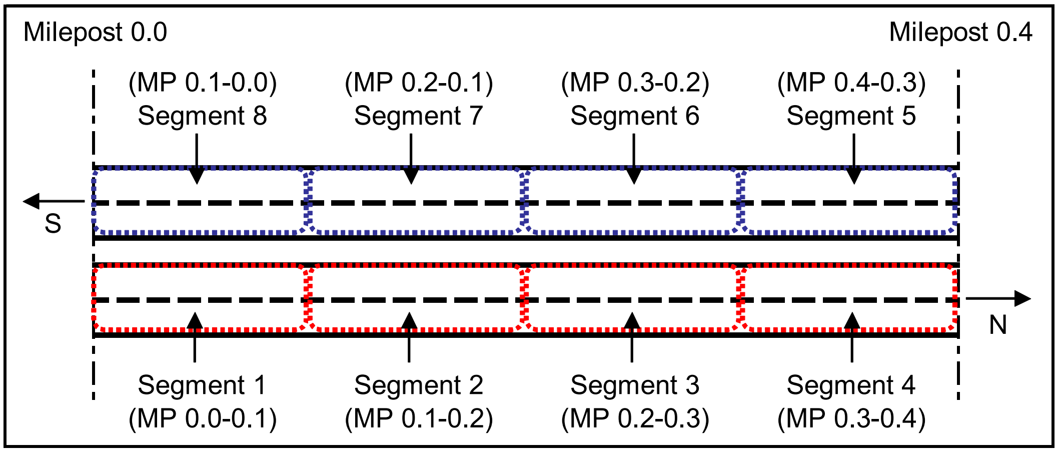
9.2.2.2. Sample Selection Process

As it was the case in the data collection plan, the sample selection procedure varied depending on the asset group. A detailed description of the sampling procedures implemented for each asset group follows.

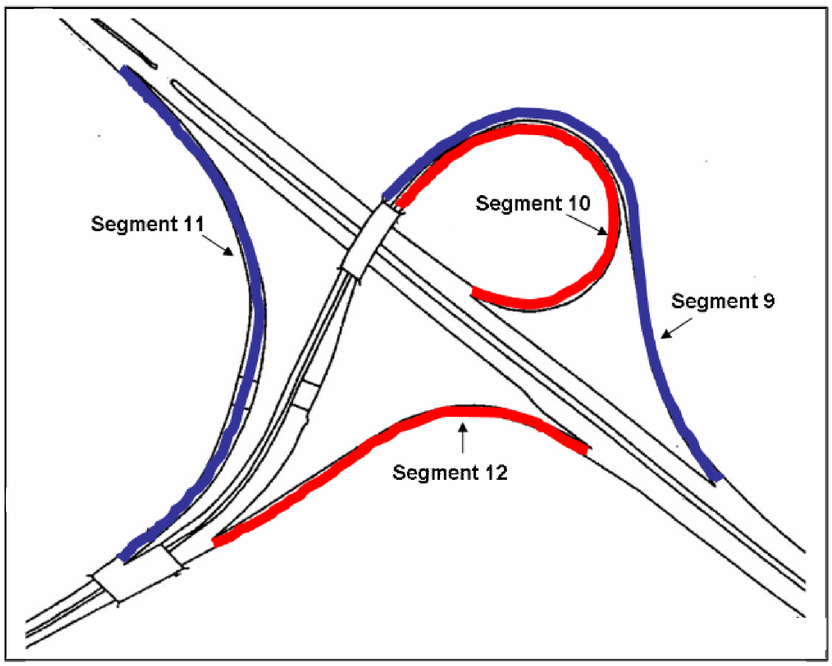
i) ***Approach for Shoulders, Roadside, Drainage, and Traffic.*** The sample selection process presented in section 4.3.2.3 was implemented to determine the required sample size for each of these asset groups. A complete application of the steps defined in section 4.3.2.3 and summarized in Flowchart B, located in Appendix B, is presented below.

<u>*Step 1. Stratification of the Population.*</u> To determine the required sample size, the twelve sections (i.e., VMS and VDOT Sections) were considered as independent populations to simplify the calculations. Moreover, Mainline and Ramps portion of the road were considered as separate populations as well. However, for the sections that contained both urban and rural zones, stratification was used to divide them in two groups, since the interest was in evaluating them separately. Only two sections, 1 and 7, from the twelve sections were located in both urban and rural zones. For this reason, stratification was implemented in only these two sections. The other ten (10) sections were considered as single populations.

<u>*Step 2. Sample Units.*</u> Two sample sizes were used in this evaluation, one for sites located in the mainline portion of the highway and other for the sites located in the Ramps. The Mainline portion of the road was divided in segments (i.e., sampling units) of one tenth of mile long (i.e., 0.1 mile). For instance, it was shown in Table 9.1 that Section 1 contains 101.24 center-lane miles, which corresponds to a total population of 2020 sampling units (i.e., 101.24 miles x 2 directions x 10 units per mile), were 14% of units were part of the urban stratum and the remaining 86% corresponded to the rural stratum. In the case of Ramps, each one of them was considered as a single unit. A ramp segment was defined from gore to gore of the ramp. Specific labels or segment numbers were assigned to each sampling unit within the mainline portion of the roadway as well as to each ramp segment. Figure 9.4 presents an example of the labeling system used in this evaluation. For example, Segment 1 in Figure 9.4 (a) goes from milepost 0 to 0.1, Segment 2 from milepost 0.1 to 0.2, and so on. On the other hand, notice in Figure 9.4 (b) that each ramp within the interchange was labeled as a single segment that goes from gore to gore of the ramp. This labeling approach was implemented in all sections.



a) Mainline



b) Ramps

Figure 9.4. Labeling of Sampling Units

Table 9.4 summarizes the total number of segments or sampling units defined in the twelve sections considered in the evaluations (i.e., VMS and VDOT Sections). According to Table 9.4, a total of 9893 sample units were defined in the twelve sections, including Ramps.

Table 9.4. Total Number of Sample Units

Section	Route	Milepost Range	Total Number of Segments
1M	I-95 Mainline	From 0.00 to 101.2	2020
1R	I-95 Ramps		367
2M	I-81 Mainline	From 0.00 to 87.30	1745
2R	I-81 Ramps		141
3M	I-77 Mainline	From 0.00 to 32.00 From 40.00 to 67.40	1187
3R	I-77 Ramps		60
4	I-381 Mainline	From 0.00 to 1.67	33
5	I-95 Mainline	From 108.90 to 132.40	469
6	I-66 Mainline	From 14.70 to 36.59	437
7	I-64 Mainline	0.00 through 1.70	577
8	I-64 Mainline	0.00 through 1.71	1143
9	I-64 Mainline	0.00 through 1.72	621
10	I-81 Mainline	0.00 through 1.73	335
11	I-581 Mainline	0.00 through 1.74	131
12	I-81 Mainline	0.00 through 1.75	627
All Sections			9893

Step 3. Existing Assets on each Sampling Unit. As stated in chapter 4, in order to be able to implement the proposed sampling procedure described in section 4.3.2.3 it was required to know whether an asset item exists or not within each sampling unit. Unfortunately, this information was not available in VDOT's records at the level of detail that was needed to support the proposed sampling methodology. For this reason, an "Asset Density Study" was conducted during summer 2002 to be able to identify the existing asset items within the twelve (12) sections, VMS and VDOT control sections. The study was performed by Anderson and Associates (i.e., private consultant) under the supervision of Virginia Tech and VDOT personnel. The objective of the study was to determine the existence and not the quantity of asset items within each site or sampling unit. The density of assets items was estimated based on wind shield inspections and revision of drawings. The product of this study was a database in Microsoft Access with 9893 records, which corresponds to the number of units summarized in Table 9.4. The database specified the existing asset items within each sampling unit. Figure 9.5 presents an example of the information that was provided from the "Asset Density Study".

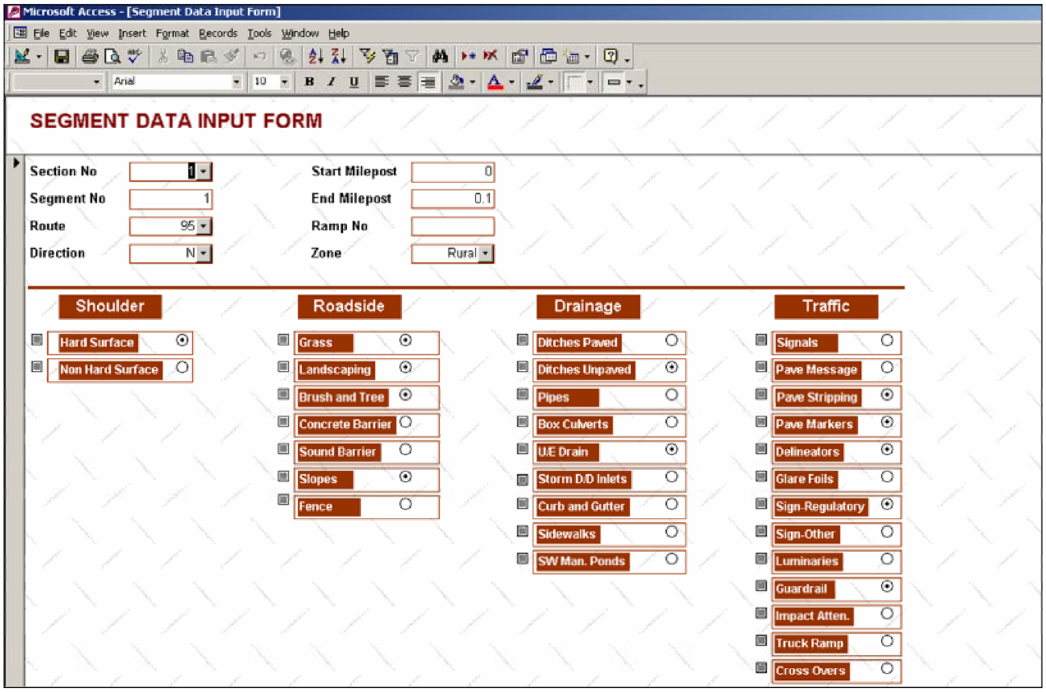


Figure 9.5. Microsoft Access Form Used in the Asset Density Study

<u>*Step 4. Databases with Sample Units containing each Asset Item.*</u> The main database with the 9893 segments was split into different databases with the sample units which contain each of the 37 asset items. This was done using a series of Macros were built in Microsoft Excel. The Macros were built in a way that the data was automatically query from these files when performing the random selection process (*Step 8*). This automation end up saving a significant amount of time.

<u>*Step 5. Parameters used to Estimate the Sample Size.*</u> The values for the parameters used to compute the sample with Eqs.4.9 through 4.13 are listed below.

- N = The value corresponds to the number of sampling units containing each asset item
- Z = 1.96 (for a 95% confidence level)
- e = A standard error equal to 0.04 when p=0.85 was used to estimate the value of e for each asset item
- p = The value of p varied depending on the performance target and the historical rating of each asset item
- w = Values were assigned proportional to the strata proportions for Sections 1 and 7

<u>*Step 6. Required Sample Size for each Asset Item.*</u> The required sample size foe asset item within each strata or section was computed with Eqs.4.9 and 4.10. An example of how the sample sizes for the asset items in Section 1 Mainline is presented in Table 9.5. Notice that Section 1 was divided in two strata, Urban and Rural Zones. The values for the parameters used to compute the sample size required for each asset item within each stratum are listed in the table. The procedure presented in Table 9.5 was repeated for each of strata or sections in order to obtain all the required sample sizes. The results from the calculations of these values are summarized in Table 9.6.

Table 9.5. Calculation of Required Sample Size for each Asset Item in Section 1 (Mainline)

<u>Section 1</u>

I-95 Mainline (MP 0.0 to 101.24)

<u>General Input</u>

Standard Error (e) = 0.04
for a value of p = 0.85
Z = 1.96

Asset Item	Urban Zones				Rural Zones			
	N	Historic p	e	$n_{Required}$	N	Historic p	e	$n_{Required}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Paved Shoulders								
Surface Defects	277	0.90	0.0317	153	1720	0.90	0.0317	286
Drop Off	277	0.90	0.0317	153	1720	0.90	0.0317	286
Separation	277	0.90	0.0317	153	1720	0.90	0.0317	286
Drainage	277	0.90	0.0317	153	1720	0.90	0.0317	286
Unpaved Shoulders								
Drop Off	0	0.50	0.0952	0	0	0.50	0.0952	0
Drainage	0	0.50	0.0952	0	0	0.50	0.0952	0
Roadside								
Grass	83	0.90	0.0317	67	1489	0.90	0.0317	279
Debris & Road Killed	276	0.97	0.0173	163	1718	0.97	0.0173	322
Litter	277	0.90	0.0317	153	1720	0.90	0.0317	286
Landscaping	1	0.50	0.0952	1	14	0.50	0.0952	12
Brush and Tree Control	258	0.95	0.0218	154	1694	0.95	0.0218	312
Concrete Barrier	258	0.93	0.0265	151	416	0.93	0.0265	194
Sound Barrier	0	0.50	0.0952	0	7	0.50	0.0952	7
Slopes	264	0.89	0.0331	148	1714	0.89	0.0331	282
Fence	43	0.91	0.0301	38	598	0.91	0.0301	221
Drainage								
Ditches Paved	14	0.90	0.0317	13	138	0.90	0.0317	98
Ditches Unpaved	42	0.90	0.0317	37	1221	0.90	0.0317	268
Pipes	1	0.86	0.0385	1	20	0.86	0.0385	19
Box Culverts	0	0.50	0.0952	0	3	0.50	0.0952	3
Under/Edge Drain	6	0.90	0.0317	6	159	0.90	0.0317	109
Storm D/D Inlets	231	0.90	0.0317	138	429	0.90	0.0317	191
Curb & Gutter	36	0.87	0.0368	32	28	0.87	0.0368	26
Sidewalks	0	0.50	0.0952	0	0	0.50	0.0952	0
SW Management Ponds	0	0.90	0.0317	0	0	0.90	0.0317	0
Traffic								
Signals	0	0.50	0.0952	0	0	0.50	0.0952	0
Pavement Message	0	0.95	0.0218	0	0	0.95	0.0218	0
Pavement Stripping	276	0.94	0.0238	159	1718	0.94	0.0238	308
Pavement Markers	247	0.90	0.0317	144	1692	0.90	0.0317	285
Delineators/Obj marker	268	0.90	0.0317	150	1144	0.90	0.0317	264
Glare Foils	68	0.60	0.0777	47	0	0.60	0.0777	0
Signs-Regulatory	56	0.95	0.0227	48	334	0.95	0.0227	172
Signs-Other	91	0.90	0.0317	72	484	0.90	0.0317	201
Luminaries	32	0.78	0.0506	28	22	0.78	0.0506	20
Guardrail	191	0.94	0.0232	127	959	0.94	0.0232	271
Impact Attenuators	5	0.99	0.0096	5	20	0.99	0.0096	19
Truck Ramps	0	0.50	0.0952	0	0	0.50	0.0952	0
Cross Overs	0	0.60	0.0777	0	73	0.60	0.0777	49
Rumble Strips								

Table 9.6. Summary of Required Sample Size for each Asset Item (All Sections)

Asset Item	$n_{Required}$														
	VMS Sections									VDOT Control Sections					
	Sec. 1 Main		Sec. 1 Ramps		Sec. 2 Main	Sec. 2 Ramps	Sec. 3 Main	Sec. 3 Ramps	Sec. 4 Main	Sec. 5 Main	Sec. 6 Main	Sec. 7,8,9 Main		Sec. 10&12 Main	Sec. 11 Main
	Urban	Rural	Urban	Rural								Urban	Rural		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Paved Shoulders															
Surface Defects	153	286	44	149	201	130	265	51	31	198	185	127	295	253	95
Drop Off	153	286	44	149	286	130	265	51	31	198	185	127	295	253	95
Separation	153	286	44	149	286	130	265	51	31	198	185	127	295	253	95
Drainage	153	286	44	149	286	130	265	51	31	198	185	127	295	253	95
Unpaved Shoulders															
Drop Off	0	0	39	77	0	131	0	39	0	0	0	0	0	0	0
Drainage	0	0	39	77	0	131	0	39	0	0	0	0	0	0	0
Roadside															
Grass	67	279	45	153	286	130	265	52	31	86	182	87	294	253	94
Debris & Road Killed	163	322	46	158	332	130	295	52	31	209	197	132	340	290	98
Litter	153	286	45	153	286	130	265	52	31	198	184	127	295	253	95
Landscaping	1	12	4	12	13	5	2	2	1	7	0	0	19	29	24
Brush and Tree Control	154	312	7	14	283	76	41	22	17	211	195	127	277	236	0
Concrete Barrier	151	194	6	26	93	2	28	2	0	17	36	60	85	29	35
Sound Barrier	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Slopes	148	282	45	134	286	130	265	49	30	196	183	120	295	253	93
Fence	38	221	38	129	304	124	279	46	15	120	113	56	217	263	83
Drainage															
Ditches Paved	13	98	2	22	120	47	159	35	3	76	14	23	148	134	14
Ditches Unpaved	37	268	37	150	284	128	262	52	17	168	163	84	287	248	86
Pipes	1	19	1	7	80	10	23	5	1	73	0	46	222	98	2
Box Culverts	0	3	0	1	2	0	0	0	0	5	0	0	11	21	0
Under/Edge Drain	6	109	2	10	51	0	12	0	0	120	5	2	79	27	0
Storm D/D Inlets	138	191	8	10	52	3	0	1	0	16	39	33	88	44	2
Curb & Gutter	32	26	1	4	0	0	7	0	0	0	0	14	5	0	1
Sidewalks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SW Management Ponds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Traffic															
Signals	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0
Pavement Message	0	0	5	17	36	40	11	15	1	0	0	0	3	6	0
Pavement Stripping	159	308	45	150	308	130	287	50	31	207	195	130	323	274	98
Pavement Markers	144	285	18	51	286	120	265	38	28	84	185	125	293	252	95
Delineators/Obj marker	150	264	40	129	178	51	38	23	0	73	72	73	101	26	0
Glare Foils	47	0	0	0	18	0	0	0	0	0	18	0	0	0	0
Signs-Regulatory	48	172	22	109	102	106	146	46	0	60	43	51	210	104	59
Signs-Other	72	201	20	79	201	95	174	41	0	83	47	41	238	120	54
Luminaries	28	20	17	17	14	2	26	2	9	0	0	16	22	3	0
Guardrail	127	271	27	97	272	81	258	38	2	111	80	108	302	255	71
Impact Attenuators	5	19	1	3	1	0	0	0	0	1	3	10	10	0	0
Truck Ramps	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Cross Overs	0	49	0	0	32	0	37	0	0	20	16	8	72	24	4
Rumble Strips															

<u>*Step 7. Required Sample Size for each Strata.*</u> Eqs.4.11, 4.12, and 4.13 were used to compute the sample size required when stratification and sampling proportional to size (PPS) are considered. The results from the applications of these equations are summarized in Table 9.7. The values were not computed for small sections (e.g., Sections with Ramps, Section 3, Section 6, Section 11), since Eqs.4.11, 4.12, and 4.13 are only valid for large populations. The values depicted in Table 9.7 will be used in Step 8 to verify if the total number of samples randomly selected for inspection is larger than these values.

Table 9.7. Summary of Required Sample Size for each Stratified Section

Party Responsible (1)	**Section** (2)	**Zone** (3)	**No. of Samples required at the strata level** (4)
VMS	Section 1 Mainline	Urban	87
		Rural	498
	Section 2 Mainline	Rural	508
	Section 3 Mainline	Rural	547
VDOT	Section 5 Mainline	Rural	342
	Section 7,8 & 9 Mainline	Urban	54
		Rural	473
	Section 10 & 12 Mainline	Rural	615

<u>*Step 8. Random Selection of Sample Units and Sufficiency Check.*</u> The procedure presented in Table 4.4, Chapter four, was performed for each strata or section to randomly select the number of samples required to meet sufficiency for each asset item. Table 9.8 presents a summary of the total number of samples required to be inspected on each strata or section. Notice that for each strata or section the total number of samples depicted in Table 9.8 is higher than the number of samples required in Table 9.7, when stratification and sampling proportional to the sample size were considered. Thus, sufficiency was met at both the asset item and the strata or section level.

Table 9.8. Number of Samples Required to Meet Sufficiency

Party Responsible (1)	Section (2)	Zone (3)	Category (4)	No. of Samples required to met sufficiency (5)	Percentage of Section Visited (4)	Percentage of Assets Inspected (Out of 37) (5)
VMS	I-95 Section 1	Urban	Mainline	232	57.5%	24.5%
			Ramps	42		
		Rural	Mainline	893		
			Ramps	208		
	I-81 Section 2	Rural	Mainline	891	53.2%	17.9%
			Ramps	114		
	I-77 Section 3	Rural	Mainline	657	56.6%	12.6%
			Ramps	50		
	Section 4	Rural	Mainline	33	97%	0.6%
	Total			**3120**		
VDOT (Control Sections)	Section 5	Rural	Mainline	407	86.6%	7.3%
	Section 6	Rural	Mainline	262	59.8%	4.7%
	Section 7,8 & 9	Urban	Mainline	143	44.3%	18.5%
		Rural	Mainline	895		
	Section 10 & 12	Rural	Mainline	654	67.8%	11.7%
	Section 11	Urban	Mainline	124	94%	2.2%
	Total			**2485**		

According to Table 9.8, a total of 5605 sites were required to be visited for inspection in 2002 in order to guarantee that the findings can be generalized to the entire population with at least 95% confidence. This corresponds to approximately 57**%** of the total population. However, as opposed to previous years in which all asset items were inspected on each site, in 2002 not all asset items on each site were required to be inspected. The fact that an asset inventory was available -- *2002 Asset Density* -- allowed to specify which asset items to inspect on each site. Table 9.9 summarizes the distribution of sites required for inspection based on the percentage of asset items specified for inspection on each site. According to Table 9.9, for 2354 sites (i.e., 42 % of the sites required to be inspected) less than 10% of the existing asset items in the site were required to be inspected, which correspond to approximately 4 asset items or less per site, out of 37 asset items.

Table 9.9. Distribution of Sites required for Inspection based on the Percentage of Asset Items specified for Inspection

% of Asset Items to Inspect	No. of Sites	% of Sites
0% to 10%	2354	42.01 %
10% to 20%	427	7.61 %
20% to 30%	247	4.41 %
30% to 40%	1771	31.59 %
40% to 50%	673	12.01 %
50% to 60%	128	2.28 %
60% to 70%	5	0.09 %
70% to 80%	0	0.00 %
80% to 90%	0	0.00 %
90% to 100%	0	0.00 %
Total =	**5605**	

Step 9. Field Inspections. Inspections in the field were conducted in the sites selected in Step 8.

Step 10. Confidence Levels. For some reasons, not all the asset items specified for inspection were actually inspected in the field. Thus adjustments in the confidence levels were required. A detailed discussion of how the adjusted confidence levels were obtained for each section is presented in the Data Analysis section.

ii) ***Sampling Approach for Pavement Structures.*** The procedure implemented for the pavement structures was very different from the approach used to determine the sample size for Shoulders, Roadside, Drainage, and Traffic asset groups. Notice from Tables 9.10 and 9.11 that for almost all the sections the entire population was inspected. The reason is because VDOT commonly drive the entire Interstate network with the equipped Van. For instance, notice in Table 9.10 that approximately 99% of the population in section 1 was inspected. Therefore, it was concluded that the findings reported for the condition of the pavement were representative of the entire population with a very high confidence level, with the exception of Sections 7 and 12 for the CCI and Sections 4 and 11 for the IRI.

Table 9.10. Sampled Population to Obtain CCI

Party Responsible	Section	Required				Actual				
		N	p	e	$n_{Required}$	Total Miles Inspected	n_{Actual}	Segment Size Statistics (mi)		
								Average	Minimum	Maximum
VMS	Section 1	2020	0.85	0.04	266	199.13	1991	1.72	0.24	9.83
	Section 2	1745	0.85	0.04	260	162.58	1626	1.91	0.08	8.35
	Section 3	1187	0.85	0.04	243	71.88	719	3.42	0.5	12.56
	Section 4	33	0.85	0.04	30	3.34	33	0.56	0.21	0.89
VDOT	Section 5	469	0.85	0.04	185	62.05	621	2.30	0.53	4.64
	Section 6	438	0.85	0.04	180	43.9	438	2.20	0.55	5.45
	Section 7	577	0.85	0.04	200	5.58	56	1.40	0.91	1.86
	Section 8	1143	0.85	0.04	241	114.33	1143	5.20	0.89	10.18
	Section 9	621	0.85	0.04	205	61.25	613	4.71	0.53	8.55
	Section 10	335	0.85	0.04	160	33.68	336	2.41	0.54	7.24
	Section 11	131	0.85	0.04	92	13.21	132	1.65	0.07	4.70
	Section 12	627	0.85	0.04	206	None	0			

Table 9.11. Sampled Population to Obtain IRI

Party Responsible	Section	Required				Actual				
		N	p	e	$n_{Required}$	Total Miles Inspected	n_{Actual}	Segment Size Statistics (mi)		
								Average	Minimum	Maximum
VMS	Section 1	2020	0.85	0.04	266	172.75	1727	0.09	0	0.14
	Section 2	1745	0.85	0.04	260	121.08	1211	0.09	0.006	0.11
	Section 3	1187	0.85	0.04	243	81.72	817	0.09	0.015	0.11
	Section 4	33	0.85	0.04	30	1.72	17	0.10	0.015	0.11
VDOT	Section 5	469	0.85	0.04	185	31.10	311	0.10	0.053	0.11
	Section 6	437	0.85	0.04	180	21.55	215	0.10	0.06	0.11
	Section 7	577	0.85	0.04	200	27.55	276	0.10	0.01	0.11
	Section 8	1143	0.85	0.04	241	55.46	555	0.10	0.011	0.11
	Section 9	621	0.85	0.04	205	30.38	304	0.10	0.02	0.11
	Section 10	335	0.85	0.04	160	30.47	305	0.09	0.02	0.11
	Section 11	131	0.85	0.04	92	None	0			
	Section 12	627	0.85	0.04	206	25.27	253	0.079707	0.05	0.09

iii) ***Sampling Approach for Bridge Structures***. Since the bridge structures are inspected every two years according to federal regulations, the database provided by VDOT's Bridge Management Division contained inspection records for approximately fifty percent (50%) of the existing bridges on each section (i.e., 50% of the population). However, if the total population each year is defined as the half portion that can really be inspected, then the actual number of records received from the Bridge Management Division was close to 100 percent of the population.

9.2.2.3. QA/QC Process

In order to increase the reliability of the data to be collected, VDOT and Virginia Tech implemented a robust QA/QC program. The QA/QC program was implemented in two stages:

(1) before conducting the actual inspections in the field and (2) while performing the field inspections. A description of the methodologies implemented at these two stages follows.

i) ***<u>QA/QC Before Conducting Inspections in the Field</u>***

The QA/QC process before conducting the actual inspection in the fields basically consisted in training the crews and evaluating if there were good agreement among them. A brief description of the training session as well as the results from the evaluation of agreement among rating crews follows.

a) *<u>Training Session.</u>* As part of the condition assessment process, VDOT personnel offers a training session every year before the inspections in the field are performed. For instance, in 2002, the training session took place in Roanoke, Virginia. Representatives from all the parties involved in the VDOT-VMS contract participated in the training. The main objectives of the training session was to discuss with the rating crews the performance standards specified by VDOT in the contractual agreement with VMS and to ensure that each crew member interprets all standards in the correct manner. The training session also had a drill exercise where the crews were sent to the field to collect data on four real segments from the population (i.e., actual sample units). All teams were required to inspect the same segments or samples. This allowed performing the assessment of agreement among the ratings made by the crews. The evaluation of agreement is discussed next.

b) *<u>Agreement among Rating Crews.</u>* The two methodologies proposed in Chapter four to measure the level of agreement among rating crews, r_{wg} index and Stivers et al. (1997) approach, were implemented in the 2002 Training Session. A step-by-step application of each approach is presented next. Refer to Flowchart B.2 in Appendix B for a graphical representation of the implementation steps associated to these two approaches.

1) *<u>Interrater Agreement Approach.</u>* The interrater agreement approach was implemented to assess agreement at the asset item level. As discussed in Chapter four, the mechanism used to serve this purpose was the r_{wg} index. The next six steps that will be presented were followed to compute the r_{wg} index for each asset item.

Step 1. Since four crews participated in the evaluations in 2002, then the value of $J = 4$.

Step 2. Table 9.12 summarizes the number of alternatives or the value of A for each one of the asset items. The values correspond to the number of performance standards defined by VDOT to evaluate each asset item. For instance, according to Table A.1, two (2) performance standards were defined to assess the condition of asset items such as Concrete Barriers and Luminaries. For this reason, the value of A for these two asset items is equal to 2.

Table 9.12. Number of Alternatives (A) for each Asset Item

Unpaved Shoulders			Paved Shoulders			Roadside			Drainage			Traffic		
Asset Item	(A)	σ_{EU}^2	Asset Item	(A)	σ_{EU}^2	Asset Item	(A)	σ_{EU}^2	Asset Item	(A)	σ_{EU}^2	Asset Item	(A)	σ_{EU}^2
Drop Off	2	0.25	Surface Defects	5	2	Grass	3	0.67	Ditches Paved	5	2	Signals	1	0
Drainage	4	1.25	Drop Off	2	0.25	Debris & Road Kill	2	0.25	Ditches Unpaved	4	1.25	Pavement Message	3	0.67
			Separation	2	0.25	Litter	2	0.25	Pipes	9	6.67	Pavement Stripping	3	0.67
			Drainage	2	0.25	Landscaping	1	0.00	Box Culverts	9	6.67	Pavement Markers	3	0.67
						Brush and Tree	5	2.00	Under/Edge Drain	3	0.67	Delineators/Obj marker	3	0.67
						Concrete Barrier	2	0.25	Storm D/D Inlets	4	1.25	Glare Foils	2	0.25
						Sound Barrier	5	2.00	Curb & Gutter	7	4.00	Signs-Regulatory	5	2.00
						Slopes	1	0.00	Sidewalks	3	0.67	Signs-Other	5	2.00
						Fence	3	0.67	SW Manag. Ponds	2	0.25	Luminaries	2	0.25
												Guardrail	8	5.25
												Impact Attenuators	2	0.25
												Truck Ramps	1	0.00
												Cross Overs	1	0.00
												Rumble Strips	1	0.00

Step 3. With the values of A defined in Step 2, the variance of the uniform distribution of the alternative number of responses (σ_{EU}^2) for each asset item were computed using the following equation: $\sigma_{EU}^2 = (A^2-1)/12$. The values are summarized in Table 9.12.

Step 4. The next step was to compute the variances of the ratings assigned by each crew to each particular asset item. Table 9.13 presents an example of how the variance of the ratings was computed with the evaluations provided by the crews in the training sites for the Guardrail asset item. The same procedure was followed to compute all the variances of the ratings for the rest of the asset items evaluated in the sample sites inspected as part of the training session.

Table 9.13. Example for Guardrail Asset Item

Sample	**Team (J=4)**				**Mean (M)**	Sx_j^2
	J=1	**J=2**	**J=3**	**J=4**		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	5	6	7	5	5.75	0.92
2	6	8	7	6	6	0.92
3	8	8	8	8	8	0.0
4	8	8	8	8	8	0.0
Mean						**0.92**

Step 5. Finally, the r_{wg} indices were computed with Eq.4.19 and using as an input the values defined in Steps 1 through 4. For example, the r_{wg} index for the Guardrail asset item was computed as follows,

$$r_{wg} = \frac{4\left(1-\frac{0.92}{5.25}\right)}{4\left(1-\frac{0.92}{5.25}\right)+\left(\frac{0.92}{5.25}\right)} = 0.98$$

Table 9.14 summarizes the r_{wg} values obtained for each of the asset item inspected in the 2002 Training Sites. In this training session, it was considered that low agreement was obtained for asset items if the r_{wg} index value was lower than 0.95. Notice from Table 9.14 that six of the asset items got an r_{wg} index value lower than 0.95. For those asset items for which a non-acceptable level of agreement was received, VDOT personnel performed a revision of the performance standards in order to improve the agreement among crews and minimize inconsistencies in the interpretation of those standards.

Table 9.14. Summary of r_{wg}'s

Unpaved Shoulders		Paved Shoulders		Roadside		Drainage		Traffic	
Asset Item	r_{wg}	Asset Item	r_{wg}	Asset Item	r_{wg}	Asset Item	r_{wg}	Asset Item	r_{wg}
Drop Off	0.87	Surface Defects	1.00	Grass	0.95	Ditches Paved	0.98	Signals	1.00
Drainage	1.00	Drop Off	0.82	Debris & Road Kill	1.00	Ditches Unpaved	0.93	Pavement Message	1.00
		Separation	0.97	Litter	1.00	Pipes	0.98	Pavement Stripping	0.86
		Drainage	1.00	Landscaping	0.92	Box Culverts	1.00	Pavement Markers	1.00
				Brush and Tree	0.99	Under/Edge Drain	1.00	Delineators/Obj marker	0.95
				Concrete Barrier	1.00	Storm D/D Inlets	0.99	Glare Foils	1.00
				Sound Barrier	1.00	Curb & Gutter	1.00	Signs-Regulatory	0.99
				Slopes	0.74	Sidewalks	1.00	Signs-Other	0.98
				Fence	0.99	SW Manag. Ponds	1.00	Luminaries	1.00
								Guardrail	0.98
								Impact Attenuators	1.00
								Truck Ramps	1.00
								Cross Overs	1.00
								Rumble Strips	NA

2) Difference in Level of Service Approach. The difference in level of service approach was implemented to assess agreement at the asset group level. As discussed in Chapter 4, the mechanism used to evaluate the level of agreement at the asset group level was the *Z* value obtained from the differences in Level of Service (LOS) rating between two crews. The steps that will be presented were followed to compute the *Z* values.

Step 1. The first step of the process was to compute the Level of Service (LOS) for each asset group. These values are summarized in Table 9.15.

Table 9.15. Summary of LOS Ratings from the Inspections Performed in the 2002 Training Session

Crew	Asset Group	LOS Rating			
		Segment1	Segment2	Segment3	Segment4
1	Paved Shoulders	100.00%	100.00%	100.00%	48.52%
	Unpaved Shoulders	NA	NA	48.54%	NA
	Roadside	100.00%	89.94%	100.00%	100.00%
	Drainage	83.83%	72.06%	100.00%	100.00%
	Traffic	100.00%	96.09%	100.00%	100.00%
2	Paved Shoulders	73.88%	73.88%	100.00%	100.00%
	Unpaved Shoulders	NA	NA	100.00%	NA
	Roadside	100.00%	86.87%	100.00%	100.00%
	Drainage	78.89%	73.36%	100.00%	90.34%
	Traffic	100.00%	100.00%	66.90%	92.84%
3	Paved Shoulders	73.88%	73.88%	73.88%	100.00%
	Unpaved Shoulders	NA	NA	48.54%	NA
	Roadside	73.36%	70.75%	83.72%	71.25%
	Drainage	71.35%	79.10%	100.00%	79.76%
	Traffic	100.00%	91.53%	58.62%	74.84%
4	Paved Shoulders	100.00%	100.00%	73.88%	100.00%
	Unpaved Shoulders	NA	NA	100.00%	NA
	Roadside	86.87%	88.96%	100.00%	68.57%
	Drainage	82.97%	88.99%	64.96%	85.26%
	Traffic	89.50%	85.71%	76.91%	100.00%

Step 2. The next step was to compute the differences in LOS ratings between any two crews. The results from these calculations are presented in Table 9.16.

Table 9.16. Summary of ΔLOS Ratings

Crew	Segment1				Segment2				Segment3				Segment4				Mean ΔLOS				Standard Deviation LOS			
	Crew1	Crew2	Crew3	Crew4	Crew1	Crew2	Crew3	Crew4	Crew1	Crew2	Crew3	Crew4	Crew1	Crew2	Crew3	Crew4	Crew1	Crew2	Crew3	Crew4	Crew1	Crew2	Crew3	Crew4
(1)	(2)				(3)				(4)				(5)				(6)				(7)			
Paved Shoulders																								
Crew1		26.1%	26.1%	0.0%		26.1%	26.1%	0.0%		0.0%	26.1%	26.1%		-51.5%	-51.5%	-51.5%		0.00	0.07	-0.06		36.6%	38.8%	32.5%
Crew2			0.0%	-26.1%			0.0%	-26.1%			26.1%	26.1%			0.0%	0.0%			0.07	-0.07			13.1%	25.0%
Crew3				-26.1%				-26.1%				0.0%				0.0%				-0.13				15.1%
Crew4																								
Unpaved Shoulders																								
Crew1		NA	NA	NA		NA	NA	NA		-51.5%	0.0%	-51.5%		NA	NA	NA		-0.51	0.00	-0.51		NA	NA	NA
Crew2			NA	NA			NA	NA			51.5%	0.0%			NA	NA			0.51	0.00			NA	NA
Crew3				NA				NA				-51.5%				NA				-0.51				NA
Crew4																								
Roadside																								
Crew1		0.0%	26.6%	13.1%		3.1%	19.2%	1.0%		0.0%	16.3%	0.0%		0.0%	28.8%	31.4%		0.01	0.23	0.11		1.5%	5.9%	14.6%
Crew2			26.6%	13.1%			16.1%	-2.1%			16.3%	0.0%			28.8%	31.4%			0.22	0.11			6.7%	15.4%
Crew3				-13.5%				-18.2%				-16.3%				2.7%				-0.11				9.5%
Crew4																								
Drainage																								
Crew1		4.9%	12.5%	0.9%		-1.3%	-7.0%	-16.9%		0.0%	0.0%	35.0%		9.7%	20.2%	14.7%		0.03	0.06	0.08		5.0%	12.2%	22.0%
Crew2			7.5%	-4.1%			-5.7%	-15.6%			0.0%	35.0%			10.6%	5.1%			0.03	0.05			7.4%	21.7%
Crew3				-11.6%				-9.9%				35.0%				-5.5%				0.02				22.2%
Crew4																								
Traffic																								
Crew1		0.0%	0.0%	10.5%		-3.9%	4.6%	10.4%		33.1%	41.4%	23.1%		7.2%	25.2%	0.0%		0.09	0.18	0.11		16.7%	19.2%	9.4%
Crew2			0.0%	10.5%			8.5%	14.3%			8.3%	-10.0%			18.0%	-7.2%			0.09	0.02			7.4%	12.3%
Crew3				10.5%				5.8%				-18.3%				-25.2%				-0.07				17.6%
Crew4																								

Step 3. After the differences in LOS ratings were obtained, the mean values for the differences in LOS ratings were computed using equation 4.21. The results from these calculations are presented in column 6 of Table 9.16.

Step 4. The variances of the differences in LOS ratings were computed by using Eq.4.22.

Step 5. In this step the standard deviations were computed from the variances obtained in Step 4. The results are presented in column 7 of Table 9.16

Step 6. Finally, the Z values for each of the asset groups considered in the evaluation were computed using Eq.4.24. The values obtained are summarized in Table 9.17. Notice from this table that significant differences between some of the crews were found in the Roadside and Traffic asset groups.

Table 9.17. Z Values Used to Evaluate Agreement among Crews

	Z Statistics				Significant Difference?			
Crew	**Crew1**	**Crew2**	**Crew3**	**Crew4**	**Crew1**	**Crew2**	**Crew3**	**Crew4**
Paved Shoulders								
Crew1		0.01	0.35	-0.39		no	no	no
Crew2			1.00	-0.52			no	no
Crew3				-1.73				no
Crew4								
Unpaved Shoulders								
Crew1		NA	NA	NA		NA	NA	NA
Crew2			NA	NA			NA	NA
Crew3				NA				NA
Crew4								
Roadside								
Crew1		1.00	7.65	1.56		no	yes	no
Crew2			6.56	1.38			yes	no
Crew3				-2.38				yes
Crew4								
Drainage								
Crew1		1.33	1.05	0.77		no	no	no
Crew2			0.84	0.47			no	no
Crew3				0.18				no
Crew4								
Traffic								
Crew1		1.09	1.85	2.33		no	no	yes
Crew2			2.36	0.31			yes	no
Crew3				-0.77				no
Crew4								

ii) ***QA/QC while Conducting Inspections in the Field***. In order to minimize errors in the data entry and errors associated with the manipulation of the data in the office, a very robust audit process was developed and implemented by Virginia Tech to guarantee the reliability of the data used for the analysis. The objective of the audit process was to improve the quality of the information received from the field crews and the reliability and consistency of the procedures used in the office to process the data and convert it into the required format for the analysis. Some of the checks that were adopted as part of the audit process are listed below.

- Smart logics were introduced in the electronic forms used in the field to help minimize inconsistencies in the data entry process.
- Queries were built in the electronic forms to help identify format errors in the data collected as well as verifying the completeness of the inspection records.
- Combinations of Macros were built using Microsoft Excel to help identify inconsistencies in the data manipulation process, such as errors in the transfer of data from the databases to the spreadsheets, and changes in formats (e.g., Web and Palm).
- Actual confidence levels were continuously monitored to guarantee the results obtained from the inspections performed in the sampled population were going to be representative of the entire population with a high confidence.

The implementation of these checks during the data collection effort was very helpful in the identification of inconsistencies in the data entry as well as in the identification of inconsistencies in the processing phase at the office. It is important that the evaluator continuously add more quality checks as part of the auditing process in order to keep meeting the goal of minimizing errors associated to the data entry as well as the data manipulation in the office.

9.2.3. Data Analysis

The data analysis process started after the field inspections were completed and all the data was validated. The result from the analysis provided the information necessary to assess the compliance of VMS to performance standards associated to the Level of Service. This evaluation focused in the following two areas: (1) actual performance and (2) long-term performance. A description of the findings on each asset group is presented next.

9.2.3.1. Data Analysis Procedures for Shoulders, Roadside, Drainage, and Traffic

This section presents the implementation of the procedures discussed in Chapter four to evaluate VMS's performance in maintaining the asset items identified within the following four asset groups: Shoulders, Roadside, Drainage, and Traffic.

a) ***Actual Performance.*** The actual performance evaluation was conducted in four stages: (1) calculation of actual ratings, (2) comparison of the actual ratings versus the performance targets, (3) comparison among different sections considered in the evaluation, and (4) comparison of VMS's performance versus the actual performance in VDOT Control Sites.

i) *Calculation of Actual Ratings.* The steps described in section 4.4.1 and graphically illustrated in Flowchart B.3, located in Appendix B, were implemented to obtain the actual LOS ratings for each section or strata. To better illustrate the procedure followed to compute the actual ratings, the information for Section 1 is used as a reference for the calculations. A description of the findings on each step follows.

Step 1. The first step was to collect the statistics from the information received from the field inspections. These statistics were generated for each section. Table 9.18 presents an example of a typical table used in this application to generate the LOS ratings for each section or strata. The data presented in this table correspond to the inspections record associated to Section 1 Mainline and Urban. Similar information for Section 1 Mainline and Rural is presented in Table 9.19. The statistics collected in this step are shown in Columns 3 and 4 of both tables.

Table 9.18. Data Analysis for Section 1 Mainline and Urban Zones

Asset Group (1)	Asset Item (2)	No. of Samples Inspected (3)	No. of Passing Samples (4)	Asset Item Weighting (5)	Total Possible Score (6)	Actual Asset Item Score (7)	Actual Rating for Asset Item (8)	VDOT Rating Required for Asset Item (9)	VDOT Score required for Asset Item (10)	Actual Rating Asset Group (11)	VDOT Rating Requirement for Asset Group (12)	Asset Group Weighting (13)	Actual Asset Group Score (14)	VDOT Score Requirement for Asset Group (15)
Shoulders														
Paved Shoulders	Surface Defects	157	157	5.33	836.81	836.81	100.00%	90.00%	753.13					
	Drop Off	157	157	5.83	915.31	915.31	100.00%	90.00%	823.78					
	Separation	157	154	5.66	888.62	871.64	98.09%	90.00%	799.76					
	Drainage	157	152	5.50	863.50	836.00	96.82%	90.00%	777.15					
	Sub Total-Paved Shoulders			7.17	3504.24	3459.76	98.73%	90.00%	3153.82					
Unpaved Shoulders	Drop Off	0	0	5.83	0.00	0.00	0.00%	90.00%	0.00					
	Drainage	0	0	5.50	0.00	0.00	0.00%	90.00%	0.00					
	Sub Total-Unpaved Shoulders			1.00	0.00	0.00	0.00%	0.00%	0.00					
	Total Pavement									98.73%	90.00%	0.1560	15.40%	14.04%
Roadside	Grass	67	36	5.67	379.89	204.12	53.73%	90.00%	341.90					
	Debris and Road Kill	204	203	8.50	1734.00	1725.50	99.51%	100.00%	1734.00					
	Litter	195	195	4.67	910.65	910.65	100.00%	90.00%	819.59					
	Landscaping	1	1	4.83	4.83	4.83	100.00%	80.00%	3.86					
	Brush and Tree Control	156	149	5.33	831.48	794.17	95.51%	95.00%	789.91					
	Concrete Barrier	157	149	8.17	1282.69	1217.33	94.90%	99.00%	1269.86					
	Sound Barrier	0	0	4.83	0.00	0.00	0.00%	95.00%	0.00					
	Slopes	151	150	5.83	880.33	874.50	99.34%	90.00%	792.30					
	Fence	40	38	5.00	200.00	190.00	95.00%	98.00%	196.00					
	Total-Roadside				6223.87	5921.10			5947.42	95.14%	95.56%	0.2350	22.36%	22.46%
Drainage	Ditches, Paved	44	37	6.67	293.48	246.79	84.09%	90.00%	264.13					
	Ditches, Unpaved	75	74	6.33	474.75	468.42	98.67%	90.00%	427.28					
	Pipes (ea.)	1	1	8.50	8.50	8.50	100.00%	95.00%	8.08					
	Box Culverts	0	0	8.00	0.00	0.00	0.00%	95.00%	0.00					
	Under/Edge Drains	12	11	8.33	99.96	91.63	91.67%	90.00%	89.96					
	Storm Drains/ Drop Inlets	285	275	8.67	2470.95	2384.25	96.49%	90.00%	2223.86					
	Curb and Gutter	76	40	4.00	304.00	160.00	52.63%	95.00%	288.80					
	Sidewalks	0	0	3.17	0.00	0.00	0.00%	90.00%	0.00					
	Stormwater Management Ponds	0	0	5.33	0.00	0.00	0.00%	95.00%	0.00					
	Total-Drainage				3651.64	3359.59			3302.10	92.00%	90.43%	0.2370	21.80%	21.43%
Traffic	Signals	1	1	9.17	9.17	9.17	100.00%	100.00%	9.17					
	Pavement Messages	2	2	6.33	12.66	12.66	100.00%	95.00%	12.03					
	Pavement Striping	176	174	8.67	1525.92	1508.58	98.86%	95.00%	1449.62					
	Pavement Markers (raised/recessed)	148	148	8.00	1184.00	1184.00	100.00%	90.00%	1065.60					
	Delineators/Object Markers	157	147	4.83	758.31	710.01	93.63%	90.00%	682.48					
	Glare Foils	40	39	5.50	220.00	214.50	97.50%	90.00%	198.00					
	Signs-Regulatory	42	42	8.00	336.00	336.00	100.00%	100.00%	336.00					
	Signs Other	147	145	8.00	1176.00	1160.00	98.64%	90.00%	1058.40					
	Luminaires	120	106	6.50	780.00	689.00	88.33%	90.00%	702.00					
	Guardrail	167	167	8.50	1419.50	1419.50	100.00%	100.00%	1419.50					
	Impact Attenuators	6	6	9.33	55.98	55.98	100.00%	100.00%	55.98					
	Truck Ramps	0	0	6.00	0.00	0.00	0.00%	100.00%	0.00					
	Cross Overs	0	0	5.00	0.00	0.00	0.00%	100.00%	0.00					
	Rumble Strips	76	76	5.00	380.00	380.00	100.00%	80.00%	304.00					
	Total-Traffic				7857.54	7679.40			7292.78	97.73%	92.81%	0.3720	36.36%	34.53%
	TOTAL RATING												**95.92%**	**92.45%**

Table 9.19. Data Analysis for Section 1 Mainline and Rural Zones

Asset Group (1)	Asset Item (2)	No. of Samples Inspected (3)	No. of Passing Samples (4)	Asset Item Weighting (5)	Total Possible Score (6)	Actual Asset Item Score (7)	Actual Rating for Asset Item (8)	VDOT Rating Required for Asset Item (9)	VDOT Score required for Asset Item (10)	Actual Rating Asset Group (11)	VDOT Rating Requirement for Asset Group (12)	Asset Group Weighting (13)	Actual Asset Group Score (14)	VDOT Score Requirement for Asset Group (15)
Shoulders														
Paved Shoulders	Surface Defects	283	270	5.33	1508.39	1439.10	95.41%	90.00%	1357.55					
	Drop Off	283	279	5.83	1649.89	1626.57	98.59%	90.00%	1484.90					
	Separation	283	273	5.66	1601.78	1545.18	96.47%	90.00%	1441.60					
	Drainage	283	280	5.50	1556.50	1540.00	98.94%	90.00%	1400.85					
	Sub Total-Paved Shoulders			7.17	6316.56	6150.85	97.38%	90.00%	5684.90					
Unpaved Shoulders	Drop Off	0	0	5.83	0.00	0.00	0.00%	90.00%	0.00					
	Drainage	0	0	5.50	0.00	0.00	0.00%	90.00%	0.00					
	Sub Total-Unpaved Shoulders			1.00	0.00	0.00	0.00%	0.00%	0.00					
	Total Pavement									97.38%	90.00%	0.1560	15.19%	14.04%
Roadside	Grass	277	275	5.67	1570.59	1559.25	99.28%	90.00%	1413.53					
	Debris and Road Kill	486	485	8.50	4131.00	4122.50	99.79%	100.00%	4131.00					
	Litter	454	454	4.67	2120.18	2120.18	100.00%	90.00%	1908.16					
	Landscaping	12	12	4.83	57.96	57.96	100.00%	80.00%	46.37					
	Brush and Tree Control	308	307	5.33	1641.64	1636.31	99.68%	95.00%	1559.56					
	Concrete Barrier	233	226	8.17	1903.61	1846.42	97.00%	99.00%	1884.57					
	Sound Barrier	6	2	4.83	28.98	9.66	33.33%	95.00%	27.53					
	Slopes	279	278	5.83	1626.57	1620.74	99.64%	90.00%	1463.91					
	Fence	222	203	5.00	1110.00	1015.00	91.44%	98.00%	1087.80					
	Total-Roadside				14190.53	13988.02			13522.44	98.57%	95.29%	0.2350	23.16%	22.39%
Drainage	Ditches, Paved	299	250	6.67	1994.33	1667.50	83.61%	90.00%	1794.90					
	Ditches, Unpaved	756	748	6.33	4785.48	4734.84	98.94%	90.00%	4306.93					
	Pipes (ea.)	32	29	8.50	272.00	246.50	90.63%	95.00%	258.40					
	Box Culverts	3	2	8.00	24.00	16.00	66.67%	95.00%	22.80					
	Under/Edge Drains	158	152	8.33	1316.14	1266.16	96.20%	90.00%	1184.53					
	Storm Drains/ Drop Inlets	297	293	8.67	2574.99	2540.31	98.65%	90.00%	2317.49					
	Curb and Gutter	41	34	4.00	164.00	136.00	82.93%	95.00%	155.80					
	Sidewalks	0	0	3.17	0.00	0.00	0.00%	90.00%	0.00					
	Stormwater Management Ponds	0	0	5.33	0.00	0.00	0.00%	95.00%	0.00					
	Total-Drainage				11130.94	10607.31			10040.85	95.30%	90.21%	0.2370	22.59%	21.38%
Traffic	Signals	1	1	9.17	9.17	9.17	100.00%	100.00%	9.17					
	Pavement Messages	2	0	6.33	12.66	0.00	0.00%	95.00%	12.03					
	Pavement Striping	304	292	8.67	2635.68	2531.64	96.05%	95.00%	2503.90					
	Pavement Markers (raised/recessed)	305	300	8.00	2440.00	2400.00	98.36%	90.00%	2196.00					
	Delineators/Object Markers	267	246	4.83	1289.61	1188.18	92.13%	90.00%	1160.65					
	Glare Foils	0	0	5.50	0.00	0.00	0.00%	90.00%	0.00					
	Signs-Regulatory	282	282	8.00	2256.00	2256.00	100.00%	100.00%	2256.00					
	Signs Other	326	324	8.00	2608.00	2592.00	99.39%	90.00%	2347.20					
	Luminaires	152	142	6.50	988.00	923.00	93.42%	90.00%	889.20					
	Guardrail	408	405	8.50	3468.00	3442.50	99.26%	100.00%	3468.00					
	Impact Attenuators	19	19	9.33	177.27	177.27	100.00%	100.00%	177.27					
	Truck Ramps	0	0	6.00	0.00	0.00	0.00%	100.00%	0.00					
	Cross Overs	35	35	5.00	175.00	175.00	100.00%	100.00%	175.00					
	Rumble Strips	953	953	5.00	4765.00	4765.00	100.00%	80.00%	3812.00					
	Total-Traffic				20824.39	20459.76			19006.41	98.25%	91.27%	0.3720	36.55%	33.95%
	TOTAL RATING												**97.49%**	**91.77%**

Step 2. The next step was to multiply the statistics summarized in Columns 3 and 4 times the relative weights among asset items within each asset group to obtain the Total Scores and Actual Scores to be used to generate the LOS ratings. These values are depicted in Columns 6 and 7 of Tables 9.18 and 9.19.

Step 3. With the scores computed in Step 2, a rating for each asset group was obtained. These ratings are listed in Columns 11 and 12.

Step 4. Finally, the overall rating at the strata or section level was obtained by applying the second set of weights, this time among asset groups (e.g., Column 13). The overall values for both the Actual Performance as well as VDOT Requirement are depicted in Columns 14 and 15.

Step 5. Steps 1 through 4 were implemented to all the Sections. The results from this analysis are presented in Table 9.20. Notice in this table that also overall ratings were generated for all VMS's Sections as well as for all VDOT Sections. The actual mileage for each Section was used as the weightings to generate the final overall ratings

ii) *Comparison of Actual Performance versus Performance Targets*

Step 6. Figure 9.6 summarizes the comparison of the Overall Actual Ratings at the asset group level for VMS and VDOT with their requirements. Notice that in VMS Sections all the requirements were met, whereas in VDOT Control Sections two of the asset groups, Roadside and Drainage, failed to meet the requirements.

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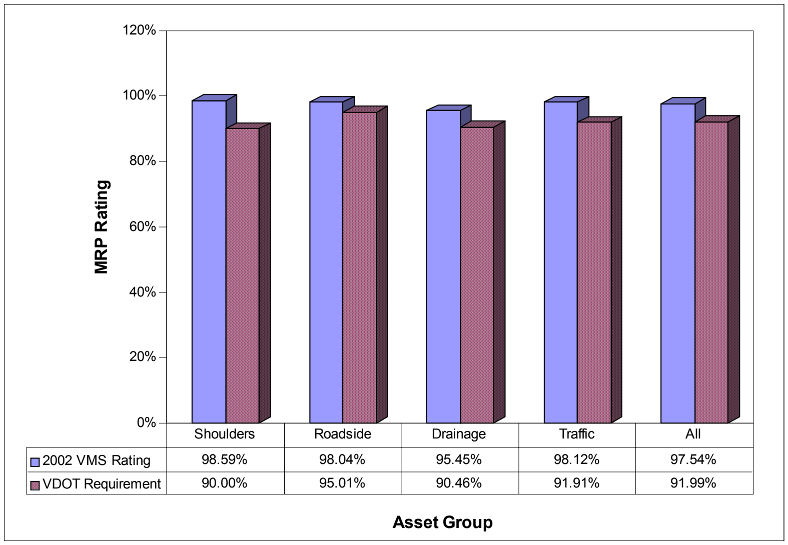
Table 9.20. All Sections Ratings

(a) VMS Sections

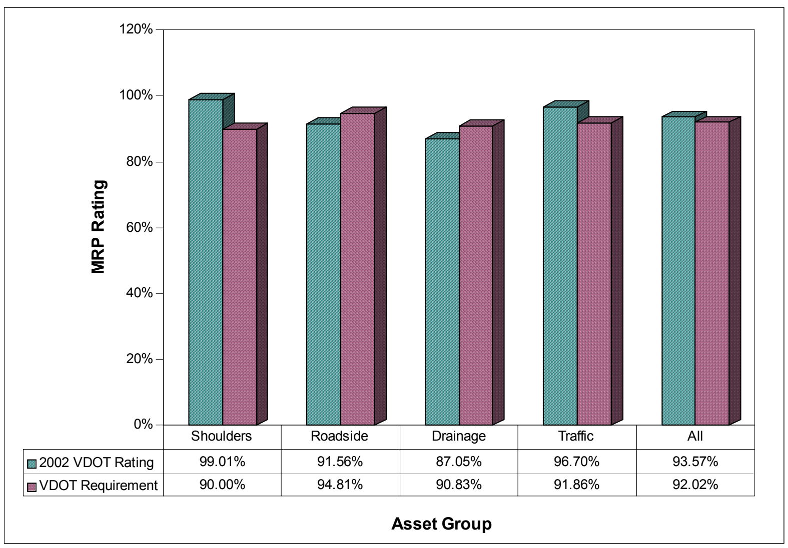
Asset Group	I-95 Mainline (Section 1)		I-81 Mainline (Section 2)		I-77 Mainline (Section 3)		I-381 Mainline (Section 4)		I-95 Ramps (Section 1)		I-81 Ramps (Section 2)		I-77 Ramps (Section 3)		All VMS Sections	
	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Shoulders	97.86%	90.00%	99.55%	90.00%	99.19%	90.00%	98.43%	90.00%	97.17%	90.00%	98.32%	90.00%	99.45%	90.00%	**98.59%**	**90.00%**
Roadside	97.52%	95.37%	98.75%	95.24%	98.94%	94.83%	98.83%	93.92%	95.30%	94.30%	98.50%	94.52%	99.21%	94.62%	**98.04%**	**95.01%**
Drainage	94.48%	90.26%	96.15%	90.61%	97.90%	90.21%	93.32%	90.58%	91.30%	90.26%	95.52%	91.26%	97.22%	91.07%	**95.45%**	**90.46%**
Traffic	98.11%	91.69%	98.16%	88.94%	99.46%	91.90%	95.25%	92.26%	95.80%	95.80%	98.05%	95.79%	97.56%	95.28%	**98.12%**	**91.91%**
All Groups	97.07%	91.95%	98.04%	90.98%	98.93%	91.89%	96.13%	91.90%	94.83%	93.23%	97.60%	93.51%	98.16%	93.30%	**97.54%**	**91.99%**

(b) VDOT Sections

Asset Group	I-95 Mainline (Section 5)		I-66 Mainline (Section 6)		I-64 Mainline (Sections 7,8 & 9)		I-81 Mainline (Sections 10 & 12)		I-581 Mainline (Section 11)		All VDOT Sections	
	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating	Actual Rating	VDOT Required Rating
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Shoulders	99.02%	90.00%	100.00%	90.00%	98.80%	90.00%	99.05%	90.00%	98.99%	90.00%	**99.01%**	**90.00%**
Roadside	82.50%	94.72%	84.74%	94.66%	92.50%	94.84%	96.08%	94.93%	96.89%	94.30%	**91.54%**	**94.81%**
Drainage	90.70%	90.55%	97.98%	90.02%	85.51%	91.07%	83.19%	90.87%	93.44%	90.09%	**87.05%**	**90.83%**
Traffic	93.74%	90.89%	99.03%	90.12%	96.49%	92.42%	97.28%	91.33%	98.80%	95.08%	**96.70%**	**91.86%**
All Groups	91.20%	91.57%	95.58%	91.15%	93.31%	92.29%	93.94%	91.86%	97.11%	92.92%	**93.57%**	**92.02%**



a) VMS Sections



b) VDOT Sections

Figure 9.6. Comparison of Actual Ratings with VDOT Requirements for all Sections

Areas of Concern

Figure 9.6 presents the overall ratings at the asset group level; however, when the actual performance ratings were compared with VDOT Targets at the asset item level, the failing asset items listed in Table 9.21 were identified. Graphs such as the one presented in Figure 9.7 were used to help identified the reasons for failure. The example presented in this figure corresponds to the Drainage asset group in Section 1 Mainline, Urban and Rural Zones.

Table 9.21. Summary of Areas of Concern

Asset Group	Asset Item	VMS Sections							VDOT Control Sections							
		I-95 Mainline (Section 1)	I-95 Ramps (Section 1)	I-81 Mainline (Section 2)	I-81 Ramps (Section 2)	I-77 Mainline (Section 3)	I-77 Ramps (Section 3)	I-381 Mainline (Section 4)	I-95 Mainline (Section 5)	I-66 Mainline (Section 6)	I-64 Mainline (Section 7)	I-64 Mainline (Section 8)	I-64 Mainline (Section 9)	I-81 Mainline (Section 10)	I-581 Mainline (Section 11)	I-81 Mainline (Section 12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Paved Shoulders	Surface Defects															
	Drop Off															
	Separation															
	Drainage															
Unpaved Shoulders	Drop Off		✓													
	Drainage															
Roadside	Grass		✓						✓	✓	✓		✓	✓		
	Debris & Road Kill	✓		✓	✓	✓			✓	✓	✓	✓		✓		✓
	Litter															
	Landscaping															
	Brush and Tree Control		✓								✓					
	Concrete Barrier	✓			✓				✓		✓	✓		✓	✓	
	Sound Barrier	✓														
	Slopes															
	Fence	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Drainage	Ditches Paved	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓
	Ditches Unpaved															
	Pipes	✓	✓		✓				✓		✓	✓	✓	✓		✓
	Box Culverts	✓	✓		✓						✓			✓		
	Under/Edge Drain		✓				✓					✓		✓		✓
	Storm D/D Inlets													✓	✓	
	Curb & Gutter	✓	✓								✓					
	Sidewalks		✓													
	SW Management Ponds															
Traffic	Signals															
	Pavement Message	✓	✓	✓	✓	✓	✓		✓					✓		
	Pavement Stripping		✓													
	Pavement Markers								✓		✓					
	Delineators/Obj marker								✓	✓	✓	✓	✓			✓
	Glare Foils															
	Signs-Regulatory		✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
	Signs-Other															
	Luminaries		✓					✓			✓					
	Guardrail	✓	✓	✓	✓	✓			✓			✓	✓	✓	✓	✓
	Impact Attenuators															
	Truck Ramps															
	Cross Overs															
	Rumble Strips															

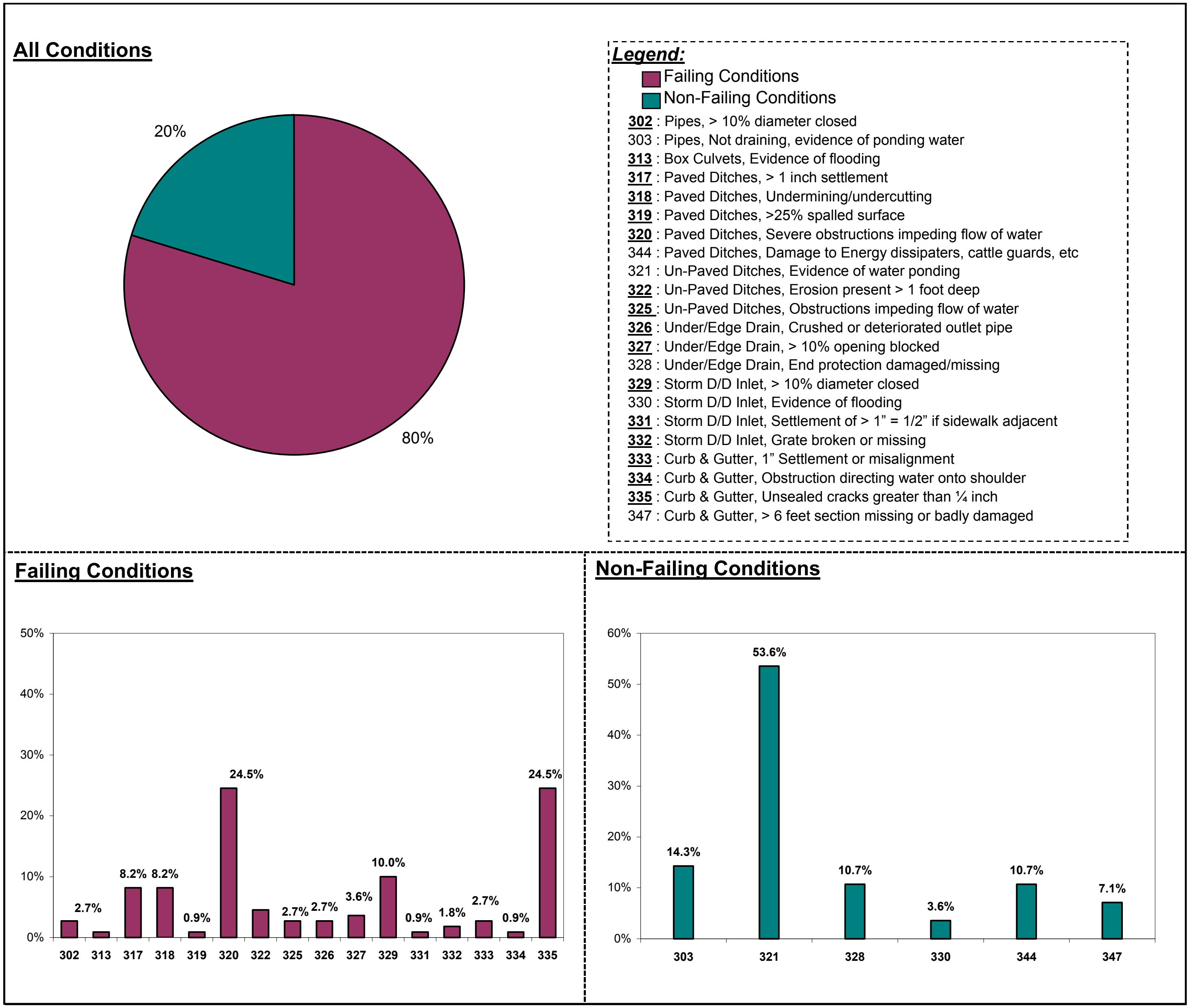


Figure 9.7. Summary of Conditions for Drainage Asset Group in I-95 Mainline (Section 1)

Step 7. As previously mentioned, if not all the asset item specified for inspection are actually inspected in the field, then the confidence levels must be adjusted according to the actual conditions. This scenario occurred in the 2002 Evaluation. Table 9.22 presents an example of how the confidence level was adjusted to account for the actual number of assets inspected. The procedure presented in Table 9.22 was repeated for each Section. The results from the calculations performed in this step are summarized for each Section in Table 9.23. Notice that the minimum confidence level obtained at the asset group level from the inspections conducted in 2002 was approximately 86% (e.g., Traffic Group in Section 6).

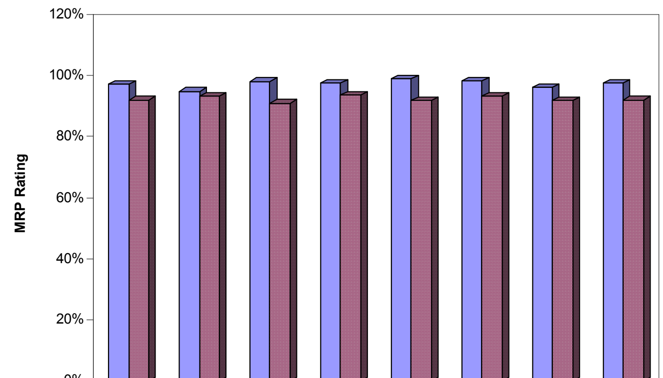
Table 9.22. Calculation of Confidence Levels obtained for Section 1

Section 1							General Input				
I-95 Mainline (MP 0.0 to 101.24)							Standard Error (e) = 0.04 for a value of p = 0.85 Z = 1.96				
Asset Item	Asset Weight	Urban Zones					Rural Zones				
		$n_{Required}$	n_{Actual}	$n_{Actual} \geq n_{Adjusted}$	Z_{Actual}	Confidence Level	$n_{Required}$	n_{Actual}	$n_{Actual} \geq n_{Adjusted}$	Z_{Actual}	Confidence Level
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Shoulders	**0.156**										**95%**
Paved Shoulders	**7.17**					**95%**					**95%**
Surface Defects	5.33	153	157	Yes	1.96	95%	286	283	No	1.95	95%
Drop Off	5.83	153	157	Yes	1.96	95%	286	283	No	1.95	95%
Separation	5.66	153	157	Yes	1.96	95%	286	283	No	1.95	95%
Drainage	5.5	153	157	Yes	1.96	95%	286	283	No	1.95	95%
Unpaved Shoulders	**1.0**										
Drop Off	5.83	0	0	NA	NA	NA	0	0	NA	NA	NA
Drainage	5.5	0	0	NA	NA	NA	0	0	NA	NA	NA
Roadside	**0.235**					**95%**					**92%**
Grass	5.67	67	67	Yes	1.96	95%	279	277	No	1.94	95%
Debris & Road Killed	8.5	163	204	Yes	1.96	95%	322	486	Yes	1.96	95%
Litter	4.67	153	195	Yes	1.96	95%	286	454	Yes	1.96	95%
Landscaping	4.83	1	1	Yes	1.96	95%	12	12	Yes	1.96	95%
Brush and Tree Control	5.33	154	156	Yes	1.96	95%	312	308	No	1.94	95%
Concrete Barrier	8.17	151	157	Yes	1.96	95%	194	233	Yes	1.96	95%
Sound Barrier	4.83	0	0	NA	NA	NA	7	6	No	0.80	58%
Slopes	5.83	148	151	Yes	1.96	95%	282	279	No	1.95	95%
Fence	5	38	40	Yes	1.96	95%	221	222	Yes	1.96	95%
Drainage	**0.237**					**95%**					**95%**
Ditches Paved	6.67	13	44	Yes	1.96	95%	98	299	Yes	1.96	95%
Ditches Unpaved	6.33	37	75	Yes	1.96	95%	268	756	Yes	1.96	95%
Pipes	8.5	1	1	Yes	1.96	95%	19	32	Yes	1.96	95%
Box Culverts	8	0	0	NA	NA	NA	3	3	Yes	1.96	95%
Under/Edge Drain	8.33	6	12	Yes	1.96	95%	109	158	Yes	1.96	95%
Storm D/D Inlets	8.67	138	285	Yes	1.96	95%	191	297	Yes	1.96	95%
Curb & Gutter	4	32	76	Yes	1.96	95%	26	41	Yes	1.96	95%
Sidewalks	3.17	0	0	NA	NA	NA	0	0	NA	NA	NA
SW Management Ponds	5.33	0	0	NA	NA	NA	0	0	NA	NA	NA
Traffic	**0.372**					**93%**					**94%**
Signals	9.17	0	1	Yes	1.96	95%	0	1	Yes	1.96	95%
Pavement Message	6.33	0	2	Yes	1.96	95%	0	2	Yes	1.96	95%
Pavement Stripping	8.67	159	176	Yes	1.96	95%	308	304	No	1.94	95%
Pavement Markers	8	144	148	Yes	1.96	95%	285	305	Yes	1.96	95%
Delineators/Obj marker	4.83	150	157	Yes	1.96	95%	264	267	Yes	1.96	95%
Glare Foils	5.5	47	40	No	1.58	89%	0	0	NA	NA	NA
Signs-Regulatory	8	48	42	No	1.34	82%	172	282	Yes	1.96	95%
Signs-Other	8	72	147	Yes	1.96	95%	201	326	Yes	1.96	95%
Luminaries	6.5	28	120	Yes	1.96	95%	20	152	Yes	1.96	95%
Guardrail	8.5	127	167	Yes	1.96	95%	271	408	Yes	1.96	95%
Impact Attenuators	9.33	5	6	Yes	1.96	95%	19	19	Yes	1.96	95%
Truck Ramps	6	0	0	NA	NA	NA	0	0	NA	NA	NA
Cross Overs	5	0	0	NA	NA	NA	49	35	No	1.31	81%
Rumble Strips	5										
All Assets											**94%**

Table 9.23. Summary of Confidence Levels Obtained for each Section

Asset Item	Asset Weight	Confidence Level																
		VMS Sections										VDOT Control Sections						
		Sec. 1 Main		Sec. 1 Ramps		Sec. 2 Main	Sec. 2 Ramps	Sec. 3 Main	Sec. 3 Ramps	Sec. 4 Main	All VMS Sections	Sec. 5 Main	Sec. 6 Main	Sec. 7,8,9 Main		Sec. 10&12 Main	Sec. 11 Main	All VDOT Sections
		Urban	Rural	Urban	Rural									Urban	Rural			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Section Weight =(Sec Miles/All Sec. Miles)		0.306		0.106		0.264	0.086	0.204	0.031	0.005		0.108	0.101	0.539		0.222	0.031	
Shoulders	**0.156**	**95%**		**94%**		**94%**	**95%**	**95%**	**94%**	**95%**	**95%**	**95%**	**93%**	**94%**		**95%**	**95%**	**94%**
Paved Shoulders	**7.17**																	
Surface Defects	5.33	95%	95%	88%	95%	94%	95%	95%	94%	95%		95%	93%	88%	95%	95%	95%	
Drop Off	5.83	95%	95%	88%	95%	94%	95%	95%	94%	95%		95%	93%	87%	95%	95%	95%	
Separation	5.66	95%	95%	88%	95%	94%	95%	95%	94%	95%		95%	93%	87%	95%	95%	95%	
Drainage	5.5	95%	95%	88%	95%	94%	95%	95%	94%	95%		95%	93%	87%	95%	95%	95%	
Unpaved Shoulders	**1.0**																	
Drop Off	5.83	NA	NA	95%	95%	NA	95%	NA	95%	NA		NA	NA	NA	NA	NA	NA	
Drainage	5.5	NA	NA	95%	95%	NA	95%	NA	95%	NA		NA	NA	NA	NA	NA	NA	
Roadside	**0.235**	**92%**		**91%**		**95%**	**95%**	**95%**	**94%**	**95%**	**93%**	**95%**	**94%**	**93%**		**95%**	**95%**	**94%**
Grass	5.67	95%	95%	88%	95%	94%	95%	95%	92%	95%		95%	93%	93%	95%	95%	95%	
Debris & Road Killed	8.5	95%	95%	87%	95%	95%	95%	95%	92%	95%		95%	94%	89%	95%	95%	95%	
Litter	4.67	95%	95%	88%	95%	95%	95%	95%	92%	95%		95%	94%	90%	95%	95%	95%	
Landscaping	4.83	95%	95%	95%	95%	95%	95%	95%	95%	95%		95%	NA	NA	95%	95%	95%	
Brush and Tree Control	5.33	95%	95%	95%	95%	93%	95%	95%	95%	95%		95%	92%	89%	95%	95%	NA	
Concrete Barrier	8.17	95%	95%	42%	87%	95%	95%	95%	95%	NA		95%	95%	76%	87%	95%	95%	
Sound Barrier	4.83	NA	58%	NA	NA	NA	95%	NA	95%	NA		NA	NA	NA	NA	NA	NA	
Slopes	5.83	95%	95%	90%	95%	94%	95%	95%	95%	95%		95%	93%	87%	95%	95%	95%	
Fence	5	95%	95%	85%	93%	95%	95%	95%	94%	95%		95%	95%	95%	95%	95%	95%	
Drainage	**0.237**	**94%**		**90%**		**95%**	**95%**	**95%**	**95%**	**95%**	**94%**	**95%**	**95%**	**88%**		**90%**	**95%**	**90%**
Ditches Paved	6.67	95%	95%	95%	95%	95%	95%	95%	95%	95%		95%	95%	95%	95%	95%	95%	
Ditches Unpaved	6.33	95%	95%	84%	94%	95%	95%	95%	92%	95%		95%	94%	92%	95%	95%	95%	
Pipes	8.5	95%	95%	95%	95%	95%	95%	95%	95%	95%		95%	95%	86%	95%	95%	95%	
Box Culverts	8	NA	95%	NA	95%	95%	95%	NA	95%	NA		95%	NA	NA	54%	95%	NA	
Under/Edge Drain	8.33	95%	95%	95%	55%	95%	95%	95%	95%	NA		93%	95%	95%	95%	67%	NA	
Storm D/D Inlets	8.67	95%	95%	95%	95%	95%	95%	95%	95%	NA		95%	95%	58%	95%	95%	95%	
Curb & Gutter	4	95%	95%	95%	95%	NA	95%	95%	95%	NA		NA	NA	87%	95%	NA	NA	
Sidewalks	3.17	NA	NA	95%	NA	NA	95%	NA	NA	NA		NA	NA	NA	NA	NA	NA	
SW Management Ponds	5.33	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	
Traffic	**0.372**	**94%**		**92%**		**90%**	**95%**	**95%**	**95%**	**94%**	**93%**	**95%**	**86%**	**94%**		**95%**	**95%**	**94%**
Signals	9.17	95%	95%	95%	NA	NA	95%	95%	95%	NA		NA	NA	NA	NA	NA	NA	
Pavement Message	6.33	95%	95%	95%	95%	73%	95%	95%	95%	95%		95%	NA	NA	95%	95%	NA	
Pavement Stripping	8.67	95%	95%	89%	95%	94%	95%	95%	95%	95%		95%	93%	87%	95%	95%	95%	
Pavement Markers	8	95%	95%	76%	79%	94%	95%	95%	95%	92%		95%	93%	87%	95%	95%	95%	
Delineators/Obj marker	4.83	95%	95%	87%	95%	94%	95%	95%	95%	NA		95%	94%	89%	95%	95%	NA	
Glare Foils	5.5	89%	NA	NA	NA	93%	NA	NA	NA	NA		NA	95%	NA	NA	NA	NA	
Signs-Regulatory	8	82%	95%	95%	95%	95%	95%	95%	95%	NA		95%	95%	95%	95%	95%	95%	
Signs-Other	8	95%	95%	95%	95%	95%	95%	95%	95%	NA		95%	95%	95%	95%	95%	95%	
Luminaries	6.5	95%	95%	95%	89%	55%	95%	95%	95%	95%		NA	NA	64%	95%	95%	NA	
Guardrail	8.5	95%	95%	76%	95%	95%	95%	95%	95%	95%		95%	93%	89%	95%	95%	95%	
Impact Attenuators	9.33	95%	95%	95%	95%	95%	NA	NA	NA	NA		95%	36%	95%	95%	NA	NA	
Truck Ramps	6	NA	NA	NA	NA	NA	NA	95%	NA	NA		NA	NA	NA	NA	NA	NA	
Cross Overs	5	NA	81%	NA	NA	92%	95%	95%	NA	NA		95%	95%	95%	95%	95%	95%	
Rumble Strips	5																	
All Asset Groups		**94%**		**91%**		**93%**	**95%**	**95%**	**95%**	**95%**	**94%**	**95%**	**91%**	**92%**		**94%**	**95%**	**93%**

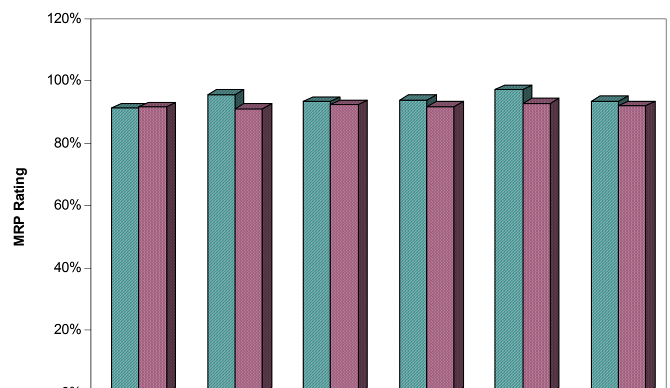
iii) *Cross-Sectional Comparison.* Figure 9.8 presents a comparison of the compliance of both VMS and VDOT to the Requirements for each Section. The figure presents the results from all the asset groups considered together. Notice that only in Section 5, one of VDOT's Control Sections, the requirements was slightly not met.



	Sec.1 Main	Sec.1 Ramp	Sec.2 Main	Sec.2 Ramp	Sec.3 Main	Sec.3 Ramp	Sec.4 Main	All Sections
2002 VMS Rating	97.07%	94.83%	98.04%	97.60%	98.93%	98.16%	96.13%	97.54%
VDOT Requirement	91.95%	93.23%	90.98%	93.51%	91.89%	93.30%	91.90%	91.99%

Route

a) VMS Sections



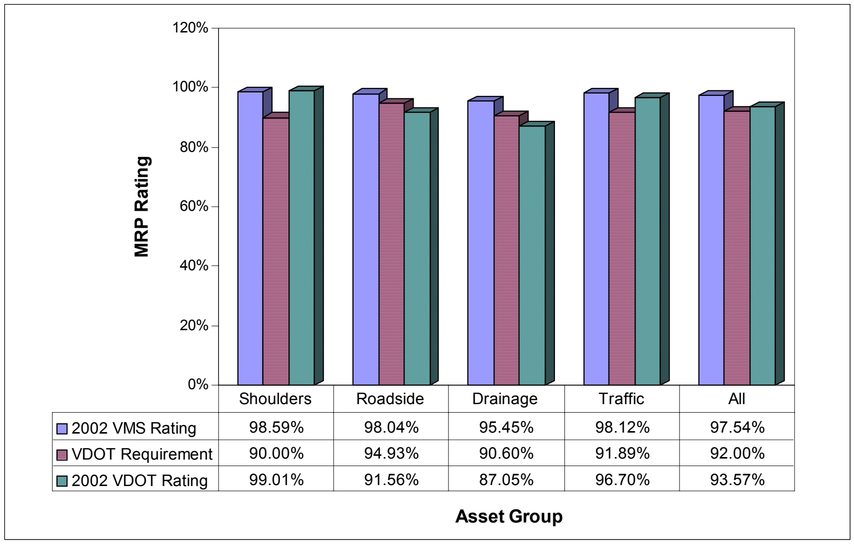
	Sec.5 Main	Sec.6 Main	Sec.7,8,&9 Main	Sec.10&12 Main	Sec.11 Main	All Sections
2002 VDOT Rating	91.20%	95.58%	93.31%	93.94%	97.11%	93.57%
VDOT Requirement	91.57%	91.15%	92.29%	91.86%	92.92%	92.02%

Route

b) VDOT Control Sections

Figure 9.8. Cross-Sectional Comparison of Actual Compliance to VDOT Requirements

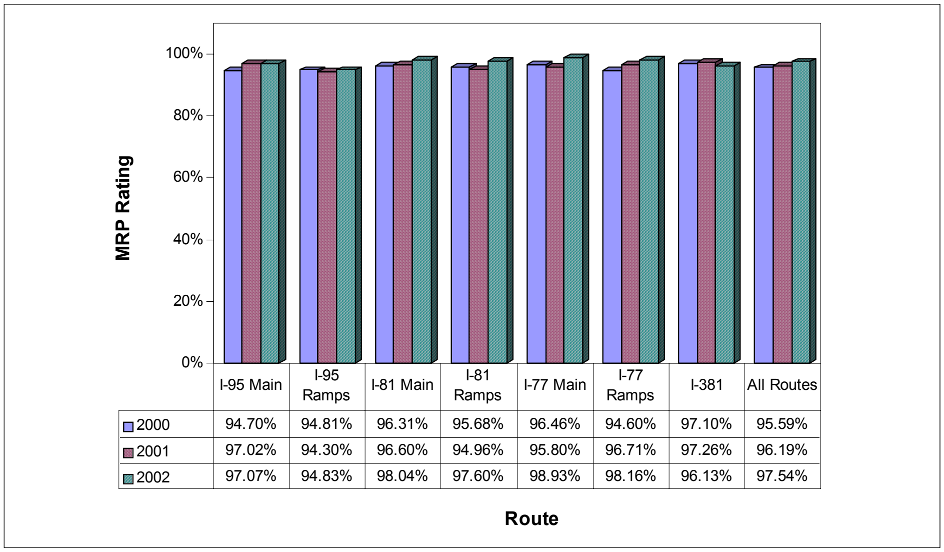
iv) *Comparison of VMS Performance versus VDOT Performance.* Figure 9.9 presents a comparison of the overall performance of VMS and VDOT at the asset group level. Notice that for all the asset groups VMS not only met the requirements but also received a higher performance rating, except for the Shoulders asset group.



	Shoulders	Roadside	Drainage	Traffic	All
2002 VMS Rating	98.59%	98.04%	95.45%	98.12%	97.54%
VDOT Requirement	90.00%	94.93%	90.60%	91.89%	92.00%
2002 VDOT Rating	99.01%	91.56%	87.05%	96.70%	93.57%

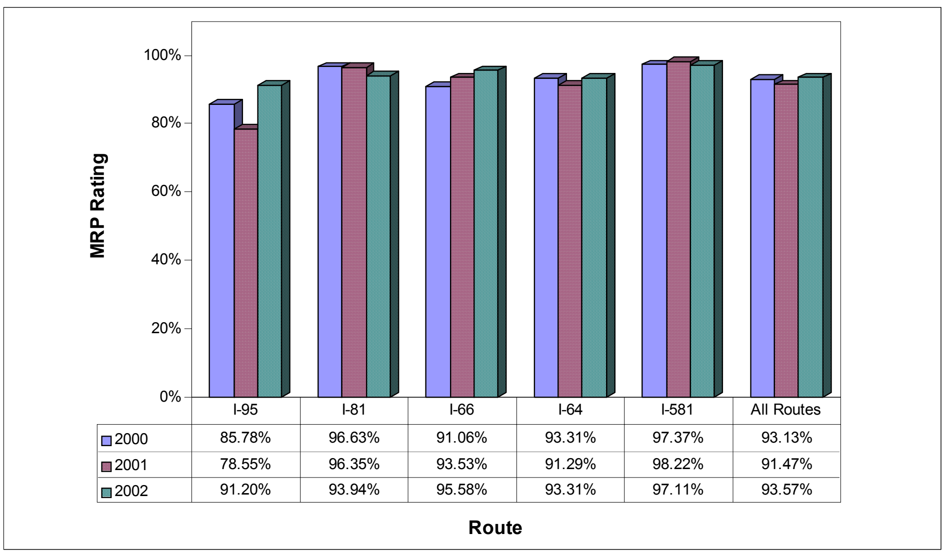
Figure 9.9. Comparison of the Overall Performance of VMS and VDOT

b) *Long-Term Performance.* Similar inspections to the one performed in 2002 also took place in 2000 and 2001. In order to get a feeling of the long-term performance of VMS and VDOT in maintaining the assets within each Section under evaluation, the procedures previously discussed were repeated for each year. The results from this evaluation are summarized in Figure 9.10. This figure presents the long term performance for each Section under evaluation. Notice that throughout the years the Sections maintained by VMS show a tendency to improve the overall condition and also seem to be more stable in terms of variations in the overall ratings. On the other hand, in the Sections maintained by VDOT, more variations in the overall ratings is evident. Notice that for Route 81, which corresponds to Sections 7, 8, & 9, the overall rating decreased every year. This should be an area of concern for VDOT personnel and action should be taken in order to stop this pattern and increase the ratings.



	I-95 Main	I-95 Ramps	I-81 Main	I-81 Ramps	I-77 Main	I-77 Ramps	I-381	All Routes
2000	94.70%	94.81%	96.31%	95.68%	96.46%	94.60%	97.10%	95.59%
2001	97.02%	94.30%	96.60%	94.96%	95.80%	96.71%	97.26%	96.19%
2002	97.07%	94.83%	98.04%	97.60%	98.93%	98.16%	96.13%	97.54%

a) VMS Sections

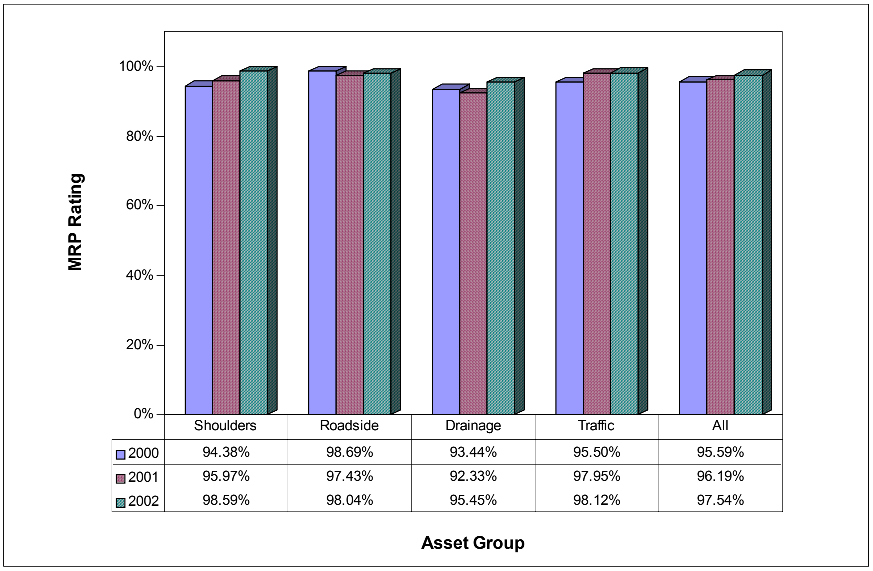


	I-95	I-81	I-66	I-64	I-581	All Routes
2000	85.78%	96.63%	91.06%	93.31%	97.37%	93.13%
2001	78.55%	96.35%	93.53%	91.29%	98.22%	91.47%
2002	91.20%	93.94%	95.58%	93.31%	97.11%	93.57%

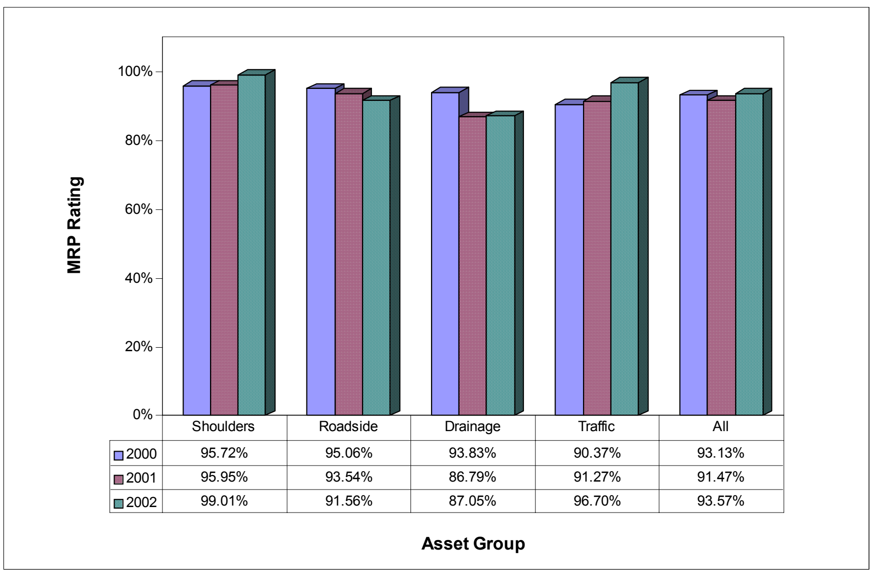
b) VDOT Control Sections

Figure 9.10. Long-term Performance for Shoulders, Roadside, Drainage, and Traffic at the Section Level

Figure 9.11 summarizes the results from the long-term performance evaluation at the asset group level. Notice that practically the same pattern observed at the Section level is observed now at the asset group level.



a) VMS Sections



b) VDOT Control Sections

Figure 9.11. Long-term Performance for Shoulders, Roadside, Drainage, and Traffic at the Asset Group Level

9.2.3.2. Data Analysis Procedures for Pavement Structures

As previously stated in the data collection section, two main indices were used in 2002 to evaluate the condition of Pavement Structures located within the Sections under evaluation. A detailed discussion of how the values for these indices were processed and converted into meaningful information follows.

a) _Actual Performance._ The actual performance refers to the condition of the pavement structures according to the most recent field evaluation. In this study the actual performance corresponds to the condition in year 2002. The following steps summarize the procedure followed to generate the findings from the data analysis.

i) _Calculation of Actual Ratings._ The main objective in the pavement evaluation was to determine the percentage of the pavement on each section that was in excellent, good, fair, poor, and very poor condition. In order to get this distribution, the following rating scales were used for the CCI and the IRI indices.

	Rating Scale for CCI	*Rating Scale for IRI*
Excellent	$90 \leq CCI \leq 100$	$IRI < 60$
Good	$70 \leq CCI \leq 89$	$61 \leq IRI \leq 100$
Fair	$60 \leq CCI \leq 69$	$101 \leq IRI \leq 140$
Poor	$50 \leq CCI \leq 59$	$141 \leq IRI \leq 200$
Very Poor	$CCI \leq 49$	$IRI \geq 201$

By applying the rating scales presented above, the distributions of the condition of the pavement was obtained based on the CCI and the IRI indices. The results from these two indices are summarized in Tables 9.24 and 9.25, respectively. For instance, according to the CCI index, which measures the distress condition of the pavement, 13% of VMS sections were in Excellent condition in 2002, 59.6% in Good condition, 17.5% in Fair condition, 7.7% in Poor condition, and 0.3% in Very Poor condition. On the other hand, according to the IRI index, which measures the roughness of the pavement, 27.6% of VMS sections were in excellent condition in 2002, 58.9% in Good condition, 10.1% in Fair condition, 3.5% in Poor condition, and 0.7% in Very Poor condition.

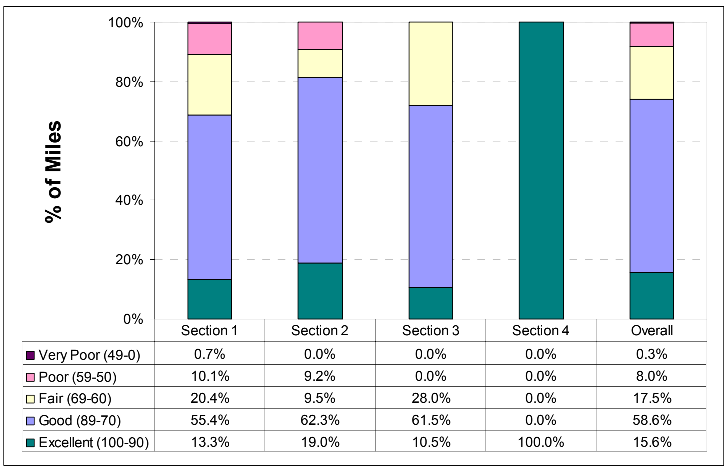
Table 9.24. Summary of Pavement Condition based on CCI

Section	Index Type	Index Rating			Excellent Condition		Good Condition		Fair Condition		Poor Condition		Very Poor Condition	
		Average	Minimum	Maximum	Miles	%	Miles	%	Miles	%	Miles	%	Miles	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	LDR	77.7	44	100	26.51	13.3%	113.33	56.9%	39.54	19.9%	18.37	9.2%	1.38	0.7%
	NDR	93.4	56	100	147.28	74.0%	39.4	19.8%	10.61	5.3%	1.84	0.9%	0	0.0%
	CCI	77.5	44	100	26.51	13.3%	110.34	55.4%	40.69	20.4%	20.21	10.1%	1.38	0.7%
2	LDR	82.0	52	100	31	19.0%	101	62.3%	15	9.5%	15	9.2%	0	0.0%
	NDR	96.5	84	100	153	94.3%	9	5.7%	0	0.0%	0	0.0%	0	0.0%
	CCI	82.0	52	100	31	19.0%	101	62.3%	15	9.5%	15	9.2%	0	0.0%
3	LDR	84.0	62	100	8	10.5%	44	61.5%	20	28.0%	0	0.0%	0	0.0%
	NDR	95.4	84	100	63	87.9%	9	12.1%	0	0.0%	0	0.0%	0	0.0%
	CCI	84.0	62	100	8	10.5%	44	61.5%	20	28.0%	0	0.0%	0	0.0%
4	LDR	67.7	54	87	0	0.0%	2	52.1%	1	39.2%	0	8.7%	0	0.0%
	NDR	97.0	94	100	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	CCI	67.7	54	87	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
5	LDR	60.1	24	85	0	0.0%	29	46.6%	9	15.0%	2	3.4%	22	35.1%
	NDR	68.1	24	94	18	28.7%	14	21.8%	16	25.0%	5	8.7%	10	15.8%
	CCI	57.2	24	82	0	0.0%	26	41.5%	10	16.4%	4	7.0%	22	35.1%
6	LDR	82.4	52	100	24	54.8%	5	11.6%	3	6.2%	12	27.4%	0	0.0%
	NDR	97.7	88	100	40	91.8%	4	8.2%	0	0.0%	0	0.0%	0	0.0%
	CCI	82.3	52	100	24	54.8%	5	11.6%	3	6.2%	12	27.4%	0	0.0%
7	LDR	87.3	78	100	3	47.8%	3	52.2%	0	0.0%	0	0.0%	0	0.0%
	NDR	93.3	89	97	5	83.7%	1	16.3%	0	0.0%	0	0.0%	0	0.0%
	CCI	84.5	78	90	2	31.5%	4	68.5%	0	0.0%	0	0.0%	0	0.0%
8	LDR	74.0	44	100	31	26.7%	41	36.1%	17	15.0%	21	18.1%	5	4.1%
	NDR	94.5	82	100	93	81.2%	21	18.8%	0	0.0%	0	0.0%	0	0.0%
	CCI	74.0	44	100	31	26.7%	41	36.1%	17	15.0%	21	18.1%	5	4.1%
9	LDR	81.5	62	100	20	32.5%	31	50.5%	10	17.0%	0	0.0%	0	0.0%
	NDR	95.3	92	100	61	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	CCI	81.4	62	100	20	32.5%	31	50.5%	10	17.0%	0	0.0%	0	0.0%
10	LDR	83.7	54	100	7	20.0%	24	71.4%	1	2.2%	2	6.3%	0	0.0%
	NDR	95.3	84	100	32	93.7%	2	6.3%	0	0.0%	0	0.0%	0	0.0%
	CCI	83.7	54	100	7	20.0%	24	71.4%	1	2.2%	2	6.3%	0	0.0%
11	LDR	78.1	48	100	5	36.1%	8	60.4%	0	2.9%	0	0.0%	0	0.6%
	NDR	94.9	84	100	13	99.4%	0	0.6%	0	0.0%	0	0.0%	0	0.0%
	CCI	78.1	48	100	5	36.1%	8	60.4%	0	2.9%	0	0.0%	0	0.6%
12	NO DATA AVAILABLE													
All VMS Sections	LDR	79.6	44.0	100.0	65	14.9%	261	59.6%	76	17.5%	34	7.7%	1	0.3%
	NDR	94.9	56.0	100.0	367	84.0%	57	13.1%	11	2.4%	2	0.4%	0	0.0%
	CCI	79.5	44.0	100.0	68	15.6%	256	58.6%	76	17.5%	35	8.0%	1	0.3%
All VDOT Sections	LDR	75.0	24	100	89	26.6%	141	42.3%	41	12.2%	37	11.0%	27	8.0%
	NDR	88.7	24	100	262	78.3%	42	12.5%	16	4.6%	5	1.6%	10	2.9%
	CCI	74.2	24	100	88	26.3%	139	41.6%	42	12.4%	39	11.7%	27	8.0%

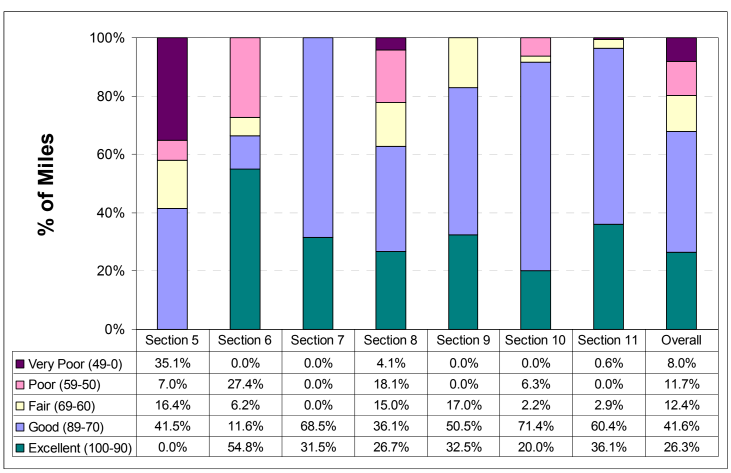
Table 9.25. Summary of Pavement Condition based on IRI

Section No. (1)	IRI Rating												
	Average (2)	Minimum (3)	Maximum (4)	Excellent		Good		Fair		Poor		Very Poor	
				Miles (5)	% (6)	Miles (7)	% (8)	Miles (9)	% (10)	Miles (11)	% (12)	Miles (13)	% (14)
1	80.8	30	335	44.63	25.8%	95.90	55.5%	22.92	13.3%	7.27	4.2%	2.04	1.2%
2	73.3	35	205	38.53	31.8%	68.76	56.8%	9.79	8.1%	3.65	3.0%	0.34	0.3%
3	74.8	36	237	20.19	24.7%	53.86	65.9%	4.99	6.1%	2.31	2.8%	0.38	0.5%
4	86.9	49	182	0.81	47.2%	0.49	28.6%	0.30	17.5%	0.12	6.7%	0.00	0.0%
5	85.1	48	189	2.70	8.7%	22.02	70.8%	5.20	16.7%	1.18	3.8%	0.00	0.0%
6	74.3	36	189	6.75	31.3%	11.92	55.3%	2.28	10.6%	0.60	2.8%	0.00	0.0%
7	134.6	57	322	0.10	0.4%	6.21	22.5%	10.17	36.9%	9.30	33.8%	1.77	6.4%
8	83.5	45	246	1.78	3.2%	47.79	86.2%	5.37	9.7%	0.49	0.9%	0.03	0.1%
9	80.3	51	236	1.80	5.9%	26.24	86.4%	1.75	5.8%	0.49	1.6%	0.10	0.3%
10	68.2	38	176	13.46	44.2%	13.64	44.8%	2.76	9.1%	0.61	2.0%	0.00	0.0%
11	NO DATA AVAILABLE												
12	74.2	45	161	5.49	21.7%	17.32	68.6%	1.94	7.7%	0.51	2.0%	0.00	0.0%
Total VMS	**77.2**	**30**	**335**	**104.15**	**27.6%**	**219.01**	**58.1%**	**38.00**	**10.1%**	**13.35**	**3.5%**	**2.76**	**0.7%**
Total VDOT	**85.2**	**36**	**322**	**29.38**	**15.4%**	**123.12**	**64.6%**	**24.27**	**12.7%**	**12.00**	**6.3%**	**1.90**	**1.0%**

Figures 9.12 and 9.13 present a graphic representation of the results presented in Tables 9.24 and 9.25, respectively.

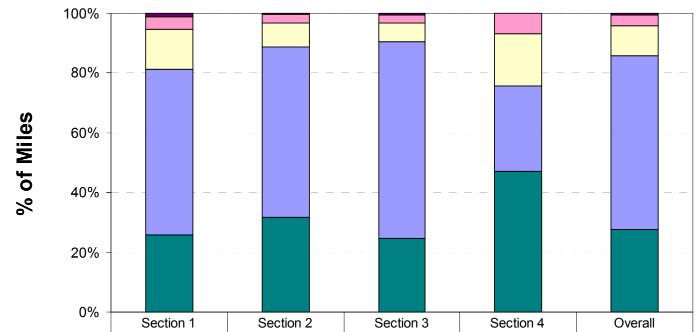


a) VMS Sections



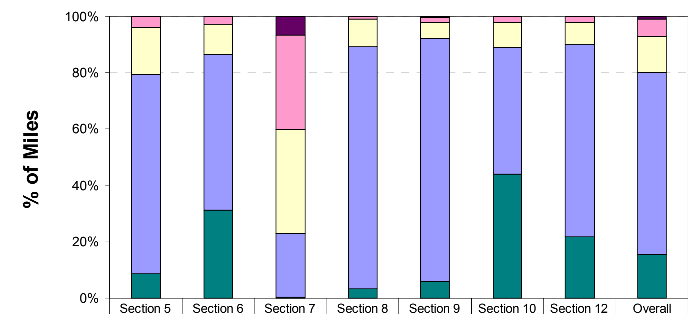
b) VDOT Sections

Figure 9.12. Graphic Representation of the Condition of the Pavement Based on the CCI



	Section 1	Section 2	Section 3	Section 4	Overall
Very Poor (>200)	1.2%	0.3%	0.5%	0.0%	0.7%
Poor (141-200)	4.2%	3.0%	2.8%	6.7%	3.5%
Fair (101-140)	13.3%	8.1%	6.1%	17.5%	10.1%
Good (61-100)	55.5%	56.8%	65.9%	28.6%	58.1%
Excellent (<60)	25.8%	31.8%	24.7%	47.2%	27.6%

a) VMS Sections



	Section 5	Section 6	Section 7	Section 8	Section 9	Section 10	Section 12	Overall
Very Poor (>200)	0.0%	0.0%	6.4%	0.1%	0.3%	0.0%	0.0%	1.0%
Poor (141-200)	3.8%	2.8%	33.8%	0.9%	1.6%	2.0%	2.0%	6.3%
Fair (101-140)	16.7%	10.6%	36.9%	9.7%	5.8%	9.1%	7.7%	12.7%
Good (61-100)	70.8%	55.3%	22.5%	86.2%	86.4%	44.8%	68.6%	64.6%
Excellent (<60)	8.7%	31.3%	0.4%	3.2%	5.9%	44.2%	21.7%	15.4%

b) VDOT Sections

Figure 9.13. Graphic Representation of the Condition of the Pavement Based on the IRI

ii) *Comparison of Actual Performance versus Performance Targets.* It was not possible to compare the actual performance versus performance targets because VDOT did not specified performance standards in the contractual agreement with VMS that addresses the acceptable levels for these indices. The contractual agreement specified standards for other indices not used in the analysis performed in 2002.

iii) *Cross-Sectional Comparison.* Figures 9.12 and 9.13 summarize the distribution of the condition of the pavement for each section based on CCI and IRI indices. Notice from Figure 9.12 that the distribution for each Section varies significantly. However, it can be seen in Figure 9.13 that practically 80% of the pavement in all the sections were in Good or Excellent condition.(i.e., both VMS and VDOT).

b) *Long-Term Performance.* Since no evaluations were performed in previous years with the same conditional indices, no long-term performance evaluation was conducted.

9.2.3.3. Data Analysis Procedures for Bridge Structures

The actual condition as well as the long-term condition of the Bridge Structures were evaluated as part of the data analysis process. As previously stated, in both evaluations the bridge elements were classified in the four main components: Deck, Superstructure, Substructure, and Slope Protection. The results from these evaluations are presented next.

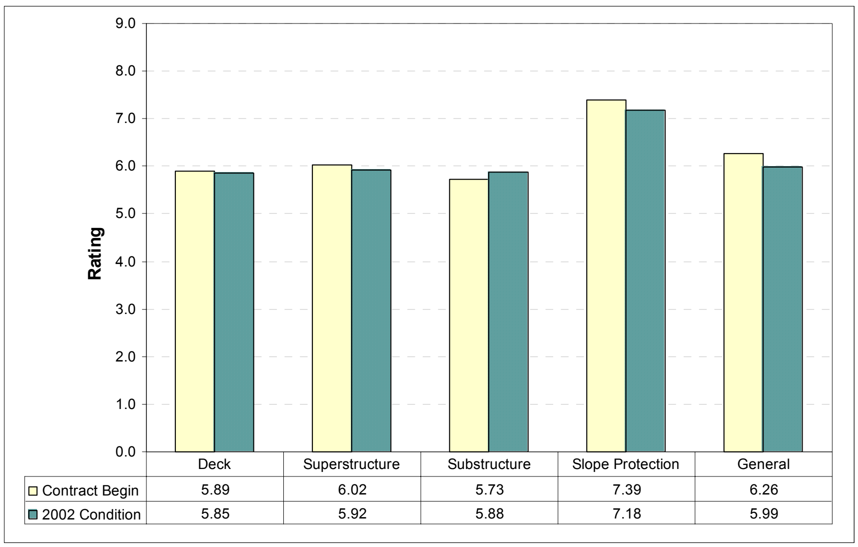
a) *Actual Performance.* A description of the methodology to evaluate the actual performance of VMS and VDOT in maintaining the bridge structures follows.

i) *Calculation of Actual Ratings.* The overall rating for each component was obtained by calculating the average of the ratings assigned to the bridge components evaluated on each particular section. Table 9.26 presents a summary of the average values obtained for each bridge component within each section.

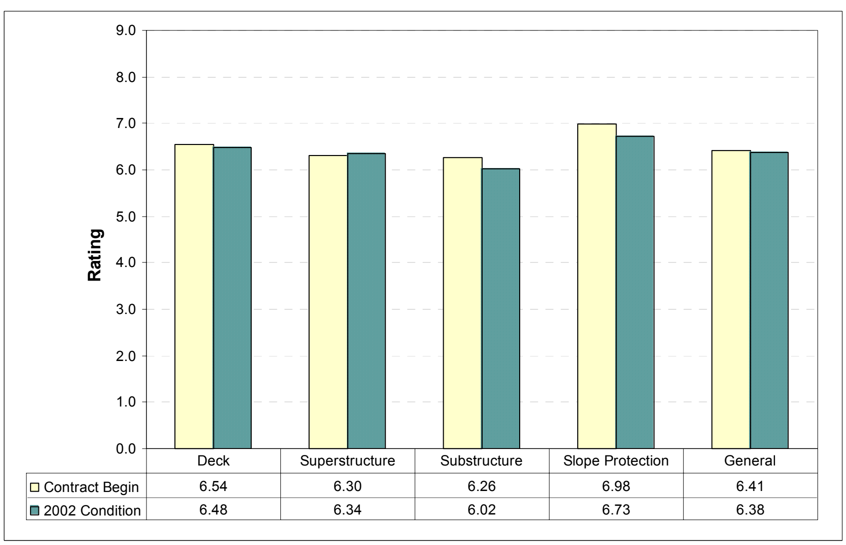
Table 9.26. Actual Condition of Bridge Structures

Party Responsible	Section	Years	Bridge Component				
			Deck	Superstructure	Substructure	Slope Protection	Overall
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VMS	I-95 Section 1	Contract Begin (1996-1997)	6.36	6.70	6.13	7.72	6.73
		Condition at 2002	6.48	6.77	6.38	7.65	6.63
		Met Target?	Yes	Yes	Yes	No	No
	I-81 Section 2	Contract Begin (1996-1997)	5.60	5.58	5.50	7.07	5.94
		Condition at 2002	5.31	5.16	5.40	6.40	5.37
		Met Target?	No	No	No	No	No
	I-77 Section 3	Contract Begin (1996-1997)	5.44	5.63	5.42	7.00	5.87
		Condition at 2002	5.31	5.31	5.58	7.56	5.62
		Met Target?	No	No	Yes	Yes	No
	All VMS Sections	Contract Begin (1996-1997)	5.89	6.02	5.73	7.39	6.26
		Condition at 2002	5.85	5.92	5.88	7.18	5.99
		Met Target?	No	No	Yes	No	No
VDOT	I-95	Contract Begin (1996-1997)	7.00	6.50	5.75	6.83	6.50
		Condition at 2002	6.57	5.57	5.71	6.20	6.11
		Met Target?	No	No	No	No	No
	I-81	Contract Begin (1996-1997)	6.03	5.97	6.03	5.75	6.00
		Condition at 2002	5.44	5.11	5.78	6.25	5.69
		Met Target?	No	No	No	Yes	No
	I-66	Contract Begin (1996-1997)	7.57	7.10	7.27	7.33	7.31
		Condition at 2002	7.00	6.43	5.81	7.00	6.51
		Met Target?	No	No	No	No	No
	I-64	Contract Begin (1996-1997)	6.58	6.34	6.20	7.30	6.45
		Condition at 2002	6.47	6.53	6.09	6.99	6.48
		Met Target?	No	Yes	No	No	Yes
	I-581	Contract Begin (1996-1997)	6.41	6.00	5.94	NA	6.12
		Condition at 2002	6.33	5.22	5.89	6.00	5.83
		Met Target?	No	No	No	NA	No
	All VDOT Sections	Contract Begin (1996-1997)	6.54	6.30	6.26	6.98	6.41
		Condition at 2002	6.48	6.34	6.02	6.73	6.38
		Met Target?	No	Yes	No	No	No

ii) <u>*Comparison of Actual Performance versus Performance Targets.*</u> The contractual agreement between VDOT and VMS specifies that the target for bridge structures is that the condition of the bridge each year must be higher than the condition of the bridge at the beginning of the contract. Table 9.26 summarizes the average ratings for each bridge component at the beginning of the contract as well as in 2002. A graphical comparison of these ratings is presented in Figure 9.14. Notice that only the substructures in bridges maintained by VMS failed to meet the target, whereas in the bridges maintained by VDOT only the superstructures failed to meet the target.



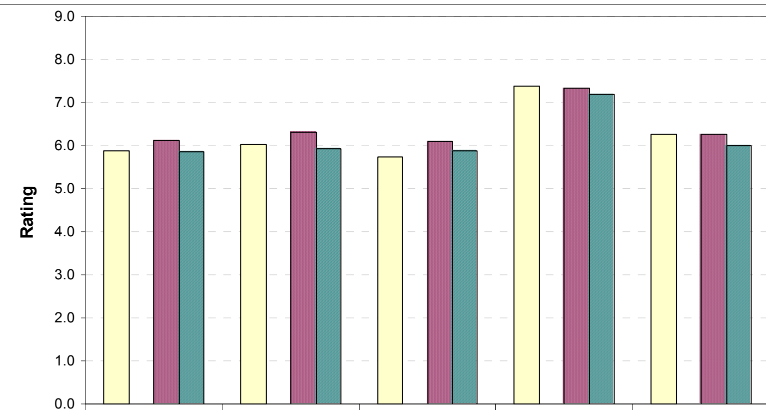
a) Bridges in VMS Sections



b) Bridges in VDOT Control Sections

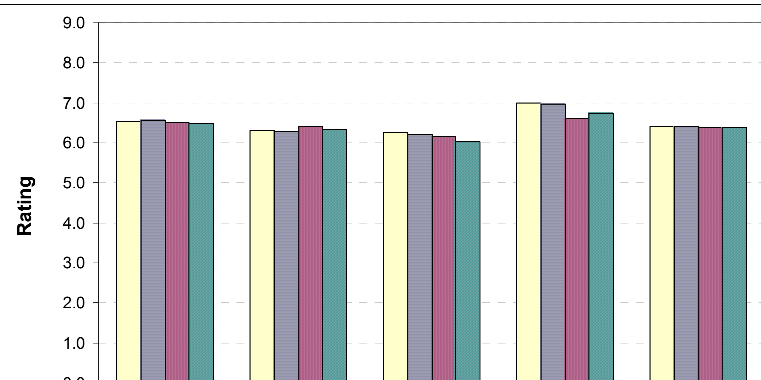
Figure 9.14. Comparison of 2002 Condition of Bridges with Performance Targets

b) <u>*Long-Term Performance.*</u> Given the fact inspection records were available since the contract started, a long-term evaluation was performed. Figure 9.15 summarizes the condition of the bridges from 1996 to 2002. By studying carefully these graphs one can notice that the bridges in both VMS and VDOT Sections are in continuous deterioration. This is really an area of concern. It is evident that action must be taken by both VMS and VDOT in order to change this trend.



	Deck	Superstructure	Substructure	Slope Protection	General
Contract Begin	5.89	6.02	5.73	7.39	6.26
1998-1999					
2000-2001	6.12	6.32	6.09	7.33	6.27
2002	5.85	5.92	5.88	7.18	5.99

a) Bridges in VMS Sections



	Deck	Superstructure	Substructure	Slope Protection	General
Contract Begin	6.54	6.30	6.26	6.98	6.41
1998-1999	6.56	6.29	6.21	6.96	6.40
2000-2001	6.51	6.40	6.16	6.60	6.39
2002	6.48	6.34	6.02	6.73	6.38

b) Bridges in VDOT Control Sections

Figure 9.15. Long-Term Condition of Bridge Structures

9.2.4. Reporting

In order to help communicate the findings presented in the previous sections, two of the elements proposed in the reporting portion of the framework were implemented by VDOT and Virginia Tech as part of the reporting phase. The two elements are the Reporting Cards and the use of Geographic Information Systems (GIS). A discussion of the products and benefits obtained from these techniques follows.

9.2.4.1. Report Cards

Refer to Flowchart B.4, located in Appendix B, for guidelines on how the Report Cards were generated. According to this flowchart, the first step is to define a grading scale. VDOT and Virginia Tech came up with the grading scale depicted in Table 9.27.

Table 9.27. Grading Scale Used to Generate the Report Cards

Grade	Condition
A	Actual Rating ≥ VDOT Requirement
B	95% VDOT Req.≤ Actual Rating < VDOT Req.
C	90% VDOT Req.≤ Actual Rating < 95% VDOT Req.
F	Actual Rating < 90% VDOT Requirement

i) *Report Cards for Shoulders, Roadside, Drainage, and Traffic.* The grading scale depicted in Table 9.27 was applied to the results presented in Table 9.20 for the Shoulders, Roadside, Drainage, and Traffic asset groups. Figure 9.16 presents the final Report Card generated for these four asset groups in sections maintained under performance-based specifications (i.e., VMS Sections) and in sections maintained under traditional maintenance specifications (i.e., VDOT Control Sections). Notice from the figure that the confidence levels summarized in Table 9.23 were included in the Report Card as well. In addition, a second report card was created for these four asset groups to illustrate the results from the long-term performance evaluation or trend analysis. This Report Card is presented in Figure 9.17.

2002 REPORT CARD *for VMS and VDOT Maintenance Performance*

Virginia Tech

Sites	Sections of Interstate	Shoulders		Roadside		Drainage		Traffic		All Groups	
		Grade	Confidence Level	Grade	Confidence Level	Grade	Confidence Level	Grade	Confidence Level	Grade	Confidence Level
VMS SITES	I-95 Mainline (Section 1)	A	95%	A	92%	A	95%	A	93%	A	94%
	I-81 Mainline (Section 2)	A	94%	A	95%	A	95%	A	90%	A	93%
	I-77 Mainline (Section 3)	A	95%	A	95%	A	95%	A	95%	A	95%
	I-381 (Section 4)	A	95%	A	95%	A	95%	A	94%	A	95%
	I-95 Ramps (Section 1)	A	94%	A	91%	A	90%	A	92%	A	91%
	I-81 Ramps (Section 2)	A	95%	A	95%	A	95%	A	95%	A	95%
	I-77 Ramps (Section 3)	A	94%	A	94%	A	95%	A	95%	A	95%
	All VMS Sites	A	95%	A	93%	A	94%	A	93%	A	94%
VDOT CONTROL SITES	I-95 Mainline (Section 5)	A	95%	F	95%	A	95%	A	95%	B	95%
	I-81 Mainline (Sections 10 and12)	A	95%	A	95%	C	90%	A	95%	A	94%
	I-66 Mainline (Section 6)	A	93%	F	94%	A	95%	A	86%	A	91%
	I-64 Mainline (Sections 7,8 and 9)	A	94%	B	93%	C	88%	A	94%	A	92%
	I-581 Mainline (Section 11)	A	95%	A	95%	A	95%	A	95%	A	95%
	All VDOT Control Sites	A	94%	B	94%	B	90%	A	94%	A	93%

Figure 9.16. 2002 Report Card for Shoulders, Roadside, Drainage, and Traffic

TREND ANALYSIS REPORT CARD *for VMS and VDOT Maintenance Performance*

Virginia Tech

Sites	Sections of Interstate	Shoulders			Roadside			Drainage			Traffic			All Groups		
		2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2001	2002
VMS SITES	I-95 Mainline (Section 1)	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	I-81 Mainline (Section 2)	A	A	A	A	A	A	A	A	A	B	A	A	A	A	A
	I-77 Mainline (Section 3)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	I-381 (Section 4)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	I-95 Ramps (Section 1)	A	A	A	A	B	A	A	A	A	A	B	A	A	A	A
	I-81 Ramps (Section 2)	A	A	A	A	A	A	B	C	A	A	A	A	A	A	A
	I-77 Ramps (Section 3)	A	A	A	A	A	A	A	A	A	B	A	A	A	A	A
	All VMS Sites	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
VDOT CONTROL SITES	I-95 Mainline (Section 5)	A	C	A	A	F	F	A	C	A	F	F	A	C	F	B
	I-81 Mainline (Sections 10 and12)	A	A	A	A	A	A	A	A	C	A	A	A	A	A	A
	I-66 Mainline (Section 6)	A	A	A	A	B	F	A	C	A	F	A	A	B	A	A
	I-64 Mainline (Sections 7,8 and 9)	A	A	A	B	B	B	A	C	C	B	B	A	A	B	A
	I-581 Mainline (Section 11)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	All VDOT Control Sites	A	A	A	A	B	B	A	B	B	B	B	A	A	B	A

Figure 9.17. Trend Analysis Report Card for Shoulders, Roadside, Drainage, and Traffic

ii) *Report Card for Pavement Structures.* No Report Card was created for the Pavement Structures. The reason for not assigning grades to the Pavement asset group is because VDOT did not include in the contractual agreement with VMS, performance standards by which the current condition of the pavement can be compared. If VDOT intent is to continue assessing the condition of the Pavement Structures under VMS responsibility based on IRI, CCI, LDR, and NDR indices, then performance standards associated to these indices must be added to the contract.

iii) *Report Cards for Bridge Structures.* The report card for the bridge structures was generated by applying the grading scale from Table 9.27 to the results presented in Table 9.26. The final Report Card for the Bridge Structures is shown in Figure 9.18.

2002 REPORT CARD *for VMS and VDOT Maintenance Performance*

Virginia Tech

Sites	Sections of Interstate	Bridge Component									
		Deck		Superstructure		Substructure		Slope Protection		All Components	
		2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
BRIDGES MAINTAINED BY VMS	I-95 (Section 1)	A	A	A	A	A	A	B	B	A	B
	I-81 (Section 2)	B	C	A	C	A	B	A	C	B	C
	I-77 (Section 3)	A	B	B	C	A	A	A	A	A	B
	I-381 (Section 4)										
	All VMS Sections	A	B	A	B	A	A	A	B	A	B
BRIDGES MAINTAINED BY VDOT	I-95 (Section 5)	C	C	C	F	B	B	B	C	C	C
	I-81 (Section 10,12)	B	C	B	F	B	B	A	A	B	C
	I-66 (Section 6)	B	C	B	C	C	F	B	B	C	F
	I-64 (Section 7,8,9)	A	B	A	A	B	B	B	B	A	A
	I-581 (Section 11)	B	B	A	F	A	B	A	NA	B	B
	All VDOT Sections	B	B	A	A	B	B	B	B	B	B

Figure 9.18. Report Card for Bridge Structures

By just looking at the Report Cards presented in Figures 9.16 through 9.18, it is very easy to get a quick and more meaningful idea of the condition of the different assets within the portions of the roadway system under evaluation.

9.2.4.2. Geographic Information Systems

One additional technique used to support reporting the findings from the condition assessment was Geographic Information Systems (GIS). GIS is considered an excellent tool because the findings can be organized and presented in a very graphical way. Geographic Information Systems (GIS) can be used to store the information related to the condition of the assets as a collection of thematic layers and display this information as maps. Geography is the glue that binds these layers together and GIS is the tool that allows you to see relationships between them. In order to properly implement the GIS technology, it was required to collect explicit geographic references (GPS coordinates) such as latitude and longitude in order to locate the corresponding sample units (beginning and ending points). As previously stated, the crews collected these coordinates with the use of GPS receivers. Figure 9.19 illustrates some of the equipment used by the crews in the field to collect those geographic references.

Figure 9.19. Equipment Used by Crews to Collect GPS Coordinates

The display of the information stored in spreadsheets and databases as a map is one of the major benefits accrued as a result of implementing GIS technology. This feature was extremely helpful to meet the goal of presenting the condition assessment in a more graphical, meaningful, and effective way. In addition, the implementation of this technique greatly helped in the identification of relationships, patterns, and trends per asset item that were otherwise difficult to see. The bottom line is that GIS provides new and exciting tools to help visualize the end result, which in this application example is the overall condition of the assets maintained by VMS. Figure 9.20 presents an example of how GIS was used in the 2002 MRP Evaluation to report the findings from a trend analysis conducted for the Paved Ditches located in Section 1 during a period of three years (2000, 2001, and 2002). Notice from Figure 9.20 that just by looking at the graph one can get better understanding of the condition performance of the Paved Ditches during the three-years period. In addition, notice that different colors can be used to identify failing and passing units, but even more important that each sample unit (represented by the dots in the figure) can be selected providing detailed information of the condition history of the assets presented within each unit. Evidently, the benefits that can be obtained as a result of using GIS to support the reporting of the findings from the analysis are unlimited.

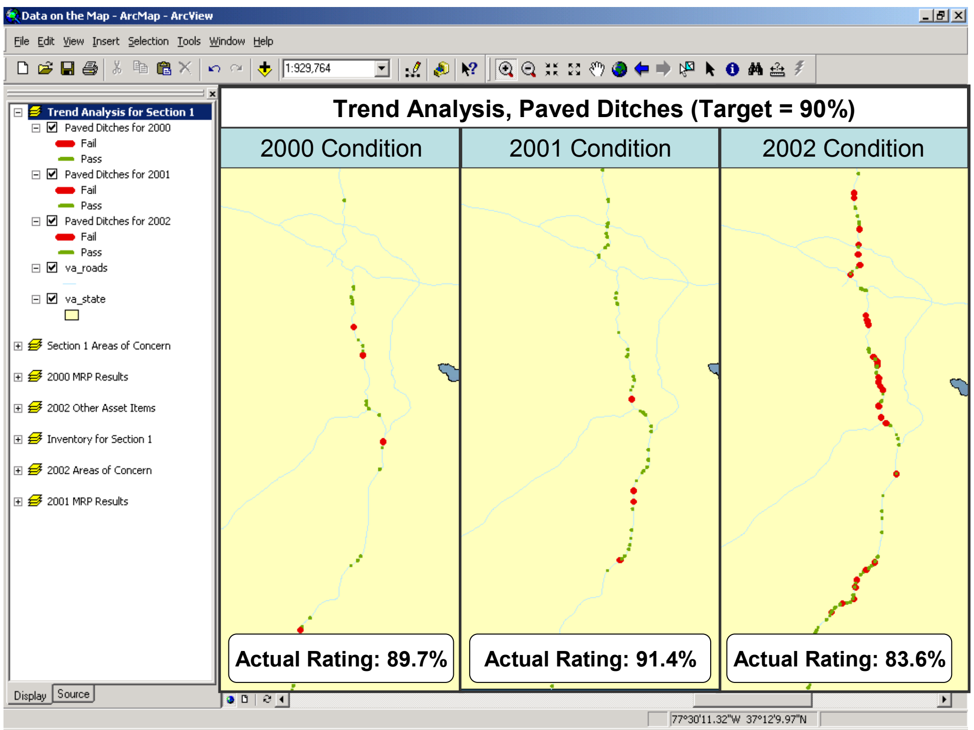


Figure 9.20. Illustration of a Trend Analysis for the Paved Ditches located in Section 1 using GIS

9.3. COST-EFFICIENCY (CE) EVALUATION

This section presents a partial application of the Cost-Efficiency component of the framework. Only the first part (i.e., Part 1) of the proposed methodology presented in Chapter five was applied to the PBRMC between VDOT and VMS. In other words, the study focused in the assess of the cost savings, if any, accrued by VDOT as a result of implementing performance-based specifications for the maintenance of a portion of the Interstate System in the Commonwealth of Virginia. The approach used to estimate the cost savings, if any, was by comparing the cost of performance-based work done by VMS with an estimated cost, based on historical bid prices, if the same work would have been done with traditional maintenance specifications.

9.3.1. Part 1: Assessment of Savings

Two alternatives were proposed in Chapter five to perform Part 1 of the Cost-Efficiency Evaluation, the Distribution Approach and the Regression Approach. It was suggested to implement both approaches and then combine the findings obtained from both of them to reach conclusions about the cost-savings, if any. However, given the fact that the cost evaluation is a very time consuming task, VDOT and Virginia Tech decided to perform the study by steps. The first step was to use the Distribution Approach to reach conclusions on the level of savings, if any, accrued by the government. This step is the only one presented in this chapter. Then, the second step would be to apply the Regression Approach and compare the findings with the results from the application of the Distribution Approach. The third step would be to conduct Part 2 of the cost-efficiency evaluation. These additional steps were not included in the application example presented in this chapter. The cost-efficiency evaluation is considered an ongoing activity. It should be evaluated from different angles and conclusions must be reached based on the findings obtained from the different approaches implemented.

Distribution Approach

The procedures described in section 5.3.2.1 for the Distribution Approach were implemented to the contract between VDOT and VMS. A detailed description of this application follows. Flowchart B.5, located in Appendix B, provides a guideline of the steps followed in the implementation of the Distribution Approach.

Step 1. Databases with Work done under Performance-Based and Traditional Specifications. The first step in the application was to obtain a database with the work done by VMS under performance-based specifications. In addition, a second database was required with historical bid prices of similar maintenance work, but performed under traditional maintenance specifications. A detailed description of these two databases follows.

a) *Work done by VMS under Performance-Based Specifications.* In Fall 2001, VMS provided Virginia Tech with a database containing all their previous contracts with the industry. The database provided information from contracts performed from 1998 through 2001. An example of the information provided in the database is presented in Table 9.28. As shown in this table, each row provided information about the bid date, contract number (e.g., district was determined from this coding), bid item or activity description, bid quantities, bid prices, and total items price. A total of 2973 contract bid items were included in the database, corresponding to a Total Bid Price of $42,842,926. As previously stated, the intent was to use historical bid prices from similar works performed under traditional maintenance specifications to generate distributions that will represent as accurate as possible the characteristics of the contract bid items listed in the database provided by VMS.

Table 9.28. Example of Contract Bid Data Provided by VMS

BID DATE	CONTRACT NUMBER	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS BID PRICE	TOTAL COST
18-Aug-99	11B00002	Fence (FE-CL)	LF	1000	$ 14.00	$ 14,000.00
		Line Brace Unit (FE-CL)	EA	5	$ 450.00	$ 2,250.00
		Corner Brace Unit (FE-CL)	EA	5	$ 450.00	$ 2,250.00
					Sub-Total=	**$ 18,500.00**
13-Sep-00	11B419	Mobilization	LS	1	$ 25,000.00	$ 25,000.00
		Traffic Control	LS	1	$ 500.00	$ 500.00
		Stone Rip Rap, Class I	TN	2030	$ 70.00	$ 142,100.00
					Sub-Total=	**$ 167,600.00**
21-Feb-01	11B489	Substructure Repair	SY	2562	$ 45.00	$ 115,290.00
		Epoxy Sealant, Type EP-3	SY	280	$ 5.00	$ 1,400.00
					Sub-Total=	**$ 116,690.00**
					TOTAL COST=	**$ 302,790.00**

b) *Historical Cost Data for Work Done under Traditional Maintenance Specifications.* In order to develop the distribution of unit prices if the work done by VMS would have been done under traditional maintenance specifications, a database program known as "*BidTabs Professional*" was used as the main data source. This unique database program contains historical bid tabulation data for over 30 different states. For instance, for the state of Virginia, which is the focus of this study, the database provided bid information of the three (3) lowest bidders that submitted bids to VDOT projects under traditional maintenance specifications from years 1993 through 2001. In addition, the database also provided other information such as the location of the job (i.e., classified in one of the nine districts of Virginia) and the workload (quantities of work). Figure 9.21 illustrates the range of historical bid data used to define the distribution of the unit prices under traditional maintenance specifications.

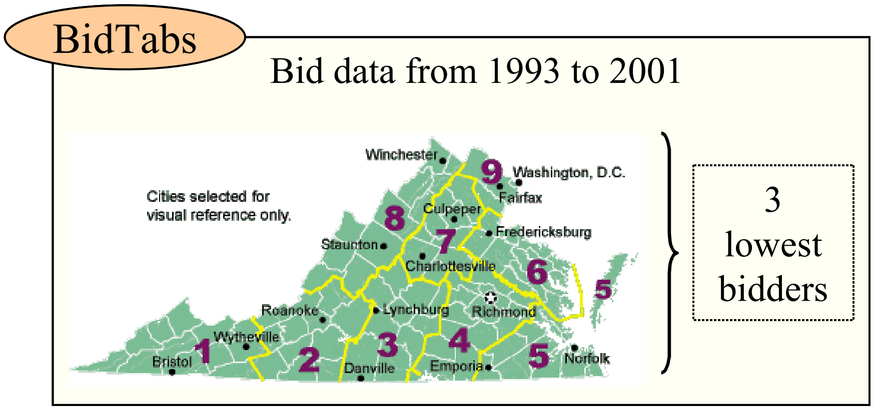
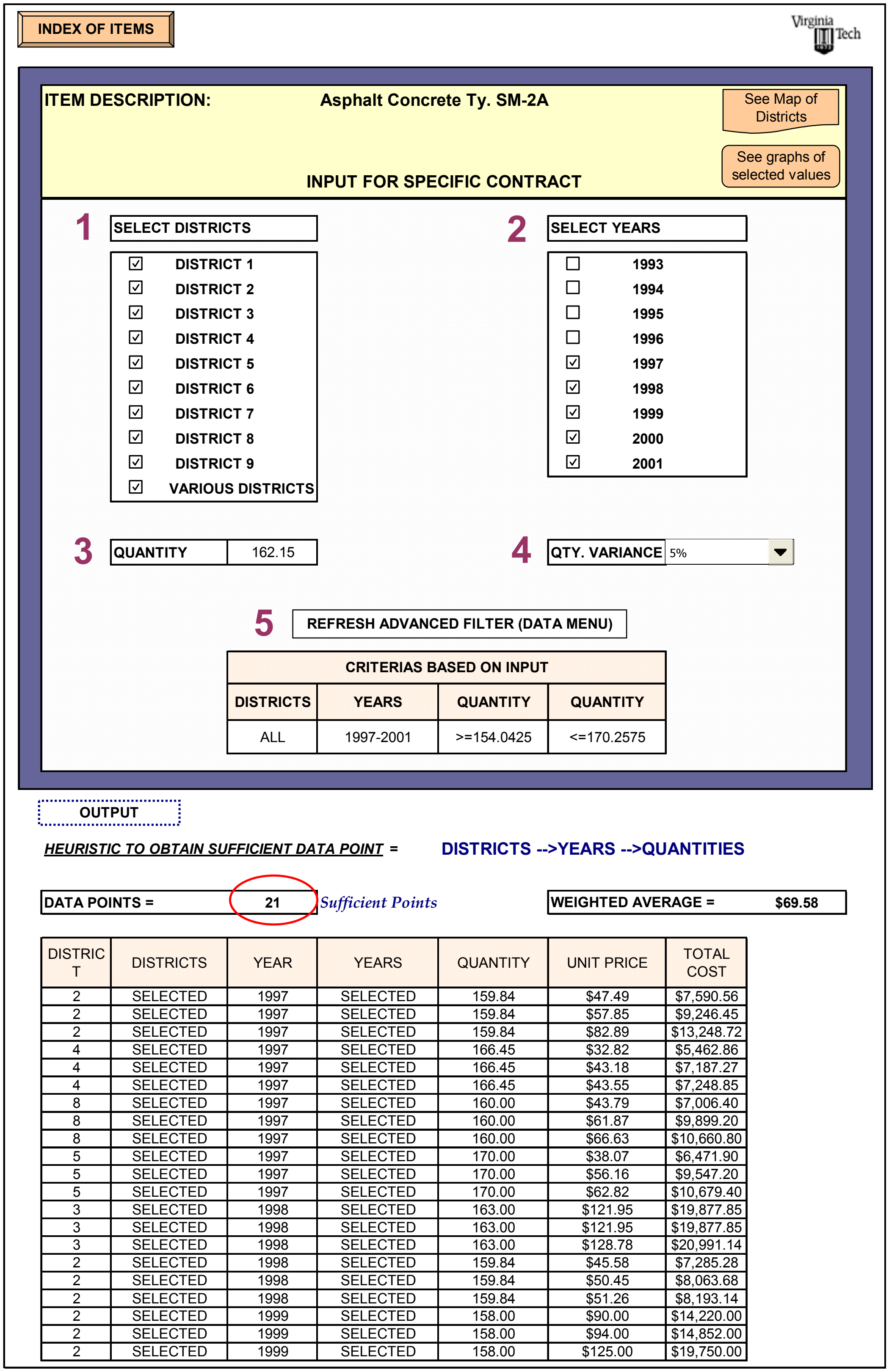


Figure 9.21. BidTabs Database

BidTabs Professional provides the users with a mechanism to perform specific queries for a given bid item. In these queries, the user can specify a geographic location (e.g., districts) as well as a period of time and range of the quantities of interest. However, some limitations were found when these queries were performed in *BidTabs.* One of the most significant limitations was related to the multiple selections of districts in a single query. For instance, if the user wanted to perform a query that included more than one district, then multiple queries were required to be conducted and then the results from those queries needed to combine into a single output file. This was very time consuming and inefficient. In order to have the advantage and capability of selecting multiple districts, years and quantity ranges in a single query, a Macro was built in Microsoft Excel to serve this purpose. A screen view of this Macro is shown on Figure 9.22. The example presented in this figure will be used later to illustrate how the Macro was used to query historical data points to develop the distributions.



DISTRICT	DISTRICTS	YEAR	YEARS	QUANTITY	UNIT PRICE	TOTAL COST
2	SELECTED	1997	SELECTED	159.84	$47.49	$7,590.56
2	SELECTED	1997	SELECTED	159.84	$57.85	$9,246.45
2	SELECTED	1997	SELECTED	159.84	$82.89	$13,248.72
4	SELECTED	1997	SELECTED	166.45	$32.82	$5,462.86
4	SELECTED	1997	SELECTED	166.45	$43.18	$7,187.27
4	SELECTED	1997	SELECTED	166.45	$43.55	$7,248.85
8	SELECTED	1997	SELECTED	160.00	$43.79	$7,006.40
8	SELECTED	1997	SELECTED	160.00	$61.87	$9,899.20
8	SELECTED	1997	SELECTED	160.00	$66.63	$10,660.80
5	SELECTED	1997	SELECTED	170.00	$38.07	$6,471.90
5	SELECTED	1997	SELECTED	170.00	$56.16	$9,547.20
5	SELECTED	1997	SELECTED	170.00	$62.82	$10,679.40
3	SELECTED	1998	SELECTED	163.00	$121.95	$19,877.85
3	SELECTED	1998	SELECTED	163.00	$121.95	$19,877.85
3	SELECTED	1998	SELECTED	163.00	$128.78	$20,991.14
2	SELECTED	1998	SELECTED	159.84	$45.58	$7,285.28
2	SELECTED	1998	SELECTED	159.84	$50.45	$8,063.68
2	SELECTED	1998	SELECTED	159.84	$51.26	$8,193.14
2	SELECTED	1999	SELECTED	158.00	$90.00	$14,220.00
2	SELECTED	1999	SELECTED	158.00	$94.00	$14,852.00
2	SELECTED	1999	SELECTED	158.00	$125.00	$19,750.00

Figure 9.22. Macro built in Microsoft Excel to Query Historic Bid Data from BidTabs

Step 2. Heuristic for Querying Data,. Once the data was classified by bid items, the next step was to determine the heuristic to be used when additional data points were required to get enough points to generate a distribution for a given contract bid item. The approach discussed in Chapter 5 to determine the heuristics was built in the Macro created in Microsoft Excel. The fact that the calculations required to define the heuristic were automatically performed by the Macro, significant amount of time was saved when conducting the queries. This process is shown in Figure 9.22. Notice that the heuristic in this example requires first specifying the addition of more districts, then, if necessary, the addition of more years, and finally if all districts and years were included and still more data points were required, a larger quantity range needed to be specified. Moreover, one additional concern was if more districts or years or even quantities were required to be specified in the query, what systematic approach will be followed to increase the number of these variables. In order to deal with this issue, the following methodology approach was incorporated in the study.

i) *Approach to Include Additional Districts.* In case that not enough data points were found when districts was considered the variable with less variance between groups, then additional districts were included on the next query based on their geographical proximity to the original district. To illustrate this process, let's take a look to districts in Virginia shown in Figure 9.21. Assuming District 1 was specified in a first query and no data points show up, then District 2 will be added on a second query since it is the closest district to District 1. If not enough points are obtained by specifying Districts 2 and 3, then a third query must be performed, but considering Districts 1, 2, 3, and 8. This process continued until enough data points are found or until all districts are selected. If this occurs, then the analyst must start varying the second variable in the heuristic.

ii) *Approach to Include Additional Years*. The methodology used to include more years in a particular query was to select the year before and after the years considered in the previous query. For example, if in a particular query only Year 1998 was considered and not enough data points show up, then Years 1997 and 1999 were added for the second query. Once again, this process continued until enough data points are found or until all years are selected.

iii) *Approach to Expand the Quantity Range.* The methodology adopted to expand the ranges of quantities was basically to apply variations to the original quantity. A total of 11 variations were considered on the study: 5%, 10%, 15%, 20%, 25 %, 30 %, 35%, 40%, 50%, 75%, and all quantities.

Step 3. Adjustment of Data,. As stated in Chapter four and depicted Flowchart B.5, the next step in the process was to adjust the values obtained from the queries performed in Step 2 in order to account for the actual characteristics of the contract item in consideration. The data was adjusted based only on the inflation rate. No adjustment factor was applied to account for variations in prices depending on the location. The reason for not considering this factor in the adjustment process was because the average adjustment factors by district were practically similar. Regarding the inflation rates used for the adjustments, the average yearly rates published by the U.S. Bureau of Statistics were used. These are listed in Table 9.29.

Table 9.29. Inflation Rates Used in the Study

Year	Yearly Inflation Rate
1993	1.00
1994	1.03
1995	1.03
1996	1.03
1997	1.02
1998	1.02
1999	1.02
2000	1.03
2001	1.03

To better illustrate this process, let's consider the example presented in Figure 9.23. Notice in Step 3 of the figure that 21 records were founded in the database that matched the criteria specified in the query. Those values were then adjusted to the year 1999 since that was the year in which the work was performed for the contract item in consideration. The inflation factors were computed using Eq.5.1. The adjusted bid prices shown in the last column of the table depicted in Step 3 of Figure 9.23 were used to generate the distribution that better characterize the behavior of the unit price of this particular contract bid item.

1

Characteristics of Asset Item						
Contract No.	District	Year	Item	Unit	Qty	Unit price
	District 1	1999	Asphalt Concrete (SM-2A)	TN	162.15	$150.00

2

Query Input						
Heuristic	Districts	Years	Item	Unit	Qty. Variance	Qty. Range
District-->Year-->Qty.	All Districts	1997-2001	Asphalt Concrete (SM-2A)	TN	± 5%	From 154.04 to 170.26

3

Output from Query

District	Year	Bid Price from Query Query	Inflation Factor	Adjusted Bid Price
2	1997	47.96	1.0404	49.90
2	1997	58.42	1.0404	60.78
2	1997	83.71	1.0404	87.09
4	1997	33.13	1.0404	34.47
4	1997	43.60	1.0404	45.36
4	1997	43.98	1.0404	45.76
8	1997	44.22	1.0404	46.00
8	1997	62.48	1.0404	65.00
8	1997	67.28	1.0404	70.00
5	1997	38.45	1.0404	40.00
5	1997	56.71	1.0404	59.00
5	1997	63.44	1.0404	66.00
3	1998	122.55	1.0200	125.00
3	1998	122.55	1.0200	125.00
3	1998	129.41	1.0200	132.00
2	1998	45.81	1.0200	46.72
2	1998	50.70	1.0200	51.71
2	1998	51.51	1.0200	52.54
2	1999	90.00	1.0000	90.00
2	1999	94.00	1.0000	94.00
2	1999	125.00	1.0000	125.00

Statistics to identify outliers in the data records

No.values under Lowerbound	=	0
Lowerbound	=	$0.00
1st Quartile	=	$45.81
Median	=	$62.48
3rd Quartile	=	$94.00
Upperbound	=	$166.29
No. of values over Upperbound	=	0

All Data Accepted

4

Fitted Distribution from STATFIT using Adjusted Unit Bid Prices

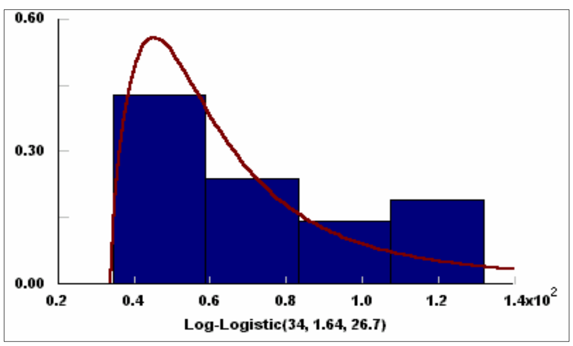


Figure 9.23. Example of How Distributions were Defined in the Study

<u>*Step 4. Develop Distribution for Bid Items.*</u> The statistical software ***STATFIT*** was used to develop these distributions. *STATFIT* is a program that fits many distributions to a data set and finally provides a detail comparison and recommendations among alternatives. Final acceptance or rejection of each distribution is provided based on the goodness of fit tests (i.e., Chi Squared,

Kolmogorov Smirnov and Anderson Darling), which determine how well each distribution fits to the data set. In addition, the program ranked the distributions based on goodness of fit to the data set. In this study, the distribution with the highest ranking was used to represent the particular data set. In order to develop a distribution in STATFIT at least 10 data points were needed. For this reason, the queries were performed up to the point that at least 10 data points were obtained. Figure 9.23 shows the distribution developed for the contract bid item highlighted in the first page of Table D.1, located in Appendix D.

Notice from Table 9.30 that approximately 13% (415) of the total number of contract bid items listed in the database provided by VMS were able to be represented with historical bid data from BidTabs, but the reality is that this 13% represents approximately 30% ($12,860,027) of the Total Bid Price ($42,842,926). Thus, the results of the study are based on a sample that represents 30% the total population, which in this study corresponds to the complete list of contract bid items provided by VMS (i.e., 2973 records).

Table 9.30. Portion of the Population Mapped

Category	No. of Contract Items	Period of Time	Total Price
Contract Bid Items from work done by VMS under Performance-Based Specifications	2973	1998-2001	$42,842,926
Contract Bid Items that were able to be represented with historical bid data under Traditional Maintenance Specifications	415	1993-2001	$12,860,027 [1]

[1] Represents 30% of the Total Bid Price

A complete list of the 415 contract bid items considered in the study is presented in Table D.1. Notice that Table D.1 includes the distributions of the unit prices developed for the mapped bid items. The distributions presented in Table D.1 were developed by following the procedures discussed in Steps 1 through 4.

Step 5. Monte Carlo Approach. The records with the distributions presented in Table D.1 were used as the input to generate the distribution of the total cost under traditional maintenance specifications. The Monte Carlo Approach was used to serve this purpose. However, before the distribution of the total cost was created, a convergence study was conducted to determine the appropriate number of repetitions required for the simulation to provide precise results. Table

9.31 summarizes the results from this study. Notice that when 2000 repetitions were conducted, convergence was achieved.

Table 9.31. Results from Convergence Study

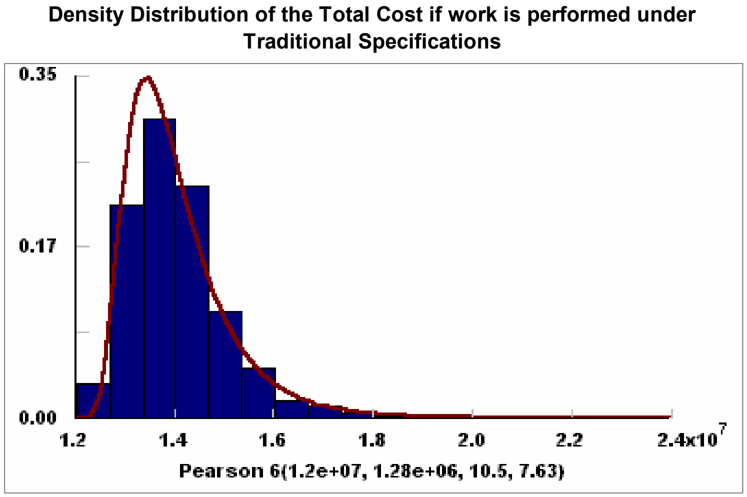
Descriptive Statistic	Repetitions		
	100	1000	2000
95 % Confidence Interval	$294,923	$68,790	$48,504
Mean	$14,155,580	$14,077,318	$14,076,306
Lowerbound	$14,008,118	$14,042,923	$14,052,054
Upperbound	$14,303,041	$14,111,713	$14,100,559
Percentile with respect to the Mean	2.08%	0.49%	0.34%

After implementing the Monte-Carlo Approach with 2000 repetitions, the results presented in Table 9.32 were obtained.

Table 9.32. Results with 2000 Repetitions

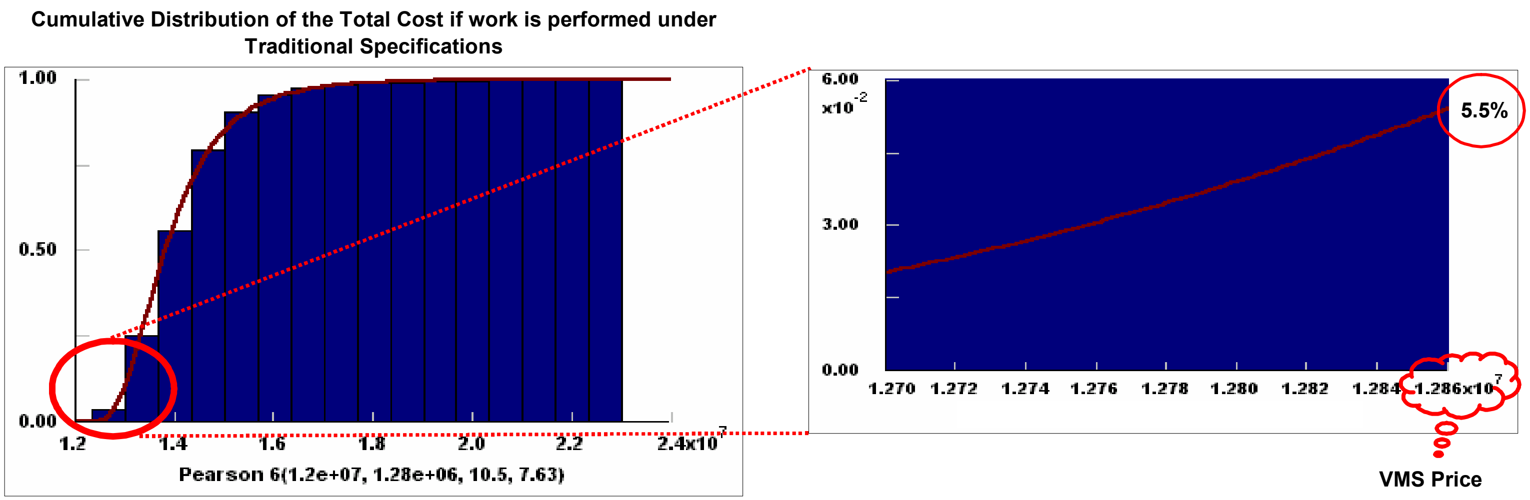
Description	Year				
	1998	1999	2000	2001	All Years
Results with Weighted Average Unit Prices					
Total Bid Price for all contracts from VMS	$7,996,453	$23,321,213	$11,476,553	$48,708	**$42,842,926**
Total Bid Price fromVMS considered in analysis	$935,707	$8,374,426	$3,520,409	$29,485	**$12,860,027**
Estimated total price with weighted average unit prices	$810,124	$8,484,445	$4,496,648	$32,041	**$13,823,258**
Estimated Savings (Estimated price - VMS price)	-$125,583	$110,019	$976,238	$2,556	**$963,230**
Percentage of Savings by using weighted unit prices	-13.42%	1.31%	27.73%	8.67%	**7.49%**
Lowerbound Results with Distributions (Simulation)					
Total estimated price with distributions	$889,132	$8,602,432	$4,485,322	$29,169	**$14,052,054**
Estimated Savings (Estimated price - VMS price)	-$46,575	$228,006	$964,913	-$316	**$1,192,027**
Percentage of Savings by using distributions	-4.98%	2.72%	27.41%	-1.07%	**9.27%**
Mean Results with Distributions (Simulation)					
Total estimated price with distributions	$933,696	$8,613,881	$4,496,734	$31,995	**$14,076,306**
Estimated Savings (Estimated price - VMS price)	-$2,011	$239,456	$976,325	$2,510	**$1,216,279**
Percentage of Savings by using distributions	-0.21%	2.86%	27.73%	8.51%	**9.46%**
Upperbound Results with Distributions (Simulation)					
Total estimated price with distributions	$978,260	$8,625,331	$4,508,146	$34,821	**$14,100,559**
Estimated Savings (Estimated price - VMS price)	$42,553	$250,905	$987,736	$5,336	**$1,240,531**
Percentage of Savings by using distributions	4.55%	3.00%	28.06%	18.10%	**9.65%**

Step 6. Cost Comparison,. Notice from Table 9.32 that the estimated savings based on the results from the simulation are approximately 9.27% to 9.65% for the total period of time considered in the study. In addition, according to the distributions presented in Figure 9.24, it can be concluded that there is approximately 96 % chance that contractors would offer higher bid prices when bidding for work under traditional maintenance specifications than when bidding on work under performance based specifications.



Descriptive Statistics:

No. of Repetitions	=	*2000*
Mean	=	*$14,076,306*
SD	=	*$1,106,746*
Minimum	=	*$12,027,349*
Maximum	=	*$22,686,349*



FINDINGS: AS SHOWN IN THE GRAPHS ABOVE , WHICH ARE BASED ON THE RESULTS OBTAINED FROM THE SIMULATION (2000 REPETITIONS), IT CAN BE CONCLUDED THAT THERE IS A 94.5% CHANCE THAT CONTRACTORS WOULD OFFER HIGHER BID PRICES WHEN BIDDING FOR WORK UNDER TRADITIONAL MAINTENANCE SPECIFICATIONS THAN WHEN BIDDING THAN WHEN BIDIING ON WORK UNDER PERFORMANCE-BASED SPECIFICATIONS.

Figure 9.24. Findings from Simulation

9.3.2. Part 2: Study of Cost versus LOS

The second part of the cost-efficiency evaluation, in which the Expenditures are related to the Level of Service, was not included in this application example for two main reasons:

(1) Unavailability of Records. Records were not available in VDOT's databases that provided the required information to support the procedures adopted in the framework to relate cost to performance.

(2) .Timely Constraints. Significant amount of time will be required to acquire the data needed to properly apply the procedures adopted in the two approaches suggested in Chapter 5. For this reason, it was proposed to conduct this part of the study in a later stage.

9.4. TIMELINESS OF RESPONSE (TOR) EVALUATION

The proposed methodology presented in Chapter six was implemented to evaluate VMS's compliance to timeliness requirements. A description of the implementation of the proposed approach to evaluate the VMS's Timeliness of Response is presented in this section.

9.4.1. Input

VDOT included in the contractual agreement with VMS a list of timeliness requirements. These timeliness requirements are summarized in Table A.4, located in Appendix A. Notice that no performance targets were defined; only performance measures were specified by VDOT as part of their timeliness requirements. This means that the agency will not be able to determine if the ratings obtained by the contractor are acceptable or not. For instance, if a contractor responded 90% of the time in a timely manner to a timeliness requirement, the agency will not be able to determine or tell the contractor if this is considered acceptable or not. VDOT must fix this deficiency in their timely related performance standards in order to be able to properly assess the commitment of VMS in responding to service request in a timely manner.

9.4.2. Data Collection

Both VDOT and VMS keep records of the response to service requests, however, for the purpose of the 2002 Evaluation only the records from the agency were taken into consideration.

A time sheet similar to the one presented in Table 6.2 was used to keep record of VMS's response to service requests. However, no information was provided in those data sheets regarding any required lane closure. For this reason, the compliance to lane closures was not included in the evaluation presented in this chapter.

As shown in Table A.4, performance standards were specified by VDOT for two types of service requests, Type 1 and Type 2. The elements evaluated within each Type of Service Request are summarized in Table 9.33 for convenience.

Table 9.33. Elements Within the Two Types of Service Requests

Incident Response Categories	
Type 1	Type 2
Incident Assistance during Working Hours (20 min.)	Guardrail (Damaged but Functional)
Incident Assistance during Non-Working Hours (45 min.)	Guardrail (Badly Damaged)
Immediate Response (60 min.)	Impact Attenuators
Debris and Road Kill Removal (60 min.)	Truck Ramps
	Highway Lighting
	Potholes
	Signs (Warning and Regulatory)

Table 9.34 summarizes the number of responses provided by VDOT in 2002. These records were considered as the input in the 2002 Timeliness Evaluation. These records were collected by VDOT Coordinators supervising VMS personnel in the field in a daily basis. Notice from Table 9.34 that a total of 190 requests were recorded by VDOT Coordinators from which practically half corresponds to Type 1 Service Requests and the other half to Type 2 Service Requests.

Table 9.34. Number of Records Considered in the 2002 Timeliness Evaluation

Response Type	Service Requests	
	Quantity	%
Incident Response (Type 1)	93	48.9%
Incident Response (Type 2)	97	51.1%
Overall	**190**	**100.0%**

9.4.3. Data Analysis

In order to assess the compliance of the contractor to timeliness requirements, the following areas were considered in the evaluation: (a) comparison of the actual response time versus timeliness standards, and (b) long-term performance.

9.4.3.1. Actual Response

The following steps were followed to obtain the actual response time from VMS and compare them with the timeliness standards specified by VDOT in the contractual agreement.

Step 1. Calculation of Response Time. The first step in the process was to calculate the response time of the contractor to each service request. The response time was calculated by basically obtaining the difference between the time when the contractor received the call and the time when the contractor personnel arrived to the site or finish the repair, if a repair was required.

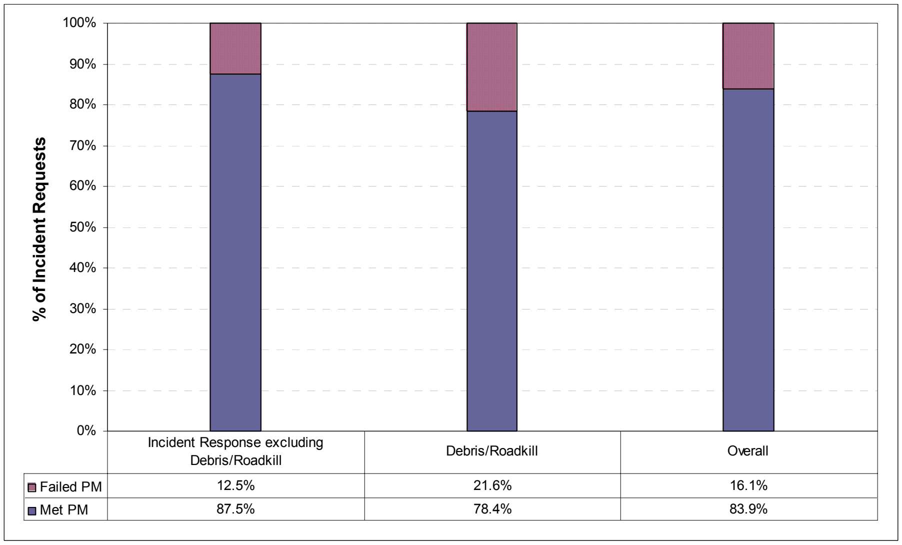
Step 2. Comparison of Response Time with Performance Measures. The response time obtained in Step 1 were then compared with the performance measures specified in the contractual agreement. Once again, those measures are listed in Table A.4. The results from these comparisons are summarized in Tables 9.35 and 9.36 for Requests of Type 1 and Type 2, respectively. In addition, a graphical representation of VMS's Compliance to timely related performance measures for Request of Type 1 and Type 2 is presented in Figure 9.25.

Table 9.35. Summary of VMS's Response to Type 1 Incident Requests

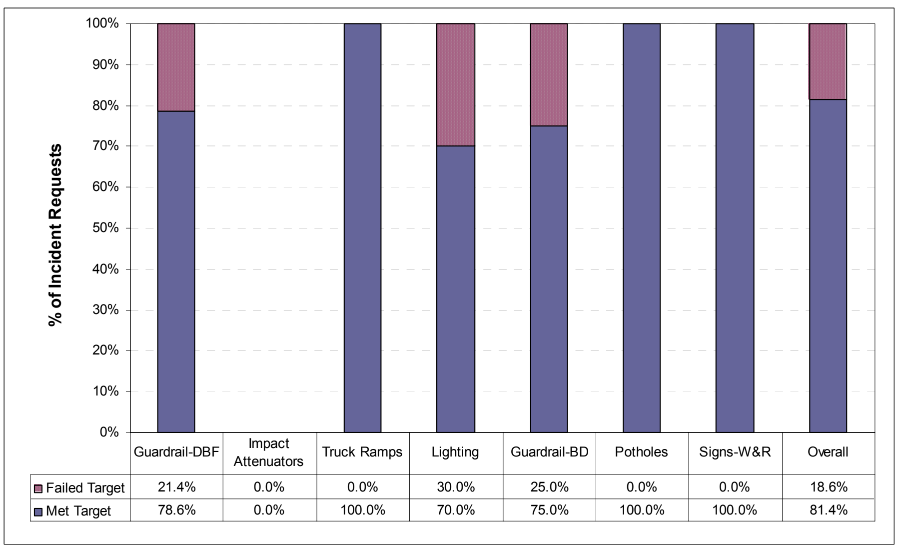
Description	Performance Measure (PM)	Condition	Jan-02		Feb-02		Mar-02		Apr-02		May-02		Jun-02		Jul-02		Aug-02		Sep-02		Oct-02		Nov-02		Dec-02		Overall (Jan02 -Dec02)	
			Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%
Incidents	20, 45 & 60 minutes, excluding Debris/Roadkill	Met PM	0	0.0%	1	100.0%	1	100.0%	2	66.7%	5	83.3%	10	100.0%	10	83.3%	7	87.5%	10	90.9%	3	75.0%	0	0.0%	0	0.0%	49	87.5%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	1	33.3%	1	16.7%	0	0.0%	2	16.7%	1	12.5%	1	9.1%	1	25.0%	0	0.0%	0	0.0%	7	12.5%
		Total	0	0.0%	1	100.0%	1	100.0%	3	100.0%	6	100.0%	10	100.0%	12	100.0%	8	100.0%	11	100.0%	4	100.0%	0	0.0%	0	0.0%	56	100.0%
Debris & Road kill	60 minutes	Met PM	0	0.0%	0	0.0%	1	100.0%	5	100.0%	1	33.3%	4	50.0%	7	100.0%	4	80.0%	5	83.3%	2	100.0%	0	0.0%	0	0.0%	29	78.4%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	66.7%	4	50.0%	0	0.0%	1	20.0%	1	16.7%	0	0.0%	0	0.0%	0	0.0%	8	21.6%
		Total	0	0.0%	0	0.0%	1	100.0%	5	100.0%	3	100.0%	8	100.0%	7	100.0%	5	100.0%	6	100.0%	2	100.0%	0	0.0%	0	0.0%	37	100.0%
All	All	Met PM	0	0.0%	1	100.0%	2	100.0%	7	87.5%	6	66.7%	14	77.8%	17	89.5%	11	84.6%	15	88.2%	5	83.3%	0	0.0%	0	0.0%	78	83.9%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	1	12.5%	3	33.3%	4	22.2%	2	10.5%	2	15.4%	2	11.8%	1	16.7%	0	0.0%	0	0.0%	15	16.1%
		Total	0	0.0%	1	100.0%	2	100.0%	8	100.0%	9	100.0%	18	100.0%	19	100.0%	13	100.0%	17	100.0%	6	100.0%	0	0.0%	0	0.0%	93	100.0%

Table 9.36. Summary of VMS's Response to Type 2 Incident Requests

Description	Performance Measure (PM)	Condition	Jan-02		Feb-02		Mar-02		Apr-02		May-02		Jun-02		Jul-02		Aug-02		Sep-02		Oct-02		Nov-02		Dec-02		Overall (Jan02 -Dec02)	
			Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Qty.	%
Guardrail (Damaged but Functional)	7 days	Met PM	0	0.0%	0	0.0%	1	100.0%	2	100.0%	3	75.0%	5	83.3%	3	75.0%	3	60.0%	5	100.0%	0	0.0%		0.0%		0.0%	22	78.6%
		Failed PM	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1	25.0%	1	16.7%	1	25.0%	2	40.0%	0	0.0%	0	0.0%		0.0%		0.0%	6	21.4%
		Total	0	0.0%	1	100.0%	1	100.0%	2	100.0%	4	100.0%	6	100.0%	4	100.0%	5	100.0%	5	100.0%	0	0.0%	0	0.0%	0	0.0%	28	100.0%
Impact Attenuators	7 days	Met PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%		0.0%		0.0%	0	0.0%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%		0.0%		0.0%	0	0.0%
		Total	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Truck Ramps	7 days	Met PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	100.0%	0	0.0%		0.0%		0.0%	1	100.0%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%		0.0%		0.0%	0	0.0%
		Total	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	100.0%	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Highway Lighting	7 days	Met PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	50.0%	2	100.0%	0	0.0%	1	50.0%	1	100.0%	2	100.0%		0.0%		0.0%	7	70.0%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	50.0%	0	0.0%	1	100.0%	1	50.0%	0	0.0%	0	0.0%		0.0%		0.0%	3	30.0%
		Total	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	100.0%	2	100.0%	1	100.0%	2	100.0%	1	100.0%	2	100.0%	0	0.0%	0	0.0%	10	100.0%
Guardrail (Badly Damaged)	2 days (48 Hours)	Met PM	1	50.0%	0	0.0%	0	0.0%	4	100.0%	1	33.3%	4	80.0%	3	60.0%	8	88.9%	4	100.0%	2	50.0%		0.0%		0.0%	27	75.0%
		Failed PM	1	50.0%	0	0.0%	0	0.0%	0	0.0%	2	66.7%	1	20.0%	2	40.0%	1	11.1%	0	0.0%	2	50.0%		0.0%		0.0%	9	25.0%
		Total	2	100.0%	0	0.0%	0	0.0%	4	100.0%	3	100.0%	5	100.0%	5	100.0%	9	100.0%	4	100.0%	4	100.0%	0	0.0%	0	0.0%	36	100.0%
Potholes	2 days (48 Hours)	Met PM	0	0.0%	0	0.0%	0	0.0%	1	100.0%	1	100.0%	1	100.0%	1	100.0%	0	0.0%	0	0.0%	1	100.0%		0.0%		0.0%	5	100.0%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%		0.0%		0.0%	0	0.0%
		Total	0	0.0%	0	0.0%	0	0.0%	1	100.0%	1	100.0%	1	100.0%	1	100.0%	0	0.0%	0	0.0%	1	100.0%	0	0.0%	0	0.0%	5	100.0%
Signs (Warning and Regulatory)	1 day (24 Hours)	Met PM	0	0.0%	0	0.0%	1	100.0%	1	100.0%	1	100.0%	1	100.0%	7	100.0%	2	100.0%	2	100.0%	2	100.0%		0.0%		0.0%	17	100.0%
		Failed PM	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%		0.0%		0.0%	0	0.0%
		Total	0	0.0%	0	0.0%	1	100.0%	1	100.0%	1	100.0%	1	100.0%	7	100.0%	2	100.0%	2	100.0%	2	100.0%	0	0.0%	0	0.0%	17	100.0%
All	All	Met PM	1	50.0%	0	0.0%	2	100.0%	8	100.0%	7	63.6%	13	86.7%	14	77.8%	14	77.8%	13	100.0%	7	77.8%	0	0.0%	0	0.0%	79	81.4%
		Failed PM	1	50.0%	1	100.0%	0	0.0%	0	0.0%	4	36.4%	2	13.3%	4	22.2%	4	22.2%	0	0.0%	2	22.2%	0	0.0%	0	0.0%	18	18.6%
		Total	2	100.0%	1	100.0%	2	100.0%	8	100.0%	11	100.0%	15	100.0%	18	100.0%	18	100.0%	13	100.0%	9	100.0%	0	0.0%	0	0.0%	97	100.0%



a) Type 1



b) Type 2

Figure 9.25. Summary of VMS's Compliance to Timeliness Requirements

Step 3. Collection of Statistics. Tables 9.35 and 9.36 summarize the statistics required for the comparison of the actual response times with the performance targets, which in this contract does not exist.

Step 4. Comparison of Statistics with Performance Targets. As previously mentioned, no performance targets were specified in the VDOT-VMS contract. For this reason, it was impossible to determine if the actual response times were considered acceptable to VDOT.

9.4.3.2. Long-Term Response

Since no timeliness information was collected before the year 2002, it was impossible to perform a long-term evaluation of the VMS's Response Times and compliance to VDOT's timeliness requirements. The timeliness information collected in 2002 became the baseline for a future long-term performance evaluation.

9.4.4. Reporting

The findings from the analysis were reported pretty much with similar tables and graphs presented in the pervious section, but with a more comprehensive level of detail, such as the performance of the contractor in a monthly basis. Unfortunately, a Report Card was not developed since any performance targets associated to the timeliness of response were specified in the contractual agreement between VDOT and VMS.

9.5. SAFETY PROCEDURES (SP) EVALUATION

As it was stated at the beginning of this chapter, the methodologies proposed in Chapter seven to assess the compliance of the contractor to Safety Procedures were not implemented in the PBRM contract between VDOT and VMS. The main reason for not conducting this application was because the sponsor of this research, the Virginia Department of Transportation, wanted to give more emphasis in the evaluation of the three components previously discussed in this chapter (i.e., Level of Service, Cost-Efficiency, and Timeliness of Response) as a result of budget constraints. However, the implementation of the procedures to evaluate the compliance of VMS to safety requirements is scheduled to take place in the near future. As a matter of fact, the development of some of the questionnaires to be sent to the parties identified in Chapter seven already started. An example of some of the questions included so far in the survey to be submitted to personnel from the Virginia State Police is presented in Figure 9.26. Similar format to the one presented in this figure will be used for the surveys to be submitted to the other parties involved in the evaluation of safety compliance.

Questionnaire for Virginia State Police

1 ***PURPOSE***

The purpose of this survey is to assesses VMS's performance in the area of incident response and safety procedures. Please indicate your experience with services received during instances of VMS assistance.

SECTIONS TO EVALUATE

The questionnaire is divided in three main sections (A, B, and C). All sections addresses different topics. In Section A we want to know about your experience with VMS in the area of incident response. In Section B we want to know about your experience with VMS's Safety Procedures. In Section C we ask you to give us a few details about your jurisdiction within VMS areas of responsibility.

2 **Section A: Incident Response**

Scoring Instructions

Please answer the questions in this section of the questionnaire using the following scale:

N/A	1	2	3	4	5
	Strongly Disagree		Neutral		Strongly Agree

	Circle One
1) VMS made available a 24-hour duty roster to the State Police.	N/A 1 2 3 4 5
2) VMS incident response personnel provide friendly and helpful service while assisting troopers in the performance of their duties.	N/A 1 2 3 4 5
3) VMS provides adequate equipment and personnel as necessary to support EMS, in a timely manner.	N/A 1 2 3 4 5
4) VMS responds to isolated emergency requests for material or equipment (i.e. sand or loader) in a reasonable period.	N/A 1 2 3 4 5
5) During the past 3 years, you have noticed a considerable improvement in incident response on interstate highways maintained by VMS.	N/A 1 2 3 4 5
6) Overall, you are satisfied with VMS's performance in this area.	N/A 1 2 3 4 5

3 **Second B: Safety Procedures**

Scoring Instructions

Please answer the questions in this section of the questionnaire using the following scale:

N/A	1	2	3	4	5
	Strongly Disagree		Neutral		Strongly Agree

	Circle One
1) Work is well coordinated with the Virginia State Police.	N/A 1 2 3 4 5
2) VMS provides adequate equipment and personnel necessary to deploy operations in a sefely manner.	N/A 1 2 3 4 5
3) Warning and/or detour signs are posted as per Manual on Uniform Traffic Control when lane closures are required	N/A 1 2 3 4 5
4) VMS personnel provides adequate supervision and guidance in order to guarantee the safety of the workers and the traveling public.	N/A 1 2 3 4 5
5) During the past 3 years, you have noticed a considerable improvement in the safety procedures implemented by VMS personnel.	N/A 1 2 3 4 5
6) Overall, you are satisfied with VMS's performance in this area.	N/A 1 2 3 4 5

4 **Section C: General Information**

Answering Instructions

Please tick the appropriate box (es) that provide the best answer to the questions.

1) Please specify your State Police Area Level of Jurisdiction.

☐ District 1 ☐ District 2 ☐ District 3 ☐ District 4

2) Please indicate the period of time you have been patrolling areas under VMS responsibility.

☐ 0-1 Year ☐ 1-2 Years ☐ 3-4 Years ☐ 4-5 Years ☐ 2-3 Years ☐ Over 5 Years

5 **Returning Address:**

Please return your complete questionnaire using the envelope provided (or any other suitable envelope) to the following FREEPOST address: **HMMP, 200 Patton Hall, Virginia Tech, Blacksburg, VA, 24061-0105**

**THANK YOU VERY MUCH FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.
YOUR VIEWS ARE MUCH APPRECIATED.**

Figure 9.26. Example Questions for the Questionnaire to be Submitted to the Virginia State Police

9.6. QUALITY OF SERVICES (QOS) EVALUATION

A similar scenario to the one previously mentioned for the Safety Procedures applies to the Quality of Services evaluation. No attempt was made to evaluate the compliance of VMS regarding the quality of services provided. Similar to the Safety evaluation, VDOT required this application to be conducted at a later time. However, some of the surveys have been developed already, such as the one to be submitted to the Sub-Contractors working for VMS. Figure 9.27 presents an example of some of the questions that will be included in the questionnaire to be submitted to them. Similar format will be used for the surveys to be submitted to DOT personnel, Emergency Units personnel, and the traveling public.

9.7. REFERENCES

de la Garza, J.M., and Vorster, M. (2000). "Assessment of VDOT's equivalent cost for the highway maintenance activities being performed by VMS." November, Final Report.

de la Garza, J.M. and Vorster, M.C. (2002). "2001 VMS and VDOT Performance Evaluation." Virginia Tech, May.

VDOT. (1996). "Comprehensive agreement for Interstate Highway Asset Management Services." Virginia Department of Transportation, December.

VDOT. (1996). "Element data collection manual." Virginia Department of Transportation, January.

VDOT. (2000). "Report on VDOT's comprehensive agreement for interstate asset management services: VMS operations for 1999/2000." Virginia Department of Transportation, Maintenance Division, December.

Questionnaire for VMS Sub-Contractors

1 ***PURPOSE***

The purpose of this survey is to evaluate your perception and opinion regarding the fairness of the procurement process used by VMS to adjudicate contracts under performance-based standards as well as your experiences on how VMS administers the contracts (e.g., supervision, dispute avoidance, and payment compliance).

SECTIONS TO EVALUATE

The questionnaire is divided in three main sections (A, B, and C). All sections addresses different topics. In Section A we want to know about your experience with VMS's procurement process. In Section B we want to know about your contractual experience with VMS's. In Section C we ask you to give us a few details about your organization and the type of contract you have with VMS.

2 **Section A: Procurement Process**

Scoring Instructions

Please answer the questions in this section of the questionnaire using the following scale:

N/A	1	2	3	4	5
	Strongly Disagree		Neutral		Strongly Agree

Circle One

1) You were given the opportunity to bid on the work(s) in a fair and competitive manner. N/A 1 2 3 4 5

3 **Second B: Contractual Experience**

Scoring Instructions

Please answer the questions in this section of the questionnaire using the following scale:

N/A	1	2	3	4	5
	Strongly Disagree		Neutral		Strongly Agree

Circle One

1) Under the terms of the contract in which you performed work for VMS, you were given the opportunity to discuss the nature of the work you were to perform. N/A 1 2 3 4 5

2) You were given sufficient instruction concerning your contractual obligation to VMS and VDOT. N/A 1 2 3 4 5

3) You were provided adequate supervision and guidance in order for you to proceed with the work as contracted. N/A 1 2 3 4 5

4) Problems were addressed and resolved in a fair manner and in mutual satisfaction. N/A 1 2 3 4 5

5) If given the opportunity, you would contract with VMS for another time under the same terms and general conditions. N/A 1 2 3 4 5

6) Overall, the contract between VDOT and VMS is very satisfactory and also you as the subcontractor benefited from that. N/A 1 2 3 4 5

4 **Section C: General Information**

Answering Instructions

Please tick the appropriate box (es) that provide the best answer to the questions.

1) Please specify the contractual amount for the work that you have performed for VMS.

☐ \$0-\$50,000 ☐ \$50,000-\$250,000 ☐ Over \$250,000

2) Please indicate the period of time you have performed work for VMS.

☐ 0-1 Year ☐ 1-2 Years ☐ 3-4 Years ☐ 4-5 Years ☐ 2-3 Years ☐ Over 5 Years

3) How did you hear about opportunities to perform work under this agreement?

☐ Newspaper ☐ VDOT Web Site ☐ VDOT Newsletter ☐ From VMS

5 **Returning Address:**

Please return your complete questionnaire using the envelope provided (or any other suitable envelope) to the following FREEPOST address: **HMMP, 200 Patton Hall, Virginia Tech, Blacksburg, VA, 24061-0105**

THANK YOU VERY MUCH FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.
YOUR VIEWS ARE MUCH APPRECIATED.

Figure 9.27. Example Questions for the Questionnaire to be submitted to VMS Sub-Contractors

CHAPTER 10

SUMMARY AND RECOMMENDATIONS

This chapter summarizes the results of this research, describes how the accomplished work contributes to the body of knowledge, and suggests several directions that could be taken in further studies.

10.1. SUMMARY

This research addressed some of the issues associated with the monitoring of performance-based road maintenance (PBRM) initiatives. The basic objective was to develop a framework that provides transportation agencies with comprehensive and reliable guidelines to assess the overall benefits by the government as a result of implementing performance-based specifications in roadway system maintenance.

The framework developed in this study is consistent with existing approaches commonly used by public and private organizations to measure and monitor performance-based work. Criteria such as the ISO 9001:2000, Malcolm Baldrige National Quality Program, and Highway Maintenance Quality Assurance Program served as the platform for defining the proposed framework to monitor PBRM initiatives. The framework emphasizes in monitoring five key areas to comprehensively evaluate PBRM initiatives. These areas or components are: (1) Level of Service Effectiveness, (2) Cost-Efficiency, (3) Timeliness of Response, (4) Safety Procedures, and (5) Quality of Services. The procedures adopted in the framework to evaluate each component are based on statistically valid techniques. These procedures are associated to the following four main areas: Input, Data Collection, Data Analysis, and Reporting. The proper implementation of these procedures and techniques will provide reliable assessments of the contractor's performance.

Many issues, as part of the Level of Service component, were addressed with the development of techniques to comprehensively account for the specific characteristics of performance-based road maintenance evaluations. The procedures and techniques adopted in this component addressed issues associated to the complete monitoring process, from the planning stage through the reporting of results from the analysis. Robust statistical techniques were developed to address the specific needs in PBRM. The implementation of sampling techniques such as the stratification of the population and the selection of samples proportional to the number of assets on each sampling unit (i.e., Sampling Proportional to Size) are some of the most important adopted techniques that make the proposed sampling procedure very efficient and reliable. Significant attention was given to the development of procedures to improve the quality of the data collected in the field and used for the analysis. The most important indicators are the r_{wg} index and the Z value approach. The adoption of reliable and comprehensive techniques suggested by Stivers et al. (1997) to generate level of service ratings added a significant value to the methodologies suggested as part of this component.

Special attention was given to the development of reliable and statistically valid techniques to evaluate the cost-efficiency component of the framework. The emphasis was in two major evaluative areas: (1) the cost savings accrued as a result of the implementation of performance based specifications and (2) the potential benefits that can be achieved by the agency if they spent in traditional maintenance at least at the same rate of expenditure as they do under performance-based specifications. Four major approaches were developed to address these needs. The Distribution and the Regression Approaches were develop address the first area of concern, the estimate of the savings accrued by the government. On the other hand, two additional approaches, Bayes Theorem and Markovian, were developed to address the second area of concern, the relationship between cost and performance. Detailed instructions on how to implement these approaches were provided in the corresponding sections in Chapter five as well as the complementary Appendix C, which provides a review of the most important basic cost concepts related to cost evaluations.

Guidelines on how to assess the performance of the contractor in meeting timeliness requirements were also provided as part of this study. Direction was given with respect to the components that should be included in the time related performance standards in order for transportation agencies to conduct a comprehensive evaluation of the contractor's performance in this area. In addition, detail description of suggested methodologies to quantitatively assess the compliance of the contractor to timeliness requirements were provided in Chapter six.

Direction was provided in Chapters seven and eight on how to assess the contractor's compliance to safety requirements and the satisfaction of the people impacted by the quality of the contractor's job. Surveys were proposed as the primary mechanism to assess the satisfaction and perspective of the public and personnel involved in a day-to-day basis with the contractor. Guidelines on the most appropriate survey types applicable to our scenario as well as the criteria to consider in the design, testing, deployment, and analysis of the information received from the surveys were provided.

Partial application of the proposed framework was performed to the current performance-based road maintenance contract between VDOT and VMS, Inc. for the maintenance of portion of the Interstate System in the Commonwealth of Virginia. This application provided the readers with a better understanding of the implementation of some of the concepts and procedures presented in Chapters four through eight of this dissertation. Issues related to further application of this framework to the contract between VDOT and VMS will be addressed in Section 10.3, Recommendations for Future Studies.

10.2. CONTRIBUTIONS OF THIS RESEARCH TO THE BODY OF KNOWLEDGE

The proposed framework presents several contributions to the body of knowledge. The contributions have been classified in two categories: (1) Major Contributions (Tier 1) and (2) Minor Contributions (Tier 2). A graphical representation of the contributions identified within each category is presented in Figure 10.1. A detailed description of each contribution follows.

1) ***Tier 1: Major Contributions***. The first major contribution of this study is the identification of the five main components and elements that define the proposed framework. The framework responds to the need of transportation agencies to perform comprehensive and reliable assessments of the efficiency and effectiveness of performance-based specification in the roadway system maintenance. The implementations of performance-based specifications in

roadway maintenance are relatively new and no previous guidelines to monitor this type of initiative were found in the extensive literature review. For this reason, this study can be categorized as unique and a major asset to the performance-based road maintenance arena.

The second major contribution of this study corresponds to the development of the robust sample selection procedure of the Level of Service evaluation. The proposed sampling procedure addresses the specific needs and characteristics of performance-based road maintenance evaluations. The implementation of the proposed sampling technique demonstrated significant improvements. Two of those improvements are: the increase in the confidence level at which the findings from the sampled population were generalized to the whole population, increasing the reliability of the final results and the reduction in the number of assets required to meet statistical sufficiency and thus making the procedure more cost-effective. No previous study has addressed the issues considered in the development of the sampling procedure presented in Chapter four. For this reason, the development of this technique is considered as a major contribution to the body of knowledge.

The third major contribution corresponds to the comprehensive methodology defined in Chapter five to assess the cost benefits accrued by the government as a result of adopting performance-based road maintenance specifications. This study has provided transportations agencies not only with statistically valid procedures to estimate the cost savings, if any, accrued as a result of the implementation of performance-based specifications, but also proved methodologies to assess the impact in Level of Service as a result of changes in the expenditure rate. Since no previous study has addressed all the issues discussed in Chapter five, the methodologies presented in that chapter can be categorized as the most comprehensive attempt until now to evaluate the Cost-Efficiency of PBRM initiatives.

2) ***Tier 2: Minor Contributions***. This study also makes several minor contributions. The first minor contribution corresponds to the procedures defined in Chapter four to assess the level of agreement among crews assessing the assets condition in the field. A portion of the proposed procedure was adopted from Stivers et al. (1997) QA Program. However, the Stivers approach was combined with the approach suggested by James et al. 1984 to address the specific needs of our study. Both approaches were combined and manipulated to make possible the evaluation of

agreement at the asset item and asset group level. Since the final proposed procedure was specifically designed to address the characteristics of PBRM evaluations, the final proposed methodology for the QA/QC process is considered as a contribution to the body of knowledge.

Another minor contribution corresponds to the procedures suggested in the framework to assess the contractor's level of compliance to timeliness requirements. These procedures are considered unique in this study, but they are at a lower level of complexity if compare them to other contributions of this research.

The other minor contributions correspond to the procedures defined in Chapters seven and eight to evaluate the contractor's compliance to safety requirements and the suggested methodology to assess the user, customer, and third party level of satisfaction regarding the job done by the contractor under performance-based specifications. Similar to the timeliness of response scenario, these procedures indeed make a contribution to the body of knowledge, since it is the first time they have been addressed in the PBRM arena, but its contribution is categorized at a lower level of importance.

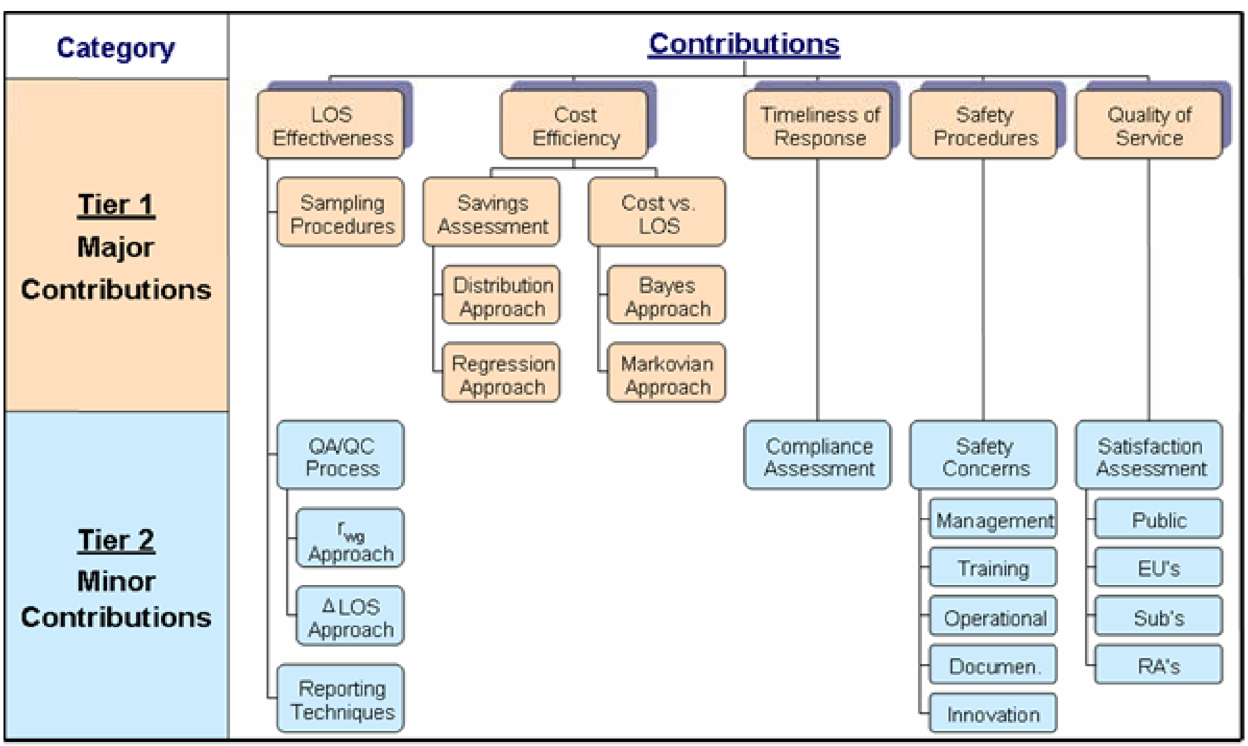


Figure 10.1. Summary of the Contributions of this Research to the Body of Knowledge

10.3. RECOMMENDATIONS FOR FUTURE STUDIES

This section describes research issues that are recommended to be addressed in further research.

i) ***Further Application of the Framework***. Chapter nine presented a partial application of the framework to the current performance-based road maintenance contract between VDOT and VMS, Inc.. The application for three out of the five components of the framework was not completed. This was determined by the limitations in the availability of data to support the proposed analytical procedures and VDOT's instructions to conduct evaluations at a later time. The first of the three components applied is the Cost-Efficiency Evaluation. From this component, only Part 1, which assesses the cost savings, if any, accrued by the government, was applied using one of the proposed approaches, the Distribution Approach. Further studies must be performed to repeat this study, but with the Regression Approach. The results from both approaches will provide good feedback to VDOT on the estimated savings, if any. This application is scheduled for the next fiscal year. On the other hand, the application of Part 2 of the Cost-Efficiency component, which relates Cost to Level of Service, will require a more significant effort since the current methodologies used by VDOT do not provide the information in the level of detail that is required to support the proposed analytical approaches. Further research must be performed in collaboration with VDOT to develop a system that will easily provide the information necessary to make the application of Part 2 of the Cost-Efficiency component possible.

The other two components of the framework that were not applied to the contract between VDOT and VMS are Safety Procedures and Quality of Services Evaluation. As previously stated in Chapter nine, VDOT recommended conducting the application of these components in a later time because of budget constraints. However, it is envisioned that the procedures suggested as part of these components will be applied in the near future.

ii) ***Interrelationship among Components***. This research defined procedures to evaluate the five areas that define the proposed framework. These procedures were defined exclusively to evaluate issues related to each component. Thus, the evaluations of each component are considered independent. No interrelationship exist in the procedures adopted on each component, except for the methodologies in Part 2 of the Cost-Efficiency evaluation, where procedures to relate cost to level of service were specified. Many of the components are related to each other. For instance, there is a direct relationship between the timeliness of response and safety procedures. For example, if a contractor does not respond in a timely manner to service requests (e.g., potholes repairs, debris, and road kill removal) serious hazards may be introduced and the safety of the traveling public is at risk. Similar relationships may exist among other components of the framework, such as the impact in Level of Service as a result of additional investments in safety. Therefore it is recommended to study the relationships among components and define valid techniques that will help transportation agencies to evaluate their interrelationship between them.

iii) ***Use of Data Envelopment Analysis to Evaluate Overall Efficiency***. As previously mentioned, the framework proposed in this study evaluates five areas that are essential to comprehensively assess the effectiveness and efficiency of performance-based specifications in the roadway system maintenance. The performance assessments of these areas are independent. This means that at the end of the evaluations the analysts will have five different measures to determine if performance based specifications are better than using traditional maintenance specifications. It will be really difficult to decide which approach is better without combining all these different measures into an overall index that will measure the overall efficiency of each alternative. To create such index is very complicated, especially when each measure under consideration is defined by different units. Data Envelopment Analysis (DEA), occasionally called Frontier Analysis, is a performance measurement technique that can be used to address this need. This technique is commonly used to evaluate the relative efficiency of decision-making units (DMU's) in organizations or projects (Charnes et al. 1994, Ferris et al. 2003). Examples of DMU's in which DEA has been applied are: banks, police stations, hospitals, tax offices, prisons, defense bases (e.g., army, navy, air force), schools, and university departments. This technique was first proposed by Charnes, Cooper and Rhodes in 1978. There are studies that have been published presenting the application of DEA to real-world situations. However, no previous attempt has been made to apply this technique to compare maintenance contracting alternatives in the transportation industry. Further research should be done to evaluate DEA as a potential tool to generate the overall index that will help road administrators identify the most efficient technique to use in the roadway system maintenance. To better illustrate the concept behind DEA, a hypothetical example of its application follows.

Hypothetical Example

The purpose of this example is to illustrate the general idea behind DEA. The intent of this section is not to discuss all the issues that must be considered when using DEA.

Let's consider the example depicted in Table 10.1. This table presents information for six sections (i.e., DMU's) under performance-based specifications and other six sections under traditional maintenance specifications. For each section, the average total number of assets per segment (e.g., one tenth of mile long) is reported (Column 3). This information is defined as the input variable on DEA. This example consider only one input variable, but DEA can handle multiple variables (e.g., input and output) even with different units (Charnes et al. 1994). On the other hand, notice that two output variables were identified in this example. These variables are: (1) percentage of failing assets per segment (Column 5) and (2) expenditure rate per segment (Column 8). How can we compare these sections (i.e., DMU's) and measure their performance using this data? A commonly used method is to use ratios. To obtain these ratios an output measure is divided by an input measure. In this example, the two variables were already represented in terms of ratios. Considering the ratios in Columns 5 and 8 as efficiency measures the twelve sections were ranked as shown in Columns 6 and 9. For instance, Section 1 (i.e., DMU 1) ranked twelfth (i.e., the less efficient) according to the first ratio, percentage of failing assets per segment, but in the second ratio, expenditure rate per segment, it ranked first (i.e., more efficient). This discrepancy highlights the problem of using ratios as a measure of efficiency, which is that different ratios can give a different picture of performance. Moreover, it will be very difficult to combine the entire set of ratios into a single numeric index. For this reason, techniques such as DEA were developed.

The objective of DEA is to simultaneously consider multiple criteria to generate an overall relative efficiency index. DEA uses linear programming to generate an efficient frontier that represents the best performance units in the analysis. The efficient frontier represents a standard of performance that the units (e.g., in our case Sections) not on the efficient frontier could try to achieve. Figure 10.2 presents a graphical representation of how DEA works. This graphical representation was obtained using hypothetical data. The output variables in the figure were plotted one against the other. The positions on the graph for Sections 10, 3, 9, 4, and 1 demonstrate a level of performance superior to all other sections. The efficient frontier will be represented by a line that connects these sections, as shown in Figure 10.2. The sections on the efficient frontier have an efficiency of 100%. As depicted in Figure 10.2, the DEA efficiency for the sections outside the efficiency frontier can be estimated from their distance to the frontier. It is important to mention that DEA only gives relative efficiencies (i.e., efficiencies are relative to the data considered). It does not give absolute efficiencies.

Hypothetical rankings were included in Table 10.1 (Column 10) based on the results from the analysis done with DEA. There is a significant difference in rankings for some of the sections when the rankings obtained with single ratios and DEA are compared. This example briefly showed the potential use of DEA to address the need of an overall index road administrator can use to determine if projects done under performance based specifications are better than projects done under traditional maintenance specifications.

iv) *Development of a Cost Database to Support the Cost-Efficiency Evaluation*. Based on the lessons learned from the application of the framework to the PBRMC between VDOT and VMS, there is a need to develop a comprehensive and reliable database that contains cost data in the format and amount of detail required to implement the second part of the cost-efficiency evaluation (i.e., use of Bayes Theorem and Markovian Approaches to relate Cost to Level of Service). By having this cost database it will allow performing the overall proposed methodology to evaluate the cost-efficiency of Performance-Based Maintenance Specifications versus Traditional Maintenance Specifications.

10.4. REFERENCES

Charnes, A., Coper, W., Lewin, A.Y., and Seiford, L.M. (1994). Data Envelopment Analysis: Theory, Methodology, and Application, Kluwer Academic Publishers, Boston.

Farris, J., Groesbeck, R., and Van Aken, E.M. (2003). "Application of Data Envelopment Analysis to evaluate projects in a government organization." Proceedings of the 2003 IERC Annual Conference, May.

Table 10.1. Hypothetical Example of the use of DEA

Type of Specification	DMU	Input	Output						DEA Ranking based on Efficiency
			Percentage of Failing Assets per Segment			Expenditure Rate per Segment			
		I1=(Assets/Segment)	O1=Failing Assets	Ratio 1=O1/I1	Ranking	O2=(Expenditure Rate/Segment)	Ratio 2=O2/I1	Ranking	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Performance Based	1	40	7	0.175	12	$2,200.00	$55.00	1	1
	2	37	4	0.108	4	$3,200.00	$86.49	8	8
	3	39	3	0.077	2	$2,500.00	$64.10	4	1
	4	36	5	0.139	9	$2,100.00	$58.33	2	1
	5	34	4	0.118	5	$2,400.00	$70.59	5	6
	6	39	6	0.154	11	$2,800.00	$71.79	6	7
Traditional	7	37	3	0.081	3	$4,600.00	$124.32	11	9
	8	39	5	0.128	7	$3,300.00	$84.62	7	10
	9	42	5	0.119	6	$2,500.00	$59.52	3	1
	10	35	2	0.057	1	$3,200.00	$91.43	9	1
	11	38	5	0.132	8	$5,500.00	$144.74	12	12
	12	41	6	0.146	10	$4,000.00	$97.56	10	11

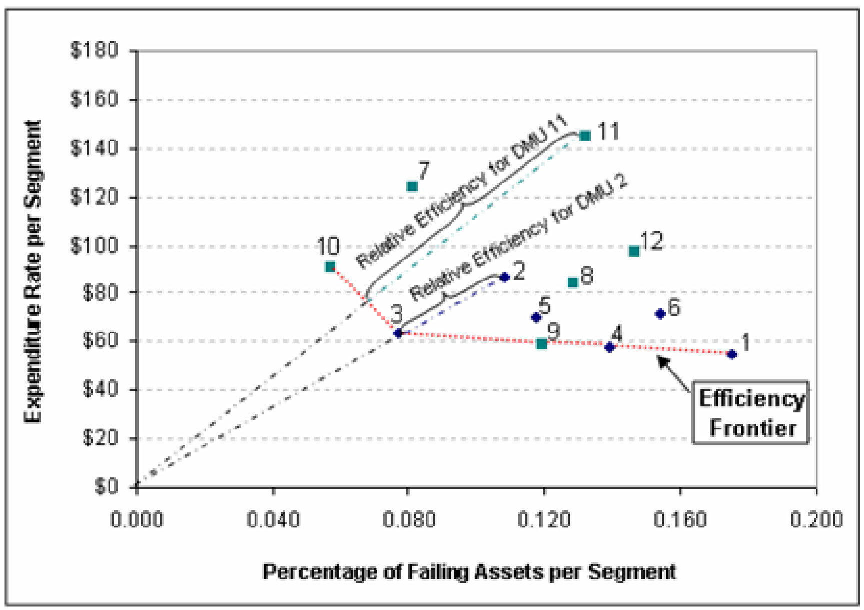


Figure 10.2. Frontier Plot generated with DEA for the Hypothetical Example presented in Table 10.1

APPENDIX A

PERFORMANCE STANDARDS IN VDOT - VMS PBRMC

This appendix presents a list some of the performance measures adopted in the PBRM contract between the Virginia Department of Transportation and the private corporation, VMS, Inc.

Table A.1. Performance Standards for Shoulders, Roadside, Drainage, and Traffic

Asset Item	Performance Standard	
	Target	Measure
Shoulders-Hard Surface		
HS-Surface Defects	90%	>10% Cracking of total surface area
		>10% Raveling of total surface area
		>10% Bleeding of total surface area
		>10% Rutting of total surface area
		Potholes > 3 inches X 12 inches,> 1.5 inches deep
HS-Drop Off	90%	> 50 LF with high shoulders >1 ½ inches high
		> 50 LF with low shoulders > 1 ½ inches low
HS-Separation	90%	> 105 LF, both shoulders combined > ½ in sep.
		> 25% of material missing. Grass growing in joints
HS-Drainage	90%	Evidence of ponding or paved shoulder buildup
		Evidence of erosion
Shoulders-Non Hard Surface		
NHS-Drop Off	90%	> 105 LF, both shoulders combined > 1 ½ in high
		> 105 LF, both shoulders combined > 1 ½ inches low
NHS-Drainage	90%	Evidence of ponding
		Evidence of erosion
		> 10% Evidence of unpaved shoulder (false ditch)
		> 50 Linear Feet with rut over 1 ½ inches deep
Roadside		
Grass	90%	5% of vegetation exceeds 12 inches in height
		Sight distance-120 feet clear vision
		5% of veget. exceeds 12 in in height,>5% bare spot
Debris & Road Killed	100%	Evidence of dump site
		Dead animal
Litter	90%	> 6 cubic feet per acre
		Impedes water flow or partially covers Drop Inlet
Landscaping	80%	> 20% of area is unhealthy or contains weeds
Brush and Tree Control	95%	Sight clearance-120 FT clear vision
		Low overhanging branches < 15 FT clearance
		Low overhanging branches < 7 FT clearance
		non-VDOT sign or unauthorized structures
		Tree that presents a leaning hazard
Concrete Barrier	99%	Misalignment >1 inch at the joints
		Settlement > 1 inch at the joints
Sound Barrier	95%	Misalignment
		Settlement
		Not free of damaging vegetation
		Damage greater than 10%
		Graffiti present
Slopes	90%	Excessive erosion > 6 inches deep
Fence	98%	> 10% need repair > 50 LF of leaning or sagging
		Opening that allows access to Right-of-way
		> 10% vegetation leaning over the fence

Table A.1.(continue) Performance Standards for Shoulders, Roadside, Drainage, and Traffic

Asset Item	Performance Standard	
	Target	Measure
Drainage		
Ditches Paved	90%	> 1 inch settlement
		Undermining/undercutting
		>25% spalled surface
		Severe obstructions impeding flow of water
		Damage to Energy dissipaters, cattle guards, etc
Ditches Unpaved	90%	Evidence of water ponding
		Erosion present > 1 foot deep
		Outfalls not functioning
		Obstructions impeding flow of water
Pipes	95%	Greater than 10% barrel deterioration
		> 10% diameter closed
		Not draining, evidence of ponding water
		Missing joint material
		Evidence of flooding
		Excessive erosion at ends > 1 foot deep
		Evidence of damaged/loose end protection units
		Dip in road > 0.5 inch above pipe
		Damage to Energy dissipaters, cattle guards, etc
Box Culverts	95%	> than 10% barrel deterioration
		> 10% diameter closed
		Not draining, evidence of ponding water
		Missing joint material
		Evidence of flooding
		Excessive erosion at ends > 1 foot deep
		Evidence of damaged/loose end protection units
		Dip in road > 0.5 inch above pipe
		Damage to Energy dissipaters, cattle guards, etc
Under/Edge Drain	90%	Crushed or deteriorated outlet pipe
		> 10% opening blocked
		End protection damaged/missing
Storm D/D Inlets	90%	> 10% diameter closed
		Evidence of flooding
		Settlement of > 1” = 1/2” if sidewalk adjacent
		Grate broken or missing
Curb & Gutter	95%	1” Settlement or misalignment
		Obstruction directing water onto shoulder
		Unsealed cracks greater than ¼ inch
		Spalling greater than ¼ inch deep
		> 25% surface spalled
		Undermining present
		> 6 feet section missing or badly damaged
Sidewalks	90%	Settlement greater than ½ inch
		Unsealed cracks greater than ¼ inch
		> 25% surface spalled
SW Management Ponds	95%	Pipes, weirs damaged/unclean
		Fence missing or damaged,notify VDOT

Table A.1.(continue) Performance Standards for Shoulders, Roadside, Drainage, and Traffic

Asset Item	Performance Standard	
	Target	Measure
Traffic		
Signals	100%	Not functioning, notify VDOT
Pavement Message	95%	Fails reflectivity stds
		Partially covered with debris
		> 10% surface damage
Pavement Stripping	95%	Fails reflectivity stds
		Covered by debris
		> 5% surface damaged
Pavement Markers	90%	> 30% missing or damaged
		2 missing in a row
		Fails reflectivity stds
Delineators/Obj marker	90%	> 10% missing
		Improper height
		> 10% dirty
Glare Foils	90%	> 10% Damaged or Missing, > 50 LF
		> 10% dirty, > 50 LF
Signs-Regulatory	100%	Falls reflectivity stds.
		> 5% dirty surface
		Fails clearance
		Damaged signs
		Downed or missing sign
Signs-Other	90%	Fails reflectivity stds
		> 5% dirty surface
		Fails clearance
		Damaged signs
		Downed or missing sign
Luminaries	90%	Not 90% working, 2 consecutive out
		Missing access panel
Guardrail	100%	missing nuts, bolts and other parts
		Post damaged
		Rust that effects structural integrity
		Strong post outside of 25” to 29” height, > 50 LF
		Weak post outside of 28” to 32” in height, > 50 LF
		Cables loose, improperly secured
		End piece missing
		Low due to new pavement
Impact Attenuators	100%	Parts Missing
		Damaged
Truck Ramps	100%	Surface rutted, not maintained
Cross Overs	100%	Not barricaded
Rumble Strips	NA	Damage affecting functionality

Table A.2. Performance Standards for Pavement Structures

Asset Item	Performance Standard	
	Target	**Measure**
Pavement		
Paved Lanes-Asphalt	95%	skid index>20
		no ruts>1/2"
	PCI and PRI:	no unsealed cracks larger than 1/4" on 95% interstate
	Equal to or better than	no potholes>than 3"x4"x1" deep
	existing conditions	bleeding, raveling<50 ft sq. (based on 0.1 mile section)
		patching-even, and<1/2" higher or lower
		Overall PCI>equal to or better than existing conditions
Paved Lanes-Concrete	95%	skid index>20
		no unsealed cracks larger than 1/4" on 95% interstate
	PCI and PRI:	<1/2" faulting at joint and otherwise
	Equal to or better than	<10% of each joint is missing material or needs repair
	existing conditions	no potholes>than 3"x4"x1" deep
		patching - <1/2" elevation diff.
		Overall PCI>equal to or better than existing conditions

Table A.3. Performance Standards for Bridge Structures

Asset Item	Performance Standard	
	Target	**Measure**
Bridges		
Deck	Overall bridge ratings equal or improved compared to current condition, based on NBS Inspection Data	minimal spalls, cracks or scalling
		meets 3R standards
		clean deck
		drains/scupper are clean and functional
Superstructure	Overall bridge ratings equal or improved compared to current condition, based on NBS Inspection Data	no loss of section or cracks
		paint in good shape
		no spalling
		proper vertical clearance
		proper opening
Substructure	Overall bridge ratings equal or improved compared to current condition, based on NBS Inspection Data	no spalls, cracks, scaling
		adequate foundation
		founded below scour depth
		bearing assemblies functional
		abutmant seats clean and sound
		abutment sound
		pier seats clean and sound
		bearings clean and sound
		truss panel points clean
Slope Protection	Overall bridge ratings equal or improved compared to current condition, based on NBS Inspection Data	vegetation clean
		protection present and functional
		no embankment erosion
		no channel drift

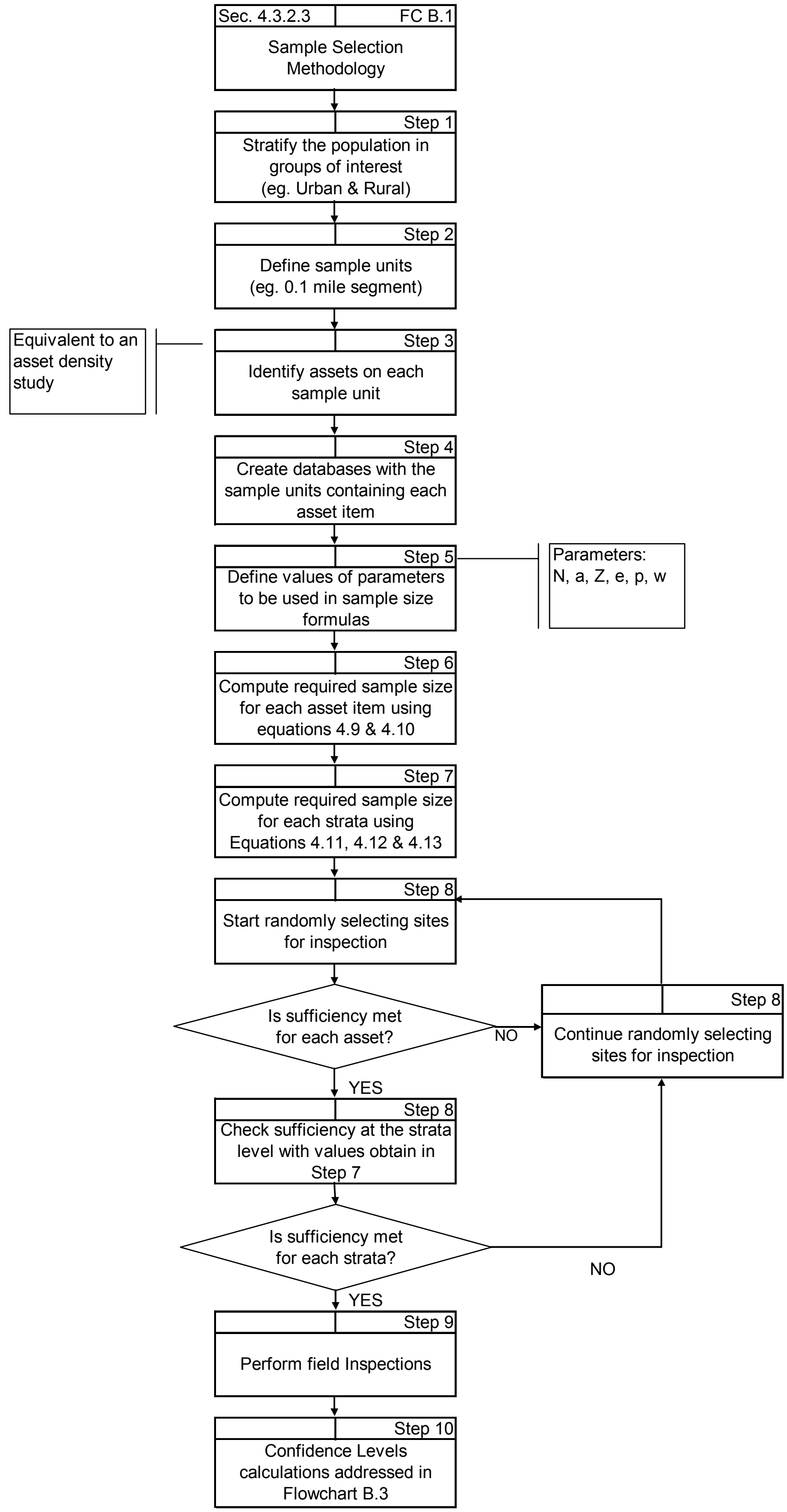
Table A.4. Timeliness Requirements

Timeliness Requirements
Incident Response
24 hour duty roster available to local EMS personnel, State Police, and VDOT
20 minute response time by Supervisory, during work hours, to site
45 minutes response time by Supervisory after work hours to site
1 hour to set up lane closures during work hours
1 1/2 hour to set up lane closures outside work hours
provide equipment and personnel as necessary to support EMS
potholes causing a treat to safety will be responded to immediately, other within 48 hours
Snow and Ice Control
Operator shall at all times maintain a minimum of one lane of travel in each direction of the Facility
Within twenty-four hours of the cessation of a winter weather event, the operator shall provide bare pavement on all travel lanes
Shoulders should be clear of all aaccumulated ice and snow as soon as possible and not later than forty-eight hours after the cessation of the winter weather event

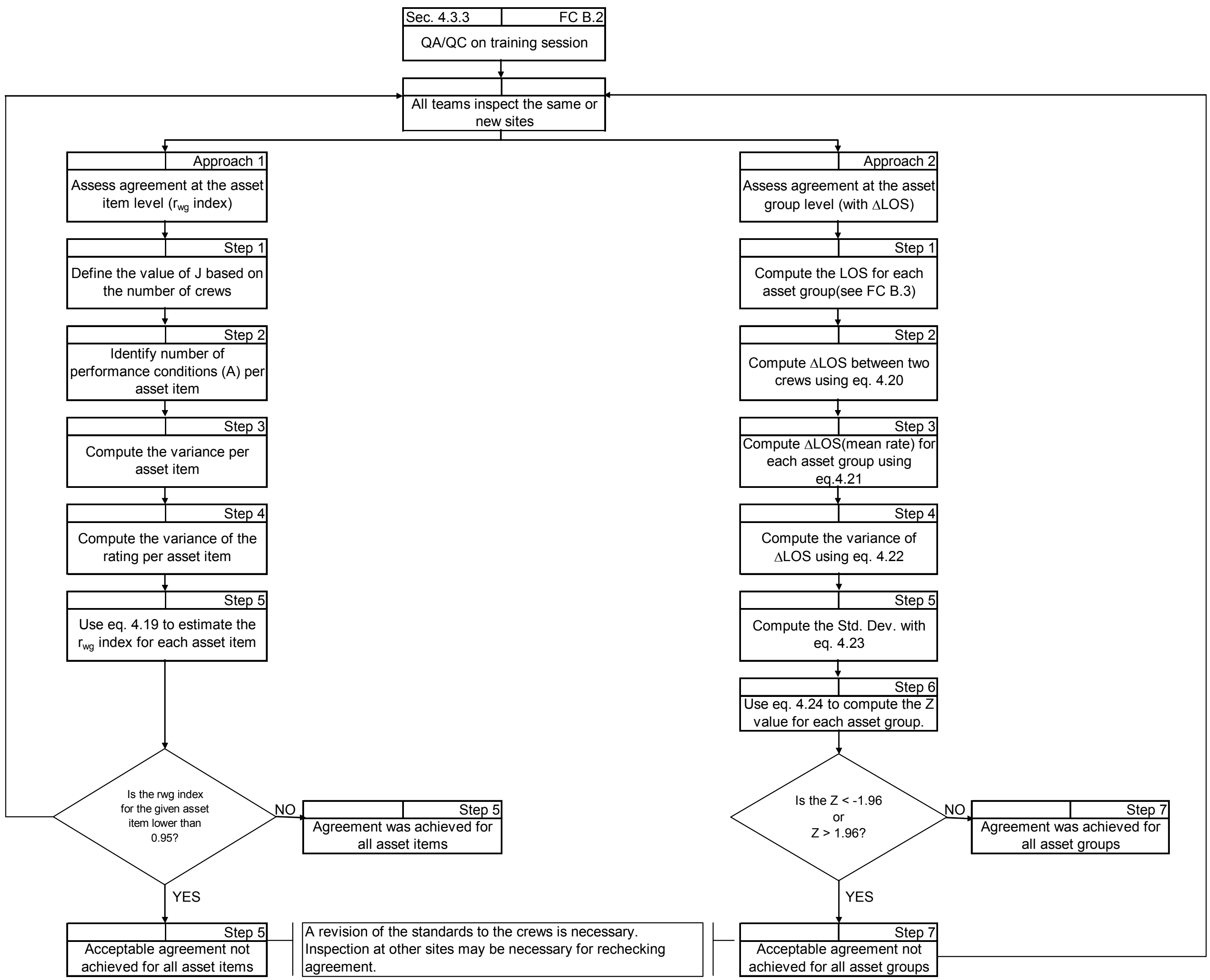
APPENDIX B

FLOWCHARTS

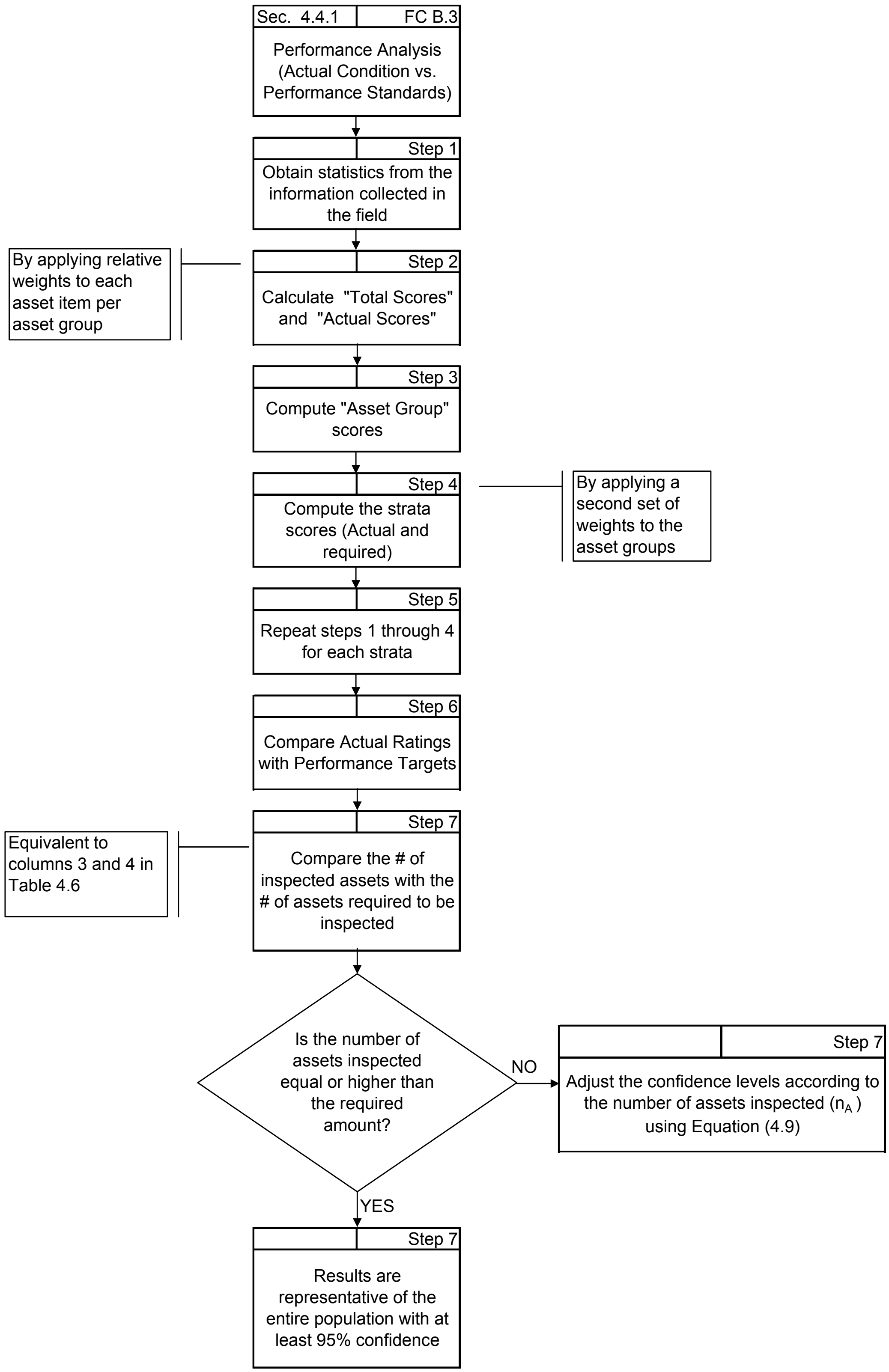
This appendix presents a series of graphical representations (i.e., Flowcharts) of some of the procedures adopted in the framework. The purpose of these flowcharts is to provide guidance to road administrators in the implementation of these procedures. A total of eleven (11) flowcharts are included in this Appendix.



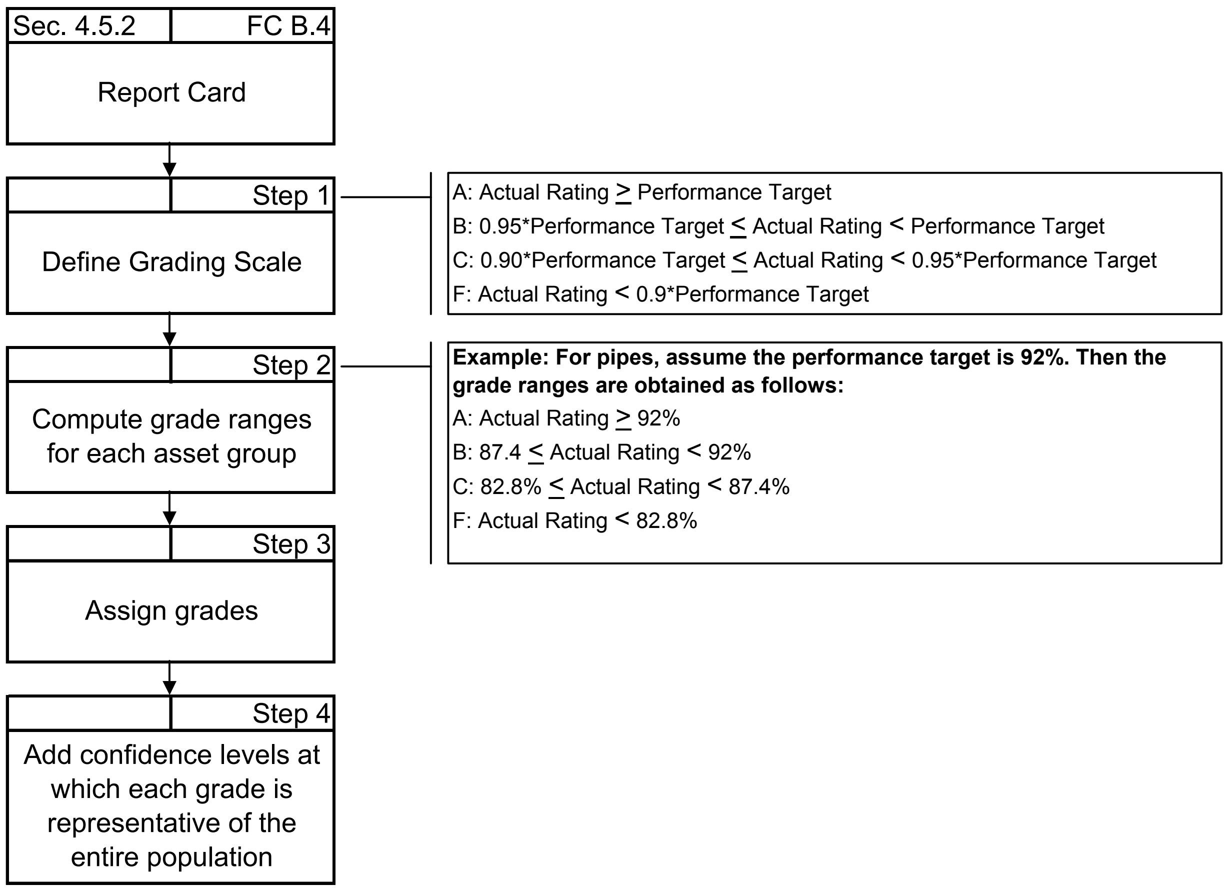
Flowchart B.1. Sample Selection Process for Level of Service Evaluation



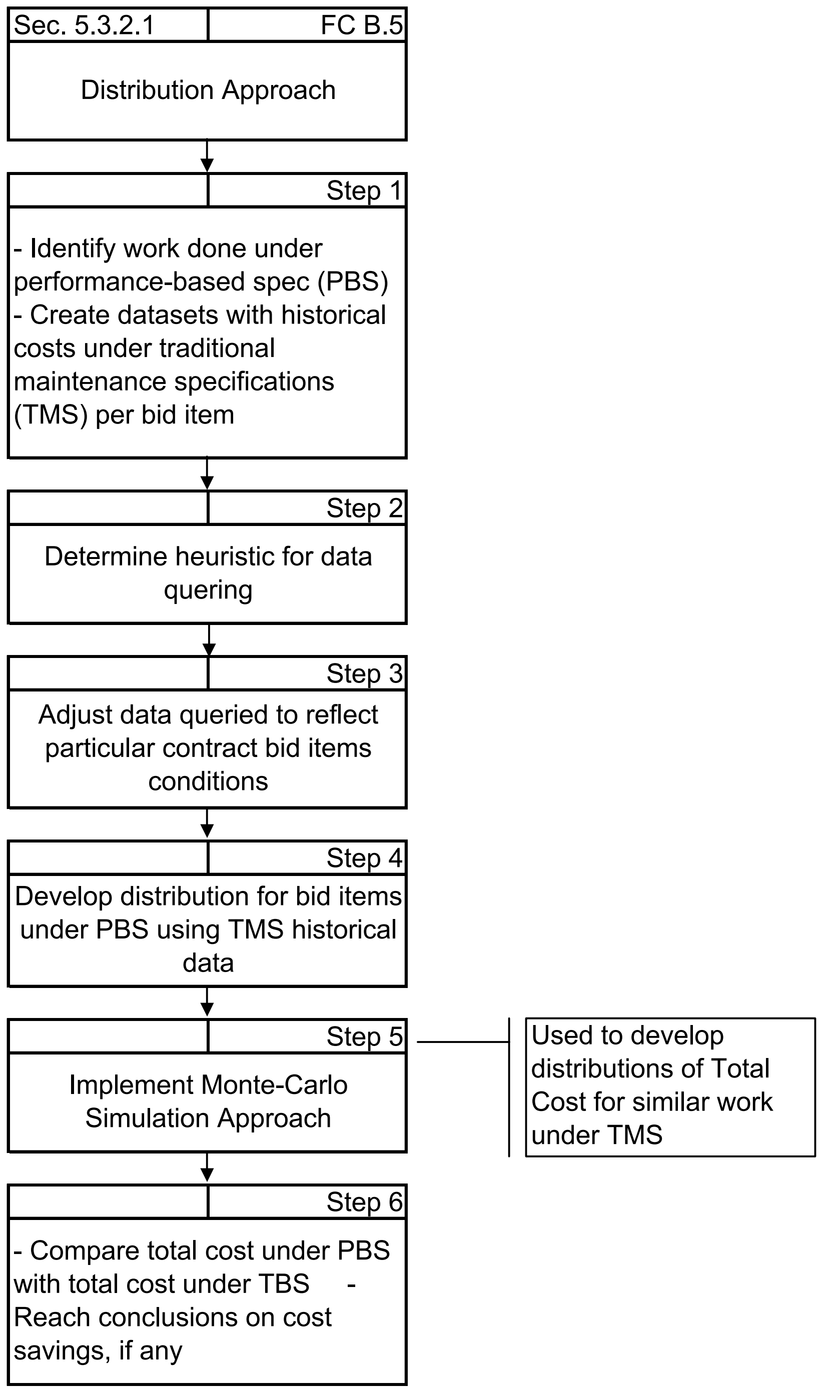
Flowchart B.2. QA/QC on Training Session for Level of Service Evaluation



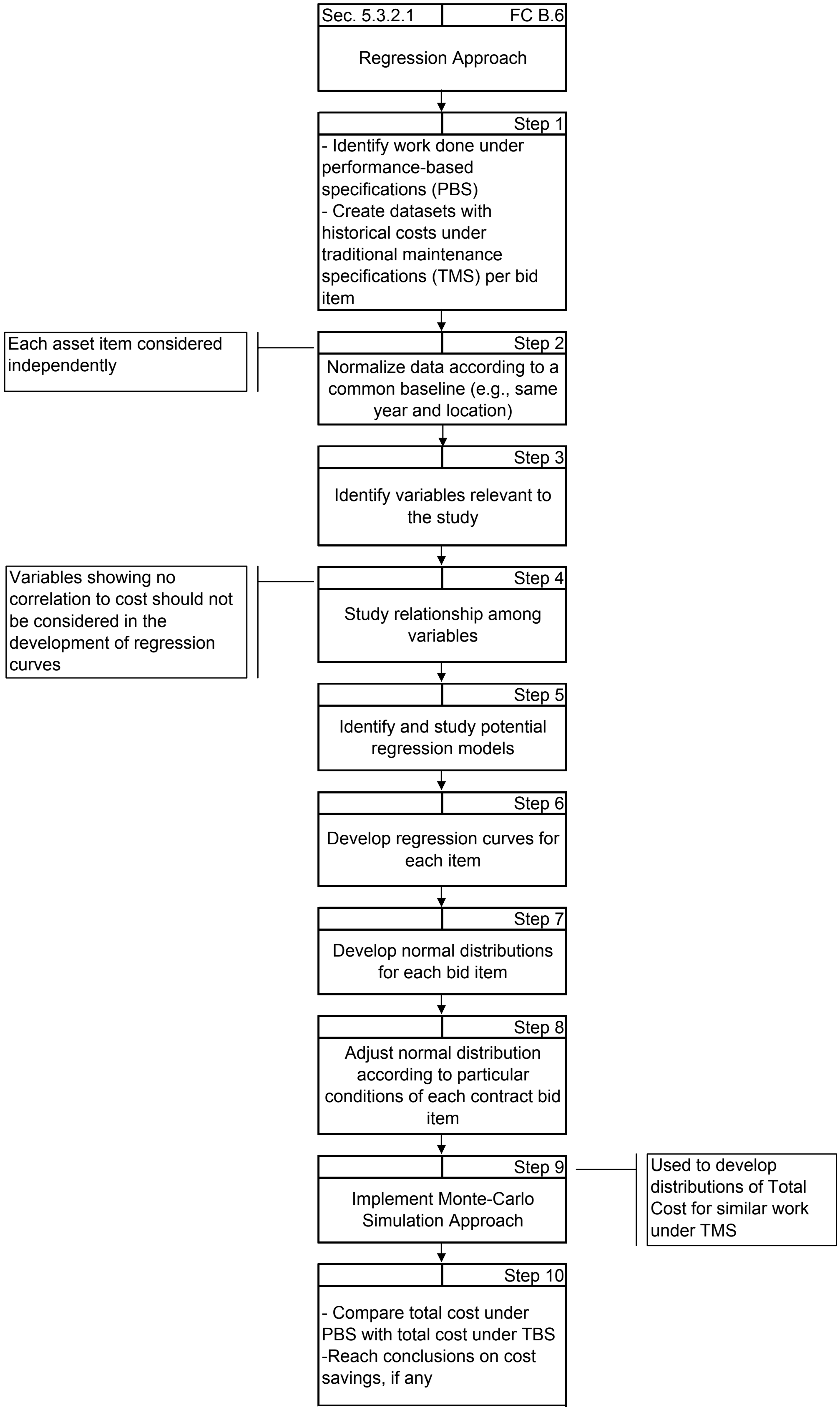
Flowchart B.3. Performance Analysis for Level of Service Evaluation



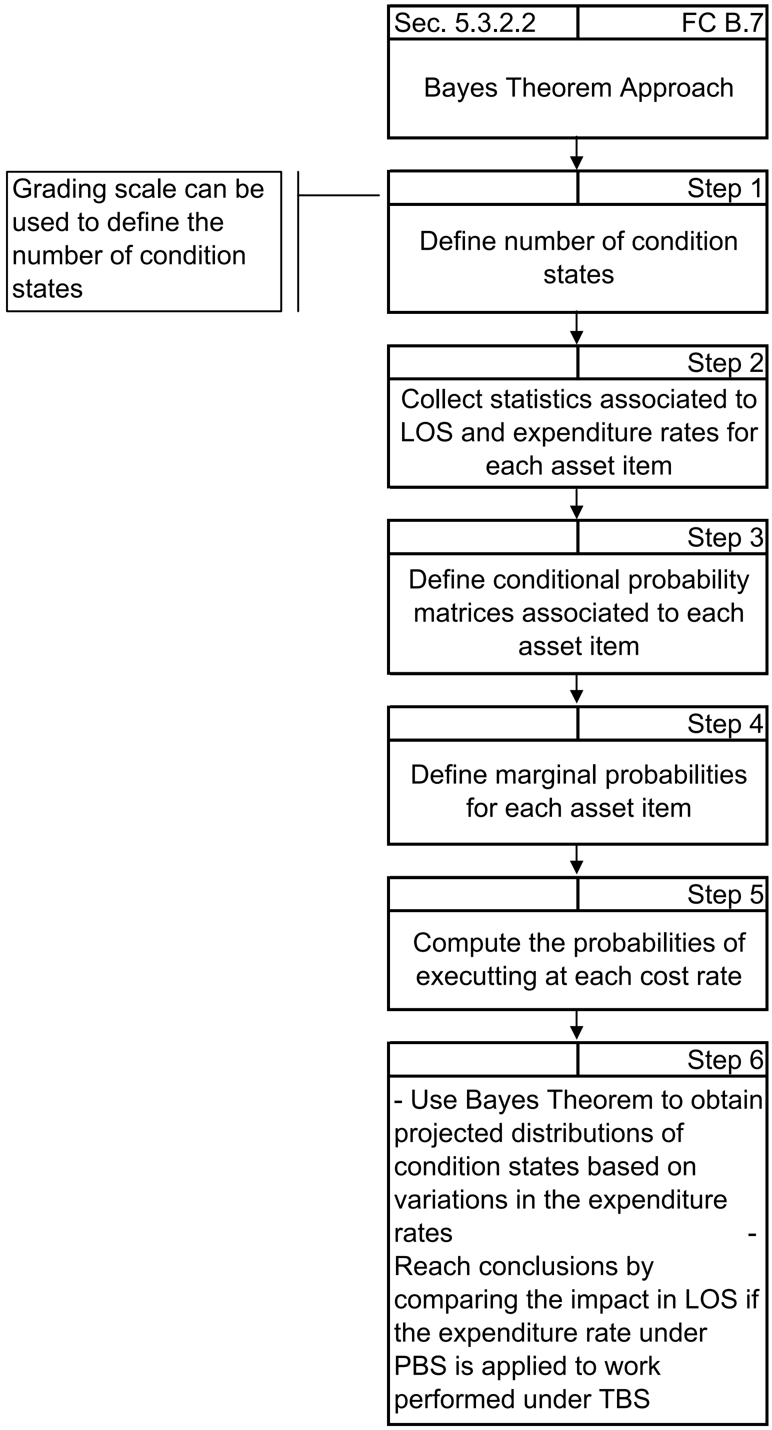
Flowchart B.4. Report Card Generation



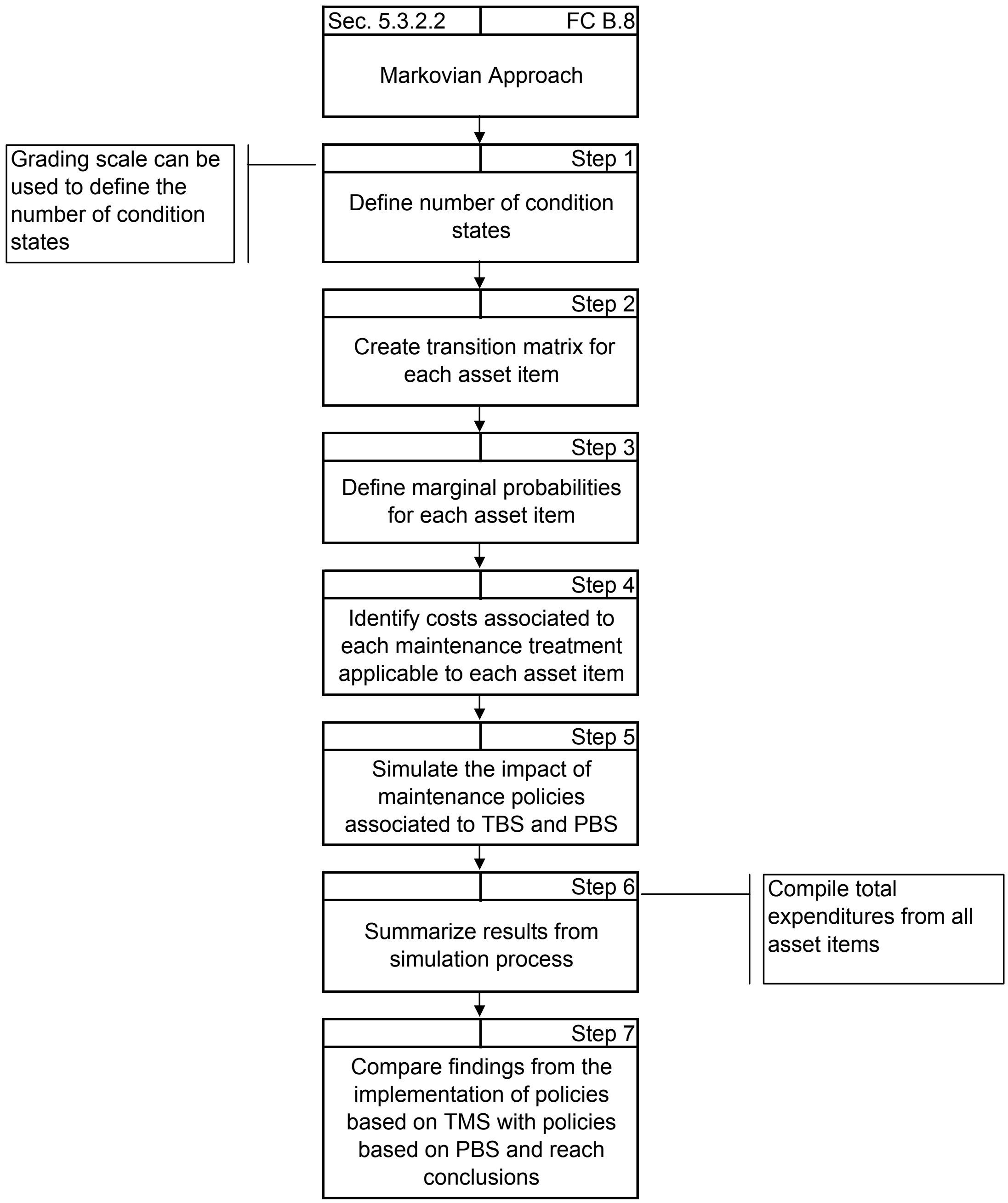
Flowchart B.5. Distribution Approach for Cost Efficiency Evaluation



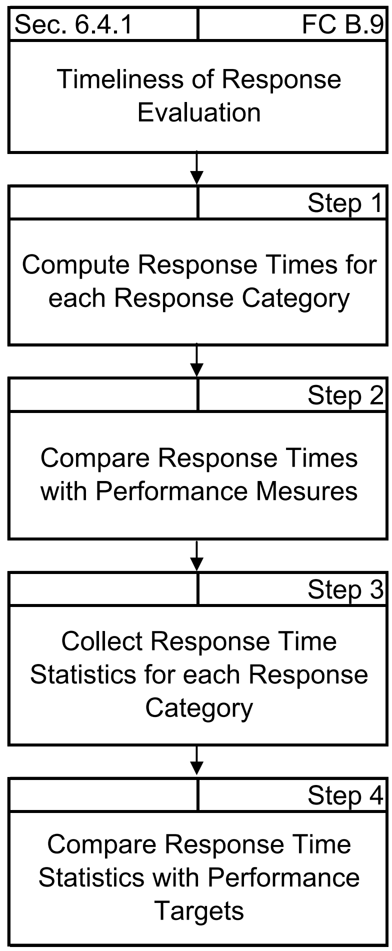
Flowchart B.6. Regression Approach for Cost Efficiency Evaluation



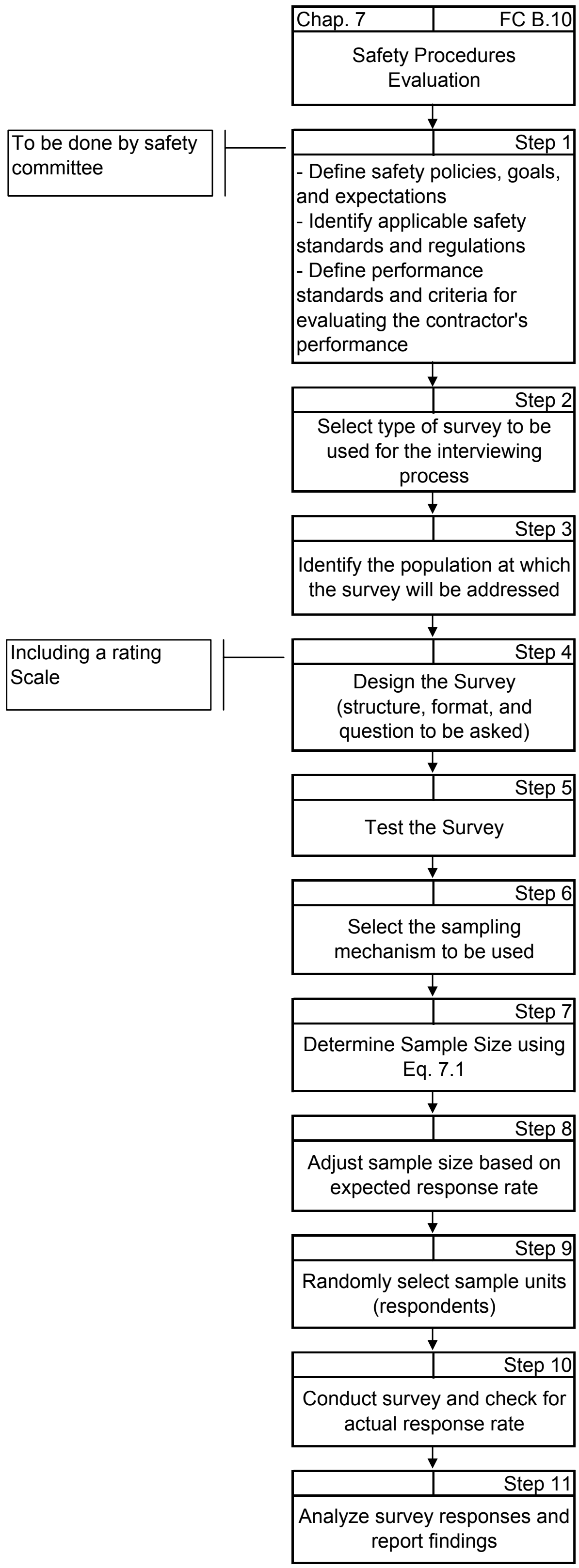
Flowchart B.7. Bayes Theorem Approach for Cost Efficiency Evaluation



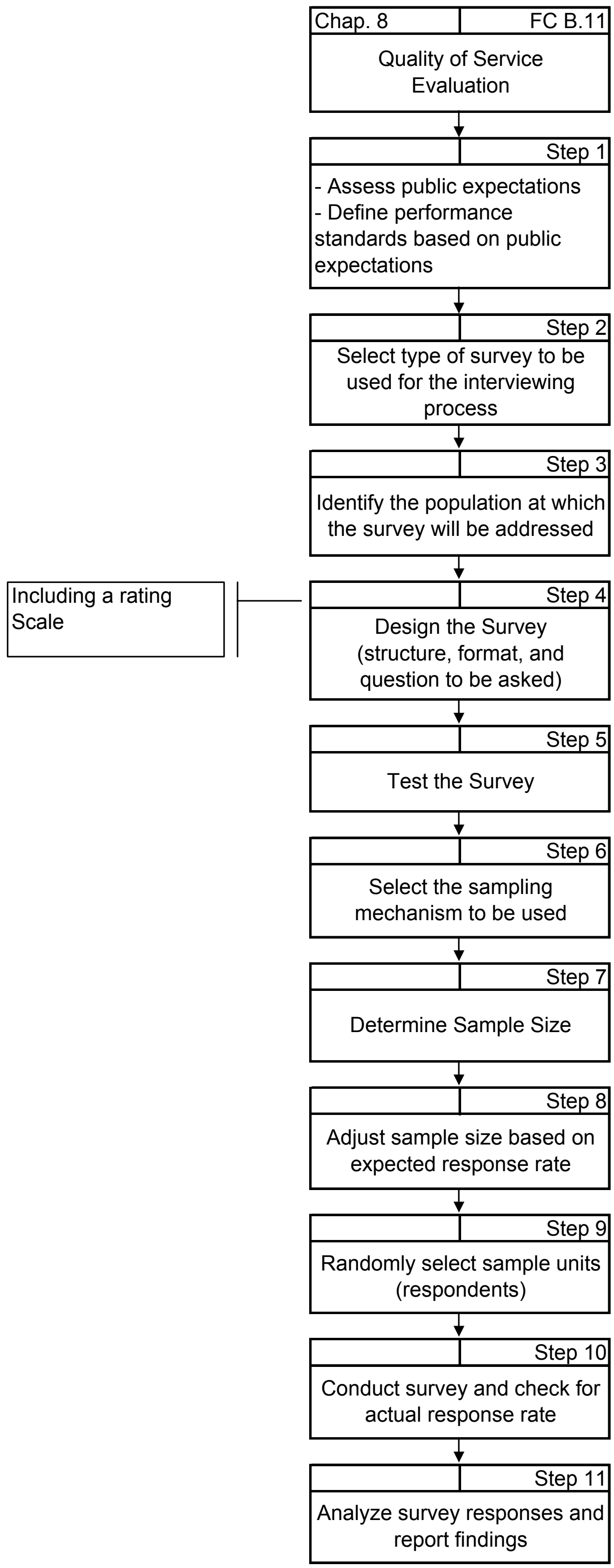
Flowchart B.8. Markovian Approach for Cost Efficiency Evaluation



Flowchart B.9. Timeliness of Response Evaluation



Flowchart B.10. Proposed Methodology to evaluate Safety Procedures in PBRM initiatives



Flowchart B.11. Quality of Service Evaluation

APPENDIX C

REVIEW OF BASIC COST CONCEPTS

This appendix presents an overview of the typical cost components that are normally present when agencies maintain roadway system as well as when the job is contracted out. Historical unit and bid prices are normally determined by combining some of these cost components in the cost estimate. The applicability and combination of these components, depending on how the work is performed, are also addressed in this appendix. The main objective for conducting this review is to assure that evaluators understand the characteristics of the data (i.e., consistency, accuracy, and proper format) required to implement the methodologies proposed in Chapter five.

Review of Basic Cost Concepts

According to Bartholomew 2000, cost components in an estimate can be summarized in two directions: horizontal and vertical. Horizontal costs are broken down into multiple components such as labor, materials, and equipment. On the other hand, the vertical format refers to the breakdown the scope of the work. The applicability of the different types of cost components will be determined based on whether the work is self-performed or contracted out. A detailed discussion of the cost components applicable to each one of these scenarios follows.

C.1) ***Self-Performed Work*.** The typical cost components which characterize the work that is self-performed by agency crews are summarized in Figure C.1. In this figure, the cost components have been structured in both horizontal and vertical direction as suggested by Bartholomew (2000). A detailed description of each one of these cost components follows.

C.1.1) ***Cost Components in Horizontal Direction*.**

The objective of splitting the costs horizontally is to provide more insight into the nature of the total costs as well as unit costs associated with a particular work activity. Notice from Figure C.1 that there are four major categories (columns 7, 11, 14, and 15) that define the total item cost. These are: labor, equipment, material, and sub-contracts. Some of these categories can be broken down into sub-components, such as materials which can be classified as permanent or expendable. A detailed description of these categories as well as the sub-components within each one of them is presented next.

i) Labor Costs. Labor costs cover the salary and associated contributions for all workers. Labor costs are generally represented by an average hourly cost rate that is then multiplied by an estimated or required number of hours to arrive at the total labor cost for a particular work activity (column 7 in Figure C.1). The hourly average labor rates are computed based on the following components (Patrausu 1988, Peurifoy & Oberlender 1989, Clark &Lorenzoni 1997, Milliner et al. 1999):

1) *Direct Wages.* Direct wages are the amount of money paid directly to employees as a result of the hours worked in a standard work period (e.g., 40 hours per week). This cost category also includes any withholdings, such as Social Security.

2) *Shift Pay Differentials.* When workers worked on shifts other than the normal day shift an additional compensation or payment is made in recognition of the disadvantage or inconvenience. The shift pay differential can be specified with an add-on to the basic wage rate or can also be specified by paying more hours than the ones worked by the employee.

3) *Overtime Premium.* The overtime premium basically covers the additional payments made as a result of overtime worked. The additional payment for overtime work is normally specified based on a percentage of the premium paid for the normal shift. For instance, if an employee worked 40 hours in a regular weekly shift and 4 additional hours over those 40 hours, then the employee will receive a payment for the 40 hours and an additional payment for the 4 hours at maybe one and a half or double the rate at which the normal 40 hours were paid.

4) *Fringe Wages.* In addition to the compensation made to the employee for the total number of hours worked (sum of direct wages, shift differential, and overtime premium), the employer may also provide other benefits to the employees, such as vacations, health and welfare, and pensions. These additional expenses to the employer are normally added to the final hourly wage rate. It is common to express these additional expenses as a percentage of the hourly wage rate. The addition of these fringes can easily increase direct wages by 15% to 20%.

5) *Subsistence Expenses.* Subsistence expenses are normally paid to workers performing jobs in remote areas. These expenses are accrued by the employer as a result of compensation made to the employee to cover housing, food, and transportation expenses. In some projects, these expenses can be very high, which will obviously be reflected in the final adjusted hour wages.

Description	Unit	Qty.	Crew								Materials			Sub-Contracts	Total Costs	Distribution	Total Distributed Costs	Unit Costs
			Labor				Equipment											
			Direct Wages	Fringe Wages	Others	Total	Oper. Exp.	Repair & Lab. Ser.	Rentals	Total	Permanent	Expendable	Total					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(1) Direct Costs																		
Item # 1			$	$	$	$$	$	$	$	$$	$	$	$$	$	$$	DF 1	TDC 1	**UC 1**
Item # 2			$	$	$	$$	$	$	$	$$	$	$	$$	$	$$	DF 2	TDC 2	**UC 2**
Item # 3			$	$	$	$$	$	$	$	$$	$	$	$$	$	$$	DF 3	TDC 3	**UC 3**
Item # 4			$	$	$	$$	$	$	$	$$	$	$	$$	$	$$	DF 4	TDC 4	**UC 4**
Total Direct Costs			$$	$$	$$	$$$	$$	$$	$$	$$$	$$	$$	$$$	$$	$$$	**DF**	**TDC**	
(2) Indirect Costs																		
Salaried Payroll			$	$	$	$$	$	$	$	$$					$$			
Project Overhead						$$				$$		$	$$	$	$$			
Insurance										$$					$$			
Mobilization			$	$	$	$$	$	$	$	$$		$	$$	$	$$			
Total Indirect Costs			$$	$$	$$	$$$	$$	$$	$$	$$$		$$	$$$	$$	**$$$**			
(3) Other Costs																		
Escalation																		
Labor Escalation			$	$	$	$$									$$			
Equip. Escalation							$		$	$$					$$			
Mat. Escalation											$	$	$$		$$			
Contingency																		
Labor Contingency						$$									$$			
Equip. Contingency										$$					$$			
Mat. Contingency												$	$$		$$			
Total Other Costs			$$	$$	$$	$$$	$$	$$	$$	$$$		$$	$$$		**$$$**			
(4) Mark-Up																		
Risk Coverage															$$			
Office O&AE															$$			
Total Mark-Up Costs															**$$$**			
TOTAL COST															**$$$$**			

Figure C.1. Cost Components when Work is Performed by the Agency

6) *Payroll Contributions.* This component refers to any additional contribution or expenses related to payroll the government may accrue as a result of any federal or state law. For instance, in the United States it is required according to the Federal Insurance Contribution Act (FICA) that all workers must pay Social Security from a portion of their salaries. In addition, FICA also requires the employer to pay matching dollars for the Social Security of the employee based on each dollar earned up to a certain level. These kinds of contributions are normally expressed as a percentage of the direct wages of the employee. They can easily amount to 12-15% of the "base" or direct pay.

7) *Payroll Insurance.* Insurance contributions are normally required to all employers. These contributions must be also considered when computing the final labor wages. In the United States, there are commonly three types of labor-related insurances: (1) worker's compensation and employer's liability insurance, (2) unemployment insurance, and (3) third-party liability insurance. The purpose of worker's compensation insurance is to reimburse the worker for injuries accrued in the course of employment. The rates paid for worker's compensation insurance are proportional to the risk associated with the work activity. With respect to unemployment insurance, the contribution is used to pay benefits to workers who are temporarily out of work for a reason out of their own control. Finally, the objective of third-party liability insurance is to cover any expenses related to damages to properties or injuries to persons as a result of accidents that occur on the job. The combination of these insurances must be included as part of the total labor rate.

ii) *Equipment.* Most work activities require or involve the use of equipment. There is no doubt that if equipment is needed to perform a job, costs will be associated. There are many different costs incurred when equipment is used and these must be considered when computing or estimating the appropriate equipment cost rates. A description of the many cost components that may dictate the final equipment cost for a particular work follows. These are grouped in three categories: operating, owning, and rental expenses (Halpin 1985, Bartolomew 2000).

a) *Operating Expenses.* Operating expenses represent the costs required to maintain the equipment. There are four major areas in which the operating costs can be classified. These are:

• Fuel, Oil, and Grease. This category basically covers all the cost associated with the fuel consumption, oil changes, lubrication oil, hydraulic fluids, and heavy grease required to keep the engines, motors, and other equipment working properly. The amount of money required to cover these expenses will depend on many factors, such as: the equipment usage, environment (e.g., terrain, climate), and age and type of equipment, among others.

• *Repair and Service*. This cost category covers the cost for replacement of parts and labor required to keep the equipment working in good condition. This type of cost is sometimes classified in two areas: (1) running, and (2) major overhauls. One can refer to running costs as those in which typical or small replacement of parts is required, whereas major overhauls are the ones that required rebuilding of equipment parts. These costs vary considerably with the type of equipment and the type of work or service for which it is used. It is reasonable to assume that as more severe the operating conditions and the more hours the equipment has been used, the higher the expected repair and service costs, and thus higher the rate which should be added to the total equipment cost to cover these expenses.

• *Tires.* Many types of equipment use pneumatic tires, which have a life span significantly less than that of the equipment. This will require investing in new tires several times throughout the life of the equipment. For some equipment, the cost of new tires can be significantly high. For this reason, this cost must be included as part of the total equipment cost. Similar to the repairs and service, the frequency of expenditures in new tires will totally depend on factors such as the hours of operation and the working environment.

• *Third-Party Service Costs.* These expenses apply when other parties have been engaged by the agency to assist in equipment maintenance and repairs. These services may include the on-site repair of equipment as well as rebuilding equipments. In some cases, the contractual agreement specifies the work provided to be all-inclusive (labor and parts). In addition, overhead and profit will be included in the service costs provided by a third party.

b) *Owning Expenses.* If the agency uses its own equipment, then several expenses must be considered when establishing equipment ownership rates. Two common scenarios will dictate the amount and type of expenses considered in the determination of the appropriate equipment ownership rates. The first scenario is when the equipment is acquired by the agency only to perform the job required for a specific project, and the equipment is sold after the work is completed. If this is the case, then the equipment expenses that will be considered in the rate calculation will be the depreciation of the equipment during the duration of the work to be done or, even more precisely the time when the contractor owned the equipment. On the other hand, in the predominant scenario where in-house units are used, an equipment ownership rate will be charged to the job as if the equipment is rented to a third-party.

c) *Rental Expenses.* The use of equipment can be secured through: purchase or rental. The scenarios associated with the purchase or ownership of equipment were addressed in the previous point. However, if the equipment is rented by the agency from a third-party, then the equipment rate will be according to the terms established in the rental agreement. Rental agreements vary. Some include all the costs associated with the work or the service to be provided, whereas others may only require the contractor to be responsible for certain costs and certain types of repairs and services. As previously mentioned, these rental rates also include the overhead and profit of the contracted party.

iii) Permanent Materials. This cost component basically represents all the costs associated with the materials required to remain permanently part of the project (Patrascu 1988). As a general rule of thumb, the permanent materials are the ones specified in the detailed drawings for the work required. Some examples of these types of materials are: concrete, asphalt, and guardrails.

iv) Expendable Materials. In addition to permanent materials, some additional materials are required that will not remain permanently in the project but are required to perform the construction or maintenance of a particular item. Typical examples of this are those materials required for concrete formwork and temporary structures, among others. Given the fact that expendable materials are required consumables they must be considered as part of the expenses associated with the materials component.

v) Subcontracts. It is very common for the agency to subcontract various parts of the work to be done. When this happens, the subcontractor becomes responsible for providing all materials, equipment, and personnel required to perform all the work described in the contractual agreement. It is important to clearly understand the amount of money paid by the agency to the subcontractor, for the job done conceptually represents all the cost, components previously described plus the subcontractor's overhead and profit. In other words, all the elements that define the final total cost are included in the subcontract column (column 15) presented in Figure C.1.

C.1.2) **Cost Components in Vertical Direction.**

As previously stated, the vertical distribution of costs basically represents the scope of the work as well as additional costs that need to be considered to determine the actual total cost for performing the job. Figure C.1 shows four major categories that define the distinct parts of the final project cost. These are: direct costs, indirect costs, other costs (escalation and contingencies), and markup. A detailed description of these cost categories is presented next. After describing these cost categories, the issue of distributing indirect costs, other costs, and markup costs to the direct cost, with the objective of obtaining the unit cost, will be addressed.

i) Direct Costs. Direct costs are those costs required to physically complete the job. These costs can be directly related to the physical elements or work activities of the project. They are normally broken down into categories such as labor, equipment, material, and subcontracts. A detailed description of the cost components associated with each category was previously discussed.

ii) Indirect Costs. The indirect costs represent the costs that cannot be easily associated with the physical elements of the project (Cash 2001). These costs pertain to the direct supervision and control of the job. In general, these are all the costs associated with maintaining a field supervisory staff on site. The indirect costs can be classified in one of the following three categories:

1) Salaried Payroll. This category basically accounts for the costs related to the salaries, insurance, and benefits paid to all employees other than hourly paid personnel, such as engineers, superintendents, supervisors, administrative personnel, and safety personnel, among others.

2) Job Overhead. The overhead expenses refer to costs for supporting the field office facilities such as office rentals, maintenance of trailers on site, site-related telephone and utility bills, outside provided services (e.g., engineering and surveying expenses, security), office consumables, office furniture, and safety equipment.

3) Insurance. The kind of insurance premiums included in this category are related to the equipment floater insurance, any liability and property insurance, and any non-labor related insurance premium needed for the job.

4) Mobilization. This category basically refers to the expenses associated with the mobilization of equipment to the site such as the freight, unloading, and erection costs. Depending on the amount of equipment needed for the job, these expenses can make a significant difference on the final total cost of the job.

iii) Escalation. The third main category presented in the vertical distribution of Figure C.1 is the escalation cost. The escalation costs need to be included as part of the total cost of the job if the job is extended for a long period of time. The objective is to account for costs variations due to factors such as inflation and major expected changes in the economy. These types of expenses, as shown in Figure C.1, are handled separately in the estimate by adding them as a separate item. The kind of costs normally subjected to escalation are: labor, permanent and expendable materials, equipment operating expenses, and, in many cases, the sub-contractor's bid prices. To properly estimate the escalation amount, all the direct and indirect costs must be identified and allocated to discrete periods of time. This will allow identification of the various points in time in which escalation is expected to occur. Normally, the escalation amount is computed based on a percentage of the direct and indirect costs allocated for the corresponding period of time.

Table C.1 gives a better understanding of this concept. In this example, the job was in progress for three years, and only the materials have been subjected to some escalation. The materials costs were estimated to increase 3% every six months. In Table C.1, an escalation cost was computed by multiplying the original estimated costs for materials with the escalation factor corresponding to each period of time (every six months). In this example, the total cost increased by $130,475 from its base estimate because of the expected increase in materials costs throughout the duration of the job.

Table C.1. Escalation Example

Description	Total Cost	Year 1		Year 2		Year 3	
		First Period	Second Period	First Period	Second Period	First Period	Second Period
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Materials	$1,475,000	$75,000	$200,000	$350,000	$275,000	$425,000	$150,000
Escalation Factor	-	0.00	0.03	0.061[(1)]	0.093[(2)]	0.126[(3)]	0.160[(4)]
Escalation Cost	**$130,475**	$0	$6,000	$21,350	$25,575	$53,550	$24,000
Total Cost	$1,605,475	$75,000	$206,000	$371,350	$300,575	$478,550	$174,000

[(1)] (1.03)(1.03)-1.0 = 0.061

[(2)] (1.061)(1.03)-1.0 = 0.093

[(3)] (1.093)(1.03)-1.0 = 0.126

[(4)] (1.126)(1.03)-1.0 = 0.160

iv) Contingency Allowances. There are many uncertainties when performing a job. For this reason, it is common to include extra money in the estimate to cover costs related to any adverse event that may occur while conducting the work. Some examples are: unfavorable site conditions, productivity problems, and the subcontractor's soft prices, among others. The amount of money added to cover contingencies normally relies on the estimator's personal judgment.

v) Markup. Markup is the amount of money added over the direct, indirect, escalation, and contingency costs to cover additional expenses the agency may have, such as office general and administrative expenses and additional risk coverage. The general administrative expenses relate to the costs of salaries, office rent and maintenance, property depreciation, transportation, utilities, insurance, and other agency expenses not chargeable to a specific job. In addition, an extra allowance is commonly included in the cost estimate to cover any risk the agency foresees such as potential change orders. An extra component that is also added to the markup is the profit. However, when the agency performs the job this component is not included since it is a public agency or a non-profit organization. The profit is only considered in the portions of the work that are sub-contracted.

There are several methods normally used for markup determination. The three most common methods are: (1) percentage of total cost, (2) percentage of labor exposure, and (3) the broad-based method. In the first method, percentage of total cost, the markup is calculated by taking a percentage of the total estimated cost. This method is probably the simplest. In the percentage labor exposure method, the markup is computed by applying a percentage to the total labor cost (including direct, indirect, escalation, and contingency costs). The last method for markup determination, the broad-based, is probably the most complex among the three methods, since it considers all the cost elements. The general approach in this method is to determine the markup by applying different percentages to the total labor cost, the expendable materials, the permanent materials, and the subcontractors to finally get an allowance to cover these expenses.

C.1.3) ***Distribution of Overhead to Obtain Unit Costs.***

Since unit costs are determined for each item identified in the project, then a distribution of the costs not directly related to those items is required before computing the unit prices (Ostawld 2001). In other words, the indirect, escalation, contingency, and markup costs must be added together and then distributed to the direct costs computed for each item (items 1, 2, 3, and 4 in Figure C.1). This procedure is illustrated in columns 17, 18, and 19 of Figure C.1. Two methods are commonly used to distribute indirect costs to the direct cost. The two methods are: (1) distribution based on total direct costs, and (2) distribution based on estimated direct labor costs. When the distribution is done based on the total direct costs, the indirect costs are distributed to the items based on the ratio of the total direct cost for each item to the total direct costs (all items included). For instance, the distribution factor for Item 1 (*DF 1*) presented in column 17 of Figure C.1 will be computed as: *DF1 = (Total direct cost for Item 1)/(Total direct cost)*. This factor is then multiplied by the sum of the indirect costs and then this quantity is finally added to the total direct cost for Item 1 to obtain the final total distributed cost for Item 1 (column 18), which is the quantity used to compute the unit costs (column 19). The other approach - distribution based on estimated direct labor costs - is slightly different from the previous one. The most significant difference is that now the distribution of the indirect costs will be made only to the items that contain labor costs. In other words, the distribution for any item not containing labor costs will be zero, whereas for any item containing labor cost the distribution will be made based on the ratio of the estimated direct labor for each item to the total direct cost. In addition to these methods, other adjustments may be made while computing the distribution factors. For instance, assume that while conducting the estimate, the estimator notices some suspicious items which may contain errors in quantities or maybe can be eliminated later on from the scope of the work. If there is a high probability any of these scenarios can take place, then one may consider not distributing indirect cost to these items.

C.2) ***Contracted Work*****.**

As previously mentioned, transportation agencies frequently engage the private contractors to perform different maintenance activities that the agency performs. When the agency contracts a private entity, the way in which unit prices are calculated varies significantly. Figure C.2 depicts the way in which unit prices are obtained when the job is contracted out by the agency. A detailed description of the elements presented in Figure C.2 follows.

Description (1)	Unit (2)	Qty. (3)	Sub-Contractor Unit Price (4)	Total Price (5)	Distribution (6)	Total Distributed Price (7)	Adjusted Unit Price (8)
(1) Direct Costs							
Bid Item # 1			$	$$	DF 1	TDP 1	**UP 1**
Bid Item # 2			$	$$	DF 2	TDP 2	**UP 2**
Bid Item # 3			$	$$	DF 3	TDP 3	**UP 3**
Bid Item # 4			$	$$	DF 4	TDP 4	**UP 4**
Total Price				$$$	**DF**	**TDP**	
(2) Agency Overhead				**$$$**			
TOTAL COST TO AGENCY				**$$$$**			

Figure C.2. Cost Components when Work is Contracted Out

C.2.1) ***Horizontal and Vertical Cost Components.***

Comparing the horizontal cost breakdown when the work is contracted out (*Figure C.2*) with the scenario when the agency performs the work (*Figure C.1*) shows how the process of obtaining the unit prices for each item is greatly simplified by switching the responsibility of performing the job to the contractor. Thus, the contractor will perform the complete estimate of labor costs, materials, and equipment required to complete the job described in the contractual agreement. The unit prices also contain extra amounts to cover expenses such as payroll taxes, union fringes, and additional corporate benefits to employees, bond premiums, and interests. The methods previously discussed for work performed by the agency are also commonly used by private contractors to estimate the final bid prices.

C.2.2) Distribution of Additional Overhead to Obtain Adjusted Unit Prices. In Figure C.2, all costs are included in the unit prices or the bid prices submitted by the contractor, but there are additional agency costs that must be considered when determining the final total cost of the job. These costs are basically the previously described agency overhead and supervision costs. In some instances, (e.g., budget allocation) it may be desirable to distribute the agency overhead to the bid item unit prices (column 8) in Table C.2 to get unit prices that will be representative of the final bid item cost when the work is contracted out. However, in other cases it is desirable to use the unit prices from the contractor and then later on apply the estimated agency overhead directly to the total estimated cost of the job. No matter which method is used, the important point is that there are additional costs which need to be taken into consideration even when the job is contracted out to a private contractor.

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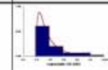
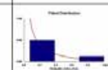
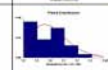
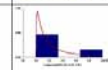
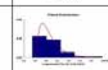
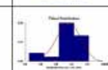
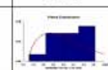
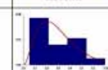
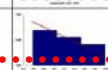
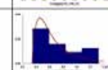
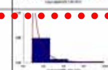
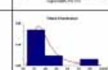
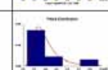
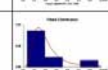
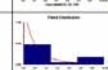
APPENDIX D

COST STUDY RECORDS

The information included in this appendix supports the Cost Study presented in Chapter9. It includes a list of the contract bid items from VMS's database for which distributions were generate using historical unit prices from traditional maintenance specifications. A total of 415 items are listed in this Appendix with their corresponding distribution.

Table D.1. Records used to generate the findings in the Cost Study

DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
12RC9940	1999	1	14260	#26 Aggregate (Crusher Run)	TN	25	$10.00	$ 250.00	Y-D-Q	ALL	1993-2001	25	ALL	39		Lognormal (9,2.02,0.983)	$ 21.62	$540.58
12RC9940	1999	1	10090	Aggregate Base Material No. 21A	TN	50	$16.00	$ 800.00	Y-D-Q	ALL	1993-2001	50	20%	10		Weibull (7,0.853,25.6)	$ 36.37	$1,818.72
013E00003	2000	1,2	13345	Alt. Breakway Cable Terminal, GR-9	EA	2	$1,800.00	$ 3,600.00	D-Q-Y	1,2	2000	2	5%	33		Weibull (1800,1.81,246)	$ 1,939.76	$3,879.53
11RC9831	1999	5,6	13345	Alt. Breakway Cable Terminal, GR-9	EA	1	$2,000.00	$ 2,000.00	D-Y-Q	4,5,6,7,9	1999	1	5%	12		Lognormal (2000,5.19,1.47)	$ 2,490.34	$2,490.34
12U090	2000	1	13345	Alt. Breakway Cable Terminal, GR-9	EA	1	$2,000.00	$ 2,000.00	D-Y-Q	1,2,3,8	2000	1	5%	42		Lognormal (1750,5.59,0.625)	$ 2,080.65	$2,080.65
12U099	1999	1	1999	Alt. Breakway Cable Terminal, GR-9	EA	1	$2,000.00	$ 2,000.00	D-Y-Q	1,2	1999	1	5%	18		Weibull (1650,3.76,561)	$ 1,803.14	$1,803.14
13U109	1999	1,2	13345	Alt. Breakway Cable Terminal, GR-9	EA	2	$1,800.00	$ 3,600.00	D-Q-Y	1,2	1999	2	5%	14		Weibull (1310,1.51,854)	$ 1,867.39	$3,734.77
12P148	1998	1	10592	Asphalt Concrete (BM-2)	TN	13738	$39.50	$ 542,651.00	Q-D-Y	1	1998	13738	20%	15		Gamma (26,2.97,1.01)	$ 29.03	$398,846.17
12RC9940	1999	1	10592	Asphalt Concrete (BM-2)	TN	32	$75.00	$ 2,400.00	D-Y-Q	ALL	1994-2001	32	5%	12		Triangular (57,240,57)	$ 117.67	$3,765.41
12P219	1999	1	10583	Asphalt Concrete (SM-2A)	TN	162.15	$150.00	$ 24,322.50	D-Y-Q	ALL	1997-2001	162.15	5%	21		Log-Logistic (34,1.64,26.7)	$ 82.52	$13,381.07
12RC9940	1999	1	10583	Asphalt Concrete (SM-2A)	TN	16	$75.00	$ 1,200.00	D-Y-Q	ALL	1993-2001	16	10%	25		Lognormal (85,4.15,1.17)	$ 208.81	$3,341.01
012A00025	2000	1	10500	Asphalt Concrete (SM-2D)	TN	38341.62	$36.98	$ 1,417,873.11	Q-Y-D	1,2	1993-2001	38341.62	ALL	16		Log-Logistic (31,2.6,7.99)	$ 41.17	$1,578,698.20
012A99057	1999	1	10500	Asphalt Concrete (SM-2D)	TN	17400	$42.10	$ 732,540.00	Q-Y-D	1,2	1993-2001	17400	ALL	16		Log-Logistic (31,2.6,7.99)	$ 41.72	$725,921.87
12P219	1999	1	10500	Asphalt Concrete (SM-2D)	TN	60112	$36.98	$ 2,222,941.76	Q-Y-D	1,2	1993-2001	60112	ALL	16		Log-Logistic (31,2.6,7.99)	$ 40.99	$2,464,263.47
11P209	1999	5,6	10502	Asphalt Concrete (SM-2E)	TN	36032	$41.60	$ 1,498,931.20	Q-D-Y	4,5,6,8,9	1999	36032	ALL	12		Log-Logistic (28,1.16,2.01)	$ 33.82	$1,218,533.68

Example in Figure 9.23

Table D.1 (continue). Records used to generat e the findings in the Cost Study

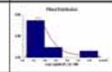
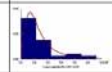
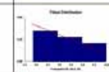
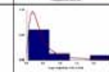
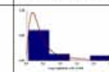
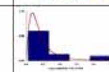
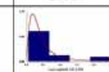
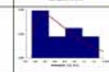
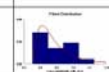
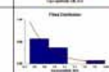
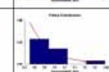
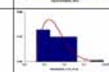
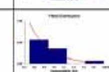
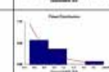
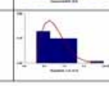
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11B489	1999	5,6	68258	Asphalt Concrete Overlay Removal	SY	16	$150.00	$ 2,400.00	Q-Y-D	5,6	1999	16	5%	12		Lognormal (3,1.7,0.945)	$ 11.68	$186.81
11P209	1999	5,6	16303	Asphalt Overlay (SM-2C)	TN	2000	$35.00	$ 70,000.00	Y-D-Q	ALL	1993-2001	2000	10%	42		Log-Logistic (25,2.07,5.72)	$ 33.26	$66,519.20
11SF99002	1999	5,6	68258	Asphalt Overlay (SM-2C)	TN	810	$65.00	$ 52,650.00	D-Y-Q	ALL	1993-2001	810	250%	12		Triangular (28,68.8,28)	$ 41.65	$33,735.21
011B00002	1999	5,6	23517	Barbed Wire (FE-W1, FE-W2, FE-B)	LF	200	$2.00	$ 400.00	D-Y-Q	ALL	1993-2001	200	ALL	26		Log-Logistic (0,1.87,0.334)	$ 0.56	$112.24
012B00003	2000	1	23517	Barbed Wire (FE-W1, FE-W2, FE-B)	LF	1250	$0.27	$ 337.50	D-Y-Q	ALL	1993-2001	1250	ALL	26		Log-Logistic (0,1.87,0.334)	$ 0.52	$651.07
12B0002	2000	1	23517	Barbed Wire (FE-W1, FE-W2, FE-B)	LF	2500	$0.27	$ 675.00	D-Y-Q	ALL	1993-2001	2500	ALL	26		Log-Logistic (0,1.87,0.334)	$ 0.54	$1,342.67
13B0002	2000	1,2	23517	Barbed Wire (FE-W1, FE-W2, FE-B)	LF	2500	$0.27	$ 675.00	D-Y-Q	ALL	1993-2001	2500	ALL	26		Log-Logistic (0,1.87,0.334)	$ 0.54	$1,340.55
012A00025	2000	1	16500	Base Repair--Surface Preparation and Restoration, Type I or II	TN	420	$150.00	$ 63,000.00	Y-Q-D	1,2,3,8	1993-2001	420	ALL	28		Weibull (56,1.33,36.2)	$ 83.24	$34,962.35
012A00025	2000	1	16504	Base Repair--Surface Preparation and Restoration, Type III	TN	1500	$100.50	$ 150,750.00	Y-Q-D	1,2,3,8	1993-2001	1500	ALL	14		Log-Logistic (50,1.86,22.7)	$ 93.09	$139,639.96
011E00002	2000	5,6	17348	Breakaway Post, GR-7	EA	3	$75.00	$ 225.00	Q-Y-D	5,6	1996-2001	3	ALL	14		Exponential (50,38.9)	$ 89.80	$269.40
011E00003	2000	5,6	17348	Breakaway Post, GR-7	EA	3	$75.00	$ 225.00	Q-Y-D	5,6	1996-2001	3	ALL	14		Exponential (50,38.9)	$ 90.12	$270.35
013E00003	2000	5,6	17348	Breakaway Post, GR-7	EA	22	$30.00	$ 660.00	Y-D-Q	ALL	1993-2001	22	10%	57		Weibull (30,1.74,52.4)	$ 60.97	$1,341.38
11RC9831	1999	5,6	17348	Breakaway Post, GR-7	EA	5	$30.00	$ 150.00	Q-Y-D	5,6	1996-2001	5	ALL	14		Exponential (50,38.9)	$ 89.98	$449.89
11U069	1999	5,6	17348	Breakaway Post, GR-7	EA	15	$75.00	$ 1,125.00	Q-Y-D	5,6	1996-2001	15	ALL	14		Exponential (50,38.9)	$ 89.48	$1,342.19
13U109	1999	1,2	17348	Breakaway Post, GR-7	EA	22	$30.00	$ 660.00	Y-D-Q	ALL	1993-2001	22	10%	57		Weibull (30,1.74,52.4)	$ 61.33	$1,349.23

Table D.1 (continue). Records used to generate the findings in the Cost Study

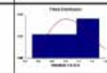
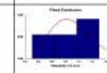
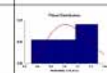
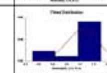
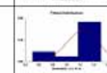
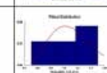
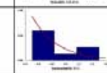
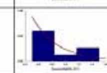
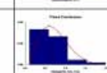
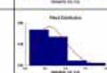
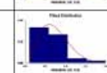
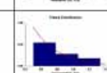
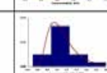
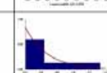
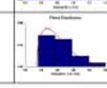
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011E00002	2000	5,6	17346	Buffered End Assembly (GR-7)	EA	4	$50.00	$ 200.00	Q-D-Y	4,5,6,7,9	2000	4	ALL	11		Weibull (50,2.19,67.5)	$ 80.85	$323.42
011E00003	2000	5,6	17346	Buffered End Assembly (GR-7)	EA	4	$50.00	$ 200.00	Q-D-Y	4,5,6,7,9	2000	4	ALL	11		Weibull (50,2.19,67.5)	$ 81.15	$324.58
013E00003	2000	1,2	17346	Buffered End Assembly (GR-7)	EA	10	$100.00	$ 1,000.00	D-Q-Y	ALL	2000	10	ALL	11		Weibull (50,2.19,67.5)	$ 81.46	$814.61
11RC9831	1999	5,6	17346	Buffered End Assembly (GR-7)	EA	3	$100.00	$ 300.00	Q-D-Y	4,5,6,7,9	1999	3	ALL	11		Weibull (50,3.73,81.5)	$ 72.46	$217.39
11U069	1999	5,6	17346	Buffered End Assembly (GR-7)	EA	30	$130.00	$ 3,900.00	Q-D-Y	4,5,6,7,9	1999	30	ALL	11		Weibull (50,3.73,81.5)	$ 71.00	$2,129.86
12U090	2000	1	17346	Buffered End Assembly (GR-7)	EA	5	$100.00	$ 500.00	Q-D-Y	ALL	2000	5	ALL	11		Weibull (50,2.19,67.5)	$ 81.72	$408.59
12U099	1999	1	17346	Buffered End Assembly (GR-7)	EA	5	$100.00	$ 500.00	Q-D-Y	ALL	1999	5	ALL	15		Exponential (50,37.7)	$ 88.17	$440.87
13U109	1999	1,2	17346	Buffered End Assembly (GR-7)	EA	10	$100.00	$ 1,000.00	D-Q-Y	ALL	1999	10	ALL	15		Exponential (50,37.7)	$ 88.26	$882.60
011E00002	2000	5,6	17351	Cable Assembly and Anchor Plates, GR-7	EA	3	$150.00	$ 450.00	Q-D-Y	ALL	2000	3	ALL	30		Weibull (10,1.92,72.6)	$ 46.14	$138.41
011E00003	2000	5,6	17351	Cable Assembly and Anchor Plates, GR-7	EA	3	$150.00	$ 450.00	Q-D-Y	ALL	2000	3	ALL	30		Weibull (10,1.92,72.6)	$ 48.37	$145.12
013E00003	2000	1,2	17351	Cable Assembly and Anchor Plates, GR-7	EA	2	$100.00	$ 200.00	Q-D-Y	ALL	1999-2001	2	ALL	30		Weibull (10,1.92,72.6)	$ 47.93	$95.86
11RC9831	1999	5,6	17351	Cable Assembly and Anchor Plates, GR-7	EA	1	$100.00	$ 100.00	Q-D-Y	4,5,6,7,9	1999	1	ALL	11		Exponential (50,30.8)	$ 81.43	$81.43
11U069	1999	5,6	17351	Cable Assembly and Anchor Plates, GR-7	EA	15	$100.00	$ 1,500.00	D-Y-Q	ALL	1995-2001	15	5%	17		Lognormal (50,4.01,0.479)	$ 111.81	$1,677.15
13U109	1999	1,2	17351	Cable Assembly and Anchor Plates, GR-7	EA	2	$100.00	$ 200.00	Q-D-Y	ALL	1999	2	ALL	15		Gamma (40,1,27.6)	$ 67.92	$135.85
012C00010	2000	1	26117	Class A1 Rip Rap	SY	80	$50.00	$ 4,000.00	Y-D-Q	1,2,3,4,7,8	1993-2001	80	5%	21		Weibull (17,1.45,14.8)	$ 27.16	$2,172.47

Table D.1 (continue). Records used to generate the findings in the Cost Study

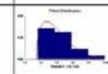
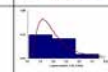
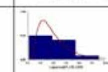
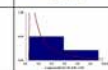
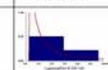
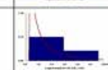
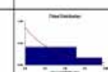
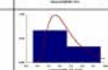
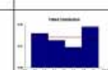
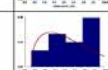
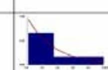
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS										
									QUERY INPUT					QUERY RESULTS					
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
012C00010	2000	1	26117	Class A1 Rip Rap	SY	80	$50.00	$ 4,000.00	Y-D-Q	1,2,3,4,7,8	1993-2001	80	5%	21		Weibull (17,1.45,14.8)	$ 27.72	$2,217.32
012C00011	2000	1	26117	Class A1 Rip Rap	SY	35	$50.00	$ 1,750.00	Y-D-Q	1,2,3,4,7,8	1993-2001	35	5%	12		Lognormal (21,2.81,0.652)	$ 41.10	$1,438.47
012C00011	2000	1	26117	Class A1 Rip Rap	SY	35	$50.00	$ 1,750.00	Y-D-Q	1,2,3,4,7,8	1993-2001	35	5%	12		Lognormal (21,2.81,0.652)	$ 41.17	$1,441.04
11B419	1999	5,6	69620	Cofferdams-Fountain Creek NBL	LS	1	$20,000.00	$ 20,000.00	Y-Q-D	5,6	1997-2001	1	5%	10		Lognormal (2500,8.97,1.55)	$ 27,021.93	$27,021.93
11B419	1999	5,6	69620	Cofferdams-Fountain Creek SBL	LS	1	$19,000.00	$ 19,000.00	Y-Q-D	5,6	1997-2001	1	5%	10		Lognormal (2500,8.97,1.55)	$ 27,206.78	$27,206.78
11B419	1999	5,6	69620	Cofferdams-Fountain Creek SBL	LS	1	$23,000.00	$ 23,000.00	Y-Q-D	5,6	1997-2001	1	5%	10		Lognormal (2500,8.97,1.55)	$ 26,157.93	$26,157.93
12B479	1999	1	26720	Concrete Block Slope Protection	SF	468	$20.00	$ 9,360.00	D-Y-Q	1	1999	468	5%	4	N/A	$41.92	$ 41.92	$19,616.91
13B469	1999	1,2	26720	Concrete Block Slope Protection	SF	260	$14.00	$ 3,640.00	D-Y-Q	1,2	1999	260	5%	4	N/A	$41.92	$ 41.92	$10,898.28
011B00002	1999	5,6	22663	Corner Brace Unit (FE-CL)	EA	5	$450.00	$ 2,250.00	D-Y-Q	ALL	1996-2001	5	5%	12		Exponential (100,74.2)	$ 175.85	$879.23
011B00002	1999	5,6	22581	Corner Brace Unit (FE-W1 or FE-W2)	EA	12	$350.00	$ 4,200.00	Y-D-Q	4,5,6,7	1993-2001	12	5%	12		Lognormal (80,4.87,0.535)	$ 230.67	$2,767.98
012B00003	2000	1	22581	Corner Brace Unit (FE-W1 or FE-W2)	EA	8	$135.00	$ 1,080.00	Y-D-Q	1	1997-2001	8	5%	12	N/A	$294.46	$ 294.46	$2,355.67
12B0002	2000	1	22581	Corner Brace Unit (FE-W1 or FE-W2)	EA	15	$135.00	$ 2,025.00	Y-D-Q	1,2	1993-2001	15	5%	18		Uniform (31,375)	$ 203.02	$3,045.28
13B0002	2000	1,2	22581	Corner Brace Unit (FE-W1 or FE-W2)	EA	15	$135.00	$ 2,025.00	Y-D-Q	1,2	1998-2001	15	5%	15		Weibull (31,1.43,225)	$ 196.71	$2,950.69
011H00005	1998	5,6	68155	Diaphragm Replacements	EA	2	$750.00	$ 1,500.00	D-Q-Y	ALL	1993-2001	2	ALL	6	N/A	1000	$ 1,000.00	$2,000.00
011D00016	2000	5,6	24281	Electronic Arrow	HR	20	$40.00	$ 800.00	Y-D-Q	ALL	1993-2001	20	5%	12		Exponential (1,17.2)	$ 18.12	$362.46

Table D.1 (continue). Records used to generate the findings in the Cost Study

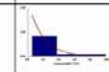
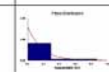
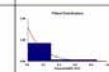
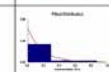
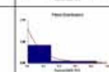
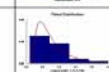
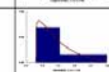
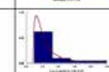
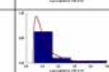
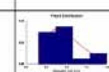
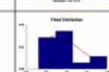
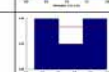
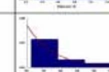
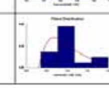
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011E00001	2000	5,6	24281	Electronic Arrow	HR	100	$15.00	$ 1,500.00	Y-D-Q	5,6	1999-2001	100	5%	12		Exponential (3,9.15)	$ 12.14	$1,213.78
011E00002	2000	5,6	24281	Electronic Arrow	HR	50	$10.00	$ 1,500.00	Y-D-Q	5,6	1999-2001	50	5%	12		Exponential (0,18.1)	$ 18.47	$923.52
011E00002	2000	5,6	24281	Electronic Arrow	HR	50	$10.00	$ 500.00	Y-D-Q	5,6	1999-2001	50	5%	12		Exponential (0,18.1)	$ 17.77	$888.30
011E00003	2000	5,6	24281	Electronic Arrow	HR	50	$10.00	$ 500.00	Y-D-Q	5,6	1999-2001	50	5%	12		Exponential (0,18.1)	$ 18.34	$916.78
011E00003	2000	5,6	24281	Electronic Arrow	HR	50	$10.00	$ 500.00	Y-D-Q	5,6	1999-2001	50	5%	12		Exponential (0,18.1)	$ 17.64	$882.04
011H00009	2000	5,6	24281	Electronic Arrow	HR	200	$5.00	$ 1,000.00	Y-D-Q	5,6	1996-2001	200	5%	22		Lognormal (1,1.72,0.746)	$ 7.92	$1,583.78
012C00010	2000	1	24281	Electronic Arrow	HR	40	$60.00	$ 2,400.00	Y-D-Q	1,2,3,8	1993-2001	40	5%	13		Weibull (8,1.11,7.14)	$ 14.52	$580.89
012C00011	2000	1	24281	Electronic Arrow	HR	10	$60.00	$ 600.00	Y-D-Q	ALL	1993-2001	10	75%	16		Log-Logistic (4,1.49,6.13)	$ 18.13	$181.29
012E01002	2001	1	24281	Electronic Arrow	HR	6	$20.00	$ 120.00	Y-D-Q	ALL	1993-2001	6	200%	16		Log-Logistic (4,1.49,6.13)	$ 17.76	$106.54
012E01002	2001	1	24281	Electronic Arrow	HR	30	$20.00	$ 600.00	Y-D-Q	ALL	1993-2001	30	5%	11	N/A	$8.36	$ 8.36	$250.91
012E01002	2001	1	24281	Electronic Arrow	HR	48	$20.00	$ 960.00	Y-D-Q	1,2	1993-2001	48	5%	16		Weibull (3,1.62,8.11)	$ 7.92	$380.10
013E00003	2000	1,2	24281	Electronic Arrow	HR	50	$5.00	$ 250.00	Y-D-Q	1,2	1994-2001	50	5%	14		Weibull (3,1.57,8.37)	$ 8.57	$428.48
013E00003	2000	1,2	24281	Electronic Arrow	HR	220	$5.00	$ 1,100.00	Y-D-Q	ALL	1993-2001	220	5%	15		Uniform (3,12)	$ 7.51	$1,652.68
11B369	1999	5,6	24281	Electronic Arrow	HR	400	$5.00	$ 2,000.00	Y-D-Q	5,6	1998-2000	400	5%	10		Exponential (0,3.02)	$ 2.95	$1,181.47
11RC9831	1999	5,6	24281	Electronic Arrow	HR	150	$5.00	$ 750.00	Y-D-Q	5,6	1998-2000	150	5%	14		Gamma (3,2.06,3.56)	$ 10.40	$1,559.44

Table D.1 (continue). Records used to generate the findings in the Cost Study

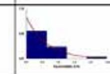
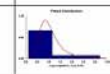
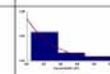
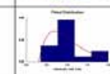
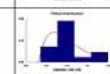
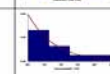
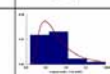
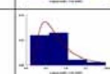
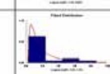
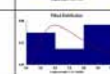
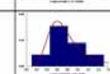
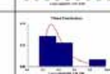
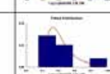
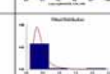
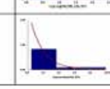
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11U059	1999	5,6	24281	Electronic Arrow	HR	250	$5.00	$ 1,250.00	Y-D-Q	5,6	1997-2001	250	5%	21		Exponential (0,6.23)	$ 6.05	$1,512.82
11U069	1999	5,6	24281	Electronic Arrow	HR	100	$1.00	$ 100.00	Y-D-Q	5,6	1999	100	5%	10		Log-Logistic (1,3.33,8.75)	$ 10.86	$1,086.04
11U069	1999	5,6	24281	Electronic Arrow	HR	400	$1.00	$ 400.00	Y-D-Q	5,6	1998-2000	400	5%	10		Exponential (0,3.02)	$ 2.91	$1,162.63
11Z059	1999	5,6	24281	Electronic Arrow	HR	150	$10.00	$ 1,500.00	Y-D-Q	5,6	1998-2000	150	5%	14		Gamma (3,2.06,3.56)	$ 10.31	$1,545.89
11Z059	1999	5,6	24281	Electronic Arrow	HR	150	$10.00	$ 1,500.00	Y-D-Q	5,6	1998-2000	150	5%	14		Gamma (3,2.06,3.56)	$ 10.19	$1,529.10
12RC9802	1998	1	24281	Electronic Arrow	HR	1	$215.00	$ 215.00	Q-Y-D	1	1998	1	ALL	19		Exponential (0,1.56)	$ 1.55	$1.55
12U090	1999	1	24281	Electronic Arrow	HR	150	$5.00	$ 750.00	Y-D-Q	1,2,3,8	1993-2001	150	5%	26		Lognormal (1,1.76,0.667)	$ 8.30	$1,244.89
12U099	1999	1	24281	Electronic Arrow	HR	150	$5.00	$ 750.00	Y-D-Q	1,2,3,8	1993-2001	150	5%	26		Lognormal (1,1.76,0.667)	$ 8.20	$1,230.14
13U089	1999	1,2	24281	Electronic Arrow	HR	100	$5.00	$ 500.00	Y-D-Q	1,2	1996-2001	100	5%	16		Lognormal (1,1.87,1.14)	$ 12.95	$1,295.14
13U109	1999	1,2	24281	Electronic Arrow	HR	225	$5.00	$ 1,125.00	Y-D-Q	ALL	1993-2001	225	5%	11		Lognormal (4,1.17,0.699)	$ 8.07	$1,814.65
K048-11	1999	5,6	24281	Electronic Arrow	HR	300	$1.00	$ 300.00	Y-D-Q	5,6	1998-2000	300	5%	15		Log-Logistic (1,3.27,6.03)	$ 8.09	$2,426.40
011E00002	2000	5,6	17373	Emergency Response	EA	12	$450.00	$ 5,400.00	Y-Q-D	5,6	1993-2001	12	75%	18		Log-Logistic (150,2.38,220)	$ 467.54	$5,610.51
011E00003	2000	5,6	17373	Emergency Response	EA	20	$450.00	$ 9,000.00	Q-Y-D	5,6	1995-2001	20	ALL	14		Log-Logistic (150,2.54,249)	$ 483.74	$9,674.81
012B00003	2000	1	17373	Emergency Response	EA	2	$145.00	$ 290.00	Y-D-Q	ALL	1993-2001	2	5%	26		Log-Logistic (100,2.65,287)	$ 457.28	$914.55
013E00003	2000	1,2	17373	Emergency Response	EA	30	$10.00	$ 300.00	Q-Y-D	1,2,3,8	1993-2001	30	ALL	13		Exponential (250,827)	$ 1,086.94	$32,608.08

Table D.1 (continue). Records used to generate the findings in the Cost Study

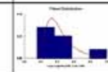
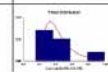
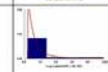
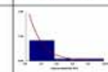
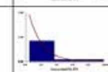
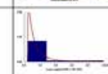
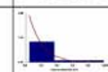
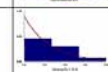
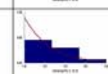
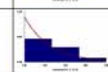
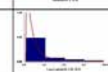
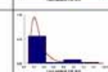
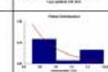
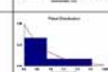
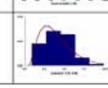
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11RC9831	1999	5,6	17373	Emergency Response	EA	10	$10.00	$ 100.00	Q-Y-D	5,6	1995-2001	10	ALL	14		Log-Logistic (150,2.54,249)	$ 477.74	$4,777.40
11U069	1999	5,6	17373	Emergency Response	EA	20	$500.00	$ 10,000.00	Q-Y-D	5,6	1995-2001	20	ALL	14		Log-Logistic (150,2.54,249)	$ 465.24	$9,304.74
12B0002	2000	1	17373	Emergency Response	EA	3	$145.00	$ 435.00	Y-D-Q	ALL	1993-2001	3	5%	19		Log-Logistic (200,1.28,359)	$ 1,263.10	$3,789.30
12U090	2000	1	17373	Emergency Response	EA	33	$10.00	$ 330.00	Q-Y-D	1,2,3,8	1993-2001	33	ALL	13		Exponential (250,827)	$ 1,138.97	$37,586.10
12U099	1999	1	17373	Emergency Response	EA	33	$10.00	$ 330.00	Q-Y-D	1,2,3,8	1993-2001	33	ALL	13		Exponential (250,827)	$ 1,051.01	$34,683.40
13B0002	2000	1,2	17373	Emergency Response	EA	3	$145.00	$ 435.00	Y-D-Q	ALL	1993-2001	3	5%	19		Log-Logistic (200,1.28,359)	$ 1,654.78	$4,964.34
13U109	1999	1,2	17373	Emergency Response	EA	30	$10.00	$ 300.00	Q-Y-D	1,2,3,8	1993-2001	30	ALL	13		Exponential (250,827)	$ 1,081.94	$32,458.34
011E00002	2000	5,6	17357	End Post Caps, GR-3	EA	2	$100.00	$ 200.00	Q-Y-D	5,6	1994-2001	2	ALL	11		Gamma (10,1,12.3)	$ 22.50	$45.00
011E00003	2000	5,6	17357	End Post Caps, GR-3	EA	2	$100.00	$ 200.00	Q-Y-D	5,6	1994-2001	2	ALL	11		Gamma (10,1,12.3)	$ 22.06	$44.11
11U069	1999	5,6	17357	End Post Caps, GR-3	EA	2	$25.00	$ 50.00	Q-Y-D	5,6	1994-2001	2	ALL	11		Gamma (10,1,12.3)	$ 22.35	$44.70
12B479	1999	1	68570	Expansion Joint Removal	LF	533	$4.50	$ 2,398.50	Q-D-Y	1,2,8	1999	533	ALL	32		Log-Logistic (8,1.39,30.3)	$ 85.50	$45,571.72
13B469	1999	1,2	68570	Expansion Joint Removal	LF	1215	$6.00	$ 7,290.00	Q-D-Y	1,2	1999	1215	ALL	24		Log-Logistic (8,2.29,18.5)	$ 33.13	$40,252.04
011B00002	1999	5,6	22643	Fence (FE-CL)	LF	500	$10.00	$ 5,000.00	Y-D-Q	3,4,5,6,7,8, 9	1993-2001	500	5%	12		Exponential (7,3.21)	$ 10.18	$5,091.41
011B00002	1999	5,6	22643	Fence (FE-CL)	LF	1000	$14.00	$ 14,000.00	Y-Q-D	5,6	1993-2001	1000	5%	12		Exponential (6,3.46)	$ 9.26	$9,255.37
011B00002	1999	5,6	23080	Fence (FE-W1 or FE-W2), Reset Existing	LF	750	$2.50	$ 1,875.00	Q-D-Y	ALL	1998-2000	750	ALL	62		Gamma (1,2.75,2.58)	$ 7.90	$5,923.43

Table D.1 (continue). Records used to generate the findings in the Cost Study

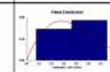
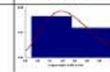
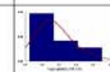
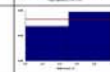
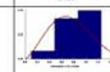
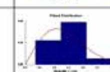
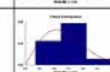
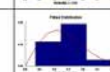
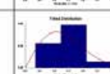
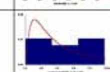
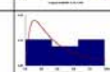
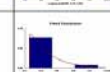
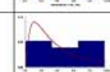
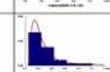
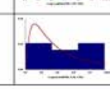
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011B00002	1999	5,6	22501	Fence (FE-W1)	LF	2510	$3.50	$ 8,785.00	Y-D-Q	3,4,5,6,7,8,9	1993-2001	2510	5%	16		Weibull (2,1.86,0.853)	$ 2.47	$6,189.23
012B00003	2000	1	22501	Fence (FE-W1)	LF	2500	$1.95	$ 4,875.00	Y-D-Q	1,2	1993-2001	2500	5%	12		Lognormal (1,0.403,0.276)	$ 2.56	$6,397.82
12B0002	2000	1	22501	Fence (FE-W1)	LF	5000	$1.95	$ 9,750.00	Q-Y-D	1	2000	5000	ALL	12		Log-Logistic (1,7.84,1.13)	$ 2.16	$10,823.25
13B0002	2000	1,2	22501	Fence (FE-W1)	LF	5000	$1.95	$ 9,750.00	Q-Y-D	1,2	2000	5000	30%	12		Uniform (2,3)	$ 2.50	$12,510.51
011B00002	1999	5,6	23515	Fence Fabric (FE-CL), Reset Existing	LF	200	$9.00	$ 1,800.00	Q-D-Y	ALL	1996-2001	200	ALL	12		Weibull (0,2.35,0.846)	$ 0.37	$73.96
011B00002	1999	5,6	23501	Fence Fabric (FE-W1)	LF	300	$2.00	$ 600.00	Q-D-Y	ALL	1996-2001	300	ALL	12		Weibull (0,2,1.54)	$ 0.76	$227.48
012B00003	2000	1	23501	Fence Fabric (FE-W1)	LF	125	$0.55	$ 68.75	Q-D-Y	ALL	1996-2001	125	ALL	12		Weibull (0,2,1.54)	$ 0.75	$94.36
12B0002	2000	1	23501	Fence Fabric (FE-W1)	LF	250	$0.55	$ 137.50	Q-D-Y	ALL	1996-2001	250	ALL	12		Weibull (0,2,1.54)	$ 0.77	$191.69
13B0002	2000	1,2	23501	Fence Fabric (FE-W1)	LF	250	$0.55	$ 137.50	Q-D-Y	ALL	1996-2001	250	ALL	12		Weibull (0,2,1.54)	$ 0.78	$194.03
011E00002	2000	5,6	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$500.00	$ 500.00	Y-Q-D	5,6	1993-2001	1	5%	11		Lognormal (300,5.14,1.05)	$ 594.18	$594.18
011E00003	2000	5,6	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$500.00	$ 500.00	Y-Q-D	5,6	1993-2001	1	5%	11		Lognormal (300,5.14,1.05)	$ 579.58	$579.58
013E00003	2000	1,2	13393	Fixed Object Att. GR-FOA-2TYII	EA	2	$300.00	$ 600.00	Y-D-Q	1,2	1995-2001	2	5%	12		Weibull (250,1.05,238)	$ 474.87	$949.75
11RC9831	1999	5,6	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$300.00	$ 300.00	Y-Q-D	5,6	1993-2001	1	5%	11		Lognormal (300,5.14,1.05)	$ 595.19	$595.19
11U059	1999	5,6	13393	Fixed Object Att. GR-FOA-2TYII	EA	5	$500.00	$ 2,500.00	Q-Y-D	5,6	1998-2000	5	ALL	33		Log-Logistic (250,1.91,164)	$ 532.63	$2,663.17
11U069	1999	5,6	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$400.00	$ 400.00	Y-Q-D	5,6	1993-2001	1	5%	11		Lognormal (300,5.14,1.05)	$ 587.86	$587.86

Table D.1 (continue). Records used to generate the findings in the Cost Study

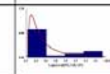
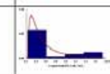
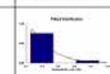
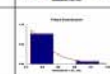
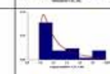
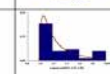
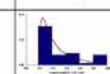
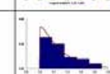
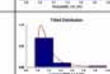
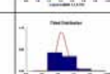
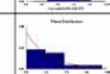
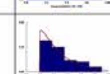
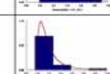
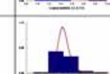
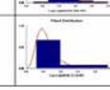
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
12U090	2000	1	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$300.00	$ 300.00	Y-Q-D	1,2,3,8	1993-2001	1	5%	20		Lognormal (225,5.46,1.07)	$ 650.14	$650.14
12U099	1999	1	13393	Fixed Object Att. GR-FOA-2TYII	EA	1	$300.00	$ 300.00	Y-Q-D	1,2,3,8	1993-2001	1	5%	20		Lognormal (225,5.46,1.07)	$ 634.36	$634.36
13U089	1999	1,2	13393	Fixed Object Att. GR-FOA-2TYII	EA	2	$400.00	$ 800.00	Y-D-Q	1,2	1995-2001	2	5%	12		Weibull (250,1.05,238)	$ 475.54	$951.09
13U109	1999	1,2	13393	Fixed Object Att. GR-FOA-2TYII	EA	2	$300.00	$ 600.00	Y-D-Q	1,2	1995-2001	2	5%	12		Weibull (250,1.05,238)	$ 483.48	$966.96
011E00002	2000	5,6	13392	Fixed Object Attach. GR-FOA-2TYI	EA	2	$900.00	$ 1,800.00	D-Y-Q	ALL	1999-2001	2	5%	37		Lognormal (975,5.32,1.06)	$ 1,369.41	$2,738.83
011E00003	2000	5,6	13392	Fixed Object Attach. GR-FOA-2TYI	EA	2	$900.00	$ 1,800.00	D-Y-Q	ALL	1999-2001	2	5%	37		Lognormal (975,5.32,1.06)	$ 1,345.02	$2,690.04
013E00003	2000	1,2	13392	Fixed Object Attach. GR-FOA-2TYI	EA	2	$950.00	$ 1,900.00	D-Y-Q	ALL	1999-2001	2	5%	37		Lognormal (975,5.32,1.06)	$ 1,341.46	$2,682.92
11RC9831	1999	5,6	13392	Fixed Object Attach. GR-FOA-2TYI	EA	1	$950.00	$ 950.00	D-Y-Q	ALL	1998-2000	1	5%	50		Weibull (989,1.07,301)	$ 1,274.31	$1,274.31
11U059	1999	5,6	13392	Fixed Object Attach. GR-FOA-2TYI	EA	3	$1,250.00	$ 3,750.00	D-Y-Q	ALL	1998-2000	3	5%	30		Lognormal (950,5.2,0.773)	$ 1,195.62	$3,586.86
11U069	1999	5,6	13392	Fixed Object Attach. GR-FOA-2TYI	EA	2	$1,200.00	$ 2,400.00	D-Y-Q	ALL	1998-2000	2	5%	62		Log-Logistic (210,8.69,921)	$ 1,160.59	$2,321.18
12U090	2000	1	13392	Fixed Object Attach. GR-FOA-2TYI	EA	1	$950.00	$ 950.00	D-Y-Q	ALL	2000	1	5%	24		Exponential (1000,218)	$ 1,219.42	$1,219.42
12U099	1999	1	13392	Fixed Object Attach. GR-FOA-2TYI	EA	1	$950.00	$ 950.00	D-Y-Q	ALL	1998-2000	1	5%	50		Weibull (989,1.07,301)	$ 1,264.55	$1,264.55
13U089	1999	1,2	13392	Fixed Object Attach. GR-FOA-2TYI	EA	3	$1,000.00	$ 3,000.00	D-Y-Q	ALL	1998-2000	3	5%	30		Lognormal (950,5.2,0.773)	$ 1,198.66	$3,595.99
13U109	1999	1,2	13392	Fixed Object Attach. GR-FOA-2TYI	EA	2	$950.00	$ 1,900.00	D-Y-Q	ALL	1998-2000	2	5%	62		Log-Logistic (210,8.69,921)	$ 1,150.71	$2,301.41
012A00025	2000	1	24282	Flexible pavement planing	SY	139453	$2.22	$ 309,585.66	Q-D-Y	1	2000	139453	95%	10		Log-Logistic (0,3.2,0.541)	$ 0.63	$87,975.13

Table D.1 (continue). Records used to generate the findings in the Cost Study

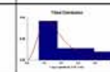
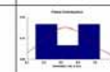
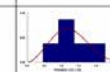
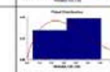
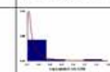
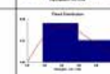
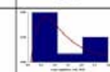
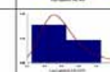
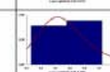
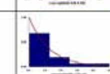
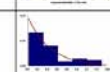
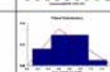
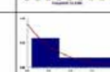
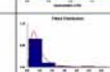
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
012A99057	1999	1	24282	Flexible pavement planing	SY	175000	$1.45	$ 253,750.00	D-Q-Y	1,2,3,8	1999	175000	5%	18		Log-Logistic (0,2.76,1.55)	$ 1.91	$334,591.84
11P209	1999	5,6	24282	Flexible pavement planing	SY	287978	$1.05	$ 302,376.90	Q-D-Y	5,6	1999	287978	85%	12		Weibull (0,2.86,0.753)	$ 0.26	$76,163.89
11SF99002	1999	5,6	24282	Flexible pavement planing	SY	14700	$1.25	$ 18,375.00	D-Y-Q	ALL	1997-2001	14700	5%	16		Weibull (0,2.63,1.39)	$ 0.52	$7,632.74
12P148	1998	1	24282	Flexible pavement planing	SY	127822	$0.84	$ 107,370.48	Q-D-Y	1	1998	127822	99%	12		Weibull (0,1.69,3.95)	$ 2.29	$292,511.48
12P219	1999	1	24282	Flexible pavement planing	SY	2820	$2.22	$ 6,260.40	D-Y-Q	ALL	1997-2001	2820	5%	14		Log-Logistic (2,1.01,0.709)	$ 6.66	$18,786.15
12P219	1999	1	24282	Flexible pavement planing	SY	121127	$2.39	$ 289,493.53	Q-D-Y	1	1999	121127	99%	11		Weibull (1,1.97,2.96)	$ 2.49	$301,618.39
12RC9940	1999	1	24282	Flexible pavement planing	SY	30	$10.00	$ 300.00	D-Y-Q	ALL	1993-2001	30	35%	10		Log-Logistic (1,1.83,10.9)	$ 20.52	$615.49
13P158	1998	1,2	24282	Flexible pavement planing	SY	51885	$1.05	$ 54,479.25	D-Y-Q	ALL	1997-1999	51885	5%	16		Log-Logistic (0,4.24,0.571)	$ 0.63	$32,687.29
13P168	1998	1,2	24282	Flexible pavement planing	SY	28724	$0.79	$ 22,691.96	D-Y-Q	ALL	1995-2001	28724	5%	15		Log-Logistic (0,6.84,0.745)	$ 0.77	$22,052.44
011H00009	2000	5,6	24277	Furnish Portable Message Sign	EA	1	$3,500.00	$ 3,500.00	D-Y-Q	5,6	2000	1	5%	31		Exponential (300,12500)	$ 12,711.98	$12,711.98
11B369	1999	5,6	24277	Furnish Portable Message Sign	EA	2	$3,000.00	$ 6,000.00	D-Y-Q	4,5,6,7,9	1999	2	5%	49		Exponential (200,4420)	$ 4,562.15	$9,124.30
011H00009	2000	5,6	24278	Group 2 Channelizing Devices	DY	6000	$0.01	$ 60.00	Y-D-Q	4,5,6,7,9	1993-2001	6000	5%	30		Triangular (0,1.6,0.588)	$ 0.72	$4,340.21
11B369	1999	5,6	24278	Group 2 Channelizing Devices	DY	3375	$0.60	$ 2,025.00	Y-D-Q	5,6	1993-2001	3375	5%	10		Exponential (0,0.706)	$ 0.69	$2,322.41
11RC9812	1999	5,6	24278	Group 2 Channelizing Devices	DY	10	$0.40	$ 4.00	Y-D-Q	5,6	1995-2001	10	ALL	74		Log-Logistic (0,2.3,0.745)	$ 1.10	$10.99
12I079	1999	1	24278	Group 2 Channelizing Devices	DY	50	$10.00	$ 500.00	Y-D-Q	ALL	1993-2001	50	5%	11	N/A	$15.36	$ 15.36	$768.18

Table D.1 (continue). Records used to generate the findings in the Cost Study

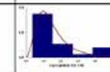
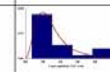
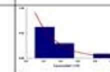
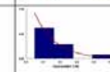
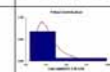
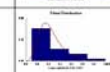
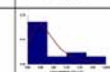
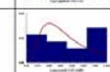
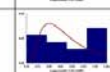
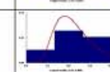
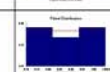
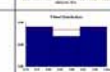
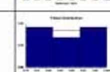
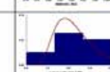
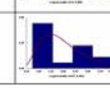
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
13I058	1999	1,2	24278	Group 2 Channelizing Devices	DY	200	$10.00	$ 2,000.00	Y-D-Q	1,2	1994-2001	200	5%	21		Log-Logistic (0,2.57,1.34)	$ 1.67	$334.30
13I058	1999	1,2	24278	Group 2 Channelizing Devices	DY	200	$10.00	$ 2,000.00	Y-D-Q	1,2	1994-2001	200	5%	21		Log-Logistic (0,2.57,1.34)	$ 1.71	$342.14
13I089	1999	1,2	24278	Group 2 Channelizing Devices	DY	25	$10.00	$ 250.00	Y-D-Q	1,2	1993-2001	25	5%	24		Exponential (1,2.44)	$ 3.43	$85.72
13I089	1999	1,2	24278	Group 2 Channelizing Devices	DY	25	$10.00	$ 250.00	Y-D-Q	1,2	1993-2001	25	5%	24		Exponential (1,2.44)	$ 3.41	$85.24
012E01002	2001	1	13320	Guardrail (Std. GR-2)I	LF	50	$9.45	$ 472.50	D-Y-Q	ALL	2000-2001	50	5%	11		Log-Logistic (11,2.44,4.29)	$ 16.79	$839.54
012E01002	2001	1	13320	Guardrail (Std. GR-2)I	LF	600	$9.45	$ 5,670.00	D-Y-Q	ALL	2000-2001	600	5%	23		Log-Logistic (9,3.32,2.07)	$ 11.41	$6,845.04
012E01002	2001	1	13320	Guardrail (Std. GR-2)I	LF	2250	$9.45	$ 21,262.50	D-Y-Q	ALL	1999-2001	2250	5%	18		Log-Logistic (9,3.24,1.17)	$ 10.38	$23,362.46
011E00002	2000	5,6	17323	Guardrail Beam	LF	4100	$8.00	$ 32,800.00	Q-D-Y	4,5,6,7,9	2000	4100	ALL	14		Lognormal (7,0.47,0.688)	$ 9.01	$36,954.52
011E00003	2000	5,6	17323	Guardrail Beam	LF	6150	$8.50	$ 52,275.00	Q-D-Y	4,5,6,7,9	2000	6150	ALL	14		Lognormal (7,0.47,0.688)	$ 9.07	$55,750.48
013E00003	2000	1,2	17323	Guardrail Beam	LF	6650	$7.25	$ 48,212.50	Q-D-Y	ALL	2000	6650	ALL	11		Lognormal (6,0.76,0.408)	$ 8.31	$55,257.19
11RC9831	1999	5,6	17323	Guardrail Beam	LF	2500	$8.00	$ 20,000.00	Q-D-Y	4,5,6,7,9	1999	2500	ALL	11		Uniform (7,10.5)	$ 8.77	$21,913.29
11U059	1999	5,6	17323	Guardrail Beam	LF	2000	$6.00	$ 12,000.00	Q-D-Y	4,5,6,7,9	1999	2000	ALL	11		Uniform (7,10.5)	$ 8.75	$17,499.67
11U069	1999	5,6	17323	Guardrail Beam	LF	15000	$8.00	$ 120,000.00	Q-D-Y	4,5,6,7,9	1999	15000	ALL	11		Uniform (7,10.5)	$ 8.77	$131,542.23
12U090	2000	1	17323	Guardrail Beam	LF	5000	$7.25	$ 36,250.00	Q-D-Y	ALL	2000	5000	ALL	11		Lognormal (6,0.76,0.408)	$ 8.31	$41,556.79
12U099	1999	1	17323	Guardrail Beam	LF	5000	$7.25	$ 36,250.00	Q-D-Y	ALL	1999	5000	ALL	15		Lognormal (6,0.617,0.483)	$ 8.10	$40,492.22

Table D.1 (continue). Records used to generate the findings in the Cost Study

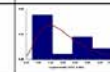
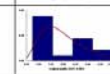
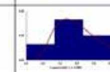
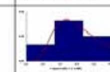
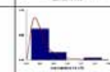
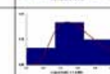
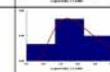
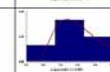
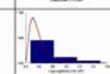
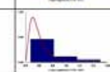
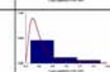
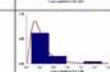
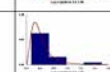
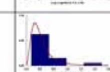
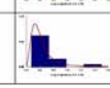
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
13U089	1999	1,2	17323	Guardrail Beam	LF	500	$8.00	$ 4,000.00	Q-D-Y	ALL	1999	500	ALL	15		Lognormal (6,0.617,0.483)	$ 8.13	$4,062.94
13U109	1999	1,2	17323	Guardrail Beam	LF	5300	$7.25	$ 38,425.00	Q-D-Y	ALL	1999	5300	ALL	15		Lognormal (6,0.617,0.483)	$ 8.14	$43,147.37
011E00002	2000	5,6	17451	Guardrail Delineator	EA	100	$5.00	$ 500.00	Q-Y-D	5,6	1999-2001	100	ALL	10		Lognormal (5,1.1,0.489)	$ 8.44	$844.38
011E00003	2000	5,6	17451	Guardrail Delineator	EA	100	$5.00	$ 500.00	Q-Y-D	5,6	1999-2001	100	ALL	10		Lognormal (5,1.1,0.489)	$ 8.39	$838.88
013E00003	1999	1,2	17451	Guardrail Delineator	EA	150	$10.00	$ 1,500.00	Q-Y-D	1,2,3,8	1993-2001	150	ALL	16		Log-Logistic (4,2.4,1.79)	$ 6.41	$961.30
11RC9831	1999	5,6	17451	Guardrail Delineator	EA	100	$10.00	$ 1,000.00	Q-Y-D	5,6	1998-2000	100	ALL	10		Lognormal (5,1.1,0.489)	$ 8.42	$841.99
11U059	1999	5,6	17451	Guardrail Delineator	EA	160	$7.00	$ 1,120.00	Q-Y-D	5,6	1998-2000	160	ALL	10		Lognormal (5,1.1,0.489)	$ 8.30	$1,328.26
11U069	1999	5,6	17451	Guardrail Delineator	EA	500	$7.00	$ 3,500.00	Q-Y-D	5,6	1998-2000	500	ALL	10		Lognormal (5,1.1,0.489)	$ 8.40	$4,200.74
12U090	2000	1	17451	Guardrail Delineator	EA	150	$10.00	$ 1,500.00	Q-Y-D	1,2,8	1993-2001	150	ALL	11		Log-Logistic (4,2.19,1.62)	$ 6.37	$955.84
12U099	1999	1	17451	Guardrail Delineator	EA	100	$10.00	$ 1,000.00	Q-Y-D	1,2,8	1993-2001	100	ALL	11		Log-Logistic (4,2.19,1.62)	$ 6.25	$624.63
12X089	1999	1	17451	Guardrail Delineator	EA	1500	$1.35	$ 2,025.00	Q-Y-D	1,2,8	1993-2001	1500	ALL	11		Log-Logistic (4,2.19,1.62)	$ 6.49	$9,730.25
13U089	1999	1,2	17451	Guardrail Delineator	EA	70	$10.00	$ 700.00	Q-Y-D	1,2,3,8	1993-2001	70	ALL	16		Log-Logistic (4,2.4,1.79)	$ 6.33	$443.45
13U109	1999	1,2	17451	Guardrail Delineator	EA	150	$10.00	$ 1,500.00	Q-Y-D	1,2,3,8	1993-2001	150	ALL	16		Log-Logistic (4,2.4,1.79)	$ 6.39	$957.88
13X099	1999	1,2	17451	Guardrail Delineator	EA	1500	$2.00	$ 3,000.00	Q-Y-D	1,2,3,8	1993-2001	1500	ALL	16		Log-Logistic (4,2.4,1.79)	$ 6.42	$9,632.42
13X099	1999	1,2	17451	Guardrail Delineator	EA	1500	$2.00	$ 3,000.00	Q-Y-D	1,2,3,8	1993-2001	1500	ALL	16		Log-Logistic (4,2.4,1.79)	$ 6.41	$9,613.06

Table D.1 (continue). Records used to generate the findings in the Cost Study

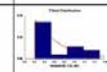
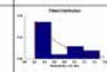
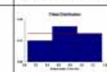
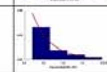
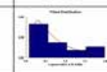
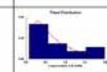
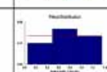
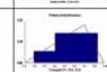
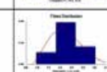
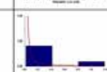
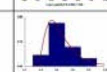
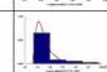
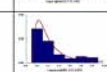
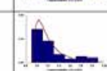
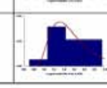
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011E00002	2000	5,6	13349	Guardrail Term. Site Preparation	EA	2	$500.00	$ 1,000.00	Y-D-Q	4,5,6,7,9	1993-2001	2	5%	15		Weibull (198,1.03,482)	$ 665.84	$1,331.69
011E00003	2000	5,6	13349	Guardrail Term. Site Preparation	EA	2	$500.00	$ 1,000.00	Y-D-Q	4,5,6,7,9	1993-2001	2	5%	15		Weibull (198,1.03,482)	$ 653.51	$1,307.02
013E00003	2000	1,2	13349	Guardrail Term. Site Preparation	EA	3	$500.00	$ 1,500.00	Y-D-Q	1,2	1997-2001	3	5%	12		Uniform (50,1350)	$ 710.07	$2,130.22
11RC9831	1999	5,6	13349	Guardrail Term. Site Preparation	EA	1	$800.00	$ 800.00	Y-D-Q	4,5,6,7,9	1993-2001	1	5%	21		Exponential (200,475)	$ 675.89	$675.89
12U090	2000	1	13349	Guardrail Term. Site Preparation	EA	1	$800.00	$ 800.00	Y-D-Q	1,2	1993-2001	1	5%	18		Lognormal (75,6.36,0.986)	$ 989.01	$989.01
12U099	1999	1	13349	Guardrail Term. Site Preparation	EA	1	$800.00	$ 800.00	Y-D-Q	1,2	1993-2001	1	5%	18		Lognormal (75,6.36,0.986)	$ 984.67	$984.67
13U109	1999	1,2	13349	Guardrail Term. Site Preparation	EA	3	$500.00	$ 1,500.00	Y-D-Q	1,2	1997-2001	3	5%	12		Uniform (50,1350)	$ 714.39	$2,143.17
011E00002	2000	5,6	13343	Guardrail Terminal (GR-6)	LF	85	$31.00	$ 2,635.00	D-Y-Q	ALL	1997-2001	85	5%	12		Triangular (11,18.9,16.9)	$ 15.58	$1,324.03
011E00003	2000	5,6	13343	Guardrail Terminal (GR-6)	LF	125	$31.00	$ 3,875.00	D-Y-Q	ALL	1997-2001	125	5%	12		Weibull (9,2.32,6.68)	$ 11.92	$1,489.53
11RC9831	1999	5,6	13343	Guardrail Terminal (GR-6)	LF	1	$600.00	$ 600.00	D-Y-Q	ALL	1993-2001	1	300%	11		Log-Logistic (16,0.683,7.84)	$ 498.14	$498.14
11U059	1999	5,6	13343	Guardrail Terminal (GR-6)	LF	40	$25.00	$ 1,000.00	D-Y-Q	ALL	1997-2001	40	5%	21		Lognormal (13,1.14,0.526)	$ 16.62	$664.66
11U069	1999	5,6	13343	Guardrail Terminal (GR-6)	LF	50	$30.00	$ 1,500.00	D-Y-Q	ALL	1997-2001	50	5%	28		Log-Logistic (13,2.11,3.95)	$ 18.82	$941.02
011E00002	2000	5,6	13344	Guardrail Terminal Upgrade (GR-7)	EA	3	$1,150.00	$ 3,450.00	D-Q-Y	ALL	2000	3	75%	77		Lognormal (900,5.53,0.827)	$ 1,258.36	$3,775.08
011E00003	2000	5,6	13344	Guardrail Terminal Upgrade (GR-7)	EA	3	$1,150.00	$ 3,450.00	D-Q-Y	ALL	2000	3	75%	77		Lognormal (900,5.53,0.827)	$ 1,247.04	$3,741.12
11U059	1999	5,6	13344	Guardrail Terminal Upgrade (GR-7)	EA	8	$1,750.00	$ 14,000.00	D-Q-Y	ALL	1999	8	50%	15		Lognormal (700,6.64,0.478)	$ 1,552.60	$12,420.78

Table D.1 (continue). Records used to generate the findings in the Cost Study

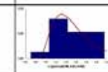
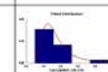
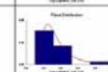
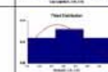
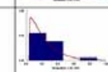
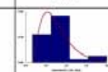
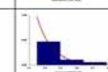
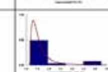
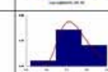
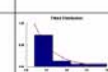
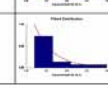
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11U069	1999	5,6	13344	Guardrail Terminal Upgrade (GR-7)	EA	15	$1,700.00	$ 25,500.00	D-Q-Y	ALL	1999	15	75%	15		Lognormal (700,6.64,0.478)	$ 1,553.89	$23,308.41
13U089	1999	1,2	13344	Guardrail Terminal Upgrade (GR-7)	EA	1	$1,200.00	$ 1,200.00	D-Y-Q	ALL	1998-2000	1	5%	94	N/A	$1,214.95	$ 1,214.95	$1,214.95
011E00002	2000	5,6	17361	Hook Bolts, GR-3	EA	100	$5.00	$ 500.00	Q-D-Y	3,2,5,6,7,8, 9	1999-2001	100	ALL	18		Log-Logistic (1,2.44,2.13)	$ 3.91	$391.48
011E00003	2000	5,6	17361	Hook Bolts, GR-3	EA	100	$5.00	$ 500.00	Q-D-Y	3,2,5,6,7,8, 9	1999-2001	100	ALL	18		Log-Logistic (1,2.44,2.13)	$ 3.91	$390.52
11U069	1999	5,6	17361	Hook Bolts, GR-3	EA	400	$1.50	$ 600.00	Q-D-Y	3,2,5,6,7,8, 9	1999	400	ALL	10		Weibull (1,2.15,2.32)	$ 2.06	$825.80
011B00002	1999	5,6	22541	Line Brace Unit (FE-W1 or FE-W2)	EA	5	$450.00	$ 2,250.00	Y-D-Q	4,5,6,7,9	1993-2001	5	5%	18		Weibull (36,1.09,202)	$ 214.07	$1,070.37
011B00002	1999	5,6	22541	Line Brace Unit (FE-W1 or FE-W2)	EA	12	$350.00	$ 4,200.00	Y-D-Q	4,5,6,7,9	1993-2001	12	5%	27		Gamma (32,2.63,45.8)	$ 152.63	$1,831.50
012B00003	2000	1	22541	Line Brace Unit (FE-W1 or FE-W2)	EA	25	$120.00	$ 3,000.00	Y-Q-D	1	1997-2001	25	5%	12		Exponential (175,47)	$ 222.36	$5,558.93
12B0002	2000	1	22541	Line Brace Unit (FE-W1 or FE-W2)	EA	50	$120.00	$ 6,000.00	Q-Y-D	1	2000	50	ALL	15		Log-Logistic (115,1.67,33)	$ 178.57	$8,928.68
13B0002	2000	1,2	22541	Line Brace Unit (FE-W1 or FE-W2)	EA	50	$120.00	$ 6,000.00	Q-Y-D	1,2	2000	50	50%	12		Lognormal (60,4.69,0.349)	$ 175.98	$8,799.16
12U090	1999	1	17331	Offset Block (wood or steel)	EA	300	$12.00	$ 3,600.00	Q-D-Y	ALL	1999	300	ALL	11	N/A	$15.65	$ 15.65	$4,694.24
12U099	1999	1	17331	Offset Block (wood or steel)	EA	300	$12.00	$ 3,600.00	Q-D-Y	ALL	1999	300	ALL	11	N/A	$15.65	$ 15.65	$4,694.24
13U109	1999	1,2	17331	Offset Block (wood or steel)	EA	1	$40.00	$ 40.00	Q-D-Y	ALL	1999	1	ALL	11	N/A	$15.65	$ 15.65	$15.65
012H00005	2000	1	68320	Patching (Type B)	SF	400	$45.00	$ 18,000.00	Q-D-Y	1	2000	400	ALL	15		Exponential (120,45.3)	$ 163.91	$65,565.13
012H00005	2000	1	68320	Patching (Type B)	SF	400	$45.00	$ 18,000.00	Q-D-Y	1	2000	400	ALL	15		Exponential (120,45.3)	$ 164.16	$65,664.88

Table D.1 (continue). Records used to generate the findings in the Cost Study

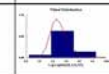
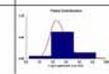
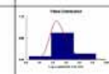
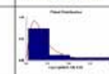
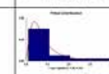
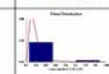
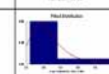
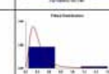
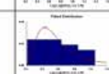
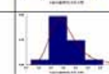
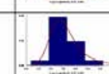
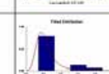
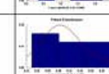
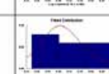
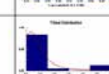
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS										
									QUERY INPUT					QUERY RESULTS					
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST	
012H00005	2000	1	68330	Patching (Type C)	SF	1755	$131.00	$ 229,905.00	Q-D-Y	1	2000	1755	ALL	12		Log-Logistic (20,5.54,223)	$ 255.37	$448,173.12	
012H00005	2000	1	68330	Patching (Type C)	SF	1755	$131.00	$ 229,905.00	Q-D-Y	1	2000	1755	ALL	12		Log-Logistic (20,5.54,223)	$ 256.03	$449,337.50	
12B479	2000	1	68330	Patching (Type C)	SF	30	$130.00	$ 3,900.00	Q-D-Y	1	2000	30	ALL	12		Log-Logistic (20,5.54,223)	$ 255.60	$7,668.08	
K048 - 11	1999	5,6	54040	Pavement Marking (Type B, Class 1, 12")	LF	1000	$1.75	$ 1,750.00	Q-Y-D	5,6	1997-2001	1000	ALL	16		Log-Logistic (1,1.95,0.34)	$ 1.53	$1,534.02	
K048 - 11	1999	5,6	54040	Pavement Marking (Type B, Class 1, 12")	LF	1000	$1.75	$ 1,750.00	Q-Y-D	5,6	1997-2001	1000	ALL	16		Log-Logistic (1,1.95,0.34)	$ 1.52	$1,523.24	
011E00005	2000	5,6	54042	Pavement Marking (Type B, Class 1, 24")	LF	90	$33.60	$ 3,024.00	D-Y-Q	5,6	2000	90	30%	13		Log-Logistic (2,2.42,1.55)	$ 3.99	$358.69	
11K089	1999	5,6	54042	Pavement Marking (Type B, Class 1, 24")	LF	190	$10.00	$ 1,900.00	D-Y-Q	5,6	1999	190	20%	10		Log-Logistic (2,3.63,1.06)	$ 3.19	$605.55	
11P209	1999	5,6	54042	Pavement Marking (Type B, Class 1, 24")	LF	80	$4.00	$ 320.00	D-Y-Q	5,6	1999	80	25%	13		Log-Logistic (2,2.4,1.78)	$ 4.60	$368.34	
12K069	1999	1	54042	Pavement Marking (Type B, Class 1, 24")	LF	275	$13.20	$ 3,630.00	D-Y-Q	1	1999	275	ALL	17		Log-Logistic (2,2.33,3.39)	$ 6.59	$1,812.29	
K048 - 11	1999	5,6	54042	Pavement Marking (Type B, Class 1, 24")	LF	2000	$3.50	$ 7,000.00	Q-D-Y	5,6	1999	2000	80%	17		Log-Logistic (0,4.33,3.02)	$ 3.29	$6,579.79	
K048 - 11	1999	5,6	54042	Pavement Marking (Type B, Class 1, 24")	LF	2000	$3.50	$ 7,000.00	Q-D-Y	5,6	1999	2000	80%	17		Log-Logistic (0,4.33,3.02)	$ 3.31	$6,615.62	
12P219	1999	1	54032	Pavement Marking (Type B, Class 1, 4")	LF	1	$0.55	$ 0.55	Q-Y-D	1	1999	1	ALL	15		Log-Logistic (0,3.55,0.506)	$ 0.58	$0.58	
K048 - 11	1999	5,6	54032	Pavement Marking (Type B, Class 1, 4")	LF	135000	$0.40	$ 54,000.00	Q-Y-D	5,6	1999	135000	75%	10		Log-Logistic (0,16.1,0.406)	$ 0.41	$55,170.86	
K048 - 11	1999	5,6	54032	Pavement Marking (Type B, Class 1, 4")	LF	135000	$0.40	$ 54,000.00	Q-Y-D	5,6	1999	135000	75%	10		Log-Logistic (0,16.1,0.406)	$ 0.41	$55,221.54	
12P219	1999	1	54037	Pavement Marking (Type B, Class 1, 8")	LF	1	$1.27	$ 1.27	Q-D-Y	1,2,3,4,7,8	1999	1	ALL	24		Log-Logistic (0,3.54,0.789)	$ 0.90	$0.90	

Table D.1 (continue). Records used to generate the findings in the Cost Study

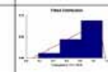
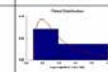
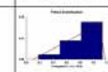
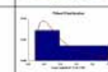
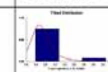
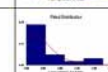
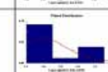
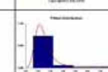
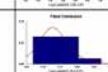
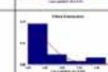
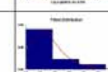
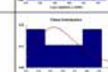
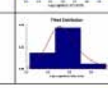
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
K048 - 11	1999	5,6	54037	Pavement Marking (Type B, Class 1, 8")	LF	3000	$0.75	$ 2,250.00	D-Y-Q	ALL	1997-2001	3000	5%	10	N/A	$1.34	$ 1.34	$4,023.00
K048 - 11	1999	5,6	54037	Pavement Marking (Type B, Class 1, 8")	LF	3000	$0.75	$ 2,250.00	D-Y-Q	ALL	1997-2001	3000	5%	10	N/A	$1.34	$ 1.34	$4,023.00
012A00025	2000	1	54048	Pavement Marking (Type B, Class 2, 24")	LF	280	$11.00	$ 3,080.00	Q-D-Y	ALL	1999-2001	280	ALL	13		Triangular (1,11.7,10.9)	$ 7.95	$2,225.59
012A99057	1999	1	54048	Pavement Marking (Type B, Class 2, 24")	LF	20	$845.00	$ 16,900.00	Q-D-Y	ALL	1998-2000	20	ALL	12		Log-Logistic (2,1.54,7.05)	$ 16.18	$323.59
012E00002	2000	1	54048	Pavement Marking (Type B, Class 2, 24")	LF	2946	$7.85	$ 23,126.10	Q-D-Y	ALL	1999-2001	2946	ALL	13		Triangular (1,11.7,10.9)	$ 7.73	$22,776.69
12P219	1999	1	54048	Pavement Marking (Type B, Class 2, 24")	LF	259	$11.00	$ 2,849.00	Q-D-Y	ALL	1998-2000	259	ALL	12		Log-Logistic (2,1.54,7.05)	$ 15.95	$4,131.18
012A00025	2000	1	54075	Pavement Marking (Type B, Class 6, 4")	LF	117387	$1.84	$ 215,992.08	Q-D-Y	1,2	2000	117387	ALL	11		Log-Logistic (1.7.35,0.902)	$ 1.93	$226,708.66
012A99057	1999	1	54075	Pavement Marking (Type B, Class 6, 4")	LF	112640	$2.00	$ 225,280.00	Q-D-Y	1	1999	112640	50%	18		Log-Logistic (1,6.5,0.732)	$ 1.77	$198,924.24
11P209	1999	5,6	54075	Pavement Marking (Type B, Class 6, 4")	LF	214325	$1.75	$ 375,068.75	Q-D-Y	5,6	1999	214325	50%	11		Log-Logistic (1,9.02,0.818)	$ 1.84	$393,516.38
11SF99002	1999	5,6	54075	Pavement Marking (Type B, Class 6, 4")	LF	1400	$2.80	$ 3,920.00	D-Y-Q	ALL	1993-2001	1400	10%	31		Log-Logistic (1,3.56,1.31)	$ 2.48	$3,475.79
12P148	1998	1	54075	Pavement Marking (Type B, Class 6, 4")	LF	94641	$1.77	$ 167,514.57	D-Q-Y	ALL	1998	94641	10%	11		Log-Logistic (1,26.4,0.73)	$ 1.73	$163,947.01
12P219	1999	1	54075	Pavement Marking (Type B, Class 6, 4")	LF	166931	$1.84	$ 307,153.04	Q-D-Y	1,2,3,4,7	1999	166931	ALL	18		Log-Logistic (1,6.5,0.732)	$ 1.76	$294,415.04
012A00025	2000	1	54077	Pavement Marking (Type B, Class 6, 8")	LF	360	$3.70	$ 1,332.00	D-Y-Q	ALL	1993-2001	360	15%	11		Log-Logistic (3,5,0.681)	$ 3.72	$1,340.96
012A99057	1999	1	54077	Pavement Marking (Type B, Class 6, 8")	LF	17400	$4.00	$ 69,600.00	Q-D-Y	1,2,3,8	1999	17400	ALL	16		Log-Logistic (3,4.71,0.578)	$ 3.63	$63,100.79
11P209	1999	5,6	54077	Pavement Marking (Type B, Class 6, 8")	LF	5316	$3.50	$ 18,606.00	D-Q-Y	ALL	1999	5316	30%	12		Log-Logistic (3,6.02,0.54)	$ 3.57	$18,961.60

Table D.1 (continue). Records used to generate the findings in the Cost Study

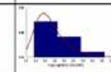
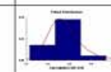
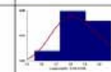
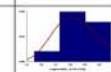
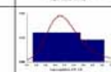
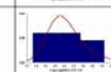
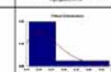
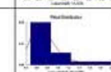
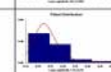
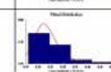
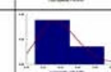
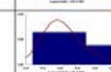
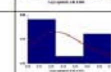
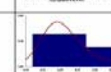
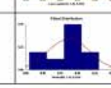
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
12P148	1998	1	54077	Pavement Marking (Type B, Class 6, 8")	LF	3168	$3.72	$ 11,784.96	D-Y-Q	ALL	1997-1999	3168	5%	12		Log-Logistic (3,3.54,0.667)	$ 3.75	$11,885.80
12P219	1999	1	54077	Pavement Marking (Type B, Class 6, 8")	LF	5330	$3.70	$ 19,721.00	D-Q-Y	ALL	1999	5330	30%	12		Log-Logistic (3,6.02,0.54)	$ 3.57	$19,013.63
K048 - 11	1999	5,6	54026	Pavement Marking, Traffic Paint (Type A, 12")	LF	1000	$3.75	$ 3,750.00	Q-D-Y	ALL	1998-2000	1000	ALL	10		Lognormal (1,-0.174,0.193)	$ 1.86	$1,856.47
K048 - 11	1999	5,6	54026	Pavement Marking, Traffic Paint (Type A, 12")	LF	1000	$3.75	$ 3,750.00	Q-D-Y	ALL	1998-2000	1000	ALL	10		Lognormal (1,-0.174,0.193)	$ 1.85	$1,854.78
K048 - 11	1999	5,6	54028	Pavement Marking, Traffic Paint (Type A, 24")	LF	2000	$4.75	$ 9,500.00	Q-Y-D	5,6	1997-2001	2000	ALL	11		Log-Logistic (1,5.21,1.2)	$ 2.28	$4,567.91
K048 - 11	1999	5,6	54028	Pavement Marking, Traffic Paint (Type A, 24")	LF	2000	$4.75	$ 9,500.00	Q-Y-D	5,6	1997-2001	2000	ALL	11		Log-Logistic (1,5.21,1.2)	$ 2.26	$4,513.82
012A00022	2000	1	54020	Pavement Marking, Traffic Paint (Type A, 4")	LF	112300	$0.12	$ 13,476.00	Y-D-Q	1,2,3,4,7,9	1993-2001	112300	5%	10		Lognormal (0,-1.5,0.33)	$ 0.23	$26,256.01
12RC9971	1999	1	54020	Pavement Marking, Traffic Paint (Type A, 4")	LF	2050	$0.73	$ 1,498.55	Y-D-Q	1,2	1993-2001	2050	5%	20		Log-Logistic (0,4.81,0.709)	$ 0.76	$1,549.49
K048 - 11	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4")	LF	30000	$0.20	$ 1,498.55	Y-D-Q	4,5,6,7,9	1993-2001	2050	5%	29		Log-Logistic (0,7.75,0.23)	$ 0.24	$7,089.62
K048 - 11	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4")	LF	30000	$0.20	$ 6,000.00	Y-D-Q	4,5,6,7,9	1993-2001	30000	5%	29		Log-Logistic (0,7.75,0.23)	$ 0.24	$7,129.12
011E00005	2000	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4", White)	LF	268308	$0.08	$ 21,464.64	Y-D-Q	ALL	1993-2001	268308	10%	14		Lognormal (0,-1.99,0.168)	$ 0.14	$37,367.53
012E00002	2000	1	54020	Pavement Marking, Traffic Paint (Type A, 4", White)	LF	518566	$0.06	$ 31,113.96	Y-D-Q	1	1993-2001	518566	90%	13		Log-Logistic (0,5.46,0.204)	$ 0.22	$112,200.73
11K089	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4", White)	LF	187700	$0.12	$ 22,524.00	Y-D-Q	4,5,6,7,9	1993-2001	187700	5%	11		Log-Logistic (0,8.38,0.127)	$ 0.13	$24,413.30
12K069	1999	1	54020	Pavement Marking, Traffic Paint (Type A, 4", White)	LF	516142	$0.04	$ 20,645.68	Y-Q-D	1	1993-2001	516142	90%	13		Log-Logistic (0,5.46,0.204)	$ 0.22	$112,255.32
011E00005	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4", Yellow)	LF	126656	$0.08	$ 10,132.48	Y-D-Q	ALL	1993-2001	126656	10%	26		Weibull (0,3.43,0.194)	$ 0.06	$7,292.40

Table D.1 (continue). Records used to generate the findings in the Cost Study

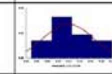
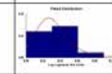
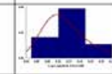
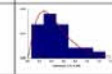
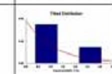
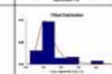
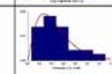
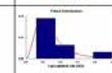
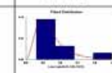
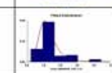
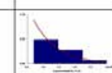
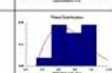
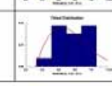
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
012E00002	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4", Yellow)	LF	423232	$0.06	$ 25,393.92	Y-D-Q	ALL	1993-2001	423232	20%	17		Weibull (0,3.12,0.134)	$ 0.04	$17,959.79
11K089	1999	5,6	54020	Pavement Marking, Traffic Paint (Type A, 4", Yellow)	LF	218200	$0.11	$ 24,002.00	Y-D-Q	4,5,6,7,9	1993-2001	218200	5%	12		Log-Logistic (0,10.8,0.129)	$ 0.13	$28,537.64
12K069	1999	1	54020	Pavement Marking, Traffic Paint (Type A, 4", Yellow)	LF	405416	$0.04	$ 16,216.64	Y-D-Q	ALL	1993-2001	405416	15%	12		Log-Logistic (0,4.24,0.109)	$ 0.12	$47,949.76
011E00005	2000	5,6	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	37500	$0.16	$ 6,000.00	Q-Y-D	4,5,6,7,9	1993-2001	37500	ALL	116		Gamma (0,2.37,0.198)	$ 0.47	$17,703.78
012A00022	2000	1	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	400	$0.24	$ 96.00	Y-D-Q	ALL	1993-2001	400	10%	10		Exponential (0,1.15)	$ 1.12	$448.45
012E00002	2000	1	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	43900	$0.20	$ 8,780.00	Q-Y-D	1,2	1993-2001	43900	ALL	69		Log-Logistic (0,3.83,1.2)	$ 1.35	$59,246.02
11K089	1999	5,6	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	31000	$0.20	$ 6,200.00	Q-Y-D	4,5,6,7,9	1993-2001	31000	ALL	116		Gamma (0,2.37,0.198)	$ 0.48	$14,743.04
K048 - 11	1999	5,6	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	1000	$0.40	$ 400.00	Y-D-Q	ALL	1993-2001	1000	10%	18		Log-Logistic (0,2.66,0.633)	$ 0.81	$811.33
K048 - 11	1999	5,6	54024	Pavement Marking, Traffic Paint (Type A, 8")	LF	1000	$0.40	$ 400.00	Y-D-Q	ALL	1993-2001	1000	10%	18		Log-Logistic (0,2.66,0.633)	$ 0.82	$816.84
12K069	1999	1	54024	Pavement Marking, Traffic Paint (Type A, 8", White)	LF	40700	$0.10	$ 4,070.00	Q-Y-D	1,2	1993-2001	40700	ALL	69		Log-Logistic (0,3.83,1.2)	$ 1.34	$54,349.44
K048 - 11	1999	5,6	54310	Pavement Message Marking, Elongated Arrow, Double	EA	10	$200.00	$ 2,000.00	Q-Y-D	5,6	1999	10	75%	10	N/A	$143.41	$ 143.41	$1,434.07
K048 - 11	1999	5,6	54310	Pavement Message Marking, Elongated Arrow, Double	EA	10	$200.00	$ 2,000.00	Q-Y-D	5,6	1999	10	75%	10	N/A	$143.41	$ 143.41	$1,434.07
13K079	1999	1,2	54300	Pavement Message Marking, Elongated Arrow, Single	EA	30	$200.00	$ 6,000.00	Y-Q-D	1,2	1993-2001	30	10%	12		Exponential (70,71.5)	$ 144.43	$4,332.80
K048 - 11	1999	5,6	54300	Pavement Message Marking, Elongated Arrow, Single	EA	10	$100.00	$ 1,000.00	Y-D-Q	5,6	1997-2001	10	5%	15		Weibull (32,1.87,47.2)	$ 56.94	$569.37
K048 - 11	1999	5,6	54300	Pavement Message Marking, Elongated Arrow, Single	EA	10	$100.00	$ 1,000.00	Y-D-Q	5,6	1997-2001	10	5%	15		Weibull (32,1.87,47.2)	$ 57.90	$578.96

Table D.1 (continue). Records used to generate the findings in the Cost Study

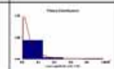
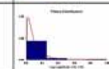
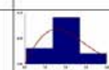
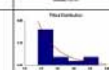
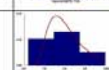
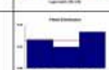
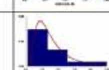
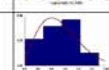
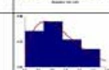
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11D039	1999	5,6	10495	Pilot Truck, Operating Rate	HR	50	$42.44	$ 2,122.00	D-Q-Y	ALL	1999	50	ALL	25	N/A	$17.56	$ 17.56	$877.92
011H00009	2000	5,6	24279	Portable Changeable Message Sign	HR	100	$7.00	$ 700.00	Y-D-Q	4,5,6,7,9	1993-2001	100	5%	26		Log-Logistic (0,1.44,7.76)	$ 19.31	$1,930.74
11B369	1999	5,6	24279	Portable Changeable Message Sign	HR	100	$25.00	$ 2,500.00	Y-D-Q	4,5,6,7,9	1993-2001	100	5%	26		Log-Logistic (0,1.44,7.76)	$ 24.89	$2,489.20
011B00002	1999	5,6	23527	Post (Metal); FE-W1, FE-W2, FE-B	EA	65	$15.00	$ 975.00	Q-Y-D	ALL	1993-2001	65	All	6	N/A	$19.33	$ 19.33	$1,256.67
012B00003	2000	1	23527	Post (Metal); FE-W1, FE-W2, FE-B	EA	15	$11.65	$ 174.75	Q-Y-D	ALL	1993-2001	15	ALL	6	N/A	$19.33	$ 19.33	$290.00
12B0002	2000	1	23527	Post (Metal); FE-W1, FE-W2, FE-B	EA	30	$11.65	$ 349.50	Q-Y-D	ALL	1993-2001	30	ALL	6	N/A	$19.33	$ 19.33	$580.00
13B0002	2000	1,2	23527	Post (Metal); FE-W1, FE-W2, FE-B	EA	15	$15.00	$ 225.00	Q-Y-D	ALL	1993-2001	15	ALL	6	N/A	$19.33	$ 19.33	$290.00
13B0002	2000	1,2	23527	Post (Metal); FE-W1, FE-W2, FE-B	EA	30	$11.65	$ 349.50	Q-Y-D	ALL	1993-2001	30	ALL	6	N/A	$19.33	$ 19.33	$580.00
011E00002	2000	5,6	17329	Post (Wood, Concrete, or Steel)	EA	60	$35.00	$ 2,100.00	D-Y-Q	ALL	1999-2001	60	5%	14		Weibull (0,1.92,23)	$ 12.05	$722.96
011E00003	2000	5,6	17329	Post (Wood, Concrete, or Steel)	EA	80	$35.00	$ 2,800.00	D-Y-Q	ALL	1999-2001	80	5%	14		Exponential (18,11.8)	$ 29.66	$2,372.79
11RC9831	1999	5,6	17329	Post (Wood, Concrete, or Steel)	EA	160	$22.00	$ 3,520.00	D-Y-Q	ALL	1998-2000	160	5%	11		Lognormal (2,2.86,0.48)	$ 21.41	$3,425.58
11U059	1999	5,6	17329	Post (Wood, Concrete, or Steel)	EA	1850	$32.50	$ 60,125.00	Q-D-Y	5,6	1999	1850	20%	12		Uniform (0,20)	$ 9.89	$18,291.06
11U069	1999	5,6	17329	Post (Wood, Concrete, or Steel)	EA	200	$35.00	$ 7,000.00	D-Y-Q	4,5,6,7,9	1999	200	5%	15		Lognormal (1,2.5,0.686)	$ 16.54	$3,307.58
011E00002	2000	5,6	23531	Post, Realign	EA	400	$5.00	$ 2,000.00	D-Q-Y	ALL	2000	400	ALL	19		Weibull (4,1.89,5.95)	$ 7.16	$2,862.17
011E00003	2000	5,6	23531	Post, Realign	EA	600	$5.00	$ 3,000.00	Q-D-Y	4,5,6,7,9	2000	600	ALL	14		Weibull (4,1.56,5.76)	$ 7.72	$4,633.28

Table D.1 (continue). Records used to generate the findings in the Cost Study

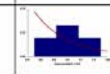
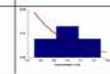
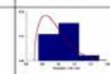
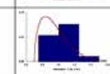
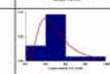
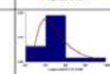
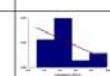
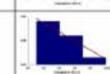
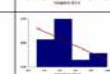
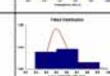
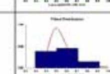
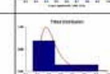
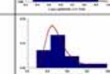
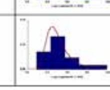
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11RC9831	1999	5,6	23531	Post, Realign	EA	150	$5.00	$ 750.00	Q-D-Y	4,5,6,7,9	1999	150	ALL	11		Exponential (5,5.04)	$ 10.24	$1,535.45
11U069	1999	5,6	23531	Post, Realign	EA	1000	$5.00	$ 5,000.00	Q-D-Y	4,5,6,7,9	1999	1000	ALL	11		Exponential (5,5.04)	$ 9.98	$9,982.61
12U090	2000	1	23531	Post, Realign	EA	300	$5.00	$ 1,500.00	D-Y-Q	ALL	1993-2001	300	10%	13		Weibull (7,1.49,2.87)	$ 8.93	$2,680.25
12U099	1999	1	23531	Post, Realign	EA	300	$5.00	$ 1,500.00	D-Y-Q	ALL	1993-2001	300	10%	13		Weibull (7,1.49,2.87)	$ 8.97	$2,691.02
011E00002	2000	5,6	17355	Post, S3X5.7, GR-3	EA	100	$35.00	$ 3,500.00	Q-D-Y	ALL	1999-2001	100	ALL	18		Lognormal (20,3.31,0.558)	$ 51.72	$5,172.09
011E00003	2000	5,6	17355	Post, S3X5.7, GR-3	EA	200	$35.00	$ 7,000.00	Q-D-Y	ALL	1999-2001	200	ALL	18		Lognormal (20,3.31,0.558)	$ 52.49	$10,497.76
11U069	1999	5,6	17355	Post, S3X5.7, GR-3	EA	550	$40.00	$ 22,000.00	D-Q-Y	ALL	1998-2000	550	ALL	16	N/A	$41.78	$ 41.78	$22,976.79
011B00002	1999	5,6	23525	Post, Wood (FE-W1, FE-W2, FE-B)	EA	2000	$14.00	$ 28,000.00	Q-Y-D	3,4,5,6,7,8,9	1993-2001	2000	ALL	14		Triangular (5,59.9,5)	$ 22.82	$45,646.03
012B00003	2000	1	23525	Post, Wood (FE-W1, FE-W2, FE-B)	EA	8	$15.00	$ 120.00	Q-Y-D	1,2,3,8	1993-2001	8	ALL	11		Triangular (5,56.5,5)	$ 22.21	$177.69
12B0002	2000	1	23525	Post, Wood (FE-W1, FE-W2, FE-B)	EA	15	$15.00	$ 225.00	Y-D-Q	ALL	1993-2001	15	ALL	14		Triangular (5,59.9,5)	$ 22.95	$344.24
011E00002	2000	5,6	17325	Radial Guardrail Beam	LF	240	$12.00	$ 2,880.00	Q-D-Y	3,4,5,6,7,8,9	2000	240	ALL	13		Log-Logistic (29,3.88,23.5)	$ 54.87	$13,169.45
011E00003	2000	5,6	17325	Radial Guardrail Beam	LF	360	$12.00	$ 4,320.00	Q-D-Y	3,4,5,6,7,8,9	2000	360	ALL	13		Log-Logistic (29,3.88,23.5)	$ 54.50	$19,621.21
013E00003	2000	1,2	17325	Radial Guardrail Beam	LF	150	$10.00	$ 1,500.00	Q-D-Y	1,2,3,8	2000	150	ALL	13		Log-Logistic (36,2.77,14.6)	$ 54.26	$8,139.31
11RC9831	1999	5,6	17325	Radial Guardrail Beam	LF	100	$9.00	$ 900.00	Q-D-Y	ALL	1998-2000	100	ALL	36		Log-Logistic (29,3,19.8)	$ 52.83	$5,282.79
11U069	1999	5,6	17325	Radial Guardrail Beam	LF	450	$10.00	$ 4,500.00	Q-D-Y	ALL	1998-2000	450	ALL	36		Log-Logistic (29,3,19.8)	$ 52.80	$23,762.03

Table D.1 (continue). Records used to generate the findings in the Cost Study

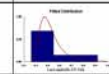
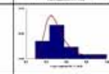
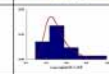
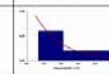
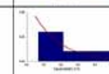
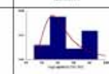
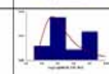
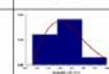
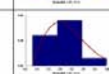
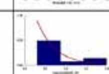
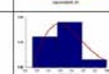
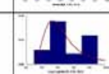
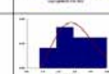
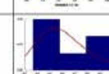
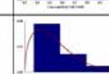
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
12U090	2000	1	17325	Radial Guardrail Beam	LF	400	$9.00	$ 3,600.00	Q-D-Y	1,2,3,8	2000	400	ALL	13		Log-Logistic (36,2.77,14.6)	$ 54.32	$21,727.13
12U099	1999	1	17325	Radial Guardrail Beam	LF	400	$9.00	$ 3,600.00	Q-D-Y	ALL	1998-2000	400	ALL	36		Log-Logistic (29.3,19.8)	$ 52.99	$21,194.29
13U109	1999	1,2	17325	Radial Guardrail Beam	LF	150	$10.00	$ 1,500.00	Q-D-Y	ALL	1998-2000	150	ALL	36		Log-Logistic (29.3,19.8)	$ 52.69	$7,902.98
12B479	1999	1	11184	Resealing Joints (HPJS)	LF	774	$3.90	$ 3,018.60	Q-Y-D	ALL	1993-2001	774	ALL	10		Exponential (1.3,11)	$ 4.05	$3,137.99
13B469	1999	1,2	11184	Resealing Joints (HPJS)	LF	455	$8.00	$ 3,640.00	Q-Y-D	ALL	1993-2001	455	ALL	10		Exponential (1.3,11)	$ 4.06	$1,847.89
012A00012	1999	1	27440	Roadside Mowing (Hourly)	HR	40	$35.00	$ 1,400.00	Y-D-Q	1,2,3,4,7	ALL	40	5%	27		Log-Logistic (15,2.51,16.3)	$ 36.24	$1,449.62
012A00012	1999	1	27440	Roadside Mowing (Hourly)	HR	40	$40.00	$ 1,600.00	Y-D-Q	1,2,3,4,7	1993-2001	40	5%	27		Log-Logistic (15,2.51,16.3)	$ 35.89	$1,435.78
12RC9917	1999	1	27440	Roadside Mowing (Hourly)	HR	1	$12.50	$ 12.50	Q-Y-D	1	1998-2000	1	ALL	11		Weibull (8,1.91,17.1)	$ 17.05	$17.05
12RC9917	1999	1	27440	Roadside Mowing (Hourly)	HR	1	$75.00	$ 75.00	Q-Y-D	1	1998-2000	1	ALL	11		Weibull (8,1.91,17.1)	$ 16.98	$16.98
12RC9918	1999	1	27440	Roadside Mowing (Hourly)	HR	3	$19.50	$ 58.50	Y-D-Q	ALL	1993-2001	3	400%	10		Exponential (30,45)	$ 74.98	$224.95
12RC9918	1999	1	27440	Roadside Mowing (Hourly)	HR	1	$65.00	$ 65.00	Q-Y-D	1	1998-2000	1	ALL	11		Weibull (8,1.91,17.1)	$ 17.27	$17.27
13RC9003	1999	1,2	27440	Roadside Mowing (Hourly)	HR	40	$35.00	$ 1,400.00	Y-D-Q	1,2,3,4,7,8	1993-2001	40	5%	27		Log-Logistic (15,2.51,16.3)	$ 35.80	$1,431.85
13RC9840	1999	1,2	27440	Roadside Mowing (Hourly)	HR	500	$45.00	$ 22,500.00	Q-Y-D	1,2	1998-2000	500	ALL	24		Weibull (8,2.2,26)	$ 19.88	$9,942.08
011A00014	2000	5,6	10700	Rumble Strips	LF	57161	$0.24	$ 13,718.64	D-Y-Q	ALL	1993-2001	57161	20%	12		Log-Logistic (0,4.46,0.594)	$ 0.65	$37,297.75
012A00026	2000	1	10700	Rumble Strips	LF	383412	$0.24	$ 92,018.88	Q-D-Y	1,2,3,8	2000	383412	ALL	12		Weibull (0,1.45,0.757)	$ 0.54	$205,541.85

Table D.1 (continue). Records used to generate the findings in the Cost Study

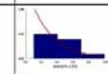
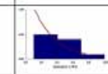
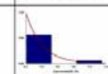
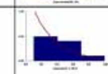
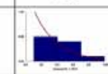
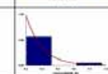
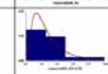
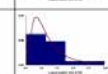
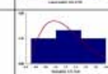
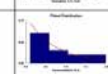
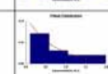
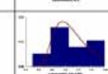
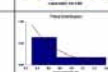
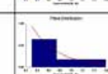
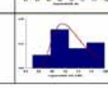
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011E00002	2000	5,6	17344	Soil Plate (GR-7)	EA	2	$100.00	$ 200.00	Q-Y-D	5,6	1999-2001	2	ALL	10		Gamma (10,1,28.5)	$ 38.36	$76.72
011E00003	2000	5,6	17344	Soil Plate (GR-7)	EA	2	$100.00	$ 200.00	Q-Y-D	5,6	1999-2001	2	ALL	10		Gamma (10,1,28.5)	$ 38.92	$77.84
013E00003	2000	1,2	17344	Soil Plate (GR-7)	EA	36	$200.00	$ 7,200.00	Q-Y-D	1,2,3,4,7,8	1993-2001	36	ALL	11		Exponential (20,20)	$ 39.74	$1,430.67
11RC9831	1999	5,6	17344	Soil Plate (GR-7)	EA	1	$200.00	$ 200.00	Q-Y-D	5,6	1998-2000	1	ALL	10		Gamma (10,1,28.5)	$ 39.24	$39.24
11U069	1999	5,6	17344	Soil Plate (GR-7)	EA	5	$40.00	$ 200.00	Q-Y-D	5,6	1998-2000	5	ALL	10		Gamma (10,1,28.5)	$ 37.92	$189.58
13U109	1999	1,2	17344	Soil Plate (GR-7)	EA	1	$200.00	$ 200.00	Q-Y-D	1,2,3,4,7,8	1993-2001	1	ALL	11		Exponential (20,20)	$ 40.49	$40.49
011E00002	2000	5,6	17367	Spring Cable End Assembly (GR-3)	EA	2	$200.00	$ 400.00	Q-D-Y	3,4,5,6,7,8, 9	2000	2	ALL	18		Lognormal (50,4.04,0.744)	$ 124.99	$249.98
011E00003	2000	5,6	17367	Spring Cable End Assembly (GR-3)	EA	2	$200.00	$ 400.00	Q-D-Y	3,4,5,6,7,8, 9	2000	2	ALL	18		Lognormal (50,4.04,0.744)	$ 122.12	$244.25
11U069	1999	5,6	17367	Spring Cable End Assembly (GR-3)	EA	3	$135.00	$ 405.00	Q-D-Y	3,4,5,6,7,8, 9	1999	3	ALL	10		Weibull (50,1.73,76.9)	$ 93.90	$281.70
011E00002	2000	5,6	17342	Steel Tube (GR-7)	EA	3	$100.00	$ 300.00	Q-D-Y	4,5,6,7,9	2000	3	ALL	14		Exponential (10,70.4)	$ 82.56	$247.67
011E00003	2000	5,6	17342	Steel Tube (GR-7)	EA	3	$100.00	$ 300.00	Q-D-Y	4,5,6,7,9	2000	3	ALL	14		Exponential (10,70.4)	$ 80.20	$240.60
013E00003	2000	1,2	17342	Steel Tube (GR-7)	EA	2	$200.00	$ 400.00	D-Y-Q	ALL	1993-2001	2	50%	15		Lognormal (50,4.05,0.468)	$ 113.72	$227.44
11RC9831	1999	5,6	17342	Steel Tube (GR-7)	EA	1	$200.00	$ 200.00	Q-D-Y	4,5,6,7,9	1999	1	ALL	11		Exponential (30,46)	$ 75.29	$75.29
11U069	1999	5,6	17342	Steel Tube (GR-7)	EA	6	$80.00	$ 480.00	Q-D-Y	4,5,6,7,9	1999	6	ALL	11		Exponential (30,46)	$ 74.84	$449.03
13U109	1999	1,2	17342	Steel Tube (GR-7)	EA	2	$200.00	$ 400.00	D-Y-Q	ALL	1933-2001	2	50%	15		Lognormal (50,4.05,0.468)	$ 114.47	$228.93

Table D.1 (continue). Records used to generate the findings in the Cost Study

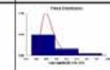
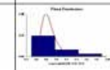
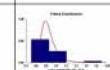
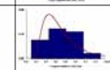
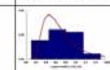
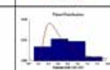
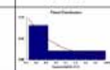
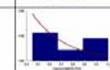
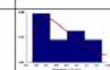
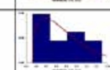
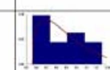
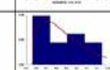
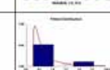
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
011E00002	2000	5,6	17365	Steel Turnbuckle Cable Assembly (GR-3)	EA	2	$100.00	$ 200.00	D-Y-Q	ALL	1994-2001	2	5%	13		Log-Logistic (50,3.76,33.1)	$ 87.76	$175.52
011E00003	2000	5,6	17365	Steel Turnbuckle Cable Assembly (GR-3)	EA	2	$100.00	$ 200.00	D-Y-Q	ALL	1994-2001	2	5%	13		Log-Logistic (50,3.76,33.1)	$ 88.00	$176.00
11U069	1999	5,6	17365	Steel Turnbuckle Cable Assembly (GR-3)	EA	3	$110.00	$ 330.00	D-Y-Q	ALL	1993-2001	3	35%	19		Log-Logistic (50,4.02,32.2)	$ 85.40	$256.21
011E00002	2000	5,6	17352	Strut and Yoke Assembly (GR-7)	EA	3	$150.00	$ 450.00	Q-D-Y	ALL	1999-2001	3	ALL	30		Lognormal (10,3.93,0.6)	$ 70.24	$210.73
011E00003	2000	5,6	17352	Strut and Yoke Assembly (GR-7)	EA	3	$150.00	$ 450.00	Q-D-Y	ALL	1999-2001	3	ALL	30		Lognormal (10,3.93,0.6)	$ 71.20	$213.59
013E00003	1999	1,2	17352	Strut and Yoke Assembly (GR-7)	EA	3	$200.00	$ 600.00	Q-D-Y	ALL	1999-2001	3	ALL	30		Pearson 5 (10,2.97,127)	$ 70.52	$211.55
11RC9831	1999	5,6	17352	Strut and Yoke Assembly (GR-7)	EA	1	$200.00	$ 200.00	D-Y-Q	ALL	1994-2001	1	5%	14		Exponential (45,57.1)	$ 101.00	$101.00
11U069	1999	5,6	17352	Strut and Yoke Assembly (GR-7)	EA	5	$65.00	$ 325.00	Q-D-Y	4,5,6,7,9	1999	5	ALL	11		Exponential (45,28.6)	$ 72.30	$361.51
13U109	1999	1,2	17352	Strut and Yoke Assembly (GR-7)	EA	3	$200.00	$ 600.00	Q-D-Y	1,2,3,4,7,9	1999	3	ALL	12	N/A	$55.21	$ 55.21	$165.64
012A00025	2000	1	16502	Surface Preparation and Restoration, Type I or II	TN	990	$150.00	$ 148,500.00	Y-Q-D	1,2,3,8	1993-2001	990	ALL	28		Weibull (56,1.33,35.2)	$ 81.67	$80,853.41
012A99057	1999	1	16502	Surface Preparation and Restoration, Type I or II	TN	100	$150.00	$ 15,000.00	Y-Q-D	1,2,3,8	1993-2001	100	ALL	28		Weibull (56,1.33,35.2)	$ 83.34	$8,333.93
11P209	1999	5,6	16502	Surface Preparation and Restoration, Type I or II	TN	750	$150.00	$ 112,500.00	Y-Q-D	4,5,6,7,9	1993-2001	750	ALL	66	N/A	$64.91	$ 64.91	$48,682.74
12P148	1998	1	16502	Surface Preparation and Restoration, Type I or II	TN	100	$150.00	$ 15,000.00	Y-Q-D	1,2,3,8	1993-2001	100	ALL	28		Weibull (56,1.33,35.2)	$ 82.85	$8,284.61
12P219	1999	1	16502	Surface Preparation and Restoration, Type I or II	TN	420	$150.00	$ 63,000.00	Y-Q-D	1,2,3,8	1993-2001	420	ALL	28		Weibull (56,1.33,35.2)	$ 82.73	$34,747.10
012A99057	1999	1	16504	Surface Preparation and Restoration, Type III	TN	100	$100.00	$ 10,000.00	Y-D-Q	ALL	1993-2001	100	30%	12		Log-Logistic (25,1.3,31.4)	$ 120.12	$12,012.25

Table D.1 (continue). Records used to generate the findings in the Cost Study

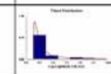
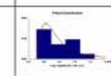
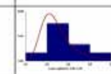
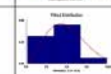
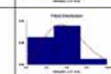
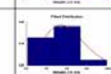
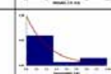
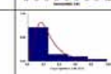
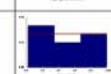
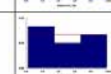
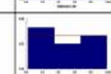
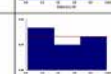
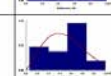
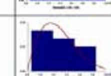
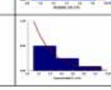
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11P209	1999	5,6	16504	Surface Preparation and Restoration, Type III	TN	2100	$90.00	$ 189,000.00	Y-Q-D	4,5,6,7,9	1993-2001	2100	ALL	33		Log-Logistic (25,1.29,23.7)	$ 91.33	$191,803.38
12P219	1999	1	16504	Surface Preparation and Restoration, Type III	TN	1500	$100.50	$ 150,750.00	Y-Q-D	1,2,3,8	1993-2001	1500	ALL	14		Log-Logistic (50,1.86,22.7)	$ 87.58	$131,363.67
11B419	1999	5,6	27505	Temporary Silt Fence	LF	150	$2.25	$ 337.50	Y-D-Q	4,5,6,7,9	1993-2001	150	5%	17		Log-Logistic (1,3.28,1.34)	$ 2.57	$385.29
011E00002	2000	5,6	17343	Terminal Connector (GR-7)	EA	3	$100.00	$ 300.00	Q-Y-D	5,6	1999-2001	3	ALL	13		Weibull (1,2.21,43.6)	$ 20.90	$62.70
011E00003	2000	5,6	17343	Terminal Connector (GR-7)	EA	3	$100.00	$ 300.00	Q-Y-D	5,6	1999-2001	3	ALL	13		Weibull (1,2.21,43.6)	$ 21.21	$63.62
11U069	1999	5,6	17343	Terminal Connector (GR-7)	EA	6	$40.00	$ 240.00	Q-Y-D	5,6	1998-2000	6	ALL	13		Weibull (1,2.21,43.6)	$ 20.80	$124.78
11B369	1999	5,6	24290	Traffic Barrier Service, Concrete	LF	384	$9.00	$ 3,456.00	D-Y-Q	ALL	1998-2000	384	5%	11		Exponential (8,4.45)	$ 12.42	$4,768.98
11P178	1998	5,6	24272	Truck Mounted Attenuator	DY	50	$250.00	$ 12,500.00	D-Q-Y	4,5,6,7,9	1998	50	5%	21		Log-Logistic (1,2.46,22.2)	$ 29.59	$1,479.63
11RC9812	1999	5,6	24272	Truck Mounted Attenuator	DY	10	$150.00	$ 1,500.00	D-Q-Y	ALL	1999	10	250%	12		Uniform (1,50)	$ 25.47	$254.74
12I079	1999	1	24272	Truck Mounted Attenuator	DY	10	$125.00	$ 1,250.00	D-Q-Y	ALL	1999	10	250%	12		Uniform (1,50)	$ 25.26	$252.58
13I089	1999	1,2	24272	Truck Mounted Attenuator	DY	15	$125.00	$ 1,875.00	D-Q-Y	ALL	1999	15	150%	12		Uniform (1,50)	$ 25.10	$376.45
13I089	1999	1,2	24272	Truck Mounted Attenuator	DY	15	$125.00	$ 1,875.00	D-Q-Y	ALL	1999	15	150%	12		Uniform (1,50)	$ 25.82	$387.23
12R119	1999	1	10123	Type 2 Repair: Furnish and install aggregate	TN	540	$15.50	$ 8,370.00	Y-D-Q	ALL	1993-2001	540	10%	21		Weibull (8,2.09,7.89)	$ 11.98	$6,468.36
13R129	1999	1,2	10123	Type 2 Repair: Furnish and install aggregate	TN	515	$10.00	$ 5,150.00	Y-D-Q	ALL	1993-2001	515	5%	12		Weibull (8,1.85,5.41)	$ 10.95	$5,639.05
13R139	1999	1,2	10123	Type 2 Repair: Furnish and install aggregate	TN	404	$12.50	$ 5,050.00	Y-D-Q	ALL	1993-2001	404	5%	10		Exponential (11,3.21)	$ 14.23	$5,750.58

Table D.1 (continue). Records used to generate the findings in the Cost Study

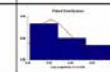
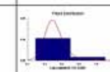
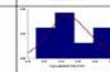
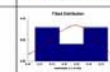
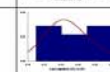
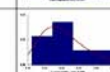
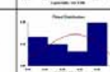
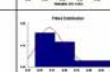
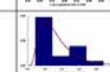
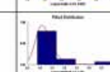
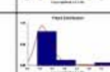
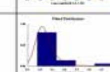
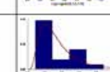
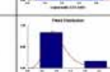
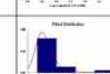
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS										
									QUERY INPUT					QUERY RESULTS					
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
13K109	1999	1,2	54020	Type A, traffic Paint Line Marking, 4" (White)	LF	22784	$0.10	$ 2,278.40	Y-D-Q	1,2,3,8	1993-2001	22784	5%	10		Log-Logistic (0,5.4,0.329)	$ 0.35	$7,942.12
13K109A	1999	1,2	54020	Type A, traffic Paint Line Marking, 4" (White)	LF	8000	$0.15	$ 1,200.00	Y-D-Q	1,2,3,8	1993-2001	8000	5%	14		Log-Logistic (0,7.51,0.502)	$ 0.52	$4,131.64
013E00002	2000	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	302433	$0.06	$ 18,145.98	Y-D-Q	ALL	1993-2001	302433	10%	16		Log-Logistic (0,9.26,0.151)	$ 0.15	$46,441.40
013E00002	2000	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	392523	$0.06	$ 23,551.38	Y-Q-D	1,2	1993-2001	392523	80%	10		Weibull (0,5.3,0.185)	$ 0.04	$14,170.67
13K079	1999	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	300493	$0.04	$ 12,019.72	Y-D-Q	ALL	1993-2001	300493	5%	11		Log-Logistic (0,8.27,0.147)	$ 0.15	$45,553.02
13K079	1999	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	366013	$0.04	$ 14,640.52	Y-Q-D	1,2	1993-2001	366013	85%	14		Lognormal (0,-1.63,0.338)	$ 0.21	$75,906.14
13K109	1999	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	36208	$0.10	$ 3,620.80	Y-D-Q	1,2	1995-2001	36208	5%	15		Weibull (0,4.81,0.353)	$ 0.07	$2,673.20
13K109A	1999	1,2	54020	Type A, Traffic Paint Line Marking, 4" (yellow)	LF	29344	$0.15	$ 4,401.60	Y-D-Q	1,2,3,4,7,8	1993-2001	29344	5%	23		Log-Logistic (0,6.62,0.249)	$ 0.26	$7,540.13
013E00002	2000	1,2	54024	Type A, Traffic Paint Line Marking, 8" (white)	LF	72597	$0.20	$ 14,519.40	Q-Y-D	1,2	2000	72597	ALL	17		Lognormal (0,0.372,0.602)	$ 1.71	$124,056.67
13K079	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (white)	LF	50441	$0.10	$ 5,044.10	Q-Y-D	1,2	1999	50441	ALL	15		Log-Logistic (0,5.4,1.16)	$ 1.21	$61,053.89
13K109	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (white)	LF	40280	$0.20	$ 8,056.00	Q-Y-D	1,2	1999	40280	ALL	15		Log-Logistic (0,5.4,1.16)	$ 1.21	$48,764.26
13K109A	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (white)	LF	40280	$0.20	$ 8,056.00	Q-Y-D	1,2	1999	40280	ALL	15		Log-Logistic (0,5.4,1.16)	$ 1.21	$48,698.32
013E00002	2000	1,2	54024	Type A, Traffic Paint Line Marking, 8" (yellow)	LF	18140	$0.20	$ 3,628.00	Q-Y-D	1,2	2000	18140	ALL	17		Lognormal (0,0.372,0.602)	$ 1.73	$31,372.80
13K079	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (yellow)	LF	7077	$0.10	$ 707.70	Y-Q-D	1,2	1993-2001	7077	50%	12		Log-Logistic (0,4.21,0.989)	$ 1.09	$7,727.02
13K109	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (yellow)	LF	30624	$0.19	$ 5,818.56	Q-Y-D	1,2	1999	30624	ALL	15		Log-Logistic (0,5.4,1.16)	$ 1.24	$37,855.24

Table D.1 (continue). Records used to generate the findings in the Cost Study

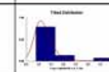
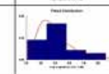
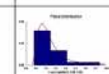
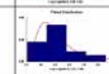
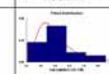
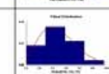
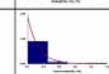
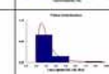
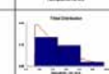
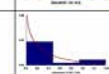
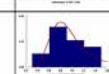
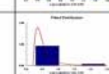
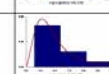
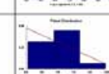
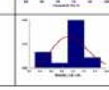
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
13K109A	1999	1,2	54024	Type A, Traffic Paint Line Marking, 8" (yellow)	LF	30624	$0.19	$ 5,818.56	Q-Y-D	1,2	1999	30624	ALL	15		Log-Logistic (0,5.4,1.16)	$ 1.22	$37,332.12
012A00025	2000	1	588	Under-Drain (UD-4)	LF	6450	$11.15	$ 71,917.50	Y-D-Q	1,2,3,4,7,8, 9	1993-2001	6450	5%	22		Log-Logistic (3,2.51,1.86)	$ 5.40	$34,816.88
012A99057	1999	1	588	Under-Drain (UD-4)	LF	150	$21.00	$ 3,150.00	Y-D-Q	ALL	1993-2001	150	20%	19		Log-Logistic (3,2.29,7.53)	$ 13.76	$2,064.38
11P209	1999	5,6	588	Under-Drain (UD-4)	LF	5307	$11.50	$ 61,030.50	Y-D-Q	ALL	1993-2001	5307	5%	22		Log-Logistic (3,2.51,1.86)	$ 5.46	$28,966.70
12P219	1999	1	588	Under-Drain (UD-4)	LF	6700	$11.15	$ 74,705.00	Y-D-Q	ALL	1993-2001	6700	5%	22		Log-Logistic (3,2.51,1.86)	$ 5.58	$37,386.55
012A00025	2000	1	596	Under-Drain Endwall (EW-12)	EA	31	$377.00	$ 11,687.00	Y-D-Q	1,2,3,4,7,8	1993-2001	31	5%	18		Weibull (150,1.95,141)	$ 223.34	$6,923.68
012A99057	1999	1	596	Under-Drain Endwall (EW-12)	EA	1	$5.30	$ 5.30	Y-D-Q	1,2	1993-2001	1	5%	29		Exponential (200,130)	$ 333.96	$333.96
11P209	1999	5,6	596	Under-Drain Endwall (EW-12)	EA	22	$575.00	$ 12,650.00	Y-D-Q	4,5,6,7,9	1993-2001	22	5%	13		Log-Logistic (195,2.05,96.9)	$ 336.04	$7,392.78
12P219	1999	1	596	Under-Drain Endwall (EW-12)	EA	33	$377.00	$ 12,441.00	Y-D-Q	1,2,3,4,7,8, 9	1993-2001	33	5%	28		Weibull (181,1.07,93.8)	$ 268.36	$8,855.94
012A00025	2000	1	595	Under-Drain Outlet Pipe	LF	513	$13.20	$ 6,771.60	Y-Q-D	1	1993-2001	513	40%	12		Gamma (5,0.782,2.55)	$ 7.02	$3,603.69
012A99057	1999	1	595	Under-Drain Outlet Pipe	LF	28	$21.00	$ 588.00	Y-D-Q	1,2,3,8	1993-2001	28	5%	15		Log-Logistic (3,3.24,6.02)	$ 10.22	$286.23
11P209	1999	5,6	595	Under-Drain Outlet Pipe	LF	580	$35.00	$ 20,300.00	Y-Q-D	5,6	1993-2001	580	30%	12		Log-Logistic (2,1.93,2.55)	$ 6.38	$3,702.93
12P219	1999	1	595	Under-Drain Outlet Pipe	LF	575	$13.20	$ 7,590.00	Y-Q-D	1	1993-2001	575	40%	12		Log-Logistic (4,3.3,1.65)	$ 5.95	$3,421.88
12B479	1999	1	24279	Variable Message Board	HR	570	$15.00	$ 8,550.00	Y-D-Q	1,2,3,4,7,8	1993-2001	570	5%	13		Triangular (0,28.5,0)	$ 9.75	$5,558.27
13B469	1999	1,2	24279	Variable Message Board	HR	600	$15.00	$ 9,000.00	Y-D-Q	1,2,3,8	1993-2001	600	5%	15		Weibull (3,2.48,7.59)	$ 5.98	$3,585.57

Table D.1 (continue). Records used to generate the findings in the Cost Study

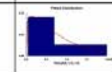
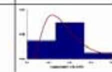
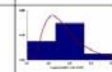
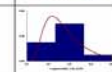
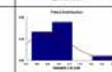
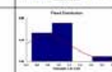
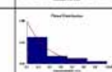
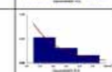
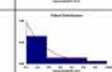
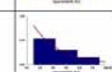
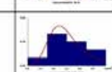
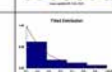
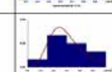
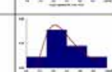
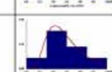
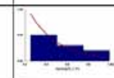
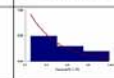
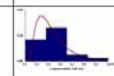
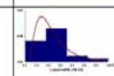
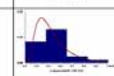
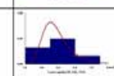
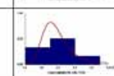
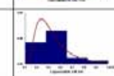
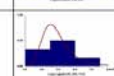
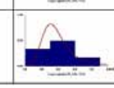
DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
11RC9812	1999	5,6	24287	Warning Light	DY	10	$0.35	$ 3.50	Y-D-Q	ALL	1993-2001	10	30%	11		Weibull (0,1.15,7.8)	$ 6.85	$68.51
12I079	1999	1	1999	Warning Light	DY	25	$15.00	$ 375.00	Y-D-Q	1,2	1993-2001	25	5%	10		Lognormal (2,1.16,0.537)	$ 5.64	$140.95
13I089	1999	1,2	24287	Warning Light	DY	25	$15.00	$ 375.00	Y-D-Q	1,2	1995-2001	25	5%	10		Lognormal (2,1.16,0.537)	$ 5.68	$141.97
13I089	1999	1,2	24287	Warning Light	DY	25	$15.00	$ 375.00	Y-D-Q	1,2	1995-2001	25	5%	10		Lognormal (2,1.16,0.537)	$ 5.73	$143.19
I058 - 13	1999	1,2	24287	Warning Light	DY	100	$15.00	$ 1,500.00	Y-D-Q	1,2	1999	100	5%	15		Weibull (0,2.36,0.98)	$ 0.41	$40.62
I058 - 13	1999	1,2	24287	Warning Light	DY	100	$15.00	$ 1,500.00	Y-D-Q	1,2	1999	100	5%	15		Weibull (0,2.36,0.98)	$ 0.40	$40.20
011E00002	2000	5,6	17313	W-Beam End Section, Flared	EA	4	$50.00	$ 200.00	D-Q-Y	ALL	2000	4	ALL	16		Exponential (30,17.5)	$ 47.35	$189.39
011E00003	2000	5,6	17313	W-Beam End Section, Flared	EA	6	$50.00	$ 300.00	D-Y-Q	ALL	1993-2001	6	35%	13		Exponential (25,20.4)	$ 45.59	$273.56
013E00003	2000	1,2	17313	W-Beam End Section, Flared	EA	15	$30.00	$ 450.00	Q-D-Y	1,2,3,4,7,8, 9	2000	15	ALL	14		Exponential (30,18.2)	$ 48.54	$728.07
11RC9831	1999	5,6	17313	W-Beam End Section, Flared	EA	4	$30.00	$ 120.00	D-Y-Q	ALL	1993-2001	4	100%	13		Exponential (25,20.4)	$ 45.94	$183.74
11U069	1999	5,6	17313	W-Beam End Section, Flared	EA	10	$35.00	$ 350.00	D-Q-Y	ALL	1999	10	ALL	20		Log-Logistic (20,3.54,14.3)	$ 36.67	$366.65
12U090	2000	1	17313	W-Beam End Section, Flared	EA	8	$30.00	$ 240.00	D-Q-Y	ALL	2000	8	ALL	16		Exponential (30,17.5)	$ 47.56	$380.46
12U099	1999	1	17313	W-Beam End Section, Flared	EA	8	$30.00	$ 240.00	D-Q-Y	ALL	1999	8	ALL	20		Log-Logistic (20,3.54,14.3)	$ 36.11	$288.90
13U089	1999	1,2	17313	W-Beam End Section, Flared	EA	1	$800.00	$ 800.00	Q-D-Y	1,2,3,4,7,8, 9	1999	1	ALL	15		Lognormal (20,2.6,0.475)	$ 35.10	$35.10
13U109	1999	1,2	17313	W-Beam End Section, Flared	EA	15	$30.00	$ 450.00	Q-D-Y	1,2,3,4,7,8, 9	1999	15	ALL	15		Lognormal (20,2.6,0.475)	$ 35.27	$529.03

Table D.1 (continue). Records used to generate the findings in the Cost Study

DESCRIPTION OF VMS SPECIFIC CONTRACT ITEMS									VDOT UNIT PRICES BASED ON QUERIES FROM BIDTABS									
									QUERY INPUT					QUERY RESULTS				
CONTRACT NUMBER	YEAR AWARDED	DISTRICT	ACTIVITY CODE	ACTIVITY DESCRIPTION	UNIT	BID QUANTITY	VMS UNIT PRICE	VMS TOTAL COST	HEURISTIC	DISTRICT	YEAR	BASE QUANTITY	QUANTITY VARIANCE	NO. OF POINTS INCLUDED	DISTRIBUTION	FORMULA	SIMULATED AVERAGE UNIT PRICE	SIMULATED AVERAGE TOTAL COST
012E01002	2001	1	17317	W-Beam End Section, Rounded	EA	1	$100.00	$ 100.00	Q-Y-D	1,2,3,8	1993-2001	1	ALL	10		Gamma (25,1,27)	$ 52.15	$52.15
012E01002	2001	1	17317	W-Beam End Section, Rounded	EA	3	$100.00	$ 300.00	Q-Y-D	1,2,3,8	1993-2001	3	ALL	10		Gamma (25,1,27)	$ 52.78	$158.34
011E00002	2000	5,6	17311	W-Beam Terminal Connector	EA	2	$200.00	$ 400.00	Q-D-Y	ALL	1999-2001	2	ALL	21		Lognormal (30,2.98,0.6)	$ 53.90	$107.80
011E00003	2000	5,6	17311	W-Beam Terminal Connector	EA	2	$200.00	$ 400.00	Q-D-Y	ALL	1999-2001	2	ALL	21		Lognormal (30,2.98,0.6)	$ 53.71	$107.42
013E00003	2000	1,2	17311	W-Beam Terminal Connector	EA	4	$30.00	$ 120.00	Q-D-Y	ALL	1999-2001	4	ALL	21		Lognormal (30,2.98,0.6)	$ 53.82	$215.28
11RC9831	1999	5,6	17311	W-Beam Terminal Connector	EA	3	$30.00	$ 90.00	Q-D-Y	ALL	1999	3	ALL	12		Log-Logistic (30,3.65,17.9)	$ 49.91	$149.72
11U069	1999	5,6	17311	W-Beam Terminal Connector	EA	5	$40.00	$ 200.00	Q-D-Y	ALL	1999	5	ALL	12		Log-Logistic (30,3.65,17.9)	$ 50.13	$250.66
12U090	2000	1	17311	W-Beam Terminal Connector	EA	5	$30.00	$ 150.00	Q-D-Y	ALL	1999-2001	5	ALL	21		Lognormal (30,2.98,0.6)	$ 53.27	$266.34
12U099	1999	1	17311	W-Beam Terminal Connector	EA	5	$30.00	$ 150.00	Q-D-Y	ALL	1999	5	ALL	12		Log-Logistic (30,3.65,17.9)	$ 49.92	$249.62
13U109	1999	1,2	17311	W-Beam Terminal Connector	EA	4	$30.00	$ 120.00	Q-D-Y	ALL	1999	4	ALL	12		Log-Logistic (30,3.65,17.9)	$ 50.10	$200.41
Total Cost								$ 12,860,027										$ 14,076,306

VITA

Juan Carlos Piñero was born on November 26, 1975 in Guaynabo, Puerto Rico, the youngest of three children of Raquel Rivera and Carlos Piñero. He attended the University of Puerto Rico – Mayagüez Campus, where he received a Bachelor of Science in Civil Engineering in May 1998. Upon graduation, a construction company hired him as a Project Engineer. In January 1999, he married Luz E. Santiago and began graduate studies in the Engineering Science and Mechanics Department at Virginia Polytechnic Institute and State University where he worked under the tutelage of Dr. M.P. Singh. He became the father of a beautiful baby boy, Christian Alexander, in February 2000. During the last summer of his graduate studies in the Engineering Science and Mechanics Department, he worked as a structural engineer for a consulting firm in Puerto Rico. In August 2000, he joined the Civil and Environmental Engineering Department of Virginia Polytechnic Institute and State University to continue doctoral studies in the area of Construction Engineering and Management under the tutelage of Dr. J.M. de la Garza. He received the degree of Master of Science in Engineering Mechanics in May 2001. While working on his doctoral studies, he obtained a Professional Engineer License from the Commonwealth of Puerto Rico. He received the degree of Doctor of Philosophy in Civil Engineering in December 2003.