Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TX-95/1968-1F		

4. Title and Subtitle	5. Report Date
A MAINTENANCE-LEVEL-OF-SERVICE EVALUATION PROCEDURE FOR TEXAS	December 1994
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Donald L. Woods, Silvana Alcoz, Roger E. Smith, and Rodger J. Koppa	Research Report 1968-1F
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Study No. 7-1968
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	Final: February 1993 - August 1994
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation.
Research Study Title: Measuring and Evaluating Levels-of-Service of the Texas Highway System.

16. Abstract

The level of maintenance within the state of Texas varies to a substantial degree. Desirably the maintenance would be a reasonably uniform level across all the various essential components. The purpose of this project was to devise methods for objectively measuring the essential elements maximizing automated data collection techniques.

The development team has reviewed the literature on maintenance evaluation. Three sources stand out: ROCOND 87 and ROCOND 90 from Australia, the Virginia Program, and the Florida Program. Each of these sources has helped shape the recommended evaluation procedure for Texas.

The various maintenance elements were divided into seasons of the year to adapt to the time when that element would be critical. Those that are not time dependent were distributed to balance the data collection workload. Many continuous elements, such as vegetation, roadside drainage, etc., are scheduled for video tape data collection. Selected features will be collected visually by the data collection operator; noxious weeds, pavement edge drop-off, and cross drainage structures are typical examples.

A random site selection program has been prepared to obtain 0.15 km (0.1 mile) length sample sites. The evaluation program has been conceptually developed and has been fully field tested prior to full scale implementation.

17. Key Words	18. Distribution Statement
Maintenance Evaluation, Maintenance Level of Service	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	144	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

A MAINTENANCE-LEVEL-OF-SERVICE EVALUATION PROCEDURE FOR TEXAS

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Sponsored by the
Texas Department of Transportation

December 1994

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IMPLEMENTATION STATEMENT

The evaluation procedure described in this report is the initial step in a statewide maintenance-level-of-service evaluation. While the research team believes that this procedure is practical, it must be fully field tested prior to a full scale application. The recommended implementation procedure is to:

1. Field test the procedure in one county;
2. Refine the procedure of its deficiencies;
3. Implement.

It is believed that full implementation of the maintenance-level-of-service evaluation process as modified after the detailed field tests, will provide unbiased data on the essential maintenance elements. This will lead to substantial improvement in the management and maintenance of the Texas Highway System.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Dr. Donald L. Woods (P.E. # 21315) was the Principal Investigator for the project.

ACKNOWLEDGMENT

The work reported herein was accomplished through a team effort. Many individuals contributed ideas and expertise. While it is not possible to identify each individual, a few must be cited for their special contributions. Among the many TTI staff, Paul Chan, Silvana Alcoz, Roger Smith, Roger Koppa, Dick Zimmer, and John Witz deserve special recognition.

The contributions of Bryan District, Abilene District, and San Antonio District maintenance personnel are gratefully acknowledged. They contributed a great deal of practical insight to the evaluation process. Joe Graff, Bob Blackwell, and Ken Boehme of the TxDOT Maintenance Division provided the guidance and support throughout the project. That guidance was crucial in the process of developing the evaluation process.

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SUMMARY

A system for evaluating the maintenance-level-of-service of Texas Highways based on a maximum of automated data collection is proposed. The random site selection ensures a reasonable level of data accuracy and objectivity. The objectivity is crucial due to the desire to compare the performance between Districts within the state. The following items are included in the proposed procedure:

1. Vegetation
2. Pavement Edge
3. Safety Appurtenances
4. Signs and Delineators
5. Litter Control
6. Drainage
7. Illumination
8. Pavement Markings

The procedure recommended is a number of randomly selected .16 kilometer (.1 mile) segments on each of four roadway classifications. Intersection vegetation and guard fence end treatment data are to be recorded whenever the data collection operator encounters one of these situations on the way to a site or within a site. This is necessary due to the low frequency of intersections and guard fence end treatments in the .16 kilometer (.1 mile) segments.

Most data are collected on video tape or electronically. Noxious weeds and cross drainage culverts require the operator to exit the vehicle to visually inspect each of these elements when they are encountered. The data collection process is then a two pass evaluation. The first is to video tape the section and the second to examine the specific features on the roadside.

A computer program was prepared to randomly select study sites from the roadway mileage in road classification within the District. The random sites are necessary for two reasons: 1) comparing Districts will be controversial; therefore, there must be no doubt that the sample is unbiased; and, 2) if the District personnel know that the site will be reviewed multiple times, the system can be manipulated to obtain a particular outcome. The purpose is to improve system wide maintenance uniformity. Thus, the random site concept entails a new set of sites each time the data collection process is undertaken within a District.

Quality control is also a dominate issue. The recommended procedure to insure a reasonable level of consistency in the data collection is to have a supervising data collection person (either in-house or by contract) sample a few of the same sites inspected in the District on the same day or within one day of the data collection team reviewing the site. The quality of the data collection is then the comparison between the supervising data person's evaluation and that of the data collection team.

1.0 INTRODUCTION

The Texas Department of Transportation (TxDOT) needs a practical method of determining if the Texas Highway System is at an "acceptable" level of service. This is necessary to comply with the Office of the State Auditor's recommendations (SAO Report N. 9-070) and to assure that maintenance funds are most effectively allocated.

1.1 LEVEL OF SERVICE COMPONENTS AND STANDARD RATING PROCEDURES

Administrative Circular Number 5-92 (AC 5-92) (1) defines Level of Service Guidelines for seventeen components in five groups: pavement maintenance, roadside maintenance, operations, bridge maintenance, and ferry maintenance. Only six of the components have a standard rating procedure that can be used to define current levels of service. The six components are:

	Component	Current System
1.	Longitudinal Cracking	PMIS (*)
2.	Alligator cracking	PMIS (*)
3.	Ride Quality	PMIS (*)
4.	Rest Areas	Contract Evaluation
5.	Picnic Areas	Contract Evaluation
6.	Bridges	BRINSAP (**)

* PMIS- Pavement Management Information System
** BRINSAP- Bridge Inventory Inspection and Appraisal Program

Those rating procedures are extremely detailed and time consuming, and there will not be allotted time, funds, and personnel to develop a detailed evaluation of the remaining components that include:

1. Vegetation
2. Litter Control
3. Pavement Edge
4. Drainage
5. Safety Appurtenances
6. Illumination
7. Traffic Signals
8. Signs and Delineators
9. Pavement Markings

1.2 CRITERIA FOR RATING PROCEDURES FOR LEVELS OF SERVICE

An economical, reliable, and objective method to rate the level of service of each component is required. The rating procedures selected will be those that minimize the time, funds, and work force required without jeopardizing the objectivity of the procedures. The levels of service established by these guidelines are affected by the level of funding available. Three funding levels were defined in AC 5-92: desirable, acceptable, and tolerable. Although not defined in the AC 5-92 there is a fourth level, intolerable.

As the level of service is generally not uniform throughout a segment, the guidelines define "substantially maintained level of service" as the level of service met or exceeded by 75 percent of a highway component.

1.3 COMPONENT PRIORITIES

The guidelines also establish the relative importance of substantially maintaining a component at the established level of service for a given level of funding. This is done by assigning a priority to each component in accordance with the level of funding. The priorities are defined as follows:

1. Safety - provide for safety of the travelling public

2. Protection of Investment and Environment - protect the investment of public dollars and the environment in the state highway, its right of way, and all its facilities

3. User Comfort - provide for the comfort of the travelling public

4. Aesthetics - provide for the beauty and the attractiveness of the roadway facilities

1.4 STUDY OBJECTIVES

Considering all the above factors, the objectives of this project are as follows:

1. Review *Maintenance Level of Service Guidelines* issued by AC 5-92 to insure they are realistic, clear, and well defined.

2. Determine the best methods to collect and record data for each roadway component.

3. Prepare a manual with clear illustrations and descriptions of the different levels of service so raters have a common reference.

4. Develop a strategy for sampling the Texas Highway System that would permit reliable maintenance level of service comparisons between districts.

There are a number of other reasons for developing a Maintenance Level of Service Manual that are expressed in References (2) and (3). These include:

1. Specify the different levels of service for the various road components

2. Give directions on how to measure and record the road status

3. Uniform and consistent rating procedures and maintenance work for the whole roadway system

4. Find out performance trends analyzing reported data

5. Collect data that are inputs to Maintenance Management Systems (MMS) and Pavement Management Information Systems (PMIS) which provide better programming of maintenance activities and better allocation of funds

This report addresses the first three objectives. Special attention is devoted to the components drainage and pavement edge condition. To approach the objectives outlined above, three activities were used: literature review, information acquired through meetings with maintenance personnel of different districts, and research.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

A major national quality initiative (NQI) was launched in 1992. The objective was to maximize the quality of highway facilities and services for the safest and most cost-effective mobility possible (4). This NQI requires the determination of highway performance measures to establish the quality of state highway programs. Some example performance measures include: level of service, quality of travel, travel cost, and safety convenience.

Good quality data and the appropriate use of that data are critical to develop comparisons between districts. If the objective is to be able to compare highway performance, it should consider among others (4):

1. Uncontrollable influencing factors that a single measure cannot consider

2. Unique factors that should be considered such as differences in costs and priorities

3. Better to reduce the comparisons to specific areas

A fair and valid comparison of one system's performance to another's needs basic understanding of the underlying phenomenon being studied and how key variables can relate to each other. There are three important elements that need particular attention: performance measures, input variables, and external factors.

2.1.1 Performance Measures

Performance measures assess the performance of a system. The principal characteristics of performance measures are as follows (4). First the measures must be defined appropriately for the intent of the performance system. For example, if the objective is deciding where maintenance is required, the performance measures need to provide this information. The measures must also be valid and must truly measure what is wanted. An invalid measure would be to compare the effectiveness of maintenance and rehabilitation expenditures by sometimes considering lane miles while others centerline miles. Performance measures must be consistently defined both spatially and temporally. If comparisons between districts are to be made, performance measures need to be similarly defined. Dimensionality of the performance needs to be reduced so that external factors have minor effects on it. For example, this can be done by reducing the many components of highway condition and performance into a composite index. This composite index is obtained with data whose basic measure is not directly influenced by external factors. Performance measures must be based on data that can be easily collected, and data collection must be consistent. Consistency in quality and quantity of data collection when comparisons are to be made is particularly important for those data items that are subject to qualitative assessment of the condition.

2.1.2 Input Variables

Performance measurements need not necessarily be related to resource inputs. Nevertheless, relating performance and resource inputs allows determination of the efficiency of resource utilization for the particular input-output production system. Caution is needed to prevent including expenditures that are not related to the ultimate performance measure of concern (4).

2.1.3 External Factors

This is the most important factor to be considered if a valid comparative assessment is needed. Examples of external factors are: weather induced effects, variation in costs of labor and materials, and physical location. The best way to control this problem is by grouping the program units so that within a group the external factors are similar (4).

2.2 MAINTENANCE LEVELS OF SERVICE

The purpose of maintenance is to preserve the physical integrity of the highway system and to provide the user safe and satisfactory service (5, 6). This is accomplished by replacing or repairing damaged elements and eliminating unnecessary components (6, 7).

2.2.1 Defining Maintenance Levels of Service

Maintenance levels of service are usually defined as the thresholds that trigger maintenance activities (5, 7, 8, 9). Sometimes standards specify only the minimum acceptable level of service, while other times they also define the level of service that can be achieved with selected maintenance activities (5). By establishing maintenance levels of service, it is possible to provide a more uniform effort and service throughout the highway system. Maintenance levels of service are also used for scheduling and budgeting processes (7).

Levels of service can be expressed by: written descriptions, numerical values, frequency of a maintenance effort or inspections in a determined time (6, 7), and the specific amount of work to be done per unit of highway (8).

Another way of defining levels of service has been proposed. Cottrell (10) developed a procedure for determining the frequency at which highway safety hardware needs to be inspected and repaired. Level of service was defined as the desired probability of inspecting and repairing the element before an accident occurs. Knowing the average annual accident frequency and the probability of no accident before completing a repair, the maximum time in days to have the repair completed is obtained.

2.2.2 Factors Effecting Levels of Service

Many factors effect maintenance levels of service. These factors may include: climatic condition, traffic density, terrain, pavement type, geographic location, age of the facility, and class of road (6). Any maintenance level has to be weighted by the knowledge of those in charge of maintaining the highway system (6).

2.3 ESTABLISHING MAINTENANCE LEVELS OF SERVICE

A systematic method to establish levels of service that are optimum and consistent for a given amount of resources was developed (5, 11). The method was coded as a computer program. The inputs for this program are determined in the following several steps. First the elements are defined (i.e., drainage) and considerations (i.e., safety, preservation of the investment) that can be used to evaluate the performance of the maintenance elements are assigned. Then an attribute (i.e., water ponds in the pavement) that will express the level of each consideration in a numerical scale is selected, and the maintenance conditions affecting it are determined (i.e., blocked or damaged drainage structures). Parameters (i.e., frequency of clean up or inspections) for defining maintenance conditions are selected, and alternate maintenance levels of service in terms of parameters are defined. Once the alternative levels of service are defined, their effects on considerations are determined. The resource needs for each level of service is then estimated, and the desirability for each level of each attribute is assessed. The program gives the optimum level of service, that is, maximizing user benefits as measured by the relative values of the attributes within the restraint of the available resources.

There is another method that replaces the deterministic deterioration of elements by a probabilistic deterioration that is assumed to be a Markov process (12). The output of the system is an optimum set of levels of service (LOS) values to be implemented. This is an expert opinion procedure. The input data needed are (12):

1. Sample deterioration model and quality standard developed using subjective expert opinion unless there is historical data

2. Annual costs of applying an action at level of service 1 to all the units of element j in stratum s (the stratification of the highway considers the differences in region, climate, geography, and road classification)

3. Determination of relative importance weight for having an element j within a desirable quality standard, and the relative importance weight for having an element j not within an undesirable quality standard

2.4 LEGAL IMPLICATIONS

Some agencies are afraid to document maintenance levels of service because they believe that funds available for maintenance are often not sufficient to comply with the established levels and that maintenance level documents may be used as evidence in tort liability suits. There is a new judicial trend that favors accepting codes, standards, and guidelines as evidence in court if these items are introduced by an expert witness, and if they are accepted, reliable, and authoritative in that particular industry or business (13). Nevertheless, the belief that documentation of levels of service standards should be avoided is not unanimous. Butler et al. (14) states that if there are not maintenance levels of service guidelines, the court will define them without considering all the influencing factors and priorities the agencies consider (14). If levels of service are specified and not met, they will produce an unfavorable impact in court. Conversely, if levels are specified and met, the impact will be favorable. However, if there is an unsafe situation, regardless of whether levels of service are specified or not, it will be an unfavorable situation in court (11).

Since maintenance activities can always be applied differently, the agency must show that its conduct was based on a rational and justified program of action that takes into account the user, the economy, the protection of the environment, and safety considerations (2, 14). In some states (Washington, Kansas, Iowa, Nebraska, and Minnesota) in an attempt to reduce tort liability on low-volume roads where maintenance activities have been reduced due to tight budgets, the legislation classifies some roads as minimum maintenance roads. However, this classification must be accompanied by appropriate warnings (15).

The impact of a guideline also depends on the way it is expressed. To violate "shall" would be negligence per se, while violating "should" would be only evidence of negligence (12).

3.0 REVIEW OF AVAILABLE MANUALS ON MAINTENANCE LEVELS OF SERVICE

3.1 INTRODUCTION

One of the objectives of this project is the development of a manual defining maintenance levels of service. Examples of manuals that are available include:

ROCOND 87 Road Condition Manual compiled by the Department of Main Roads, New South Wales, Australia (2),

ROCOND 90 Road Condition Manual compiled by the Roads and Traffic Authority, New South Wales, Australia (3),

Quality Evaluation Manual by the Condition Evaluation Unit of the Virginia Department of Transportation (VDOT) (17),

Maintenance Rating Program Manual by the Roadway Maintenance and Operations Section of the Florida Department of Transportation (FDOT)(18), and

Roadway Maintenance Evaluation User's Manual by Epps et al. (8).

The *Roadway Maintenance Evaluation User's Manual* (8), which was developed for Texas, was never fully implemented.

A review of these manuals helps in determining which items need to be considered and studied. Each manual includes a section addressing general information including: objectives of the manual, selection of segments, necessary equipment, procedures for rating, rating score scales, and ways to record data. Another section in the manuals focuses on specific information about levels of service for each component.

3.2 SECTION I. GENERAL INFORMATION

3.2.1 Selection of Segments

Segments are selected at the implementation stage. Once segments are selected, they do not need to change unless rehabilitation or reconstruction activities occur. Each segment should have a uniform treatment history, a similar condition status, and similar terrain (3). In addition to these typical limits establishing segments, there are other factors that may also divide segments. These factors are:

1. Change in roadway geometry

2. Change in number of lanes
3. Change from lane divided to lane undivided
4. Change from rural to urban areas
5. Change from a section with curb and gutter to a section without curb and gutter
6. Change from noncontrolled access to controlled access
7. Change from paved to unpaved shoulders
8. Change of county

The average segment length considered is generally between 0.5 km (0.3 miles) and 1.75 km (1.1 miles). However, the length of the segment may be as great as 3 km (1.9 miles).

VDOT (17) evaluates segments of length 0.15 km (0.1 mile). The sample size used is obtained by a statistical formulation. The formulation depends on the desired confidence level, the population size (centerline miles times 10), expected failure rate, and desired precision. This formula is valid for a stratification by highway systems (i.e., Interstates, Primary, Secondary). For further stratification, larger samples are needed to maintain the level of confidence. After the sample size is obtained, sites are picked from the road inventory using a random number procedure (17). Before evaluation, the sites are marked in a map to determine the best travel plan for evaluators.

FDOT (18) also applies a random number generator program to the Department's Roadway Characteristic Inventory to select the locations to be surveyed. Again, the number of samples required for a certain population is determined using a statistical formula, that provides an accuracy within 3 percent at 95 percent confidence level.

3.2.2 Equipment

The equipment needed to evaluate the status of the component includes: rulers, string line, heavy duty pry bars for removal of manhole covers and grates, measuring wheel. In addition to this equipment, safety equipment is also needed for situations where the vehicle must stop at the site (18). Safety equipment for these situations includes:

1. Safety vests for personnel
2. Approved safety hats
3. Traffic control devices, such as guidance cones, flag person, flashing directional arrow
4. Appropriate warning signs
5. Amber flashing light

ROCOND 90 uses electronic odometers to localize the component being surveyed. These odometers are equipped with dual read facilities (accuracy +/- 10 m (35 ft)) to measure distance to points of reference always starting from zero at the start of each segment.

3.2.3 Procedures for Rating

ROCOND 90 assesses the average status of each component. Conditions that are a hazard for drivers are not considered in the assessment of the overall segment and are immediately reported to be repaired. Since action has to take place as quickly as possible, they cannot be considered in the maintenance planning.

The components that are assessed over the total length of the segment are rated from a slow moving vehicle. The team consists of a trained local rater and a rating assistant. Some passes may be needed first to get a general idea of the whole segment. It is recommend that a segment be fully rated, both sides, before changing to other segments. Each segment should be traveled in both directions. The side being traveled is the one to be assessed.

Components are divided into: those inspected from the vehicle ("in vehicle") and those requiring close inspection ("exit vehicle"). For instance in ROCUND 90 (3), culverts are "exit vehicle" components while other drainage structures are "in vehicle."

A training program for those who conduct the roadway maintenance evaluation is recommended by Epps et al. (8).

VDOT's (17) rating procedure consists of a walking survey of the segment. When the site is reached, the vehicle is driven to the end of the site and parked, and the rater walks the entire segment to evaluate it. FDOT's rating procedure is also a walking survey. FDOT's rating team is composed of two persons in each district. They walk the segment together facing the oncoming traffic for safety reasons (18).

3.2.4 Rating Scale

ROCOND 90 uses a rating code consisting of a scale of 1 to 5 (3). In order to rate some components, the manual provides condition descriptions and may require that simple dimensions be measured. For other components,both severity and extent of distress are required to determine the rating. ROCOND 87's code rating is similar to that of ROCOND 90, but in the former most of the level of service descriptions are accompanied by clear illustrations (2).

The *Roadway Maintenance Evaluation User's Manual* (8) provides a rating scale for shoulder, roadside, drainage, and traffic services. The rating scale ranges from 1 (very good) to 9 (very poor). A rating score is then obtained by formulas that subtract obtained values known as deduct values from 100.

VDOT (17) establishes three possible inputs to the field form: Y = yes or N = no, depending on the compliance or noncompliance of the component with the standards, and an O, when the component is not applicable for that section. Once these data are obtained, the level of service for a characteristic (i.e., cracking) is found by dividing the number of Y's by the number of sites where the characteristic is applicable, and then multiplying the ratio by 100. Each characteristic has a weight assigned depending on its relative priority among all the others. This weight varies from 1 to 10. The level of service of a component (i.e., flexible surface that includes characteristics such as cracking, patching, etc.) is obtained by dividing the sum of the number of Y's for all the characteristics, each multiplied by the corresponding weight, by the sum of the number of "applicable" for all the characteristics, each multiplied by the corresponding weight. The level of service of the component is that ratio times 100.

The level of service for the component traveling surface is a special case since it includes three types of surfaces: flexible, rigid, and stabilized surfaces. Its Level of Service (LOS) rating is the sum of the ratios of the number of sites of a type of surface and the total number of sites each ratio multiplied by the corresponding LOS. Finally, to find out the overall rate, weights are given to the traveling surface, shoulder, drainage, traffic control and safety, and roadside. The sum of those weights is 1. Each weight is multiplied by the corresponding LOS, and then all are summed to give the overall rate.

FDOT considers different levels: facility type, county, maintenance, district, and statewide areas. The facility types (i.e., Rural Arterials, Urban Arterials) are divided into elements (i.e., Roadside, Drainage). Each element combines different characteristics (i.e., Roadside includes shoulders, turnouts, front slopes). To calculate the rating for a maintenance area, the number of characteristics meeting standards is multiplied by the numerical level of importance. Then the number of characteristics not meeting the standards is multiplied by level of importance. The ratio of the former divided by the sum of both gives the rating for an element. The percent of characteristics meeting or not meeting standards were previously considered. The modification was made to reduce skews of the data. FDOT, like VDOT, assigns appropriate weights to arrive at the overall rating for a section.

3.2.5 How to Record Data

In ROCOND 90, data are entered on field worksheets. Using these worksheets, necessary calculations are done, and the rating code is determined (3). The information is then transferred to a data entry form that is a copy of the data entry computer screen. Hand held data recorders (bar code readers) may be adopted in the future. Rating codes could then be entered in the field and transferred to a host computer via cable, avoiding separate data entry into the computer.

Data items included on the data entry form can be categorized as either essential or optional. Items of information considered essential for the data entry form include (3):

1. Segment number
2. Location
3. Survey year
4. Date
5. Survey type (complete or partial survey)

6. Rater's name
7. Pavement type
8. Surface type
9. Length, width, and area
10. Condition data

Optional data items are:

1. ADT
2. Commercial vehicle percentage
3. Environment
4. Construction year
5. Treatment year
6. Treatment type
7. Rater's comments

Site location is identified using the following data by Epps et al. (8):

1. District number
2. County number
3. Highway class (rural or urban, number of lanes, controlled or uncontrolled access)
4. Highway number
5. Length of segment defined by mile post numbering system

VDOT personnel record data on field worksheets. When the evaluation is completed, the information is entered using a desktop computer.

3.3 SECTION II. SPECIFIC INFORMATION

3.3.1 Pavement Edge Drop-off

Neither ROCOND 87 (2) nor ROCOND 90 (3) has level of service guidelines for pavement edge drop-off. These manuals do consider horizontal edge break. ROCOND 90 defines horizontal edge break as "fretting along the edge of a seal or asphalt surfacing and is associated with rutting or erosion of the shoulder near the edge of the bitumen." If the shoulder is sealed to a width greater than 1 m (3.28 ft) beyond the edge line, edge break is not assessed by ROCOND 90. ROCOND 87 assesses the edge break at the extremity, if the shoulder is sealed, and the extent is evaluated. An experienced inspector collects data from a vehicle along the total edge length.

Pavement edge drop-off is considered in both VDOT and FDOT's maintenance evaluation procedures. VDOT differentiates between hard-surfaced shoulders and non hard-surfaced shoulders. The procedure also establishes different acceptable limits depending on the type of facility. For hard-surfaced shoulders, 90 percent of Interstate and Primary Systems and 75 percent of the Secondary

System must be free of pavement edge drop-off greater than 15 mm (0.5 in). For non-hard-surfaced shoulders, 90 percent of Interstate and Primary Systems must not exceed 40 mm (1.5 in), and on Secondary System the maximum drop-off is 65 mm (2.5 in). FDOT considers the size of the drop-off to establish the level of service standards, and specifies the lateral position and the extension of the condition. FDOT limits drop-off for unpaved shoulders to 75 mm (3 in) within 0.31 m (1 ft) of the pavement edge for a continuous 7.5 m (25 ft) section.

3.3.2 Drainage Structures

In both ROCOND 87 and ROCOND 90 manuals, drainage structures are divided into the following categories: culverts, ditches, and ditches in flat terrain. The structures are evaluated over total length. ROCOND 87 evaluates ditches recording the worst condition present in at least 10 percent of the ditch. ROCOND 90 evaluates the average maintenance condition.

Table 1 compares the maintenance thresholds for culverts and ditches considered by FDOT and VDOT.

TABLE 1. FDOT and VDOT's Maintenance Thresholds - Drainage Structures

	FDOT	VDOT
CULVERTS	40 % or more is obstructed	50 % or more is obstructed
ROADSIDE DITCHES MEDIAN DITCHES	Depth of less than 0.91 m (3 ft), and/or erosion or build ups	50 % or more of depth is obstructed
OUTFALL DITCHES	60 % or more of the depth is obstructed	50 % or more of depth is obstructed
PAVED DITCHES	10 % or more does not function as intended	25 % or more does not function as intended

4.0 MEETINGS WITH MAINTENANCE PERSONNEL

4.1 INTRODUCTION

Meetings were held to determine the point of view of TxDOT District personnel who are actually supervising or doing maintenance work. Maintenance supervisors and engineers from TxDOT Districts 7, 15, and 17 contributed their views about Maintenance Levels of Service Guidelines in Administrative Circular N 5-92 (1). The three districts appeared to be interested in the project. District personnel attending the meetings were very helpful and provided valuable information. Specific topics discussed included:

1. Drainage
2. Pavement edges
3. Illumination
4. Pavement markers
5. Safety appurtenances
6. Signs and delineators
7. Traffic signals
8. Litter
9. Vegetation

4.1.1 Funding Concerns

Problems created by limited funding were brought up throughout the meetings. Although highway department personnel are greatly concerned about providing the best maintenance possible, due to limited resources, the majority of the components addressed in this project are maintained on a "reactive mode" basis. This may vary in certain districts where, due to better sub-grades, better climate conditions, or less population, less funds are needed to repair longitudinal rutting, alligator cracking, and ride quality conditions. These districts may have more funds to maintain the components addressed in this study. The size of the maintenance area also differentiates districts: the larger the area, the greater the travel time needed just to get to and from the site. This may reflect on the level of maintenance that can be achieved by personnel.

4.1.2 Meaning of Levels of Service to Districts

A general concern is the exposure of TxDOT to tort liability caused by standards whose levels of service are higher than those possible to achieve with the current level of funding. Maintenance personnel insist that guidelines should differentiate only two levels of funding (acceptable and not acceptable) or at most three for certain components. Four levels of funding (desirable, acceptable, tolerable, and intolerable) is considered excessive, especially when funding is rarely enough to achieve more than tolerable. Definitions of desirable and tolerable levels of service were defined as follows:

"Desirable level"	was generally related to the possibility of conducting routine scheduled maintenance so the components function as they were designed.
"Tolerable level"	was associated with the minimum level of service for the component to be functional and to maintain safety conditions.

4.2 OBSERVATIONS ABOUT THE DIFFERENT COMPONENTS

The following observations were made about various components during the meetings.

4.2.1 Drainage

Safety and preservation of the pavement's structure are basically the trigger for maintenance activities. Blockage or ponding are not addressed, unless someone complains, if they do not affect the safety or preservation of the roadway.

Drainage structures should be maintained to avoid the accumulation of silt, grass, or other obstructions. Ditch shape and depth should be controlled. Ditches without adequate bottom width may cause flooding. Erosion is also a concern.

Proposed levels of service include only three levels of funding:

LEVEL	CRITERIA
DESIRABLE	0 percent-20 percent blockage/silting up
ACCEPTABLE	20 percent-50 percent blockage/silting up
INTOLERABLE	More than 50 percent blockage/silting up

4.2.2 Pavement Edge

Both pavement edge and shoulder edge maintenance problems are dangerous, and drop-offs need to be considered. Pavements without shoulders are higher priority for evaluation than those with shoulders.

The use of excessive herbicides on pavement edges may have more negative than positive consequences because of erosion. This is especially seen under post and cable barriers.

It was suggested that pavement edge breakage should be taken into account in the maintenance guidelines. When the break off is around 75 mm (3 in), maintenance action is needed.

4.2.3 Vegetation

Vegetation maintenance needs are strongly related to the season of the year and to the rainfall conditions. Rainfall varies considerably is some areas. Roadways may not require mowing some years, while four or more mowings may be needed in other years. Districts with arid soils have an easier task.

Vegetation maintenance needs also depend on whether it is an urban or a rural area. Intersection sight distance is the highest priority, because public safety is affected. In rural areas, the main concern is traffic safety. In urban areas, community beautification and tourism need to be considered. Those goals should be reflected in the evaluation criterion.

Vegetation maintenance and drainage maintenance are related. After mowing, balls of vegetation may block drainage structures. The problem increases if the mowing is not done at the appropriate time. This problem may occur when a single contractor is in charge of several mowing contracts. When they are needed in a certain area, they are working on another. Therefore, the mowing is delayed.

There are concerns about not mowing the full width of the right of way. Vegetation attracts wildlife, and many accidents occur involving deer each year. There is practically no cost difference between full width mowing and strip mowing. Mowing full right of way width provides a uniform appearance between districts.

The recommended guidelines for vegetation maintenance are:

RURAL SECTIONS LEVEL	CRITERIA
DESIRABLE	0.15 m to 0.45 m (6" to 18") of vegetation; 0 percent bare earth
TOLERABLE	0.40 m to 1.06 m (18" to 42") of vegetation; 1 percent to 25 percent bare earth
INTOLERABLE	1.00 m (42") or higher of vegetation; more than 25 percent bare earth

Two methods were suggested to determine when the height of the vegetation is intolerable:

1. Delineators are not visible
2. Vegetation is above the driver's eye height when driving a passenger vehicle

URBAN SECTIONS

LEVEL	CRITERIA
DESIRABLE	0.1 m to 0.3 m (4" to 12") of vegetation
TOLERABLE	0.3 m to 0.45 m (12" to 18") of vegetation
INTOLERABLE	greater than 0.45 m (18") of vegetation

4.2.4 Illumination

Lamps are replaced when they burn out and when the necessary equipment is available. No work is done on luminaries or their supporting structures unless structural integrity is threatened. Crews doing this maintenance are understaffed.

Guidelines suggested are:

LEVEL	CRITERIA
TOLERABLE	1 or 2 luminaries out of 10 burned out
INTOLERABLE	3 or more luminaries out of 10 burned out

4.2.5 Raised Pavement Markers

The maintenance level is determined by non-functional or missing markers. The levels of service suggested are:

LEVEL	CRITERIA
DESIRABLE	No more than 2 missing in a row
INTOLERABLE	Three or more missing in a row

4.2.6 Painted Lines

Water-base paint is not durable, and the level of reflectivity is low. The lifespan for water-base paint is 50 percent of oil-base paint, which is less costly than the water-base paint gallon for gallon. Currently, more money is being expended for less quality. The levels of service suggested are:

LEVEL	CRITERIA
DESIRABLE	Clearly visible by day and night
ACCEPTABLE	Clearly visible by day but marginally visible at night
INTOLERABLE	Difficult to see at night

4.2.7 Guard-Fence

The maintenance levels for guard-fence is often determined by considering functionality of the guard-fence once it has been struck by a vehicle. The proposed guidelines for guard-fence maintenance are:

LEVEL	CRITERIA
DESIRABLE	No apparent guard-fence damage
TOLERABLE	No end treatments damaged but some minor damage in the run
INTOLERABLE	End treatment damage or more than 10 percent of the run damaged

4.2.8 Signs

The level of maintenance for signs, is usually evaluated by determining the fading and loss of reflectivity for the sign. Faded signs and signs that have lost reflectivity are replaced. Reflectivity checks are normally conducted at night, however, electronic units are available for direct measurement of reflectivity. The two levels of service proposed are:

LEVEL	CRITERIA
TOLERABLE	Readable by day and night
INTOLERABLE	Not readable either by day or night

4.2.9 Delineators

The Texas Manual on Uniform Traffic Control Devices (TxMUTCD) requirement for delineation on lighted urban freeways was questioned during the meeting. Some doubt was also expressed about delineators in islands, because if they are knocked down they can be very dangerous for pedestrians. Maintenance of delineators is a full time job for a four person crew. Suggested levels are:

LEVEL	CRITERIA
DESIRABLE	The requirements of the TxMUTCD are met
INTOLERABLE	The requirements of the TxMUTCD are not met

4.2.10 Litter

Illegal dumping in the right of way is very common, especially under bridges. Graffiti under bridges is also a big problem. Routes to solid waste deposit sites require much more frequent litter pickup than others. For some areas, the average daily traffic limits in the AC 5-92 are too high. The public would complain if those guidelines were followed. Recommended levels of service evaluation for litter are:

LEVEL	CRITERIA
DESIRABLE	None visible when driving at high speed
ACCEPTABLE	Some litter visible, but not objectionable
INTOLERABLE	Litter visible at an objectionable level or when the public complains, whichever comes first

5.0 DATA COLLECTION AND RECORDING PROCEDURES

This chapter describes advantages and disadvantages of different data collection and recording procedures that could be followed to evaluate the condition of the different components.

5.1 COLLECTION OF DATA

5.1.1 Accuracy and Precision

There are many different ways of collecting data to determine the condition of a component. These methods are more or less objective. Collection methods vary in cost, time, work force, accuracy, precision, and resolution. Accuracy is the degree to which the procedure gives a true value. Precision measures the possibility of repeating the method and obtaining the same results. Resolution is the smallest increment that can be measured (19). The selection of the best method is a trade off between all the above factors.

All the methods evaluate the same levels of service that are defined in the Maintenance Level of Service Manual. Some methods may be more suitable than others. The accuracy and precision of the data for any data collection method will depend on various factors. These include:

1. Number of components to be rated at a time
2. Training of the rater
3. Clarity and completeness in the definitions of the maintenance levels of service defined in the manual (4)
4. Calibration of the instruments used
5. Factors that cannot be completely controlled such as position of the sun and precipitation (4, 19)
6. Simplicity of the procedure to record data (i.e., time it takes, possibility of entering mistakes)
7. Presence of a quality control program (20)

5.1.2 Rating Procedures

In some states, maintenance quality reviews are completed every year, recognizing the good and bad maintenance procedures in different areas. The reviews have proven to be a successful tool to stimulate desired maintenance practices (20).

Subjectivity cannot be eliminated completely from the data collection procedures. However, the judgment expressed by the rater should always be anchored. Although there may be some variance in the judgments of raters, this variance may be considered a random error (21). Raters should be aware of possible systematic errors that they may introduce in the data, and attempt to minimize them. A rater may tend to constantly rate too high or too low (error of leniency or error in criticality). He or she may influence the rating by attributes other than the one being evaluated (halo effect), or may hesitate in giving extreme rates when they are appropriate (error of central tendency) (21).

The rating procedure has to be valid and reliable. Valid means that the rating truly represents the condition of what is being surveyed. Reliable refers to the consistency of the rating done by different raters or by the same rater at different times (21). To validate a rating procedure, it is necessary to compare the ratings with more objective measures of the condition (21). Validation of videologging, for example, can be done by comparing the rating obtained with this method with the one obtained observing the corresponding 35 mm photographs.

5.1.3 Data Collection Methods

Data collection methods can be divided in three groups (2, 8, 19, 22):

1. Manual data collection
2. Automated data collection
3. Information gathered from maintenance management systems or from data collected for other purposes

It is important to remember that data collection is an expensive procedure, and therefore, the greatest possible use must be made of that data (23).

5.1.4 Manual Data Collection

Manual data collection methods include (19):

1. Walking survey either measuring or estimating the condition
2. Riding survey while driving on the shoulder at slow speed
3. Riding survey either at slow speed or normal traffic speed

Procedures 2 and 3 may be combined with periodic stops to estimate or measure the condition.

5.1.5 Automated Data Collection

Automated data collection methods may use (19):

1. 35 mm still photographs
2. High resolution video cameras or strip photographic images
3. Ultrasonic or laser devices to measure distances

Manual data collection surveys in the field when compared with automated procedures, have the advantage of providing a more global image of the right of way. This is especially important when the rating is not clear. For example, a global image of the right of way helps the rater evaluate the drainage system and determine the direction the water should be traveling. On the other hand, manual data collection surveys require more time on the road than automated data collection surveys. More personnel may also be required to conduct a manual data collection survey. Automated procedures allow data to be collected and then analyzed by a trained rater later in the office (19).

5.1.6 Videologging

Videologging has many advantages with respect to manual data collection methods (22). Videologging minimizes personnel and time required in the roadway, and there is less exposure of personnel to hazardous traffic. The examination of the condition can be completed any time at the office, as many times as necessary, and at various effective speeds ranging from a still screen to 240 km/h (150 mph). The videolog is useful to evaluate the status of the component, to make comparisons after maintenance work is completed, and to prepare or update inventories. The same videotape may be used for the evaluation of many components. Sometimes the installation of a second camera in the vehicle could be needed, but this would always be less expensive than requiring another vehicle to complete the survey. Videologging can also have legal applications (22). It can be used to defend the agency against claims that result from accidents and also as evidence that the agency is making a reasonable effort to find locations where maintenance is needed.

Some factors may hamper the determination of the condition when using videologging (19). For example, the position of the sun, presence of vegetation, or the location of the component may influence the image.

Videologging also has advantages with respect to photologging (24). Photologging requires processing, whereas, videologging is a final product. Video tapes are inexpensive and can be reused. Voice can be added to the videologging, either in real-time videolog or later. However, the rater and driver must be trained regarding what may be said on tape. The basic guideline is to stick to facts and omit opinions.

Usually, 35 mm still photographs have higher resolution than freeze video frames, but that difference may vary with the equipment used (19).

5.1.7 Ultrasonic or Laser Sensors

The third method outlined in automated data collection is the use of ultrasonic or laser sensors to measure distances. The Rutbar is a good example of this technology. The Rutbar is a bar mounted on the bumper of the survey van with a number of sensors that measure the distances from the bar to the riding surface. The resolution of this method is increased as the number of sensors is increased (19). The precision of the procedure depends in part on the lateral displacement of the vehicle in the different runs (19). Given any displacement from the previous runs, the sensors will be measuring different points, and therefore, the results may change completely. The required time on the road and traffic interruptions are minimized reducing the chance of possible accidents.

5.2 RECORDING AND STORING DATA

5.2.1 Recording Data

There are a number of methods that may be used for recording data. These methods include:

1. Paper collection sheets
2. Pen-based computers
3. Notebook computers

Portable data collection devices should be easy to handle, rugged, and capable of resisting humidity, dirt, and changes in temperature (25).

The use of well-designed worksheets has been the most widespread method for recording data (25). However, computers are replacing them as computers are made lighter, smaller, more user-friendly, and with greater storage and processor capabilities. Pen-based computers resemble the traditional worksheet and pencil. They allow data to be entered by writing on the screen, or they can be programmed so that the operator needs only to check a selected option from a preprogrammed menu. Nevertheless, sometimes the use of function keys may be more suitable because the rater does not need to look at the screen to input the information.

The process of entering data gathered on paper collection sheets into the database is time consuming, and there is always the possibility of making mistakes. There is approximately a 10 percent chance of this type of error occurring. Direct data entry from the field to portable computers increases the accuracy of the information and minimizes personnel time and effort.

The entry device used should be able to receive feedback and check that the entries are in the admitted range (error trap entry data). It is also recommended that all the data be tagged with date and time. It is helpful if the location can also be attached (25). However, to encourage acceptance of these electronic devices among maintenance personnel, the procedures to input, output, and transmit data to the host computer have to remain simple.

The choice of the best alternative depends on the selected data collection procedure. A notebook computer with function keys may be the best option for recording data when a driving survey is used, whereas, a palm-held-pen-based computer may be more appropriate for a walking survey.

5.2.2 Storing Data

The four options currently available for storing data are (26):

1. Manual filing systems
2. Computerized files
3. Database managers
4. GIS

For all four options, the data entry, editing, storing, sorting, and retrieval capabilities are maximized. The Geographic Information System is the most complete way of storing data. This option efficiently links data to a location on a map (26).

There are two primary methods for automated determination of location: distance measuring instruments (DMIs) and satellite global positioning systems receivers (GPS) (25). There are a wide variety of DMIs on the market. These include odometers installed in vehicles with an accuracy of 0.2 km (0.1 miles). More sophisticated DMIs are available with accuracy to within plus or minus 1 m (3 ft). In order to relate the roadway feature to DMI readings, the vehicle speed should be between 25 and 30 km/h (15 and 20 miles/h) (25). DMI has been incorporated in automated data collection systems, such as the TxDOT pavement video devices. It is very important that the starting reference points be precisely established.

For agencies that have a Geographic Information System (GIS) or are planning to implement one, GPS is recommended for use (25). A GIS locates highway features using coordinates. With GPS, and with assistance of satellites, latitude and longitude of a point can be determined. At the moment, not all the projected satellites are in place (21 active and 3 spares), but with 24 satellites in orbits, it will be possible to determine 3-dimensional positions on a 24-hour basis around the world. The coarse acquisition channel (C/A) is available to the public. The precision channel is reserved for military use (25). The standard accuracy for the C/A channel is 25 m (80 ft). If electronic errors are introduced by the military (selective availability), the accuracy may drop to 100 m (325 ft). Errors due to atmospheric conditions or selective availability can be eliminated by use of a reference receiver placed at a known location. This can reduce the error to 10 m (30 ft). This correction can be completed in real-time or during post processing. For real-time correction, a separate radio channel is needed.

5.3 THE ARAN VEHICLE

Since 1986, TxDOT has used an Automated Road Analyzer Vehicle (ARAN) (FIGURE 1). ARAN is a multipurpose road survey vehicle (27). This vehicle videologs both the right of way and the surface for later analysis. It also collects rut depth data using the Rutbar. Roughness is recorded by accelerometers placed on the body and axle of the vehicle. Travel direction and geometrics of the road such as radius of curvature, grade, and crossfall are determined by two gyroscopes.

The ARAN, with appropriate modifications or additions as explained in Chapter 8, could be suitable for the evaluation of the maintenance levels of service of the components. The data required for this purpose are defined in the Maintenance Level of Service Manual being developed in this project.

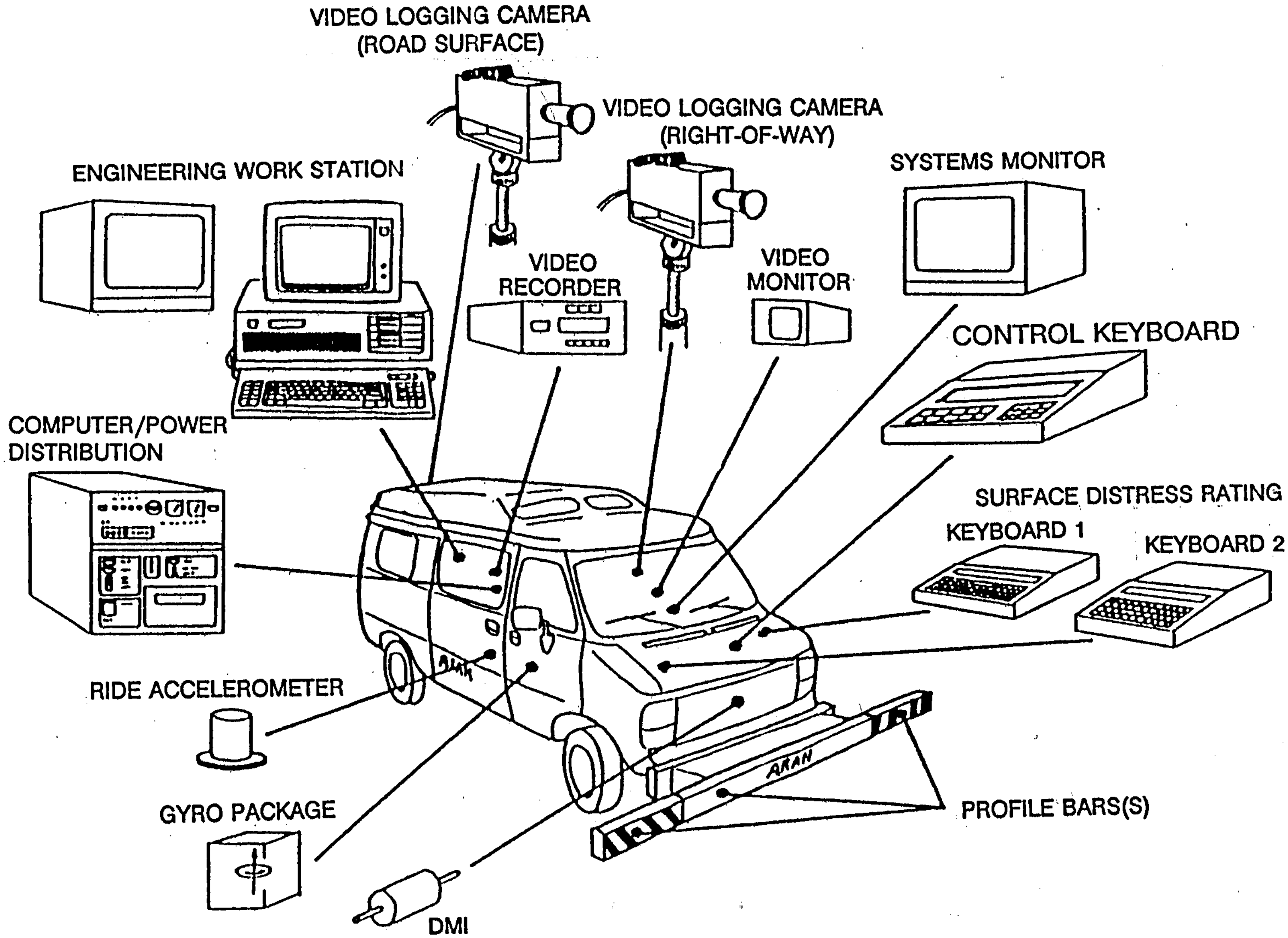

Figure 1. Functional Schematics of ARAN Vehicle (ARAN-Product Bulletin)

6.0 DEVELOPMENT OF THE MAINTENANCE LEVELS OF SERVICE MANUAL

6.1 INTRODUCTION

The Maintenance Level of Service Manual provides a standard method for determining maintenance levels of service of the roadway system in Texas. It was developed based on information gathered through literature review, meetings with maintenance personnel, and available examples, including: *ROCUND87 Road Condition Manual* (2), *ROCUND90 Road Condition Manual* (3), *The Roadway Maintenance Evaluation User's Manual* (8), the VDOT *Quality Evaluation Manual* (17), and the FDOT *Maintenance Rating Program Manual* (18).

The components considered in the manual are:

1. Vegetation
2. Litter
3. Pavement edge
4. Drainage
5. Guard-fence
6. Mail boxes
7. Roadway illumination
8. Traffic signs
9. Roadside delineators
10. Roadside object markers
11. Raised pavement markers
12. Painted lines
13. Pavement markings

6.2 COMPONENT VEGETATION

The Maintenance manual considers component vegetation for both rural and urban sites. The component vegetation for rural sites consists of:

1. Safety strip vegetation
2. Intersection vegetation control
3. Sparse turf in safety strip
4. Herbaceous encroachment
5. Woody encroachment
6. Bare spots on slopes
7. Control of noxious weeds
8. Ornamental plants

For urban sites, the component vegetation is divided in three types:

1. Roadside vegetation
2. Woody encroachment
3. Intersection sight distance *

* Intersection sight distance includes not only problems due to vegetation but also due to any structure that may obstruct the necessary visibility

6.3 RATING SCALE

A good rating scale must be neither too coarse nor too fine. If it is too coarse, the rater's discrimination abilities can not be effectively used. On the other hand, if levels apply to a range finer than the rater's discrimination abilities, reliability decreases (21). Following maintenance personnel's suggestions, only two or three levels of service are considered. The two level scale consists of desirable and intolerable, while the three level scale has the ratings of desirable, tolerable, and intolerable. The definition of these levels are:

Desirable - Is both safe and pleasing to the public

Tolerable - May not look good, but is still safe and not damaging the roadway

Intolerable - Component neither looks good nor is safe, the roadway may also be in danger of being damaged

For certain components, a three-level rating scale rather than a two-level seems more appropriate. For example, a pavement edge is considered desirable if no dropoff exists, tolerable if the dropoff is smaller than .051 meters (2 inches), and intolerable if the dropoff is greater than .076 meters (3 inches). Therefore, to make the rating scale uniform and simple, the three-level scale is considered for all the components. The advantage of a two-level rating scale compared with a three-level scale is that the former forces the rater to make a decision, whereas, the latter allows the rater not to choose by always assigning the intermediate level. This is one reason why training of the raters is essential, and if ratings are far apart in time, training should be repeated prior to each data collection period.

The cues for each level of service have to be unique for that level (21). The manual word description of the level of service of each component is accompanied by a clear illustration. The illustrations are the anchors to the word descriptions and help keep the rating uniform over the whole highway system.

6.4 LAYOUT OF MANUAL

The manual is divided into four sections. Each section corresponds to one of the four seasons of the year. The different components are distributed among the seasons with the following criteria.

The level of service for some components does not vary with the seasons of the year, and therefore, are placed by looking at the work load in each season. The components that are not seasonally related are:

1. Woody encroachment
2. Pavement edge
3. Guard-fence
4. Mail boxes
5. Roadway illumination
6. Traffic signs
7. Roadside delineators
8. Roadside object markers
9. Raised pavement markers
10. Painted lines
11. Pavement markings

6.5 COMPONENT SURVEYS

The rest of the components should be surveyed at a specific season of the year. Their distribution is shown in Table 2 for rural sites and in Table 3 for urban sites. For example, rural drainage evaluation is placed in winter for rural sites because that is when vegetation does not hamper the view of the drainage system. Vegetation is not a problem in urban sites with curbs and gutters, so drainage systems are evaluated in the spring when rainfall is generally the highest in Texas and drainage facilities may overflow. Another consideration in the grouping decision is the data collection procedure chosen for each component. Data collection procedures are addressed in Chapter 7. Those components whose condition could be collected with videolog are aggregated.

TABLE 2. Distribution of Vegetation Components to be Surveyed by Season for Rural Sites

SPRING	SUMMER	FALL	WINTER
Sparse turf in safety strip	Safety strip vegetation		Bare slopes
Ornamental plants	Intersection vegetation control		Drainage
Noxious weeds	Herbaceous encroachment		
	Roadside litter		
	Noxious weeds		

TABLE 3. Distribution of Vegetation Components to be Surveyed by Season for Urban Sites

SPRING	SUMMER	FALL	WINTER
Roadside vegetation	Intersection sight distance		
Ornamental plants	Roadside litter		
Drainage			

In the fall, TxDOT uses the ARAN to videolog the pavement surface in urban areas. If the ARAN is modified as necessary, it could be used to get information needed for the level-of-service data system as well.

Traffic signals are mostly found in urban sites. Traffic signals are inspected frequently and require a detailed inspection. The TxDOT Steering Committee directed that traffic signals be deleted from the list of components to be evaluated in MLOS data collection system. Therefore, the schedule of maintenance level of service is presented in Table 4 and Table 5.

Some components need to be rechecked at nighttime for reflectivity. These include:

1. Signs
2. Delineators
3. Object markers
4. Pavement markings
5. Painted lines

Two components will be evaluated only at night: raised pavement markers and illumination. The most important function of raised pavement markers is reflectivity, and it is not feasible to evaluate during daytime. A daytime survey of the component illumination would be useful because any light on during the day is a sign of malfunction. Nevertheless, not all the information needed can be gathered during the day and as the evaluation has to remain as simple as possible, only a nighttime evaluation for this component is considered.

TABLE 4. Schedule of Maintenance Level of Service Evaluation for Rural Sites

SPRING	SUMMER	FALL	WINTER
Sparse Turf In Safety Strip	Safety Strip	Pavement Edge	Bare Slopes
Ornamental Plants	Intersection Vegetation Control	Woody Encroachment	Drainage
Noxious Weeds	Herbaceous Encroachment	Guard-fence	
	Roadside Litter	Mail Boxes	
	Noxious Weeds	Traffic Signs	
		Roadside Delineators	
		Roadside Object Markers	
		Painted Lines	
		Pavement Markings	

TABLE 5. Schedule of Maintenance LOS for Urban Sites

SPRING	SUMMER	FALL	WINTER
Roadside Vegetation	Intersection Sight Distance	Pavement Edge	
Ornamental Plants	Roadside Litter	Woody Encroachment	
Drainage		Guard-fence	
		Mail Boxes	
		Traffic Signs	
		Roadside Delineators	
		Roadside object markers	
		Painted lines	
		Pavement markings	

6.6 PAVEMENT EDGE DISCONTINUITIES

When a uniform evaluation among raters of the component pavement edge is desired, it is necessary to clearly define the scale used. This requires establishing which drop-off conditions are going to be considered:

- Drop-off at the edge of the driving surface,
- Drop-off at the edge of the shoulder,
- Drop-off at the edge of the driving surface and at the end of the shoulder, or
- Drop-off at a critical distance to be determined.

From the meetings with maintenance personnel reported in Chapter 4 it was clear that both pavement edge and shoulder edge are dangerous, and both drop-offs need to be considered. The distance between the white stripe marking the edge of the driving surface and the location of the drop-off varies considerably. In a study by Ivey et al. (28), pavement drop-offs are considered regardless of their lateral position. Of course, the farther the drop-off is from the wheelpath, the greater is the margin of safety.

A decision of whether to consider the shape of the edge in the Level of Service Guidelines was also necessary. In a study by Zimmer and Ivey (29), the effect that pavement edge shape and height have on vehicle control loss was shown. Three shapes were identified: 90-degree edge, rounded edge, and 45-degree edge. For a 90-degree edge, a 75 mm (3 in) drop-off would not be tolerable because it would already be in the marginally safe zone. Thus, for a 90-degree edge, a stricter limit in the level of service is suggested than for a rounded or 45-degree edge.

The recommended maintenance levels of service for pavement edge drop-offs are:

LEVEL	CRITERIA
DESIRABLE	No drop-off

TOLERABLE

SHAPE	DROPOFF
45-DEGREE OR ROUNDED	< 75 mm (3 in)
90-DEGREE	< 50 mm (2 in)

INTOLERABLE

SHAPE	DROPOFF
45-DEGREE OR ROUNDED	> 75 mm (3 in)
90-DEGREE	> 50 mm (2 in)

6.7 DRAINAGE

The drainage component considered in TxDOT Maintenance Levels of Service Guidelines, as a whole, is made up of many components. Among the components considered are:

1. Paved surface
2. Open ditches
3. Culverts*
4. Curbs and gutters
5. Inlets

* culverts that are being considered are of all sizes and shapes up to 6 m (20 ft) in total span. If the span is greater than 6m (20 ft) they are included in the Bridge Maintenance group and are covered by BRINSAP.

Drainage is divided into two groups: drainage of rural roads, and drainage of urban roads. The former includes open ditches and culverts and the latter curbs, gutters, and inlets.

Drainage of paved surface is an important characteristic of the drainage component that, in the future, should be considered to be added to the evaluation. This could be done by combining pavement edge, rutting, and cross slope information. If the level of the shoulder is higher than that of the riding surface (negative edge drop-off) the water is hampered in running off the surface.

Ruts may also be a sign of water ponding on the surface. The cross slope, that can be measured using a gyroscope in the survey van, will show how easy or difficult it is for the water to runoff.

6.8 DRAINAGE OF RURAL ROADS

LEVEL	CRITERIA
DESIRABLE	Ditch has adequate shape and depth; vegetation, siltation, or scour does not affect runoff and longitudinal drainage Culvert clear throughout or obstructed less than 5 percent of its depth Inlet or culvert channel restricted less than 5 percent of depth of culvert
TOLERABLE	Ditch has minor irregularities to shape and depth; Ditch has minor obstructions to longitudinal drainage; Culvert obstructed 5-30 percent of its depth Inlet or outlet channel restricted 5-30 percent of depth of culvert
INTOLERABLE	Ditch does not have adequate shape or depth Vegetation, siltation, or scour obstructions runoff or longitudinal drainage Culvert obstructed more than 30 percent of its depth; Inlet or outlet channels restricted more than 30 percent of depth of culvert Headwall or endwall does not protect the travelling public from the side slope Clear misalignment or settlement of culvert

6.9 DRAINAGE OF URBAN ROADS

LEVEL	CRITERIA
DESIRABLE	No breaks, cracks, or significant settlement of curbs and gutters; Curbs and gutters have adequate slope Inlets are not obstructed, are well aligned vertically, and covers are in good condition
TOLERABLE	Curbs and gutters have adequate slope but minor cracks or breaks are present Inlets are obstructed less than 30 percent; Covers are in acceptable condition
INTOLERABLE	Curbs and gutters do not have adequate slope Curbs and gutters are broken, severely cracked, or have settled Inlets are obstructed more than 30 percent, are misaligned, or cover is damaged

7.0 DETERMINATION OF THE BEST PROCEDURES TO COLLECT DATA

This chapter addresses different procedures that could be followed to collect the condition of the different components. These procedures were tested and compared to determine the best among all the alternatives.

7.1 LOCATING THE SEGMENT IN THE HIGHWAY SYSTEM

There are nearly 125,525 centerline kilometers (78,000 centerline miles) on the Texas highway system. Two-way undivided highways and boulevards (two-way divided roads) account for 93 percent of the roadway mileage. The remaining percentage corresponds to expressways and freeways with or without service roads. Figure 2 shows a schematic representation of undivided highways and divided highways with frontage roads. Lanes K1 and K6 should be surveyed, as they are the lanes by the roadside, and are generally the most distressed.

When surveying divided roads, we should also consider lanes R5 and L5 to get the condition of the median, and lanes A1 and X1 for frontage roads. It is difficult to evaluate the median of a divided road if the survey is not made by videologging. Not only are lanes R5 and L5 fast speed lanes, but the driver is the closer person to the roadside.

The section length found to be most suitable in the Florida procedure was .16 kilometers (0.1 miles). Greater data precision is achieved with more individual sites of shorter length than a fewer number of longer sites.

The sections are identified by Reference Markers. Reference Markers are highway route signs with numbers placed below them. The Reference Markers are located approximately every 3.2 km (2 miles) except for interstate highways where they are at every mile in both directions. Reference Marker numbers increase if travelling south on a north-south road or east on a west-east road. The exception is north-south Interstate highways, whose reference marker numbers increase when travelling north. Generally, the start and finish points of the rating segment will not be exactly at a Reference Marker. The starting and ending displacements have to be determined. If they are positive, it means that they are past the Reference Marker in the direction of increasing Reference Marker numbers. If they are negative, the location is before the Reference Marker.

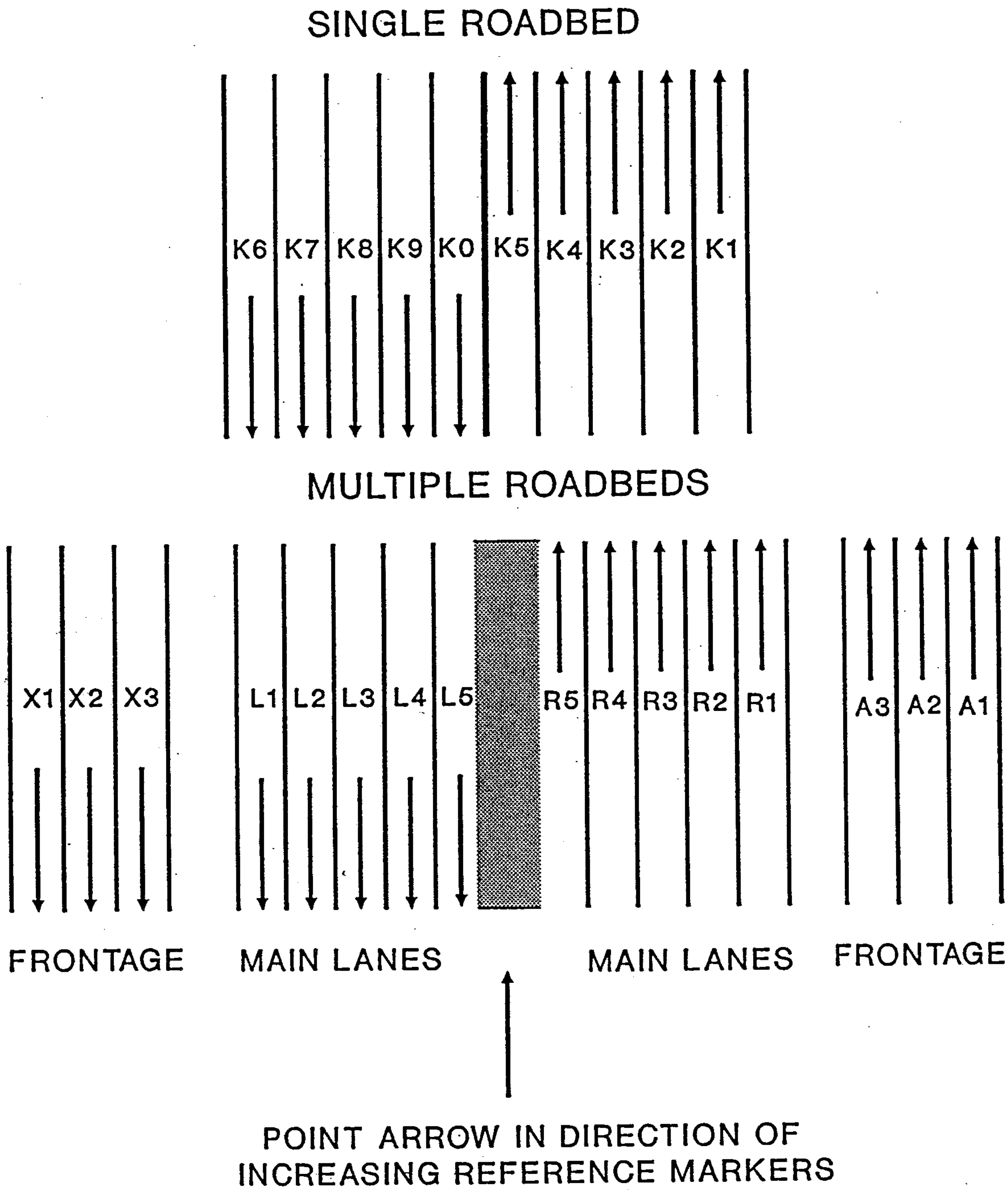

FIGURE 2. Identifying the Rated Lanes (30)

7.2 RECORDING THE DATA

At the first stage of the project a data entry form, like the one shown in Figure 3, was used to record the data. The legend of the worksheet is:

LEGEND

Dist.= District
Pre. = Prefix
Su. = Suffix
Ref. Mark. = Reference Marker
Displace. = Displacement
Pav. Edge = Pavement Edge
Woody E. = Woody Encroachment
Traff. Sign = Traffic Sign
Obj. Mark. = Object Markers
Painted L. = Painted Lines
Pav. Mark. = Pavement Markings
D = Desirable
T = Tolerable
I = Intolerable

One worksheet is needed for each season for rural sites. An additional worksheet is needed for each season where urban site components are collected. One extra worksheet is required for nighttime evaluation in the fall for both rural and urban sites. Later in the project, data may be recorded by pressing memory functions in a computer, when doing windshield survey, or when analyzing videos at the office. Nevertheless, it is always good to have worksheets for those times when, for any reason, a computer is not available.

The data entry form is divided into two parts. The first part refers to the location of the information being entered: district number, county number, highway identification, and starting and ending points of the segment. The second part of the form is composed of the components rated for the appropriate season, site, and time of day. Each component is subdivided in three blocks, each corresponding to the three maintenance levels of service established for it in the manual. For those components that are discrete (i.e., guard fence, traffic signs, traffic signals, roadside delineators, object markers, pavement markings, and mail boxes), a mark in the appropriate box is made for each one encountered in the study section. For the components that are continuous, only one mark is recorded in the block, which represents at least 75 percent of the status of the component. If the status is not clear and a video tape is being analyzed, it is possible using DMI to sum the different lengths of the segment with a certain status and divide it by the total length (usually 0.8 km (0.5 miles)) to determine the corresponding percentage. One solution to the difficulty of keeping track of continuous components is to space the rating in time. If the length of the segment is too long, the

Maintenance Level-of-Service Evaluation

Fall Season - Rural Sites - Day Time

Date: ______

Location		Highway			From			To			Pav. Edge			Woody E			Guard.			M. Box			Traf.Sign			Delineato			Obj. Mark			Painted L			Pav. Mark		
Dist.	County	Pre.	Number	Su	Ref. Mark	Su-/-	Displace	Ref. Mark	Su-/-	Displace	D	T	I	D	T	I	D	T	I	D	T	I	D	T	I	D	T	I	D	T	I	D	T	I	D	T	I

Figure 3. Maintenance Level of Service Evaluation Worksheet

segment is subdivided, and all those ratings are combined to determine the rate of the whole segment. For example, a timed interval of 20 seconds between recording could be used. The observer would observe the roadside until the 20 seconds time sounded. At that point, the composite observation for the interval could be recorded.

The columns under characteristics that are not present in the section being surveyed should be crossed out. Clear numbers and letters should be used to avoid mistakes.

7.3 TESTING OF DATA COLLECTION PROCEDURES

The manual (31) establishes the maintenance levels of service for the different components. To determine the most appropriate methods to collect and record the data, a loop was selected in Burleson county. The length of each segment was 0.8 km (0.5 miles), which is in agreement with the length of most of the segments of the PMIS. A distance measurement instrument with a resolution of 0.0016 km (0.001 miles) was incorporated with the video, and was used to determine the displacements of the start and end of the segments with respect to the closest Reference Marker numbers.

7.3.1 Videologging

The first method considered for collecting data was videologging. The decision about this method being adequate or not, for each of the components under study was based only on its capability of gathering the information required by the manual. If in the future a deeper evaluation of the component is desired, this procedure should be verified again to see if it is still suitable.

The loop was traversed twice by the ARAN to first videolog the roadside, and then the riding surface. The playback equipment allows the speed of the image to vary as necessary. The videolog display used in this project includes: date, beginning reference marker with displacement, county number, section identification, vehicle speed, and actual position of the vehicle. The videolog is completed with the camera angled slightly to the right of the center line of travel. This is the area of interest because of the roadside hardware and the traffic control devices which are located on the right side of the traveled direction. Another camera is pointed forward and angled slightly downward to obtain coverage of deficiencies on the pavement surface. A first look at the whole segment, even at high speed, gives a general feeling of what is going to be encountered. It shows whether it rained previous to the videolog, and if the right of way had been recently mowed. Mowing facilitates the evaluation of drainage in ditches, drainage of paved surface, culverts, curbs and gutters, and inlets. It is also easier to detect litter after mowing.

The test video tape was analyzed in the office and the following conclusions were drawn:

culverts - Culverts are either impossible or very difficult to evaluate. The culverts which are perpendicular to the road are not captured by the video. Culverts parallel to the road are generally too low, with respect to the riding surface, making it difficult to see if they are clear of obstructions. Motion blur and vegetation makes the evaluation even more difficult. Nevertheless, it may be possible to evaluate the inlet channel and the headwall.

litter - Pieces of litter are not always easy to differentiate from shadows or reflections of water ponding on the roadside.

inlets - This component considers all kind of inlets. It may be possible to check curb inlets and gutter inlets because generally they will be close to the camera, but this may not be the case for those inlets in the roadside.

pavement edge - It is not possible to measure or even estimate the drop-off using the video because there is no reference.

Therefore, the above four components are not recommended to be evaluated by videolog. The rest of the components are divided in two groups:

Group I. The components collected in a roadside videolog are:

1.	Guard fence	8.	Safety strip vegetation
2.	Signs	9.	Sparse turf in safety strip
3.	Delineators	10.	Herbaceous encroachment
4.	Object markers	11.	Control of noxious weeds
5.	Drainage of ditches	12.	bare spots on slope
6.	Curbs and gutters	13.	Intersection vegetation control
7.	Mail boxes	14.	Woody encroachment

Group II. The components collected in a riding surface videolog are:

1. Pavement markings
2. Painted lines
3. Raised pavement markings

It is not possible to evaluate all the components at one time. Two or at most three may be appropriate, but the decision will ultimately depend on the rater.

In accordance with the Maintenance Level of Service Manual (31), different video tape speeds, as well as freeze frames, were tested for the determination of the condition of the different components. Freeze frame evaluations were not productive because of lack of definition of the components. Motion blur increases as the angle of regard increases with respect to the highway direction. The ARAN was used to record the data being analyzed in this study. The camera is placed on the left side of the van. If the camera is on the right side, the angle of regard can be reduced, as well as motion blur of freeze frames. A high shutter speed camera setting is necessary to capture a still image that is free from blurring when the survey vehicle travels at 80 km/h (50 miles/h). Real-time playback of the tape recorded at 88 km/h (55 miles/h) appeared to be acceptable. Two different components could be evaluated at one time.

Slower playback speeds do not seem to provide any significant additional information. The only advantage is that the rater has more time to observe the components rated. On the other hand, doubling real-time speed is satisfactory for rating one component at a time. However, it is harder at double real-time speed to fix the eyes on the component. Double real-time speed also requires more concentration, and the rater will get tired sooner. Therefore, real-time playback appears to be the most appropriate speed, and this permits data reduction to be done with ordinary VCRs.

A parametric study was conducted to evaluate the effect of selected shutter speed for the camera on the quality of the videotape. The general characteristics of the image obtained with high and low shutter speeds are summarized in Table 6.

TABLE 6. Image Characteristics for High and Low Shutter Speeds

SHUTTER SPEED	BRIGHTNESS	BLUR	RANGE OF FOCAL DEPTH
high	low	less	smaller
low	high	more	greater

The camera used for the study was a Canon L1 8 mm. Figure 4 shows the vehicle used for the test. The camera was mounted on the roof of the van on the right side. A VCR and a monitor installed at the back of the van (Figure 5) were used to determine the best setting of the camera. As a rule of thumb, the camera needs to be angled to the roadside so that both the pavement edge and the ditch are captured. The zoom is controlled by the height of the traffic signs. If the camera is zoomed out too much, the signs will not be readable until the camera is very close to the sign.

In addition, too much right of way of little interest will be a big portion of the image. If it is zoomed in too much, the only part of the traffic sign captured by the video will be the post. Therefore, the zoom has to be set between those two extremes.

Specifying the best camera setting given the vertical angle with respect to the horizontal plane, and lateral angle with respect to the driving direction is difficult because the angle depends on both the width of the roadside and its slope. The height of the camera is also a variable if the place prepared for the camera to set varies vertically in vehicles used for survey. It is preferable to have the camera mounted on the right side of the vehicle because it allows capture of more details. The camera can be set either inside the van or in a housing constructed to protect it from the climate. The vehicle's speed chosen for the test was 67 kmph (40 mph).

Figure 4. Survey Van With Video Camera Placed on the Right Side

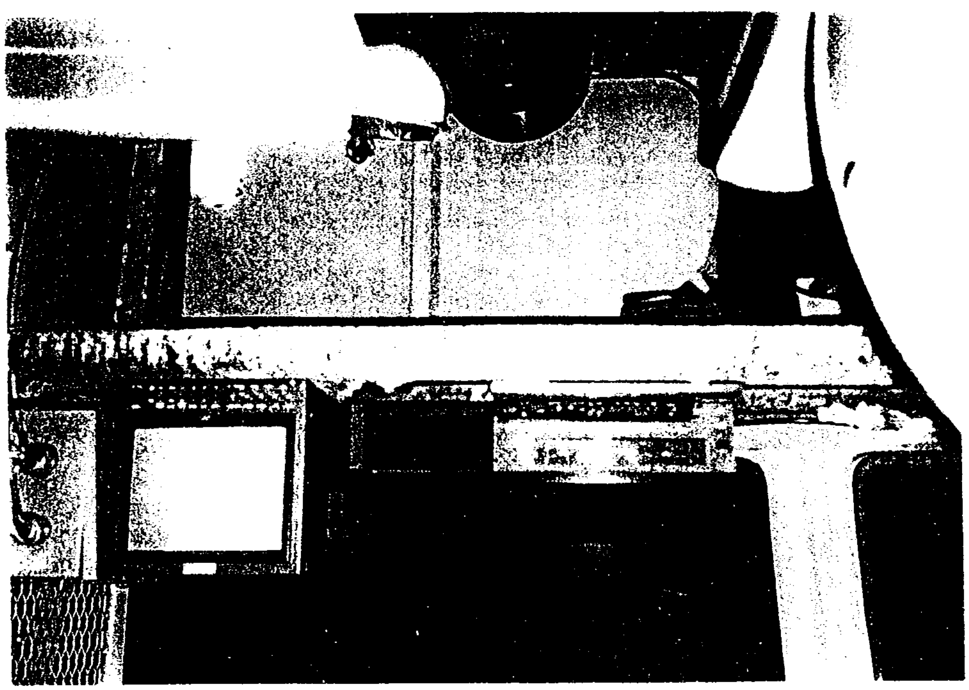

Figure 5. A Monitor and a VCR are Placed at the Back of the Survey Van

Traffic signs that were present at the section and an extra sign (without post) that was placed on the ground were the principal objects considered to compare the effect of different shutter speeds. Four different shutter speeds were tested: 1/60, 1/1,000, 1/4,000, and 1/10,000 seconds. A hard copy for each case was printed from frozen frames shown as Figures 6, 7, 8, and 9. There is definitely a reduction of blur when a shutter speed of 1/10,000 second is used, as compared with a shutter speed of 1/60 second. Shutter speeds 1/1,000 and 1/4,000 seconds fall between in quality. The highest shutter speed proved to be the best. Although there is not any apparent variation in brightness between the pictures, this may be affected by ambient light. On dark days, if the image gets too dim, the shutter speed could be reduced to 1/4,000 second.

7.3.2 Walking and Windshield Surveys

Walking and windshield surveys were conducted on the same segment. These surveys were prior to the components being divided by seasons. Therefore, the load of work for the rater was much higher than the recommendations of this report. However, it gives an idea of the relative effort and time required for both procedures. The components present to be evaluated on that segment were: litter, culverts (6 were present), ditch, guard-fence (1 was present), signs (4 were present), object markers (3 were present), raised pavement markers, painted lines, pavement markings, and drainage of paved surface. The walking survey of one side of the section took 22 minutes. The rater was required to keep track of the condition of the continuous components, rate the discrete items every time they were encountered, and observe both the riding surface and the roadside to be able to evaluate all the components. Depending on the degree of difficulty of the segment, the time required for the survey could vary. Walking surveys allow more information to be gathered than the other procedures. Conversely, they require more time, greater effort from the rater, and are the most dangerous method. The walking survey permits the rater to check both ends of culverts, look at the steep zone behind the guard-fence, and count pieces of litter that summed 230.

The segment was then rated by riding at 65 km/h (40 miles/h). Three passes were completed, and it took 6.5 min to rate both sides. This time includes the time to drive along the segment plus the time required to safely change the vehicle's direction for the different runs. The latter may vary depending on the location of the section, whether there is a place to safely turn around close to the segment, and on the traffic in the area. Components were divided in three groups. In the first run, discrete elements were evaluated. In the second run, drainage, culverts, and litter were rated. The riding surface components were evaluated on the third run. This distribution seemed appropriate for the section where there were a considerable number of components. One culvert and its corresponding object marker were missed, and the number of pieces of litter observed decreased by about ten times. Only culvert inlets can be observed in the driving survey, and it is difficult to effectively evaluate it. This procedure could be modified by stops in the second pass to check culverts. If there are numerous culverts in the section, the vehicle speed must be reduced considerably to facilitate stopping. A 15 km/h (10 mph) survey may be more advantageous than a 65 km/h (40 mph) survey if the number of passes can be reduced. The same detail could be observed at both those speeds. It took 13.5 minutes to rate both sides. The two groups were riding surface components and roadside components. It turned out to be too many components to be rated at a time.

Figure 6. Hard Copy from Frozen Video Frame, Shutter Speed 1/60 Seconds

Figure 7. Hard Copy from Frozen Video Frame, Shutter Speed 1/1,000 Seconds

Figure 8. Hard Copy from Frozen Video Frame, Shutter Speed 1/4,000 Seconds

Figure 9. Hard Copy from Frozen Video Frame, Shutter Speed 1/10,000 Seconds

All surveys conducted based on the point of view of the motorists. Therefore, if the component litter is considered, there is no interest in the evaluation of litter in the roadside not seen by the motorists. As previously noted, there may be a big difference between those two evaluations. When conducting a driving survey at 65 km/h (40 miles/h), or even at 15 km/h (10 miles/h) the amount of litter ranged between 20 to 40 pieces, while walking survey found that the amount increased to more than 200 pieces. Counting the pieces of litter is not very practical. In the end what the motorist sees is a general picture of the segment. Therefore, pictures were taken where the different litter levels of service are represented, and the rating can be anchored by these photographs.

7.4 PAVEMENT EDGE DROP-OFF'S

Manual procedures for the evaluation of pavement edge (walking survey and riding survey with stops) take a lot of time and effort and may cause traffic interruptions. It is also very hard, if feasible, to estimate the drop-off from windshield surveys and from the analysis of video frames due to the lack of a reference. It may be possible to detect zones where clearly intolerable drop-offs are present, but not to distinguish between two sections where the difference in the drop-off is in inches.

7.4.1 Rutbar Method

TxDOT has a fleet of roadway condition survey vehicles, some of which are equipped with Rutbar to measure wheel path rutting. The Rutbar is a measuring distance device that can be set to measure pavement edge dropoffs. If one ultrasonic range sensor is placed close to the pavement edge and another off the edge, the difference between those two measurements is the drop-off. A positive value is obtained when the riding surface is higher than the shoulder and a negative value when the shoulder is higher than the riding surface. A null value means that the two surfaces are level.

The Rutbar used to test this alternative procedure has five sensors: sensors #1 and #5 are placed 0.45 m (18 in) to the left (or right) of the left (or right) wheel path. Sensors #2 and #4 are at the left and right wheel paths, respectively. Sensor #3 is placed in the middle of the two wheels. Only two of those five sensors, #4 and #5, were used to measure edge drop-off.

The ultrasonic sensor estimates the distance between the sensor and the target surface by measuring the time passed from the emission until the reception of the echo. The sensors are placed approximately 0.3 m (1 ft) from the ground and have a resolution of 2.54 mm (0.1 in). The effective sensing area on the surface is about 9 cm (3.5 in) in diameter. Some foreseeable limitations to these procedures are:

- The lateral position of the pavement edge with respect to the white stripe varies, especially with the type of facility.
- Vegetation encroachment could interfere with the signals and, therefore, affect the measures.
- The Rutbar measures the distance between two horizontal planes that pass by the points where the ultrasonic sensors touch the surfaces. That distance is different from

the effective edge height which is what could be dangerous.

- The Rutbar measurement is also different from manual measures unless the sensors touch the surfaces exactly at the same places where the rulers are placed.
- The riding surface has a cross slope for drainage; therefore, the horizontal planes vary with the position.
- The vehicle's speed may also affect the measures. Higher speeds are desired because a 15 km/h (10 miles/h) decrease in speed doubles the chances of accident (D. Woods, unpublished data).
- The shape of the pavement edge is not collected by the Rutbar.
- If manual and Rutbar measures of a segment are compared, a shift of values is expected to be found. This is caused by the difficulty of starting the collection of data with the Rutbar just at the starting point of the segment. If the vehicle is running 80 km/h (50 miles), a half a second delay means a shift of 10 m (30 ft).

Some possible solutions to those limitations are summarized. An increase in the number of sensors between the location of #4 and #5 would give better information on the shape, place, and dropoff of the pavement edge. The sensors could be extended from 0.45 to 0.75 m (18 to 30 in) beyond the vehicle end to increase the chance of including the pavement edge, but it would be a potential hazard. The shape of the pavement edge could be collected by combining automated and manual procedures. While driving along the pavement edge, a rater could input the starting and ending points of sections with 90-degree shaped edges. The rest would be considered rounded or 45-degree edge. No distinction is needed between them because the levels of service described in the Maintenance Level of Service Manual are the same for both shapes. Later, in the office, the shape of the edges would be matched with Rutbar measures to assess the condition of the component.

7.4.2 Initial Testing Procedure

A 600 m (2000 ft) segment was chosen on FM 1179. The survey van traversed the segment with the driver keeping the right wheels on top of the white stripe. From experience, it is known that there may be a deviation of the survey van from the white stripe of 10 to 40 cm (4 to 6 in). Every 1.2 m (4 ft), a measurement was taken, although a smaller spacing between measurements is possible. Manual measurements were also collected using two rulers. One ruler was used to represent the horizontal plane and the other to determine the difference in levels. Data were collected at intervals of 1.5 m (5 ft) or 6 m (20 ft), depending on whether the area was with or without pavement edge drop-off.

7.4.3 Initial Testing Results

Figures 10 to 16 show pavement edge drop-off versus position in the segment. The raw data were processed with a Spencer smoothing function to eliminate noise spikes. Figure 10 presents the

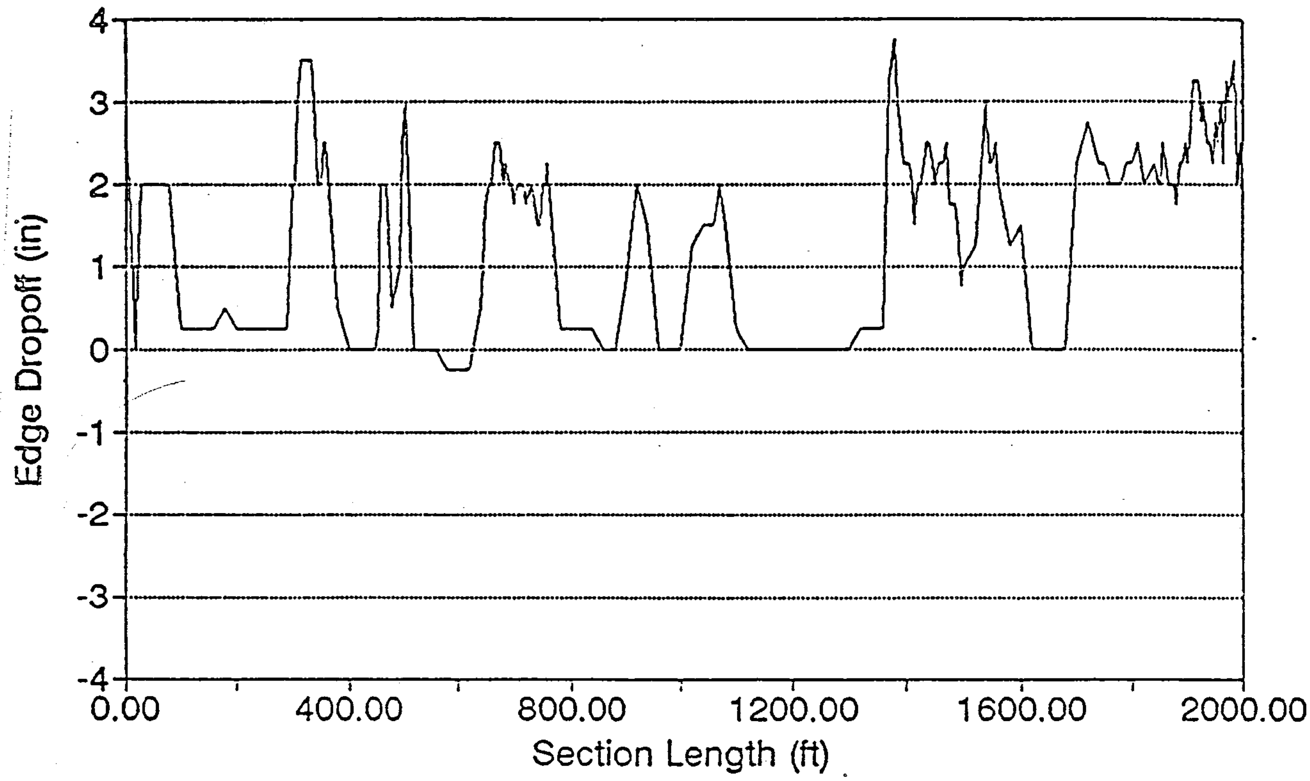

Figure 10. Manual Measures of Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

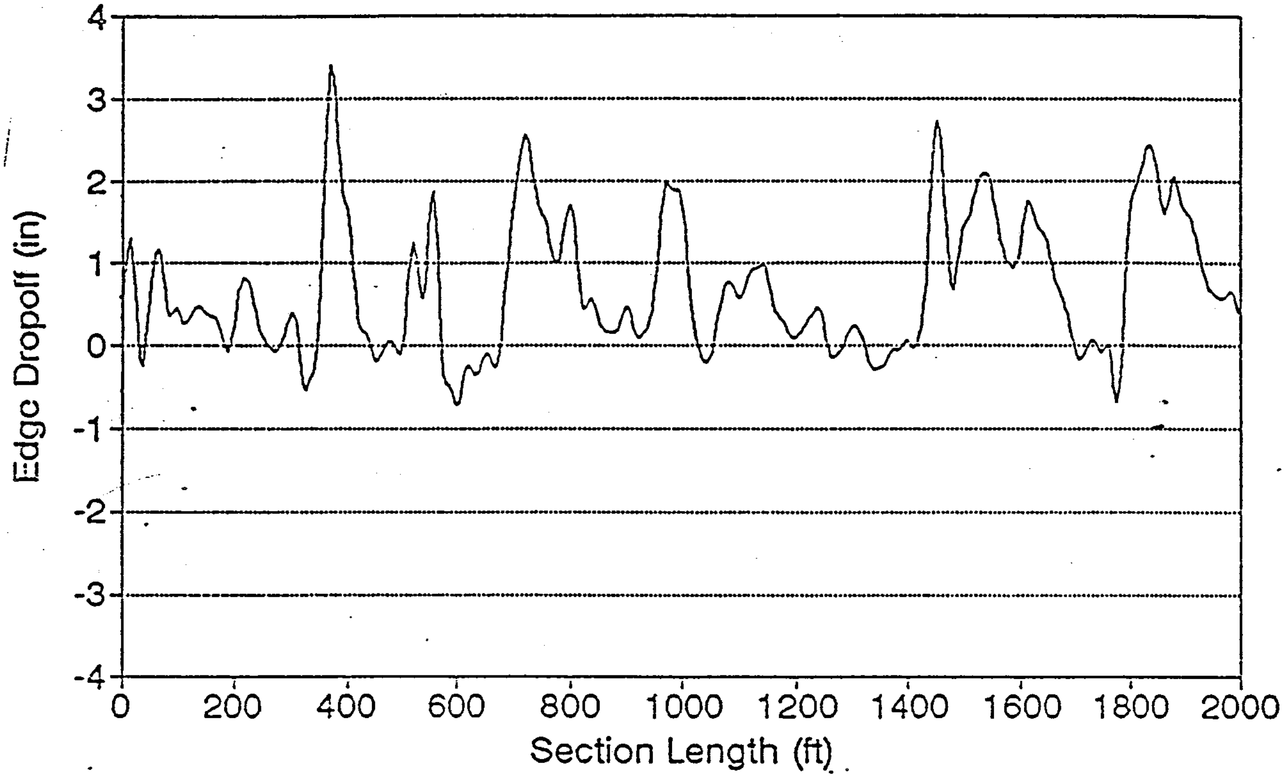

Figure 11. Ultrasonic Sensor Measures of Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 16 km/h (10 mph), Run 1

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

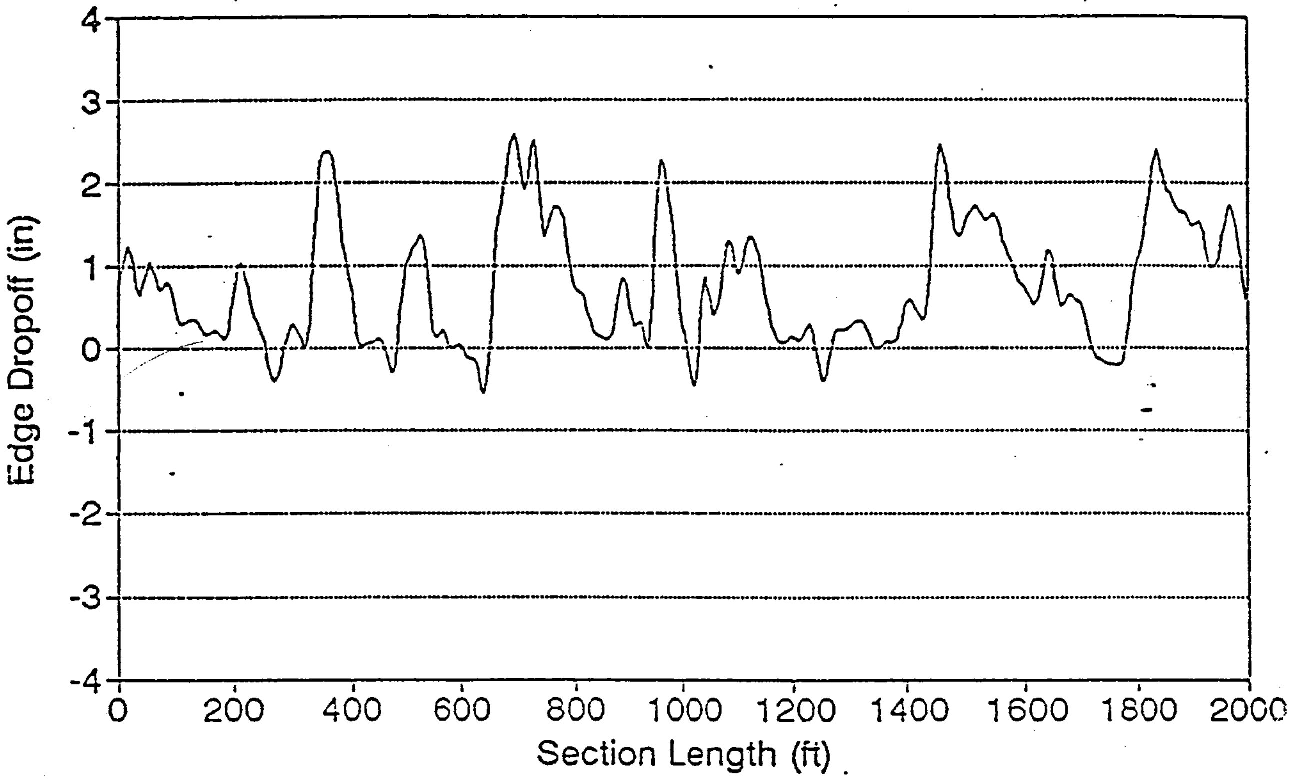

Figure 12. Ultrasonic Sensor Measures of Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 16 km/hr (10 mph), Run 2

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

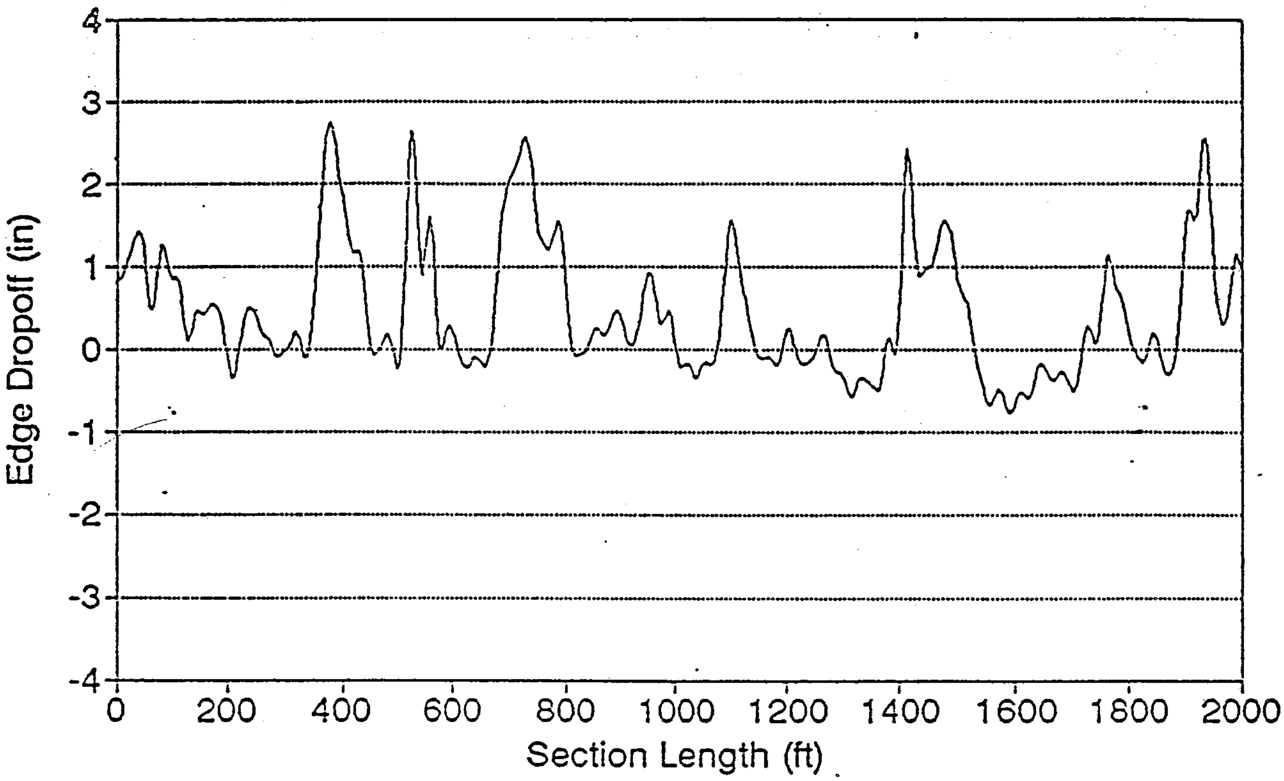

Figure 13. Ultrasonic Sensor Measures of Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 48 km/h (30 mph), Run 1

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

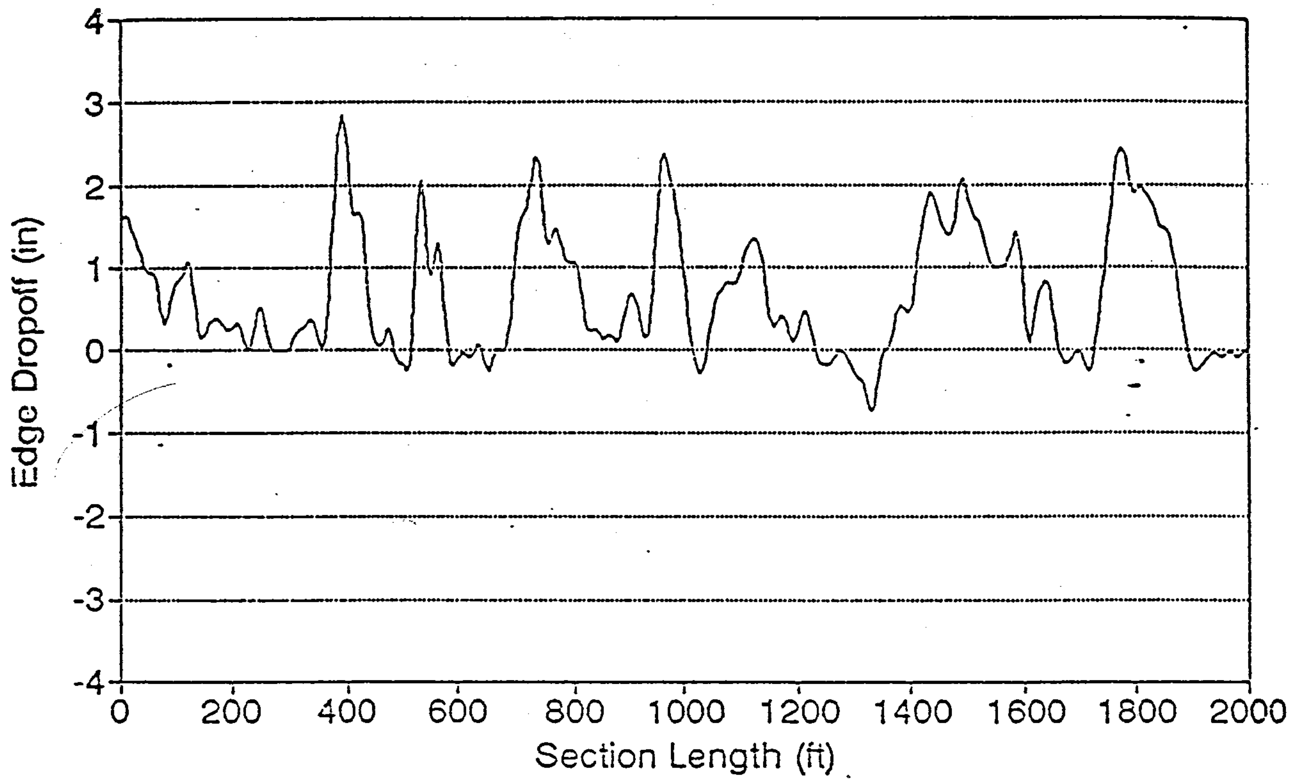

Figure 14. Ultrasonic Sensor Measures Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 48 km/h (30 mph), Run 2

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

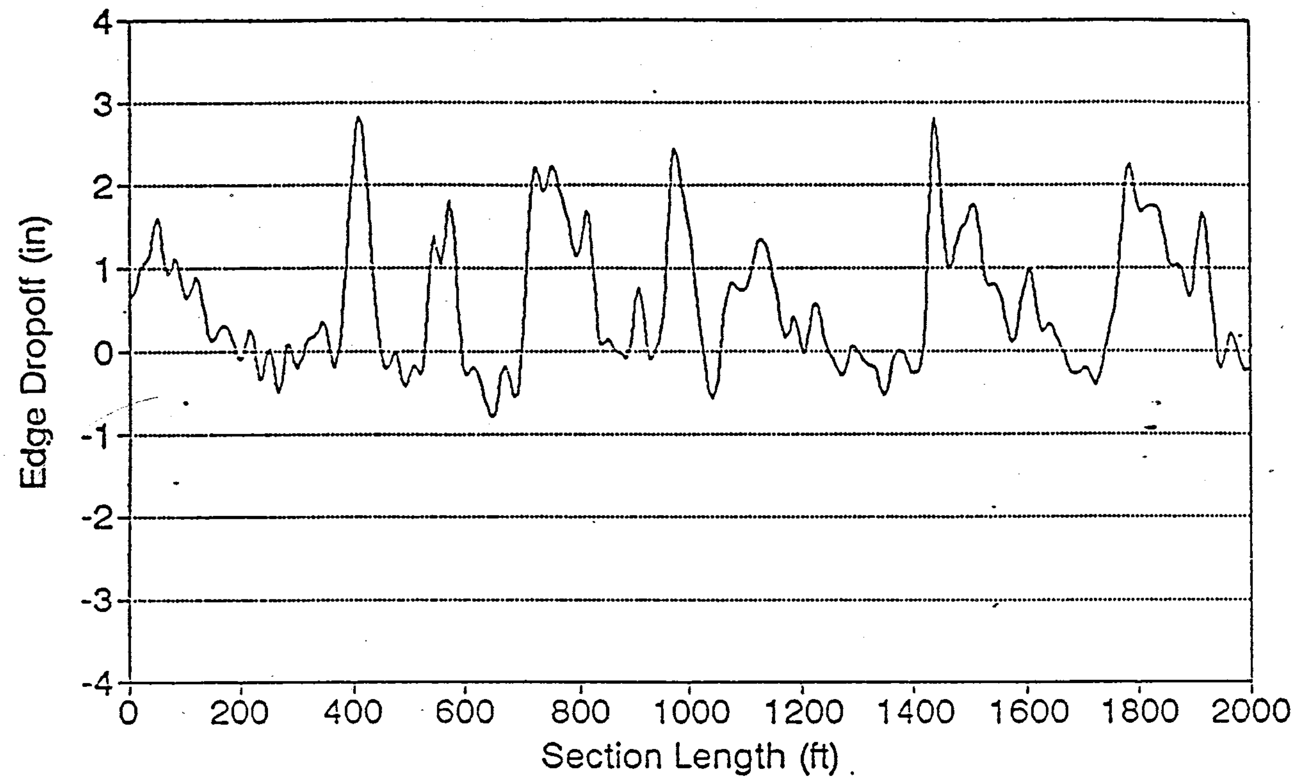

Figure 15. Ultrasonic Sensor Measures Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 80 km/h (50 mph), Run 1

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

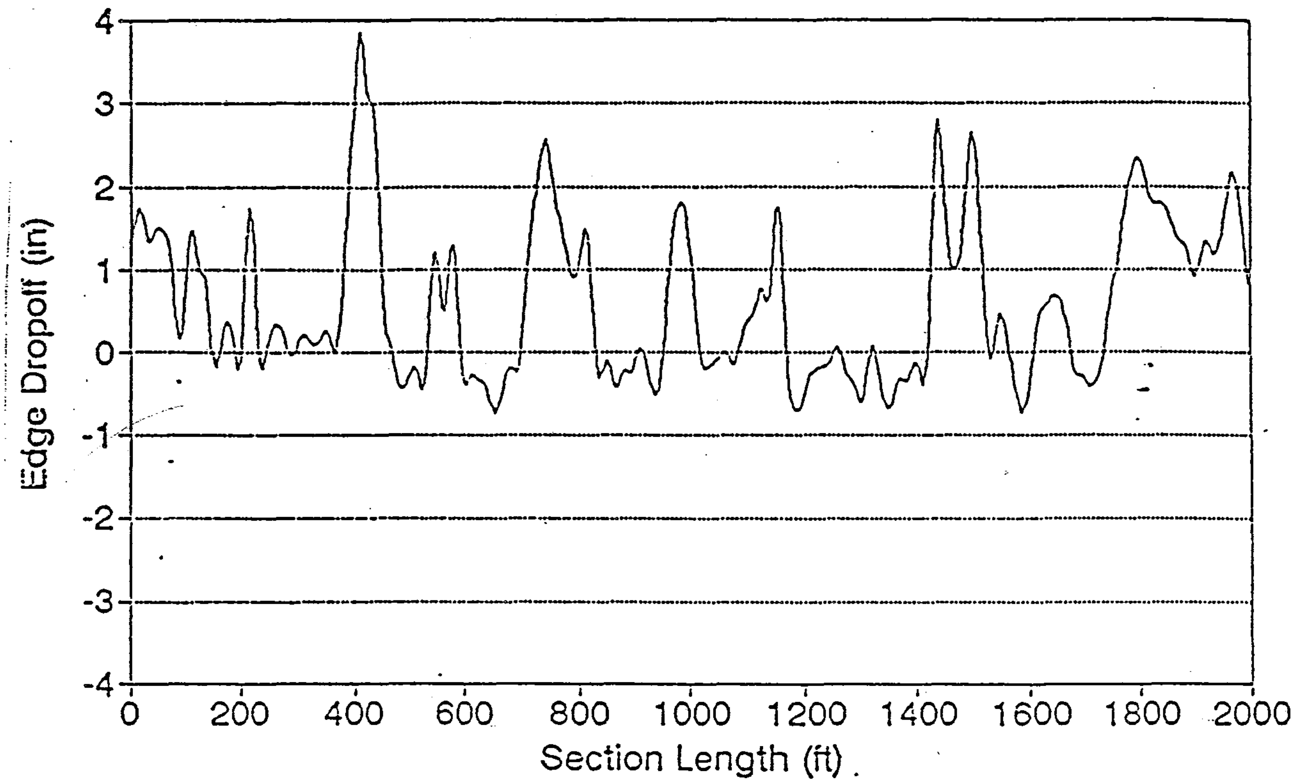

Figure 16. Ultrasonic Sensor Measures of Pavement Edge Drop-off Along 610 Meter (2000 Foot) Section at 80 km/h (50 mph), Run 2

Note: 1 inch = 25.4 mm and 1 foot = .305 meters

manual measures. Figures 11 through 16 show the results obtained from three pairs of runs completed at 16, 48, and 80 km/h (10, 30, and 50 miles/h). It is observed that the shape of the ultrasonic curves resemble the shape of the manual curve. If any of the ultrasonic curves is superimposed on the manual curve and the necessary shift is done, the peaks seem to match pretty well.

The drop-off data were further analyzed by subdividing them in four categories: less than 2.5 cm (1 in), between 2.5 and 5 cm (1 and 2 in), between 5 and 7.5 cm (2 and 3 in), and greater than 7.5 cm (3 in). Those values were expressed as percentages of the length of the section, as seen in Table 7. Ultrasonic measures show smaller drop-offs than manual measures. Speed does not seem to be an important factor in the drop-off measures.

TABLE 7. Percentage of the Length of the Segment With a Certain Drop-off for Different Collection Procedures

	DROP-OFF			
	< 2.5 cm	2.5 - 5 cm	5 - 7.5 cm	> 7.5 cm
Rutbar 16 km/h	69.0	23.8	6.6	0.6
Rutbar 16 km/h	65.6	27.2	7.2	0.0
Rutbar 48 km/h	76.2	18.0	5.8	0.0
Rutbar 48 km/h	67.6	26.8	5.6	0.0
Rutbar 80 km/h	69.8	24.4	5.8	0.0
Rutbar 80 km/h	66.0	25.2	7.2	1.6
Manual	50.8	13.7	29.8	5.7

Note: 1 in = 2.54 cm and 1 mile = 1.6093 km

7.4.4 Testing Procedures for 95 Percent Confidence Level

The second step in testing the proposed measures was to investigate whether the difference between manual and ultrasonic measures is statistically significant with 95 percent confidence. Three controlled sections were chosen (Table 8). Those sections had been constructed for previous research with selected constant drop-offs. Figures 17, 18, and 19 show sections A, B, and C, respectively.

TABLE 8. Section Characteristics

SECTION	LENGTH	SHAPE	DEPTH
A	60 m	60-degree	shallow
B	30 m	60-degree	shallow
C	30 m	rounded	deep

Note: 1 foot = .305 meters

Figures 20 and 21 are also photographs of section B. Figure 20 shows some vegetation encroachment close to the edge. Figure 21 illustrates, by the end of the ruler, the closest to the edge sensor #5 is expected to be. This is because the distance between sensors is 45 cm (18 in), and the right wheels are not expected to deviate from the edge more than 15 cm (6 in). Therefore, section B measurements are not expected to be influenced by vegetation because most of the time, vegetation will fall between the two sensors. Table 9 presents the number of repetitions done for each procedure.

Table 9. Number of Repetitions in Each Section

		SECTION A	SECTION B	SECTION C
NUMBER OF REPETITIONS	Manual	3	3	3
	Rutbar 16 km/h	2	3	3
	Rutbar 65 km/h		3	
	Rutbar 80 km/h	4		

Note: 1 mile = 1.609 km
Section C was not run at high speeds because of safety reasons.

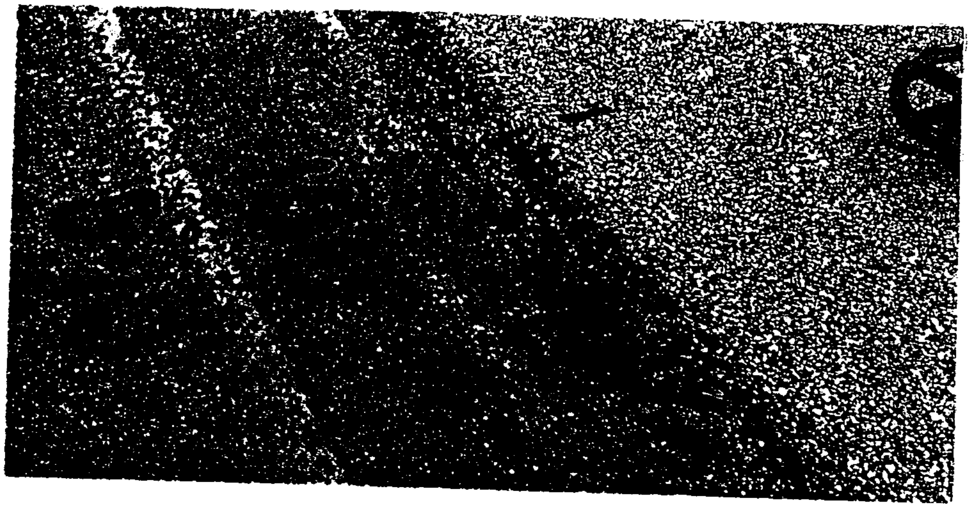

Figure 17. Section A

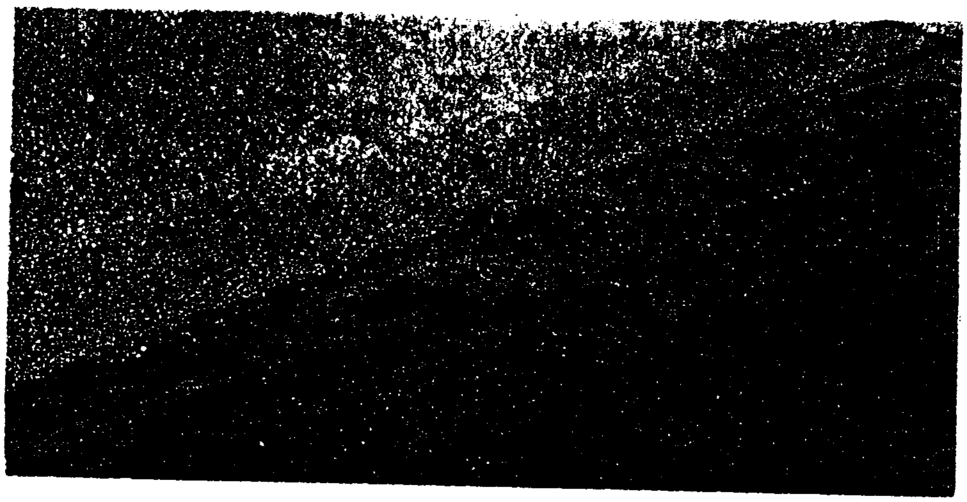

Figure 18. Section B

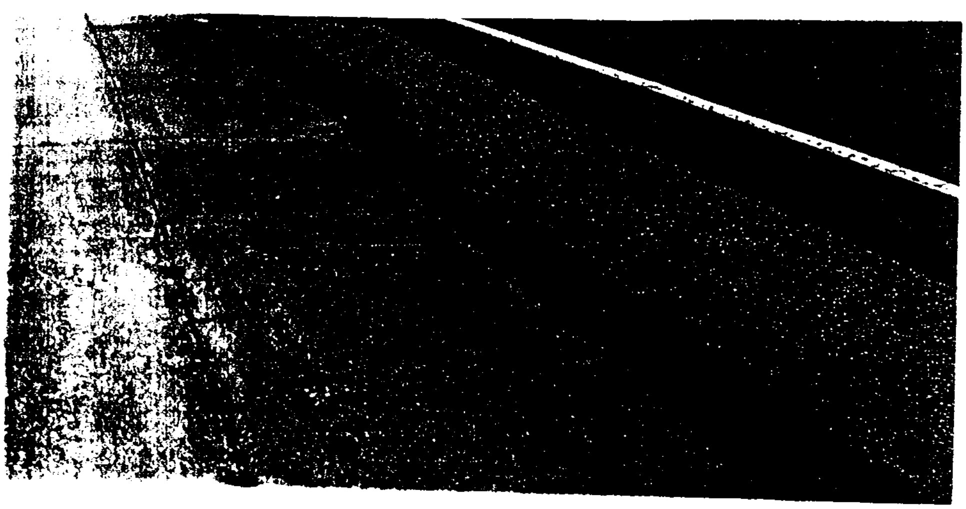

Figure 19. Section C

Figure 20. Section B

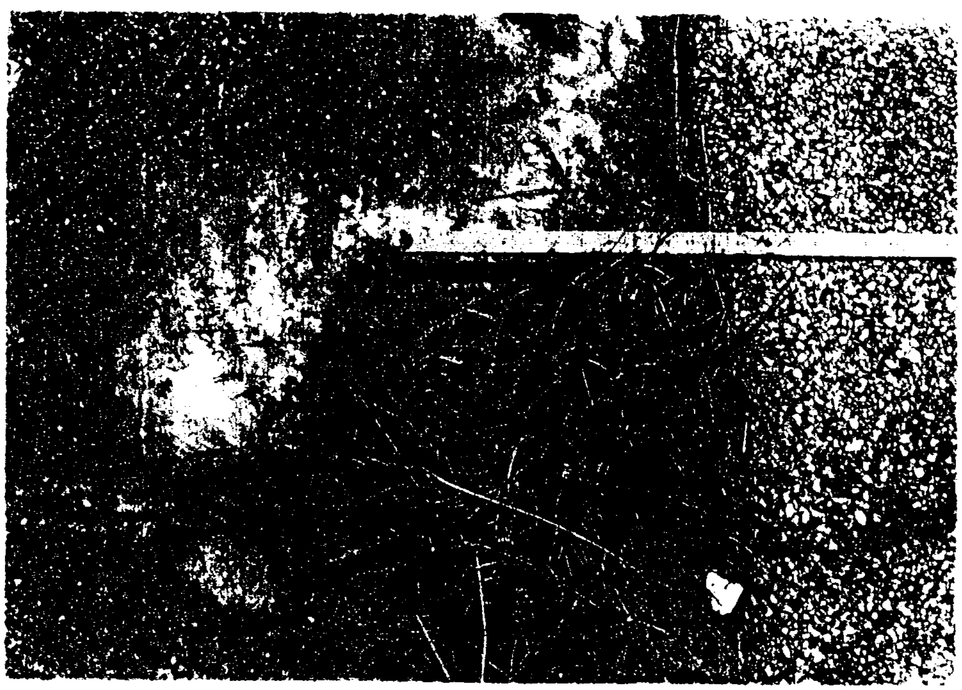

Figure 21. Section B

7.4.4 Results for 95 Percent Confidence Level

Figures 22 through 26 show manual and ultrasonic measures for a section and a certain speed. Figures 27 through 31 present the corresponding regression lines and 95 percent confidence intervals that were developed. The regression model considered was the following:

$$y = bo + b1 * dist + b2 * z + b3 * z * dist + E \qquad \text{(III)}$$

where:

	y	=	drop-off
	dist	=	position along the segment
	z	=	dummy variable that is equal to 1 for manual measures and equal to 0 for ultrasonic measures
	E	=	error

The model for manual measures is:

$$y = (bo + b2) + (b1 + b3) * dist \qquad \text{(IV)}$$

The model for ultrasonic measures is:

$$y = bo + b1 * dist \qquad \text{(V)}$$

A significant test was completed for b2 and b3, where b2 is the difference in intercepts, and b3 is the difference in slopes for ultrasonic and manual regression lines. A test for b2 tests if intercepts for the manual and ultrasonic measures are equal. A test for b3 tests if slopes for the manual and ultrasonic measures are equal. If the two tests have a p value greater than 0.05, then the slope and the intercept for both methods are not significantly different with 95 percent confidence for that section. If the slopes turn out to be not significantly different, but the intercepts are, then the difference in intercepts is the average shift between the two procedures. If both the slopes and intercepts are significantly different, that means that the difference between those two methods varies with the position in the section. The results obtained are shown in Table 10. The test statistic for the slope is:

$$t = ((b3u - b3m) - 0) / SE_{(b3u - b3m)} \qquad \text{(VI)}$$

where:

u	=	ultrasonic
m	=	manual
SE	=	standard error

The test statistic for the intercept is:

$$t = ((b2u - b2m) - 0) / SE_{(b2u - b2m)} \qquad \text{(VII)}$$

Table 10 shows that with 95 percent confidence, only for section B at 16 km/h (10 miles/h) the slopes are not significantly different. Therefore, for all the other cases, there is interaction, which means the difference in drop-off between those two methods varies with the position along the segment. Even though the two procedures are statistically significantly different with 95percent confidence, that difference may not be significant in practice.

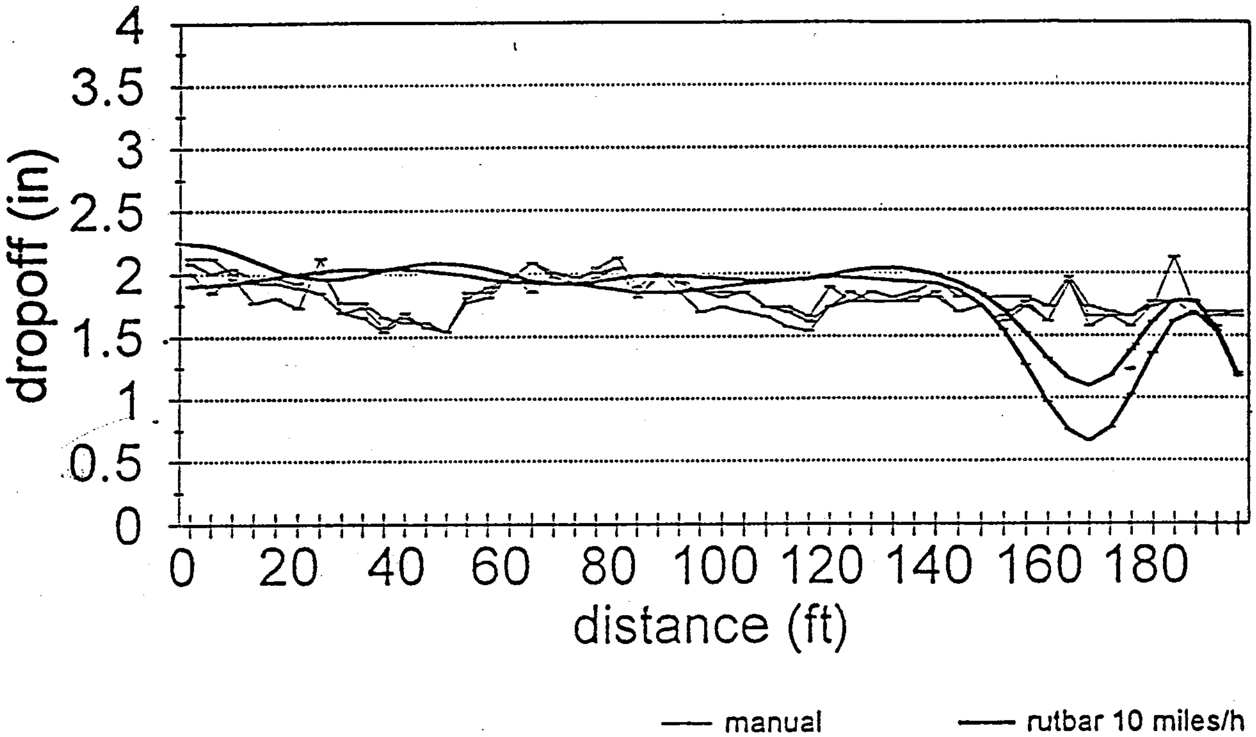

Figure 22. Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off, Section A

Note: 1 in = 25.4 mm

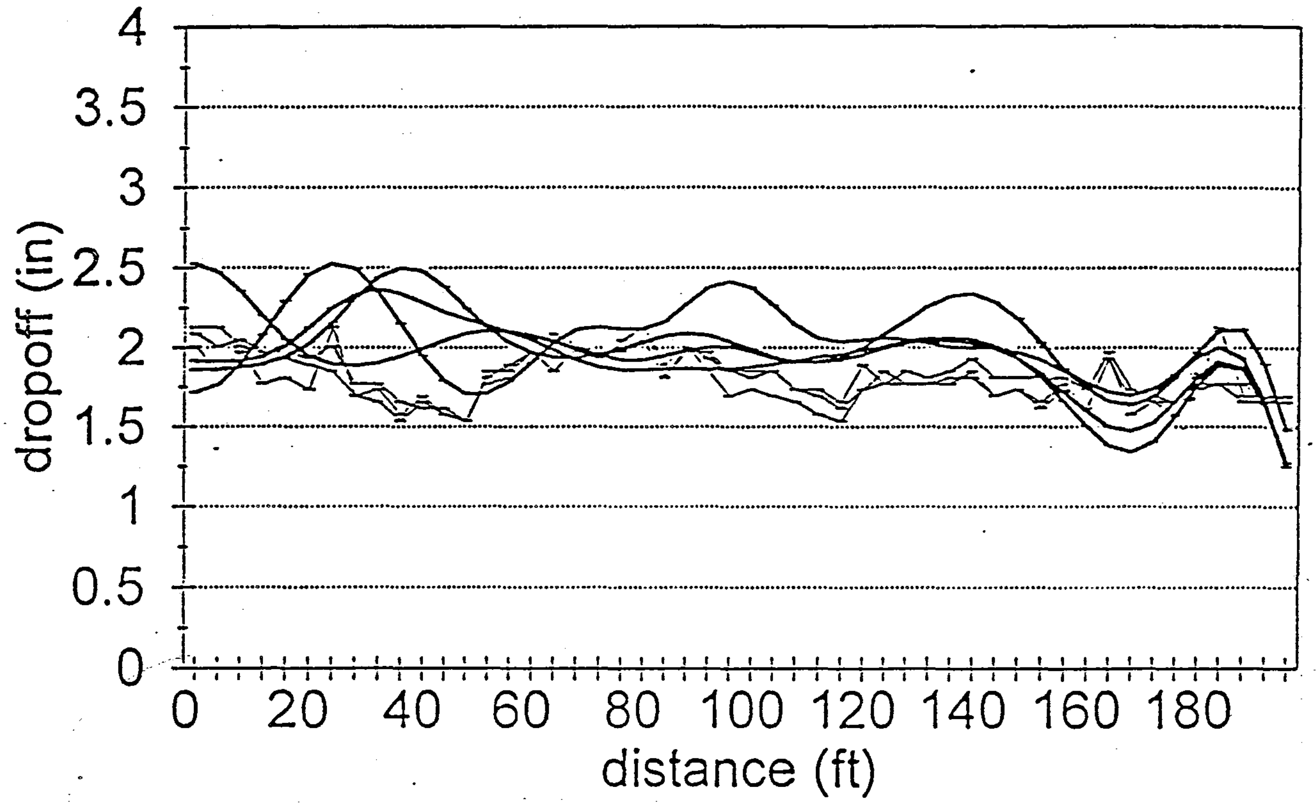

Figure 23. Manual Measures and Ultrasonic Measures at 80 km/h (50 mph) of Pavement Edge Drop-off, Section A

Note: 1 in = 25.4 mm

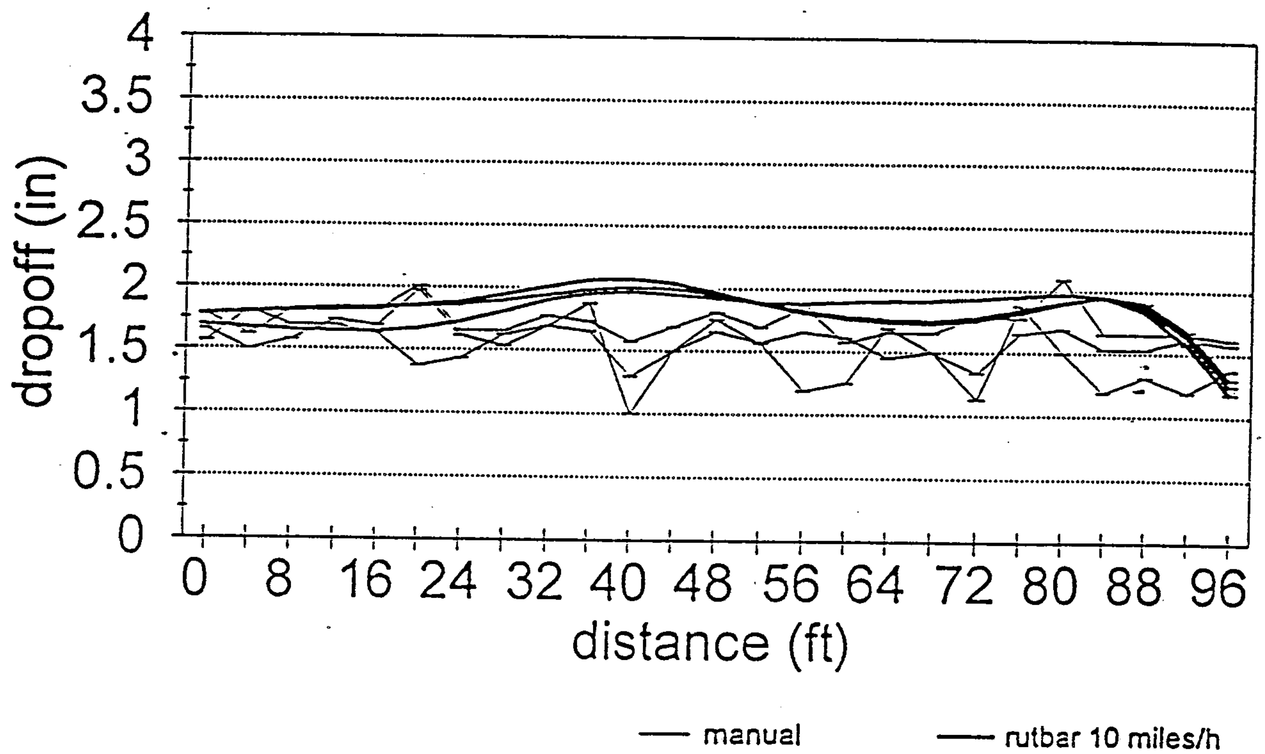

Figure 24. Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off, Section B

Note: 1 in = 25.4 mm

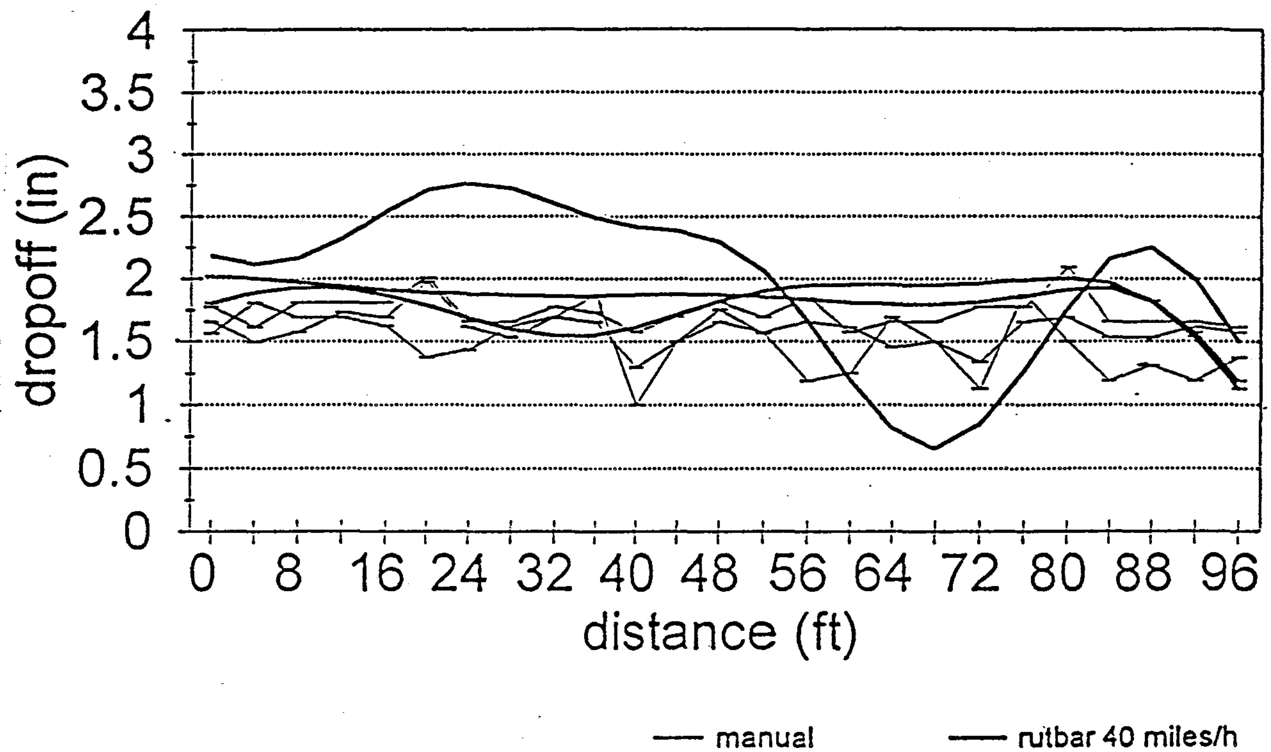

Figure 25. Manual Measures and Ultrasonic Measures at 64 km/h (40 mph) of Pavement Edge Drop-off, Section B

Note: 1 in = 25.4 mm

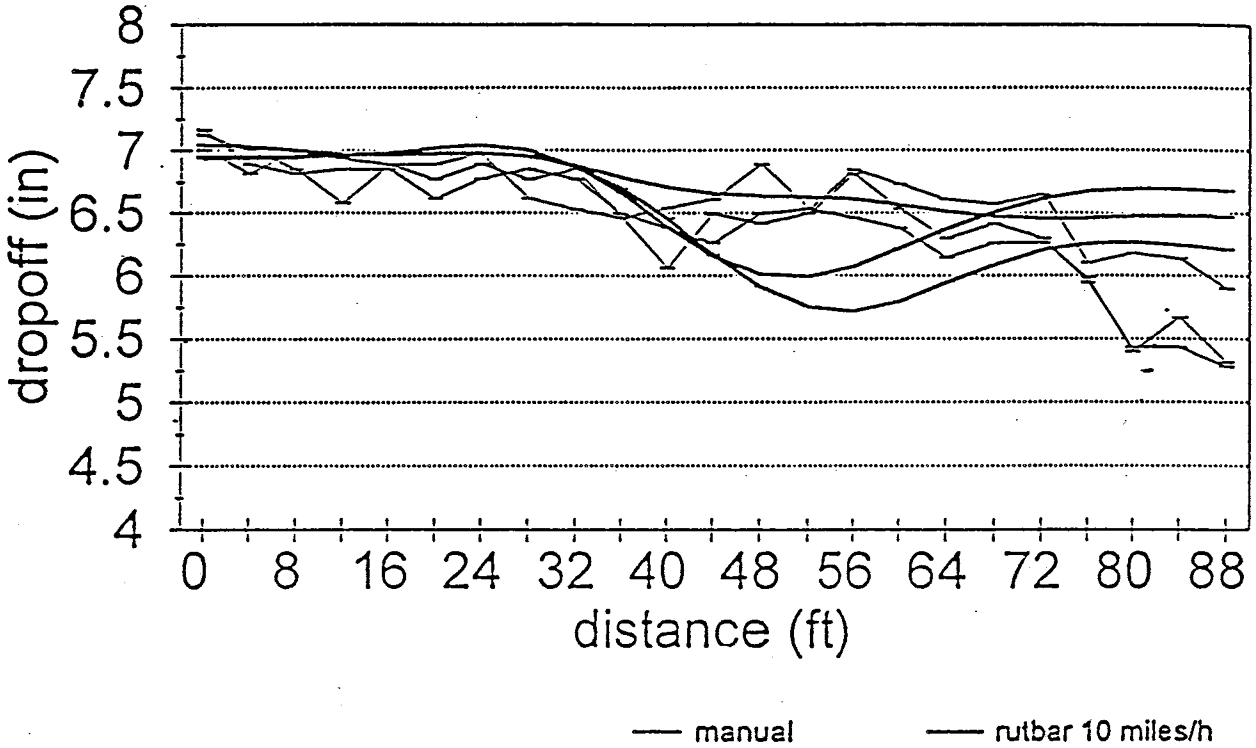

Figure 26. Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off, Section C

Note: 1 in = 25.4 mm

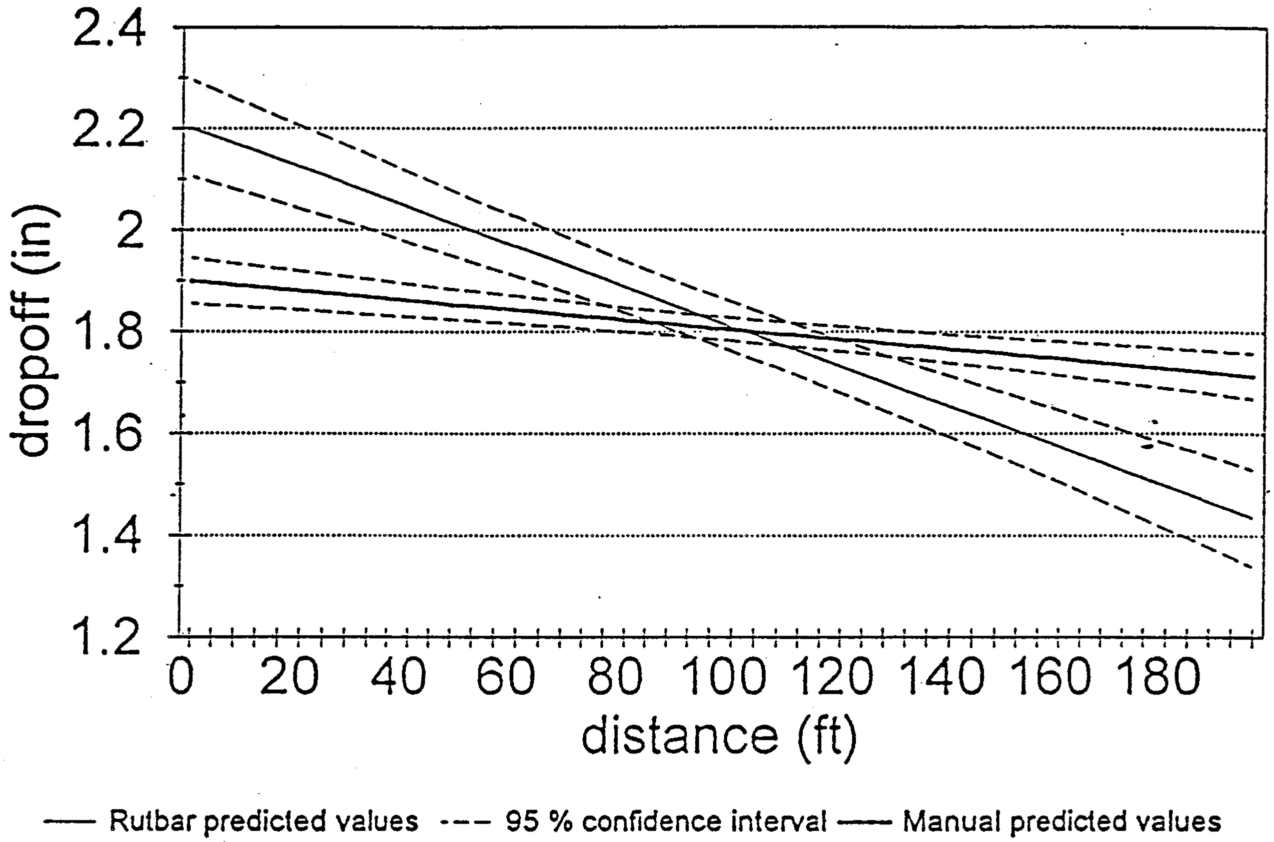

Figure 27. Predicted Values for Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off and Their Respective 95 Percent Confidence Interval, Section A

Note: 1 in = 25.4 mm

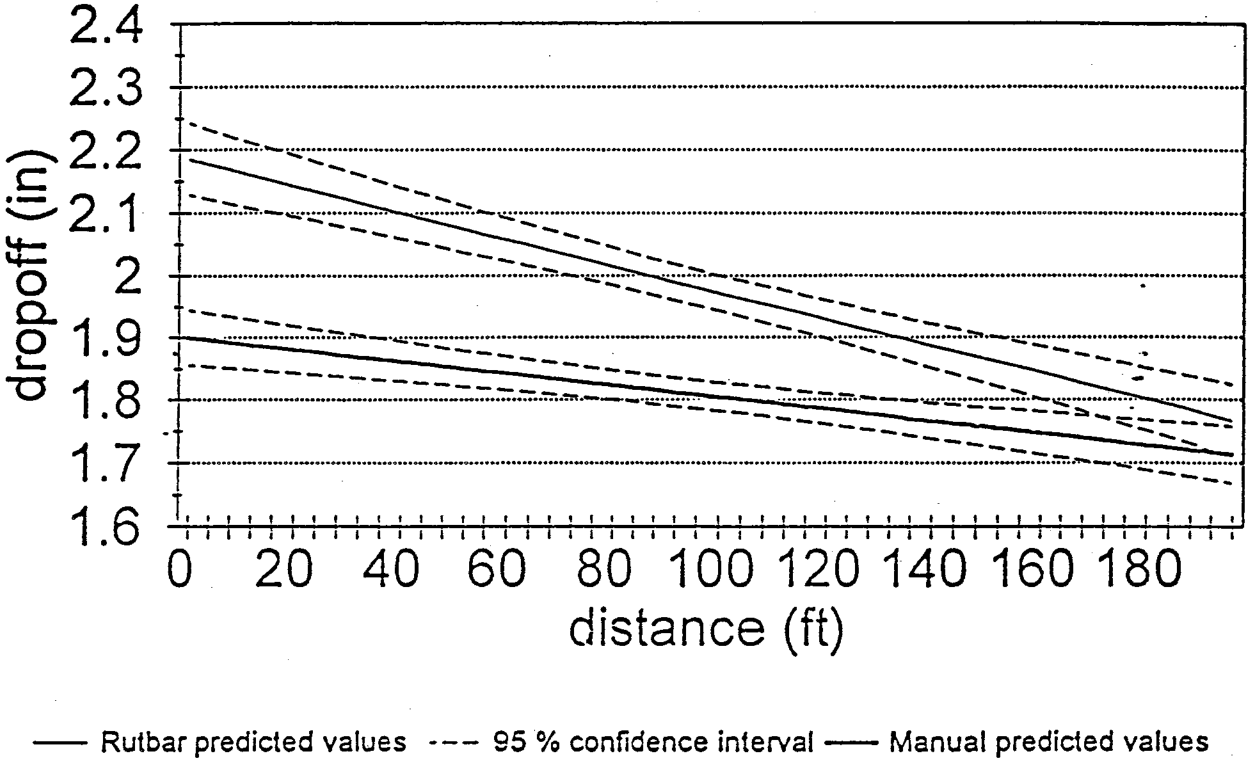

Figure 28. Predicted Values for Manual Measures and Ultrasonic Measures at 80 km/h (50 mph) of Pavement Edge Drop-off and Their Respective 95 Percent Confidence Interval, Section A

Note: 1 in = 25.4 mm

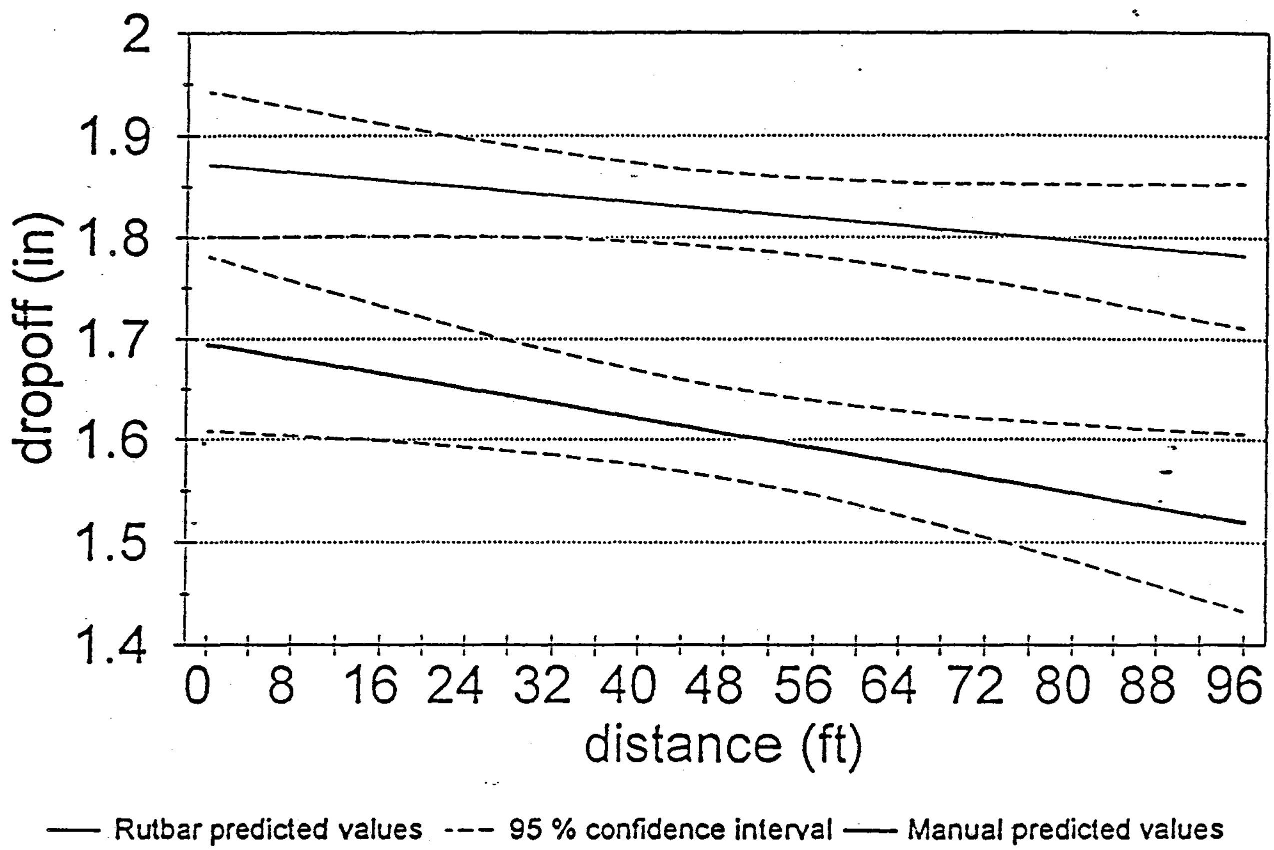

Figure 29. Predicted Values for Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off and Their Respective 95 Percent Confidence Interval, Section B

Note: 1 in = 25.4 mm

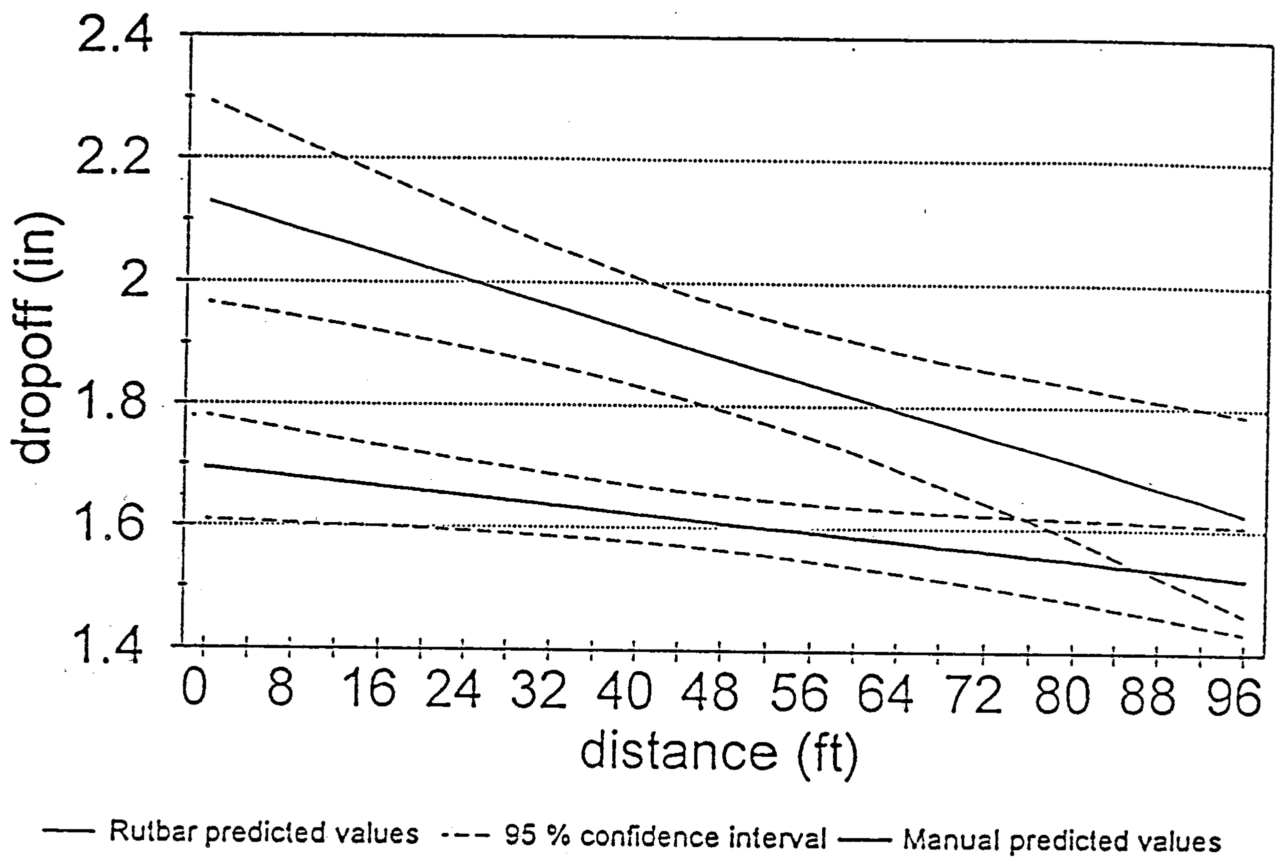

Figure 30. Predicted Values for Manual Measures and Ultrasonic Measures at 64 km/h (40 mph) of Pavement Edge Drop-off and Their Respective 95 Percent Confidence Interval, Section B

Note: 1 in = 25.4 mm

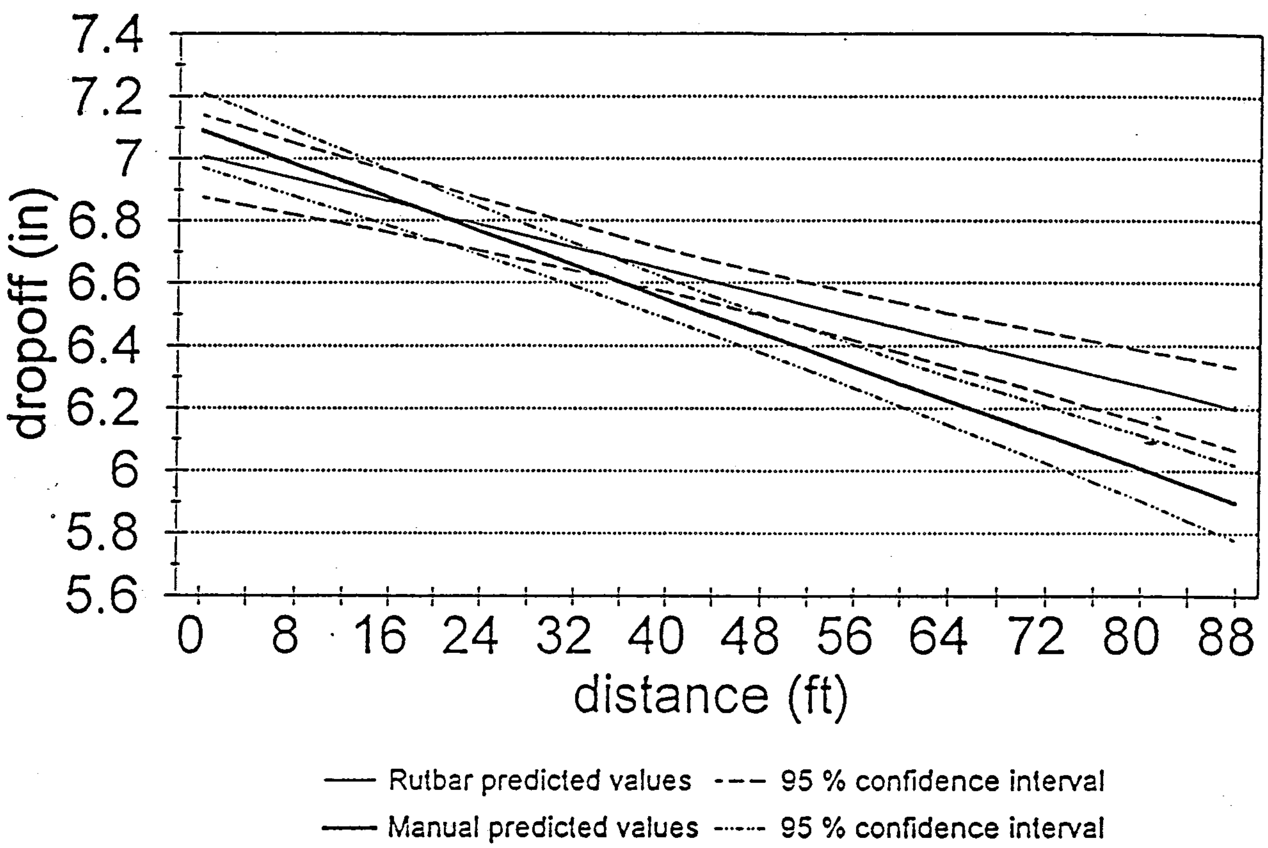

Figure 31. Predicted Values for Manual Measures and Ultrasonic Measures at 16 km/h (10 mph) of Pavement Edge Drop-off and Their Respective 95 Percent Confidence Interval, Section C

Note: 1 in = 25.4 mm

Table 10. p Values for the Difference in Intercepts and Slopes Between Ultrasonic and Manual Procedures

	p value	
	intercept	slope
Section A 16 km/h	0.0001	0.0001
Section A 80 km/h	0.0001	0.0006
Section B 16 km/h	0.0021	0.3765
Section B 65 km/h	0.0001	0.0407
Section C 16 km/h	0.3570	0.0143

Note: 1 mile = 1.6093 km

For further analysis, the following definitions are needed:

LDu half the difference in upper and lower limits of the 95 percent confidence interval for the ultrasonic procedure

LDm half the difference in upper and lower limits of the 95 percent confidence interval for the manual procedure

yu predicted value for the ultrasonic procedure

ym predicted value for the manual procedure

LDu - LDm measures the difference in variance between the ultrasonic and manual measurements. For instance, in the best case for section A at 16 km/h (10 miles/h), the manual measurement is expected to be within +/- 0.57 mm (0.0227 in), and the ultrasonic measurement is expected to be within +/- 1.23 mm (0.0483 in). Therefore, the ultrasonic measurement is only 0.65 mm (0.0256 in) greater than manual with 95 percent confidence. yu - ym measures the shift between predicted average values for ultrasonic and manual measures.

Table 11 summarizes for each section and speed the best and worst shift, and best and worst LDu - LDm. The average worst shift was 7.5 mm (0.3 in) with a standard deviation of 2.33 mm (0.092 in).

Table 11. Summary of Best and Worst Shifts of Predicted Ultrasonic Measures from Predicted Manual Measures Accompanied with the Best and Worst Differences in Variance Between Both Methods

	BEST LDu-LDm (mm)	WORST LDu-LDm (mm)	BEST SHIFT PREDICTED VALUES (mm)	WORST SHIFT PREDICTED VALUES (mm)
SECTION A 16 km/h	0.650	1.270	0.000	7.645
SECTION A 80 km/h	0.152	0.305	1.372	7.239
SECTION B 16 km/h	-0.381	-0.203	4.495	6.655
SECTION B 65 km/h	1.575	1.956	2.692	11.049
SECTION C 16 km/h	0.152	0.279	0.000	7.569

Note: 1 mile = 1.6093 km and 1 in = 25.4 mm

7.4.5 Random Site Selection

The random site selection program for the Maintenance Level of Service Evaluation is a computer program that is designed to provide a random list of sites to be surveyed. The program runs on a PC compatible computer with 6 megabytes of disk space. Each execution of the program provides a new list of sites for four different roadway categories in all 25 Highway Districts.

The 1992 TxDOT Inventory of State Highway Roadway Characteristics and Traffic Volumes, referred to as the RI-2 file, was used to develop a data base for the program. A set of 25 data files were prepared, one for each District, containing the required information for the random selection process. In addition to selecting data by District, only records with a Highway Status code other than 1 were extracted. Omitted records, those having a Highway Status Code of 1, are segments of highway that are under construction or are being designed for future construction.

Information extracted and saved in the data files include County, Highway-System, Highway-Number, Number-of-Lanes, Highway-Design, Beginning-Mile point, Length and Control and Section Number. The primary location reference system in the RI-2 file is that of the Control-Section-Mile point. The secondary system is that of County, Highway-System (e.g., U.S. Highway or Farm-To-Market-Road) and Highway-Number. Both of these are included in the site selection printout.

Random sites are selected for four different highway categories. They are selected based on variables in the RI-2 file as follows:

1. Two-Lane, Two-Way:
   Number-Of-Lanes = 2
   Highway-Design = 1

2. Four-Lane, Two-Way:
   Number-Of-Lanes = 4,
   Highway-Design = 1

3. Four-Lane, Divided:
   Number-Of-Lanes = 4
   Highway-Design = 3 or 4 or 5 or 6

4. Four-Lane, Expressway:
   Number-Of-Lanes = 4
   Highway-Design = 7 or 8 or 9.

The random site selection program is coded to make four passes through the District data file. With each pass, the program selects records from one category and totals the length of the highway in that category. The total length in miles is multiplied by 10 to give the potential 1/10th mile points from which the random sites are selected.

The number of sites to be randomly drawn were predetermined for each highway category (as described above). A uniform random number generator is used to draw, without replacement, the desired number of sites from the pool of potential sites. The location information for each selected site is then produced.

After four passes are completed for one District and four tables are sent to the file entitled "REPORT.TXT," the program then opens a new data set and repeats the process for another District. This process continues until all 25 Districts have been processed. The report file (REPORT.TXT) contains ASCII text that is formatted for direct printing using the DOS Editor file print command. It may also be imported into a word processing package for special formatting or printing control.

8.0 SUMMARY OF FINDINGS

Maintenance levels of service are defined as the thresholds that trigger maintenance activities. The Texas Department of Transportation needs to develop objective, economical, and reliable rating procedures for the evaluation of maintenance levels of service of the following components:

1. Vegetation
2. Litter
3. Pavement edge
4. Drainage
5. Safety appurtenances
6. Illumination
7. Traffic signals
8. Signs and delineators
9. Pavement markings

For this reason, Maintenance Levels of Service Guidelines presented in Administrative Circular N 5-92 were examined, based on meetings with maintenance personnel and literature review. A three-level of service scale was defined for each component, and each level was illustrated with clear color photographs (31).

The proposed seasonal daytime schedules for the evaluation of the condition of the different components for rural and urban sites were presented in Tables 4 and 5 respectively. A nighttime evaluation is also required for some of the components. The segments to be rated are those determined by the sampling procedure to be adopted.

The rating team is composed of the driver and the principal rater. The selection of the best data collection procedure is based on the relative advantages and disadvantages of each. Videologging appears to be the most appropriate one, yet it needs to be complemented for some components with manual and other automated data collection procedures. These components are: drainage (specifically culverts) and pavement edge. Only one run of the segment is necessary if culverts are not present. This run makes the videolog and also identifies any condition that requires immediate work. The video tape is taken back to the office to be analyzed. The tape is viewed at a data reduction station, and two components are rated at a time. Two cameras will be required in the fall survey when both roadside and pavement surface components are considered.

When pavement edge is evaluated, the principal rater should record the shape of the pavement edge in a data file using predefined keys of a notebook computer so that later this information is combined with that information obtained by the ultrasonic sensors (Rutbar). Even though the power of the Rutbar to measure the pavement edge's condition is limited, if compared with the effort and time required for manual observations, it should be used. The Rutbar used consists of a bar with a sensor placed at the right wheel path and another placed 0.45 m (18 in) apart to the right. More sensors could be installed to increase the accuracy of the procedure. The measures in the testing procedure were done every 1.2 m (4 ft), but this separation could be reduced. If there are culverts in the segment, a second run with stops will be needed for the principal rater to exit the vehicle and check the condition.

Safely stopping the survey vehicle for evaluation can sometimes be troublesome. Problems in stopping may occur when the survey involves roads without shoulders and with steep roadsides. If the segment has to be run twice, the vehicle needs to find a place to turn around. High traffic areas and divided roads challenge this action. Last but not least, a vehicle speed reduction of 15 km/h (10 miles/h) doubles the chance of a possible accident. Therefore, it is clear that the required number of stops and number of runs should be minimized and the vehicle's speed should remain at the traffic speed as much as possible. Safety should always be the first consideration when conducting a survey.

The basic equipment mounted in the survey van includes:

1. Video camera angled slightly to the right of the centerline of travel
2. Video camera pointed forward and slightly downward
3. Notebook computer
4. Monitor
5. VCR
6. Rutbar (ultrasonic sensors)
7. DMI (in the future GPS)

Continuing evaluation of the rating procedure and attention to the appearance of new technology are necessary for a more accurate, economical, and easier evaluation.

While the automated data collection process is desireable, the testing indicates that implementation of the automation will be expensive and time consuming. To expedite the implementation process, it is recommended that a manual recording method be used while walking the .16 kilometer (0.1 mile) randomly selected section.

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10.0 APPENDIX A

RANDOM SITE SELECTION PROCESS
AND
DEMONSTRATION OF SAMPLE SITE RATING PROCEDURES

10.1 RANDOM SITE SELECTION PROCESS

The test sites were selected using a random site selection program Random numbers are used to identify a 160 meter (0.1 mile) section of each roadway classification. A stand alone PC based program entitled "RANDSITE" was prepared by the Accident Analysis Division of the Texas Transportation Institute. This program allows the user to identify sites in each of the TxDOT Districts. The listing of the candidate sites is stored in a file named "REPORT.TXT." It can be viewed or printed using any word processing package. Each run with the "RANDSITE" Program yields sites in each of the TxDOT Districts. Thus, a full season's study sites can be obtained by a single run of the program.

More candidate sites will be listed than will be needed for each roadway classification. This flexibility allows for site deletion if the site is under construction or otherwise unacceptable for field evaluation. Also, the extended list allows for more economical data collection. Very remote sites can be replaced with one that better fits the routing that is proposed by evaluators. The final list of sites should be developed on the day of the field survey using the District Personnel's knowledge of the roadways in question. In particular, any conditions that would make a site unacceptable as a basic Maintenance-Level-of-Service data site must be evaluated. Valid reasons for designating the site as unacceptable include the following situations:

- Site is under construction,
- Site is scheduled for reconstruction in the immediate future and thus maintenance is being deferred on the site,
- Shoulder or side slope work is underway at the site, or
- Other valid concerns that the data may not be representative or that the conditions at the site may pose undue risk to survey personnel

Invalid reasons for deeming a site as unacceptable include: "We don't want to look at that one" or "Let's look at these sites instead, they are closer to the District Office."

In general, the first "X" sites on the list should be the target sites. Substitution, when a valid point is expressed about the site, must always be the next site on the list. The general procedure is as follows:

> "These are the study sites. Is there any reason that one or more of these sites may not be representative of the general Maintenance-Level-of-Service on that roadway classification as a whole?"
>
> If the answer is "YES," the expressed concern must be evaluated by the rater, and a decision made regarding the validity of the concern. If the concern is valid, the site should be deleted, and the next site on the list added.

10.2 NUMBER OF SITES NEEDED

The minimum number of sites is five. However, due to the difference in mileage in each roadway class, the number of two-lane, two-way sites must be much larger than the freeway sites to have a balanced representation of the Maintenance-Level-Of-Service in the District. As a starting point, the following guidelines are suggested:

Table 12. Recommended Study Sites

ROADWAY CLASSIFICATION	NUMBER OF SITES
FREEWAYS	3
4 OR MORE LANE ARTERIALS	5
TWO-LANE, TWO-WAY HIGHWAYS	10

The scheduling of data collection at each site may be in any order that logically connects the sites on a travel right.

10.3 NEED FOR RANDOM SITE SELECTION

The need for random site selection stems from two concerns:

1. If the District's know the site or sites that will be surveyed, or are allowed to select the sites to survey, there is a risk that the survey data can be manipulated. In all likelihood, they will not be truly representative of the general maintenance level as a whole.

2. If the rater is allowed to choose the sites, there is a risk that others will claim that the evaluation results are biased and do not reflect the true Maintenance-Level-Of-Service the District is providing.

Random site selection insures an adequate number of sites in each roadway class. Any claim the sample is biased is unfounded, as the process is completely random The random site selection process also provides greater stability in the ratings.

10.4 DEMONSTRATION OF SAMPLE SITE RATING PROCEDURES

A limited demonstration of rating procedures was conducted during the early months of 1995. This demonstration had the following objectives:

1. To compare two basic methods for rating continuous and some discrete items of maintenance: walking the sample site and riding past

2. To estimate how much variability might exist between individuals rating the same sites

3. To compare "expert" ratings with those of raters that were not familiar with the study and had only the pictorial manual and the procedures described in the next section to guide them. These raters might be representative of worst-case raters assigned to this task by TxDOT.

10.4.1 Sample Sites

Five sample sites were found in District 17 of TxDOT within the confines of Brazos County, Texas (see Exhibit 1, Brazos County map). These sites were:

SITE 1: FM 60, Control Section 506-1, Milepoint 9.0

SITE 2: FM 60, Control Section 506-1, Milepoint 10.3

SITE 3: US 190/SH 21, Control Section 117-1, Milepoint 8.9

SITE 4: FM 974, Control Section 1691-2, Milepoint 4.5

SITE 5: FM 1687, Control Section 1560-1, Milepost 7.9

Each of these sites were videotaped (for a separate evaluation of rating using videotape only) and also documented by still photography. The photographs capture level of service conditions prevailing at each of the sites. Site 1 and Site 2 are on a Farm-to-Market road in close proximity to residential areas and a regional mall in College Station, and thus are well-traveled. Site 3 is on a major arterial east of Bryan. Sites 4 and 5 are very rural and little traveled. All these sites are two-lane undivided facilities.

10.4.2 Raters

"Expert" raters for the sample sites were the three project principal researchers, Drs. Don Woods, Wayne McCulley, and Rodger Koppa. Six of the seven "amateur" raters were graduate students at Texas A&M University, four in Civil Engineering and two in Industrial Engineering. The seventh rater was a technician on the staff of TTI. The seven "amateur" raters were randomly assigned to either the site-walking condition (4) or to the site-riding condition (3). The differences between these two procedures are described in the Procedures section below.

10.4.3 Procedures

The "amateur" raters were given the following written instructions which were read and explained to them as they examined the pictorial Manual. Identical procedures (walking) were used by the "expert" raters.

This procedures guide, together with the pictorial Manual provides a method for evaluating the condition and how well maintenance has been performed ("level of service") for the following:

- **Vegetation**
- **Litter**
- **Pavement Edges**
- **Roadway and Roadside Drainage**
- **Guard-Fence**
- **Mail Boxes**
- **Roadway Illumination**
- **Traffic Signals**
- **Traffic Signs**
- **Roadside Delineators**
- **Roadside Object Markers**
- **Raised Pavement Markers**
- **Pavement Markings**

We have come up with a measurement scale that uses only three levels for these components. This scale was taken from comments and actual practices of many of the Districts in the Texas Department of Transportation. The scale is a rating:

Rating	Description	Explanation
1	Desirable	What any component should be to be both safe and pleasing to the public
2	Tolerable	The component may not look so good, but it is still safe and not hurting the roadway
3	Intolerable	The component neither looks good nor is safe; the roadway may also be in danger

In order to help you make these ratings, the manual has color photographs for each component, **vegetation, litter**, etc., illustrating the above levels of service. When you tell another person that a certain segment of highway has guard-fence at Level of Service 2, they will have a good idea of what you mean, if they use this manual.

SAMPLE SITES

A Sample Site is a stretch of roadway on the State System exactly 160 meters (0.1 mile(or about 500 ft)) long, in the specified direction from the locator. The site specification will give:

(1) Highway or FM designation

(2) Location on that facility (milepost, physical feature, distance from intersection, etc.)

(3) Direction (cardinal) from start point at location to end point

Rating Continuous (strip) Items of Maintenance

The following continuous items of maintenance must be rated within the distance of 160 meters (500 feet), on the side of the roadway designated by the direction given in the site designation. If the site designation is eastbound, for example, you are to rate on the eastbound side of the facility. You are to look at the condition of the right-of-way as a whole within that distance, and rate on the basis of what you see in just that distance. If, for some reason, the condition changes just beyond 160 m (500 ft), your rating is for what you see *within the 160 m (500 ft).* Continuous items are:

- Vegetation (several different items)
- Litter
- Pavement Edges
- Raised Pavement Markers
- Pavement Markings

Rating Discrete Items of Maintenance

Discrete items are where you find them in the vicinity of the sample site (within 1.6 kilometers (1 mile) in the designated direction from the start point). They can be located on either side of the highway.

- Roadway and Roadside Drainage
- Guard-Fence
- Mail Boxes (supports)
- Roadway Illumination (can only be done at night)
- Traffic Signals
- Traffic Signs
- Roadside Delineators
- Roadside Object Markers

You may find a number of these discrete items of maintenance in the 160 m (500 ft) sample site, but you may not find any. As you move from the beginning to the end of the site, look for these items, and either rate them on the spot or note them for later rating. Some will not be present in the vicinity (for example traffic signals on a rural FM road). Others may be in the vicinity. Your quota for each site for items that could be expected to be present is two.

If you can't find two examples of the item in the 160 m (500 ft), move on down the road at least 1.6 km (1 mile) until you do. Give up, and go to the next site.

Data Sheets

The data sheets that you have been provided will be the tool you use to record your ratings of the conditions you find at the site. Take a few minutes to study these forms. When you arrive at a site, be sure to fill in all the descriptive information at the top of each form.

There are two ways to rate items of maintenance at a site: (1) walking and (2) riding. You will use one of these procedures, but not both. Here in the next few sheets is how to do each:

WALKING SAMPLES

Drive to the site and park your vehicle safely off the shoulder as close as you can to the start of the sample distance of 160 m (500 ft). Leave the hazard flashers on. Take your data sheets, manual, and clipboard with you. You must wear a safety vest and hard hat whenever you are doing a walking sample.

(1) Fill in the descriptive material on the data sheet for this site.

(2) Look at your data sheet, and find the first continuous item of maintenance to be rated.

(3) Look that item up in your pictorial manual, and refresh your memory on what the three levels of maintenance look like.

(4) Walk in the specified direction well off the travel way for 160 m (500 ft) to the end of the sample site. Pay attention to conditions

on *your* side of the road and the adjacent right-of-way. Ignore conditions across the road or facility on the other side. As you walk, look at the first item of maintenance. Try not to notice the other items for now.

(5) As you reach the end of the 160 m (500 ft), rate that item by circling the rating 1, 2, or 3 that best describes the condition of that item.

(6) As you walk for the first time, note any discrete items that are on your data sheets. Stop and rate any items that you find. For discrete items, it is OK to cross over to the other side of the highway or move beyond the start and end point to find discrete items and rate them. Use your manual as a guide. If you encounter two examples, you are through with that item at this site.

(7) Look up a second item in your manual. Return to the other end of the site, rating that item as you walk. Record your rating at the end of the walk.

(8) Repeat Step (7) until you have rated all the applicable items of maintenance.

NOTES: As you get more expert at rating, you will find that you will be able to note and rate more than one item on a single trip. Do not try to rate more than three items at the same time.

You may find that you can see enough of the site at midpoint to rate an item. If so, rate the item at that point, but be sure to walk the site back and forth at least twice, before you rate any continuous items.

(9) If you do not encounter at least two discrete items of maintenance that can be expected at your site, get back in the vehicle, and move past the end of the sample site until you do get your quota. Stop at each item that you encounter, examine the item as close as necessary, and make your rating. You may be able to do this from your vehicle, or you may have to get out to see the item well enough to

rate it (for example, drainage in a cross culvert).

RIDING SAMPLES

Drive to the site and park your vehicle safely off the shoulder as close as you can to the start of the sample distance of 160 m (500 ft). Put the hazard flashers on.

(1) Fill in the descriptive material on the data sheets for this site.

(2) Look at your top data sheet, and find the first continuous item of maintenance to be rated.

(3) Look that item up in your pictorial manual, and refresh your memory on what the three levels of maintenance look like.

(4) Drive in the specified direction at as low but safe a speed as possible 160 meters (0.1 mile or 500 ft) to the end of the sample site. Pay attention to conditions on *your* side of the road and the adjacent right-of-way. Ignore conditions across the road or facility on the other side. As you drive, look at the first item of maintenance. Try not to notice the other items for now.

(5) As you reach the end of the 160 m (500 ft), pull off the road and rate that item by circling the rating 1, 2, or 3 that best describes the condition of that item.

(6) As you drive for the first time, mentally note any discrete items that occur and that are on your data sheets.

(7) Return to the starting point, look up a second item in your manual, and then rate it as you once again drive in the specified direction. Record your rating at the end of the sample site. Repeat this until all applicable items have been rated.

Also pick a discrete item, look it up in the manual, and rate it as you pass by. If you can't see it well enough to rate from the vehicle as you pass by, stop. If you still can't see it well enough, wait until the end of the site visit to rate that item.

NOTES: As you get more expert at rating, you will find that you will be able to note and rate more than one item on a single trip. Do not try to rate more than three items at the same time.

You may find that you can see enough of the site at midpoint to rate an item. If so, rate the item at that point, but be sure to drive the site back and forth at least twice, before you rate any continuous items.

(8) If there are discrete items that require leaving the vehicle to rate, park the vehicle in a safe place off the travel way, leave the hazard flashers on, and put on a safety vest and hard hat.

(9) If you do not encounter at least two discrete items of maintenance that can be expected at your site, drive the vehicle in the specified direction past the end of the sample site until you do get your quota. Stop at each item that you encounter, examine the item as close as necessary, and make your rating. You may be able to do this from your vehicle, or you may have to get out to see the item well enough to rate it (for example, drainage in a culvert).

Although the raters went out in teams of two or three to these sites, they rated independently. They were cautioned not to compare notes or ratings of items until they had finished rating all five sites and turned in their data sheets (Figure A-2). So far as can be ascertained, they complied with these instructions. All sites were evaluated within a two-week time span in early to middle February 1995. No maintenance activity occurred at any of these sites in that time. Ratings were done during the hours of ten AM to four PM on days that were dry.

10.4.4 Results

Data sheets from "expert" and "amateur" raters were tabulated, and summaries rounded to the nearest integer were produced. These summaries appear as Figures A- 3, A-4, A-5, A-6, and A-7. These summaries are identically structured for each of the five sites. The nine continuous elements and the eight (two examples each) discrete elements are identified in Column 1. The mean (arithmetic average) rating on the scale of three for the three "experts" for each element are given in Column 2. Then the average ratings for the four walkers and three riders appear in Columns 3 and 4. Then comparisons between walkers and riders and between the "experts" and "amateurs" are contained in Columns 4, 5, and 6. The word "ERROR" means that no data are contained in that particular cell of the matrix.

Ratings for discrete elements tended to be lower (higher numerically) when made by the "experts" as compared to the "amateurs." Since the particular items to be rated were not specified, as they would not be in a routine sample visit, individual raters were free to pick the discrete installations or conditions within the 1.6 kilometer (1mile) window downrange of the site. Hence, comparisons between ratings for continuous level of service elements are probably easier to make than for discrete elements. Since continuous elements are rated on a composite impression gained in the same 160 m (500 ft) section of right-of-way, the basis of rating should be the same for all raters.

Figure A-8 graphically portrays differences tabulated in Figure A-3 between the "experts" and either "walkers" or Riders" in the ratings of continuous elements at Site 1. Positive mean differences express the finding that the "amateurs" rated the element *better* (lower numerical rating) than the "experts." Negative mean differences denote elements rated *worse* than the "experts."

A mean difference of more than 0.5 rating point should be considered significant, because it suggests that perception of the element may be subjective enough to change its rating, depending on who is rating it. At Site 1, Pavement Edge Drop, Herbaceous Encroachment, Woody Encroachment, Litter (denoted "Junk"), Weeds, Slope Coverage, and Lines exceed 0.5 in either direction, for either walkers, riders, or both.

Figures A-9 through A-12 graphically summarize the mean differences among "experts," "walkers," and "riders" at each of the four remaining sites. Another way to look at these data is in tabular form, Figure A-13. The columns reflect ratings significantly better than or worse than the "experts" by either walkers or riders. If all disagreements are summed (column 7) and then the various continuous elements are re-ordered by the rank order of these disagreements, a picture emerges of those elements which are trouble spots at sites. Woody Encroachment heads the list, closely followed by Herbaceous Encroachment. It is evident that the rating guidance provided in the pictorial manual may have been insufficient for these two elements. Pavement Edge Drop was intermediate in the extent of disagreement. Figure A-13 also suggests (7 B's versus 12 W's) that those raters who walked tended to rate the sites as being worse than the "expert" raters did (who also walked). Riders, on the other hand, tended to view the sites as better than the "experts," by a proportion of 8:5. Figure A-14 shows how the rating differences were distributed among the five sites as a function of continuous elements. The first site may have given rise to differences because it *was* the first site for all participants. Site 2 and 3 were relatively trouble-free, perhaps because they were reasonably straightforward, well-maintained sections of roadway. Site 4 was rather complex, as was Site 5; at these sites the tendency was for the "amateurs" to down rate the site as compared to the "experts," especially if they were walking the site.

10.4.5 Conclusions

1. Considerable training and practice (both classroom and on-the-job) will have to be afforded TxDOT personnel that are assigned to perform Level of Service ratings, to assure the validity and reliability of sampling. In this context, "validity" means that the rating made of a particular item of maintenance bears a reasonably close correspondence to its actual state. "Reliability" means that if more than one person rates the item of maintenance, they will come up with comparable ratings. These two concepts are obviously interconnected.

2. There is little to be gained with a riding sample for continuous elements. Ratings tend to be somewhat biased upward (rated better) if a rating pass at any speed is attempted. Such maneuvers pose some risk, also, for both raters and the motoring public. In many cases, a 160 m (500 ft) sample length can be adequately observed and the various continuous elements rated after a single traverse, with the rater standing (or even seated in the vehicle) somewhere in the middle of the segment length. Those discrete elements present within the sample site can also be examined and rated during this procedure. To meet the quota of discrete elements that can be expected to be present at a given site, it will be necessary to pick up items as the raters go from one site to the next, just as they did in this demonstration. Depending upon what these items are, they can be rated while the person(s) are seated in a motor vehicle. More "hidden" elements (especially cross-drain culverts) will require leaving the vehicle.

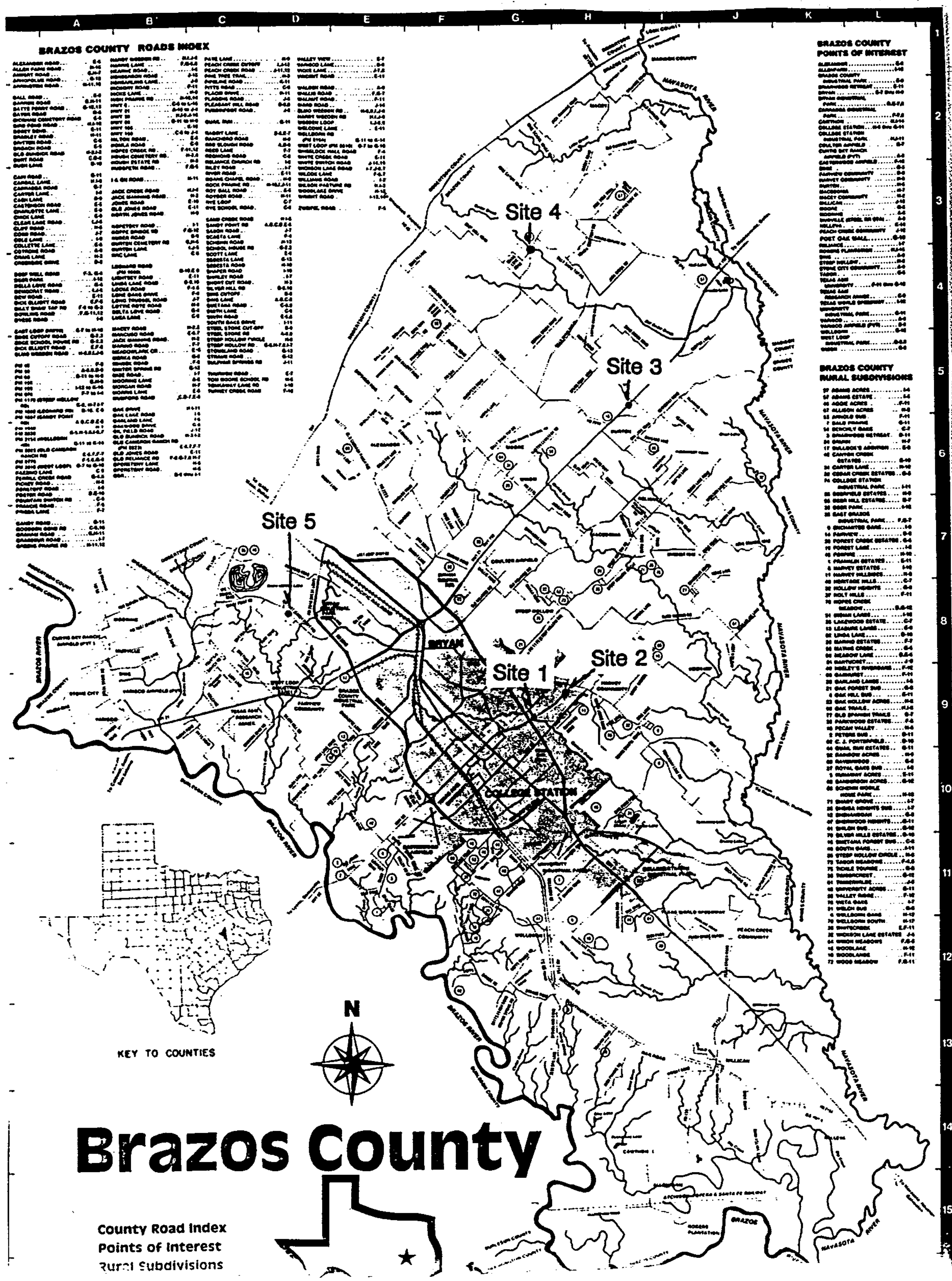

Figure A-1. Location of Sample Sites

TxDOT FIELD DATA RECORDING FORM
FOR RATING LEVEL OF SERVICE

SITE:____________ DATE:____________ TIME:____________ RATER:________

Circle the Level of Service rating that best describes this element at this site:

Continuous Elements:	Level of Service Rating			
	Desirable	Tolerable	Intolerable	REMARKS
Pavement Edge Drop.................	1	2	3	________
Herbaceous Encroachment........	1	2	3	________
Woody Encroachment................	1	2	3	________
Roadside Litter............................	1	2	3	________
Noxious Weeds...........................	1	2	3	________
Turf Coverage in Safety Strip......	1	2	3	________
Slope Coverage..........................	1	2	3	________
Drainage Ditch............................	1	2	3	________
Painted Lines..............................	1	2	3	________
Discrete Elements:				
Guardfence................................	1	2	3	________
Guardfence................................	1	2	3	________
Sign..	1	2	3	________
Sign..	1	2	3	________
Object Marker............................	1	2	3	________
Object Marker............................	1	2	3	________
Mail Box Support........................	1	2	3	________
Mail Box Support........................	1	2	3	________
Culvert, Parallel, Drainage..........	1	2	3	________
Culvert, Parallel, Safety...............	1	2	3	________
Culvert, Parallel, Drainage..........	1	2	3	________
Culvert, Parallel, Safety...............	1	2	3	________
Culvert, Cross, Drainage.............	1	2	3	________
Culvert, Cross, Safety.................	1	2	3	________
Culvert, Cross, Drainage.............	1	2	3	________
Culvert, Cross, Safety.................	1	2	3	________

Figure A-2. TxDOT Field Data Recording Form

SITE 1	Mean Expert	Mean Walk	Mean Ride	Mean Diff Walk-Ride	Mean Diff Exp-walk	Mean Diff Exp-Ride
Continuous Elements						
Pavement Edge Drop	3	3	2	0	0	1
Herbaceous Encroachment	2	1	1	0	1	1
Woody Encroachment		1	1	0	-1	-1
Roadside Litter	1	2	1	1	-1	0
Nxious Weeds	2	1	1	0	0	1
Turf in Safety Strip	2	1	1	0	0	0
Slope Coverage	1	1	2	-1	0	-1
Drainage Ditch	1	1	1	0	0	0
Painted Lines	2	2	2	-1	0	-1
Discrete Elements						
Guardfence	2	1	1	0	1	1
Guardfence	1	1	1	0	0	0
Sign	2	2	1	1	0	1
Sign	1		1	-1	1	0
Object Marker	1	1	1	0	0	0
Object Marker	1	1	1	0	0	0
Mailbox Post	1					
Mailbox Post						
Culvert, Parallel, Drain	1	1	2	-1	0	-1
Culvert, Parallel, Safety	1	1	1	0	0	0
Culvert, Parallel, Drain	3	1	2	-1	2	1
Culvert, Parallel, Safety	1	1	1	0	0	0
Culvert, Cross, Drain	ERROR	1	2	-1	ERROR	ERROR
Culvert,Cross, Safety	ERROR	1	1	0	ERROR	ERROR
Culvert, Cross, Drain	ERROR	ERROR		ERROR	ERROR	ERROR
Culvert,Cross, Safety	ERROR	ERROR		ERROR	ERROR	ERROR

Figure A-3. Summary of Results for Sample Site 1

SITE 2	Mean	Mean Walk	Mean Ride	Mean Diff Walk-Ride	Mean Diff Exp-walk	Mean Diff Exp-Ride
Continuous Elements						
Pavement Edge Drop	1	1	1	0	0	0
Herbaceous Encroachment	3	2	1	0	1	2
Woody Encroachment	2	1	1	0	1	1
Roadside Litter	2	2	2	0	0	0
Nxious Weeds	1	1	1	0	0	0
Turf in Safety Strip	1	1	1	0	0	0
Slope Coverage	1	1	1	0	0	0
Drainage Ditch	1	1	1	0	0	0
Painted Lines	1	1	1	0	0	0
Discrete Elements						
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Sign	1	1	1	0	0	0
Sign	2		1	-1	2	1
Object Marker	1	1	2	-1	0	-1
Object Marker	3	ERROR	3	ERROR	ERROR	-1
Mailbox Post	1					
Mailbox Post						
Culvert, Parallel, Drain	2	1	1	0	1	1
Culvert, Parallel, Safety	1	1	1	0	0	0
Culvert, Parallel, Drain	2	ERROR	ERROR	ERROR	ERROR	ERROR
Culvert, Parallel, Safety	2	ERROR	ERROR	ERROR	ERROR	ERROR
Culvert, Cross, Drain	1	1	2	-1	0	0
Culvert,Cross, Safety	1	1	1	0	0	0
Culvert, Cross, Drain	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Culvert,Cross, Safety	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR

Figure A-4. Summary of Results for Sample Site 2

SITE 3	Mean	Mean Walk	Mean Ride	Mean Diff Walk-Ride	Mean Diff Exp-walk	Mean Diff Exp-Ride
Continuous Elements						
Pavement Edge Drop	1	1	1	0	0	0
Herbaceous Encroachment	1	1	1	0	0	0
Woody Encroachment	ERROR	1	1	0	ERROR	ERROR
Roadside Litter	2	2	2	1	-1	0
Nxious Weeds	1	1	2	-1	0	0
Turf in Safety Strip	1	1	1	0	0	0
Slope Coverage	1	1	1	0	0	0
Drainage Ditch	2	1	1	0	1	0
Painted Lines	1	1	1	0	0	0
Discrete Elements						
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Sign	ERROR	1	1	0	ERROR	ERROR
Sign	ERROR		2	-2	ERROR	ERROR
Object Marker	1	1	1	0	0	0
Object Marker	1	1	1	0	0	0
Mailbox Post	1		1			
Mailbox Post			ERROR			
Culvert, Parallel, Drain	2	2	2	1	0	0
Culvert, Parallel, Safety	2	1	1	0	1	0
Culvert, Parallel, Drain	2	2	1	0	1	1
Culvert, Parallel, Safety	1	1	1	0	0	0
Culvert, Cross, Drain	1	1	1	0	0	0
Culvert,Cross, Safety	2	3	3	0	-1	-1
Culvert, Cross, Drain	1	2	2	0	-1	-1
Culvert,Cross, Safety	1	3	3	0	-2	-2

Figure A-5. Summary of Results for Sample Site 3

SITE 4	Mean	Mean Walk	Mean Ride	Mean Diff Walk-Ride	Mean Diff Exp-walk	Mean Diff Exp-Ride
Continuous Elements						
Pavement Edge Drop	2	1	2	-1	1	1
Herbaceous Encroachment	1	1	1	0	0	0
Woody Encroachment	2	3	2	1	-1	0
Roadside Litter	2	3	2	1	-1	0
Nxious Weeds	1	2	1	1	-1	0
Turf in Safety Strip	2	2	2	1	-1	0
Slope Coverage	1	1	2	-1	0	-1
Drainage Ditch	2	1	2	-1	1	1
Painted Lines	1	2	1	1	-1	0
Discrete Elements						
Guardfence	1	ERROR	ERROR	ERROR	ERROR	ERROR
Guardfence	1	ERROR	ERROR	ERROR	ERROR	ERROR
Sign	1	1	1	0	0	0
Sign	1		1	-1	1	0
Object Marker	1	2	1	1	-1	0
Object Marker	1	2	1	1	-1	0
Mailbox Post	2		ERROR			
Mailbox Post			ERROR			
Culvert, Parallel, Drain	2	2	2	0	0	0
Culvert, Parallel, Safety	2	1	2	-1	1	0
Culvert, Parallel, Drain	2	3	2	1	-1	0
Culvert, Parallel, Safety	3	3	3	0	0	0
Culvert, Cross, Drain	1	2	1	1	-1	0
Culvert,Cross, Safety	2	3	2	1	-1	0
Culvert, Cross, Drain	1	2	3	-1	-1	-2
Culvert,Cross, Safety	2	3	3	0	-1	-1

Figure A-6. Summary of Results for Sample Site 4

SITE 5	Mean Expert	Mean Walk	Mean Ride	Mean Diff Walk-Ride	Mean Diff Exp-walk	Mean Diff Exp-Ride
Continuous Elements						
Pavement Edge Drop	2	2	2	0	0	0
Herbaceous Encroachment	2	1	2	-1	1	1
Woody Encroachment	3	1	2	-1	2	1
Roadside Litter	3	2	2	1	0	1
Nxious Weeds	1	2	2	1	-1	-1
Turf in Safety Strip	2	3	2	1	-1	0
Slope Coverage	3	2	2	0	0	1
Drainage Ditch	2	1	2	0	0	0
Painted Lines	1	2	1	1	-1	0
Discrete Elements						
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Guardfence	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Sign	1	1	1	0	0	0
Sign	1	ERROR	ERROR	ERROR	ERROR	ERROR
Object Marker	1	2	1	1	0	0
Object Marker	1	ERROR	1	ERROR	ERROR	0
Mailbox Post	1	ERROR	ERROR			
Mailbox Post		ERROR	ERROR			
Culvert, Parallel, Drain	2	1	1	0	1	1
Culvert, Parallel, Safety	3	1	1	0	2	2
Culvert, Parallel, Drain	2	1	1	0	1	1
Culvert, Parallel, Safety	1	1	1	0	0	0
Culvert, Cross, Drain	2	3	3	0	-1	-1
Culvert, Cross, Safety	2	1	2	0	0	0
Culvert, Cross, Drain	3	ERROR	2	ERROR	ERROR	1
Culvert, Cross, Safety	1	ERROR	2	ERROR	ERROR	-1

Figure A-7. Summary of Results for Sample Site 5

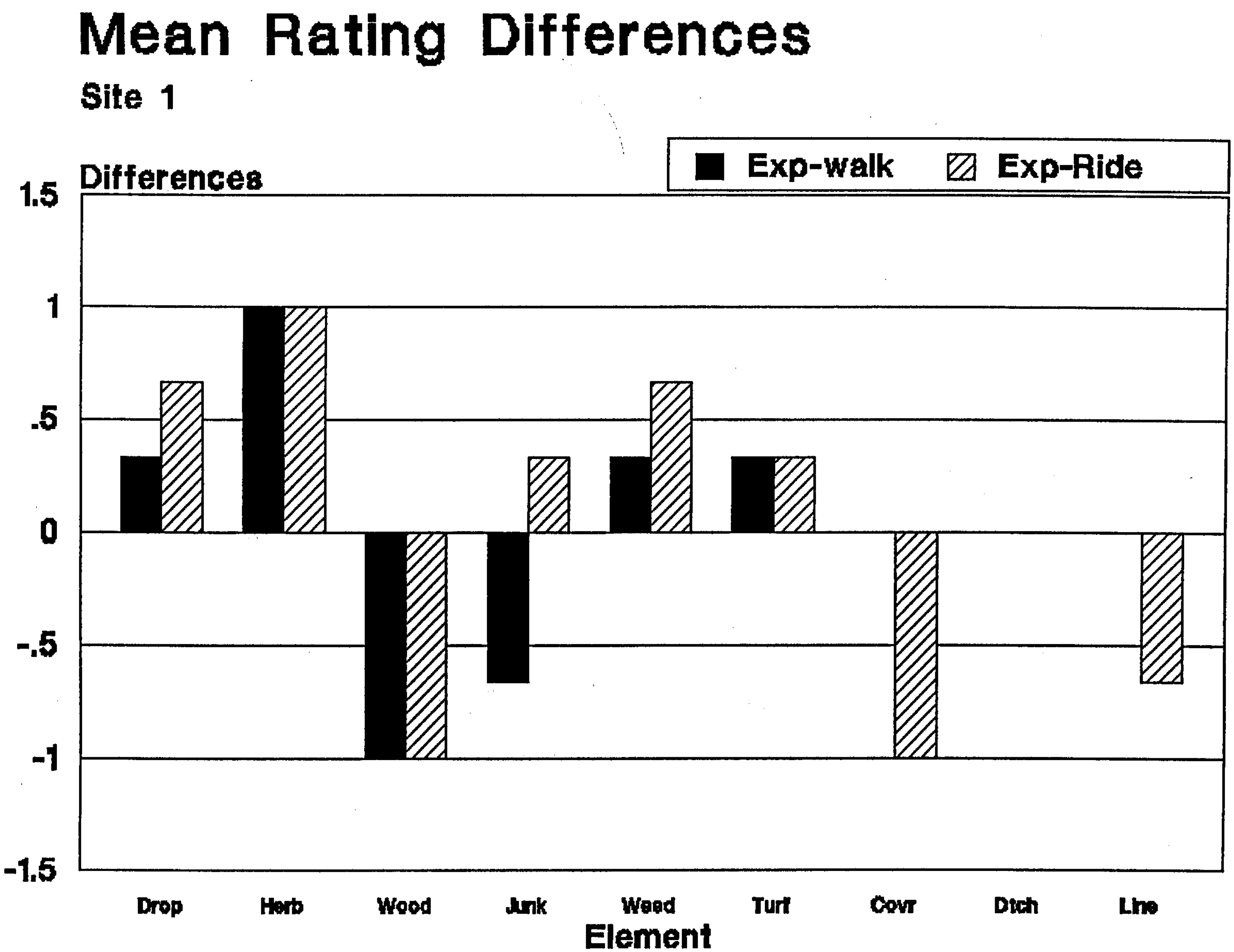

Figure A-8. Mean Rating Differences for Sample Site 1

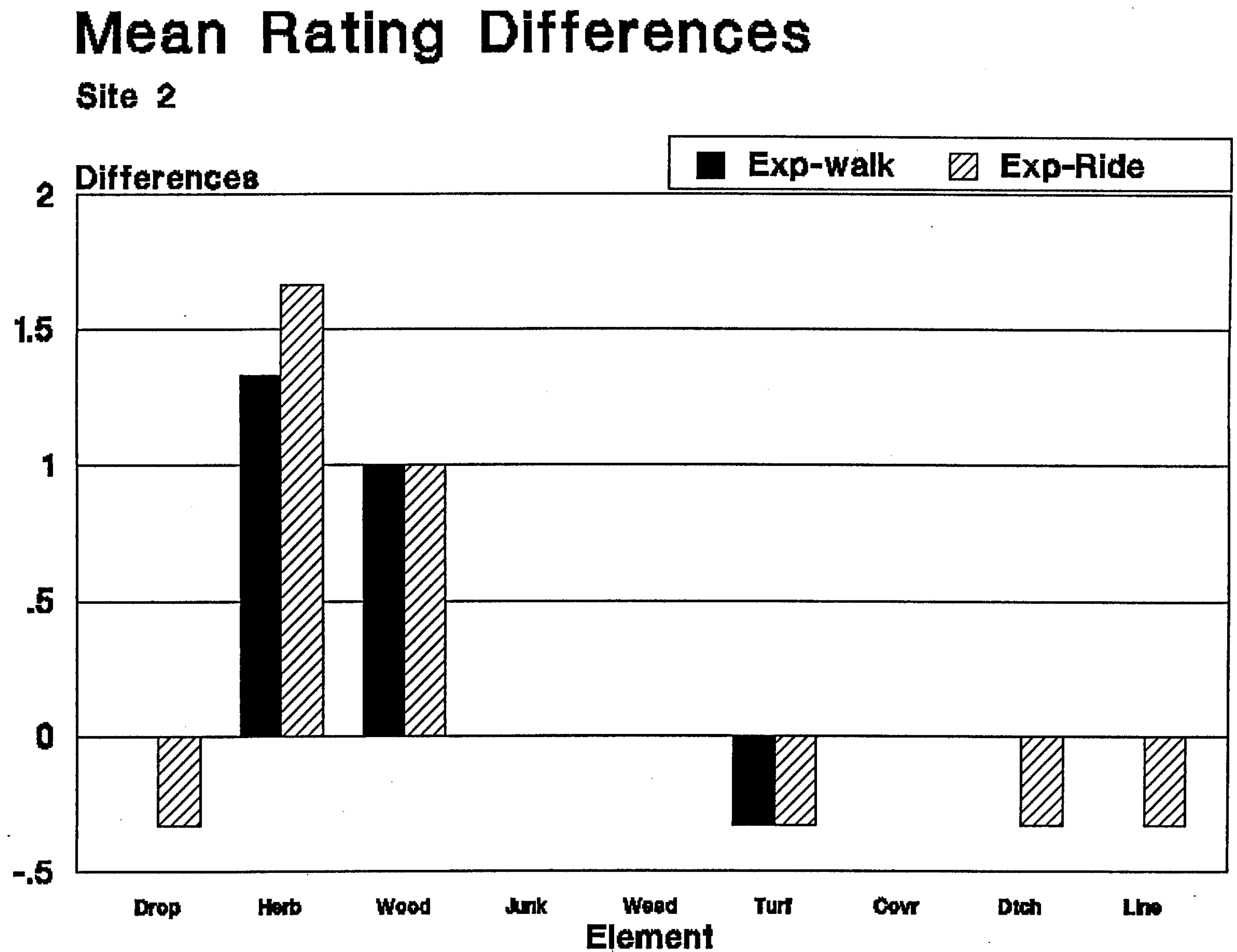

Figure A-9. Mean Rating Differences for Sample Site 2

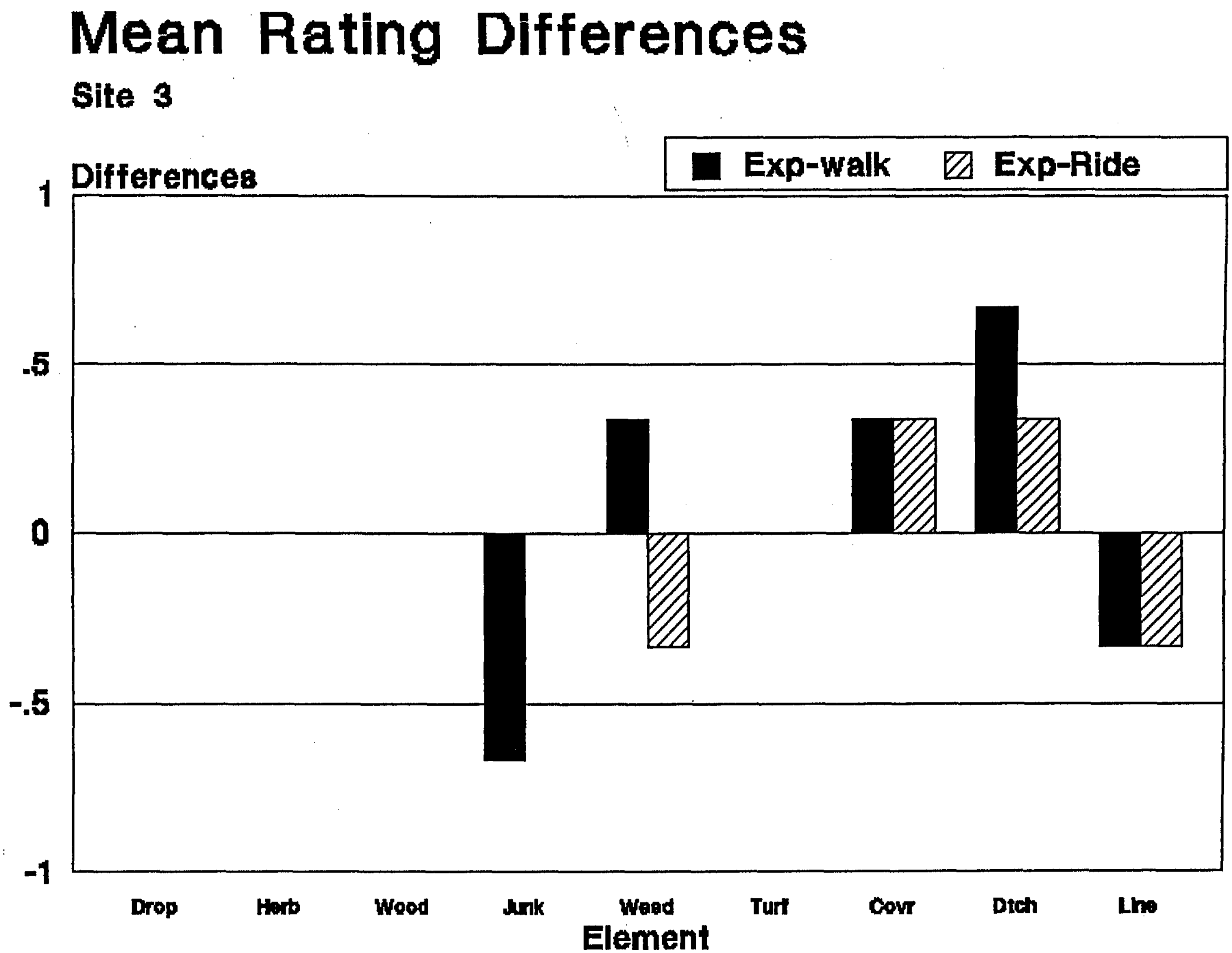

Figure A-10. Mean Rating Differences for Sample Site 3

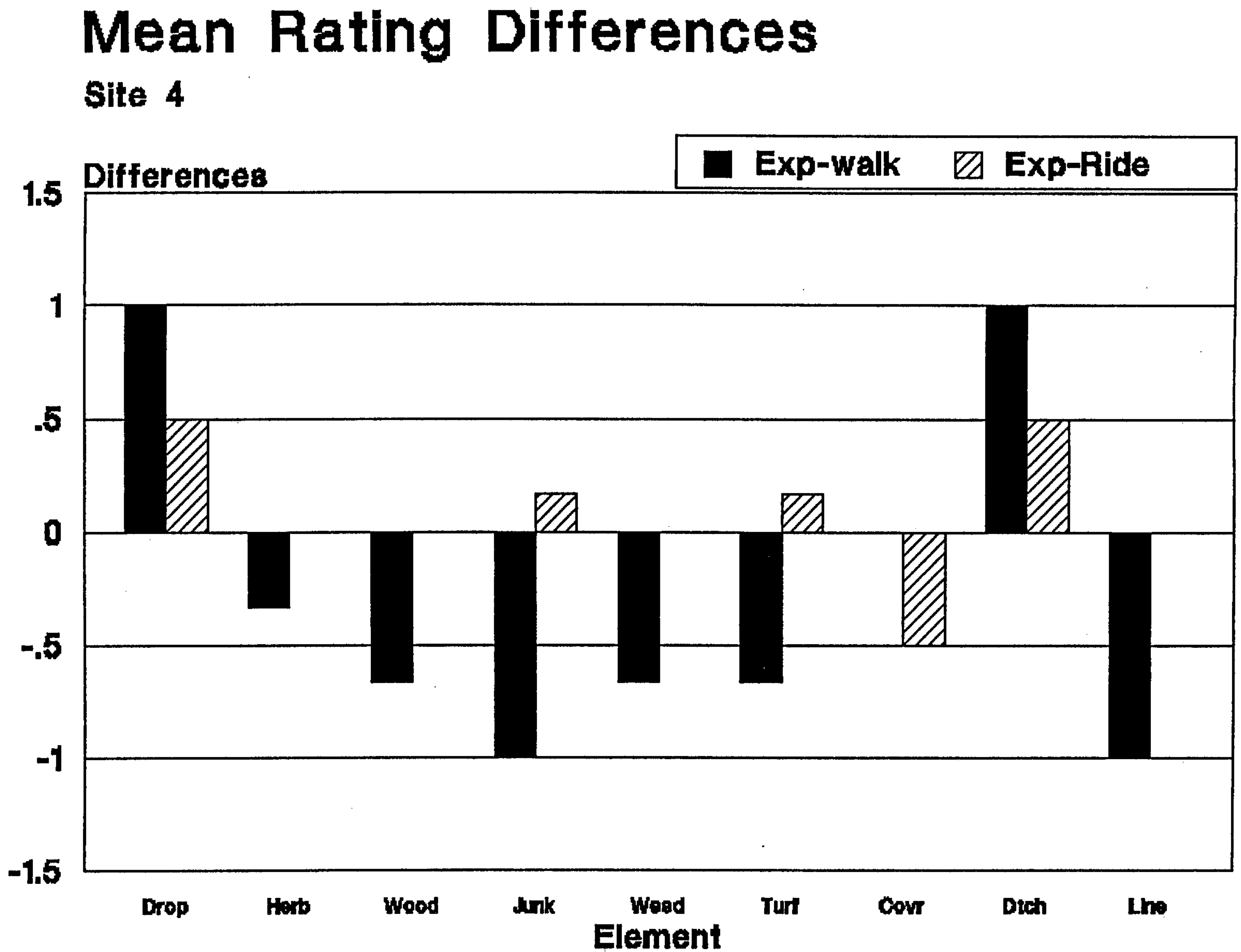

Figure A-11. Mean Rating Differences for Sample Site 4

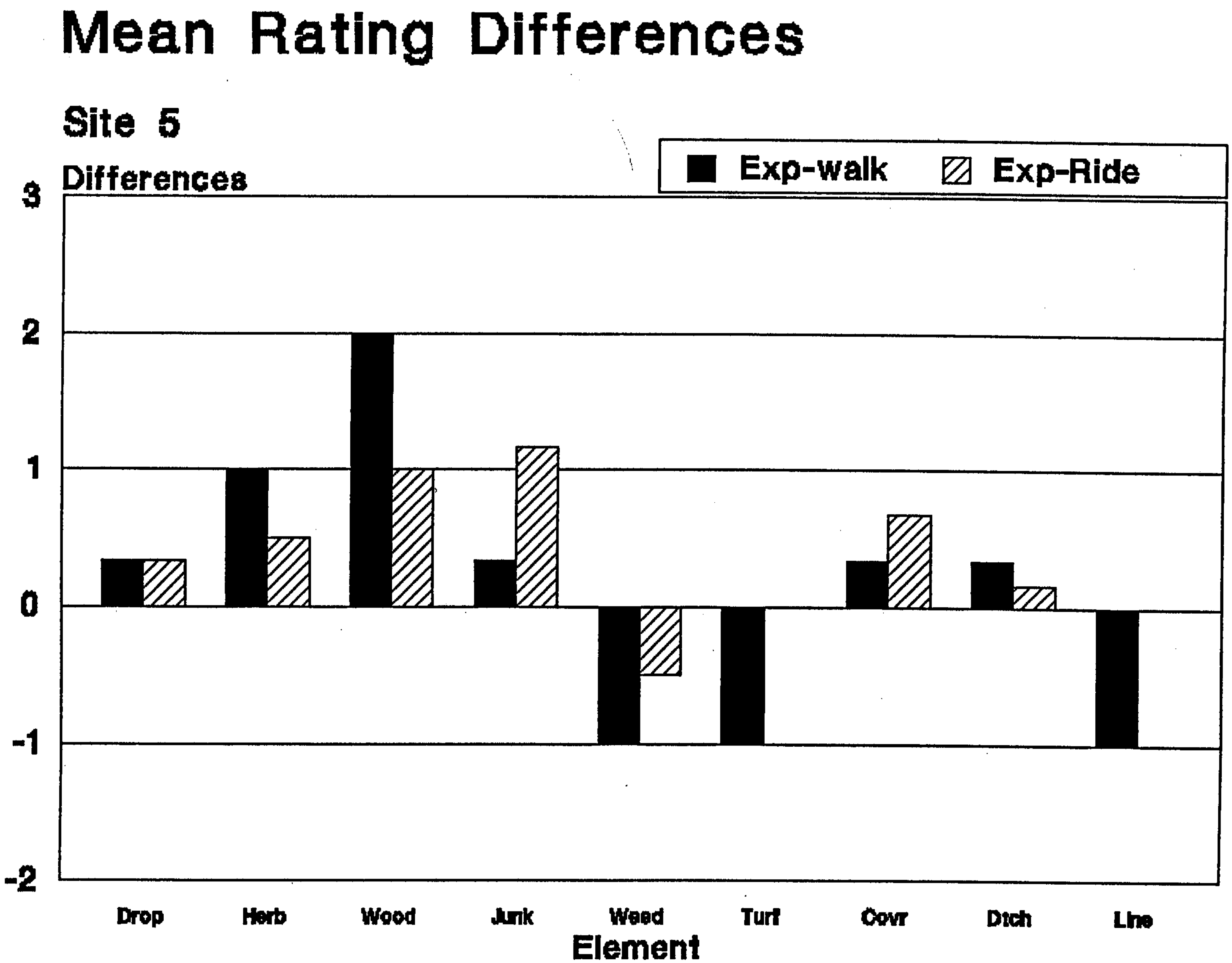

Figure A-12. Mean Rating Differences for Sample Site 5

SUMMARY OF MEAN DIFFERENCES IN RATINGS						
Continuous Elements		Walk	Walk	Ride	Ride	Sum All
		Sum B	Sum W	Sum B	Sum W	
Woody Encroachment	Wood	2	2	2	1	7
Herbaceous Encroachment	Herb	3	0	3	0	6
Pavement Edge Drop	Drop	1	0	2	1	4
Roadside Litter	Junk	0	3	0	0	3
Noxious Weeds	Weed	0	2	1	0	3
Painted Lines	Line	0	2	0	1	3
Turf in Safety Strip	Turf	0	2	0	0	2
Slope Coverage	Covr	0	0	0	2	2
Drainage Ditch	Dtch	1	1	0	0	2
		7	12	8	5	

Figure A-13. Summary of Mean Differences in Rating for Sample Sites

11.0 APPENDIX B

APPROACHES FOR LEVEL OF SERVICE RATING DATA ANALYSIS

11.1 INTRODUCTION

Part of the charge in this project was to devise a strategy for sampling highways and streets in each of the 24 Districts of the Texas Department of Transportation that will allow reliable comparisons to be made among the Districts concerning level of service (i.e., degree of maintenance of the infrastructure) for each of the nine areas of concern on this project.

In order to analyze the feasibility of different strategies to accomplish the goals of TxDOT, a number of assumptions had to be made. These assumptions were discussed with the Technical Panel and received support, but it should be recognized that different assumptions would radically alter the feasibility of strategies for data collection and analysis.

11.1.1 Assumptions

1. Six traveling technicians will be assigned full-time by TxDOT for this activity. Each District will allot a person to assist the LOS technician when he or she is visiting in the District.

2. Districts can be classified as either predominantly rural or predominantly urban.

3. LOS technicians will visit their assigned Districts once each quarter, and will also spend additional time in each District for night-time evaluations of illumination, sign reflectance, and retroreflective markers during the fall.

4. Activities in the Districts for each season and ratings of both continuous and discrete items will follow the approach outlined. This means that there will be a three-point Likert rating scale: 1 = Desirable, 2 = Tolerable, 3 = Intolerable.

11.1.2 The Population to be Sampled

According to the 1992 RI2-T data bank maintained by the Transportation Planning Division of TTI, there are nearly 125,525 actual road kilometers (78,000 miles) on the State system. Table 12 provides a breakdown of those miles by the classification of roadway. There are nine classifications, ranging from 2-way traffic highways to freeways with service roads on both sides. Two-way highways (undivided) and boulevards (2-way, usually 4 lane, with a median separation for turning traffic) predominate, accounting for 93 percent of roadway mileage. The other classifications are only a small minority of the total roadway mileage. The breakdown between rural and urban mileage, in terms of actual miles and percent of rural, urban, and total mileage are also shown in this Table.

Table 13 takes the same data as in Table 12 and depicts a possible division of responsibility of the 24 Districts among the six traveling LOS technicians. Districts are grouped by region and assigned so as to allocate roughly the same mileage to each of the six. Some other summary statistics are also given in Table 13.

These two Tables show the magnitude of the job that confronts the LOS technicians. It is necessary to focus in on activities in both rural and urban districts to see how much time must be spent in a District to get an adequate sample. This immediately raises the question, "How big a sample?" That depends upon what questions must be answered in an analysis of the data. Sample size requirements are far more modest for a simple rank ordering than they are for performing statistical tests of significance for differences in proportions of 1 or 3 ratings between districts. Let us consider what it takes to collect the data at a site, and how many sites can be visited in a given period of activity in a district of TxDOT. Then we will be able to consider alternatives for using the rating data once it has been collected.

11.2 CHARACTERISTICS OF A SAMPLE

A sample consists of a rating of 1, 2, or 3 assigned to either a continuous stretch of right-of-way, or to a discrete feature such as a guard rail. An item of maintenance is either continuous or discrete. If the sample is *continuous*, it is 160 meters (0.1 mile) of right-of-way which begins at a mile post marker or other locator on the Texas highway system. There are at least two ways to survey the levels of service at a sample site. One way is to do a complete survey of all features and conditions within the right-of-way for the 160 meter (0.1 mile) segment. The other way is to survey and rate only those elements encountered moving in one direction on a given side of the right-of-way, say, in the specified direction of travel.

For a complete survey, a continuous sample is traversed at least twice (once in each direction) on a 2-way traffic facility (Site Class 1). Any *discrete* features that may exist in that 160 meter (0.1 mile) stretch of right-of-way are also rated. If a facility has a sufficiently divided pavement that it requires four passes (traverse, retrace, then traverse and retrace) to cover the four sides of the travel way, it is a Site Class 2, and takes more time to survey. Similar considerations apply for Class 3 and Class 4, which will be explained shortly.

For a one-way sample visit (regardless of facility classification), further random selection of *which* directions and *which* parts of the more complex facilities to be surveyed would have to be made. For example, if a freeway segment with two frontage roads is selected, the survey team would have to then select whether they will move along one of the two main travelways, and in which direction, or along one or the other of the frontage roads. Such facilities are large enough in cross section that accurate visual or videotape rating would be precluded for most items except for those in close proximity to the vehicle. As can be seen in Table 11, such complex facilities would be rather rare; however, they are also very visible to the public.

11.3 ESTIMATES OF TIME IN DISTRICT TO COMPLETE SAMPLING AND DATA REDUCTION

Based on the considerations above, spread sheets were created to attempt to summarize operations and time during a District visit. The LOS technician is teamed with a District employee who provides driving and support services under the direction of the technician. Table 14 is typical of the spreadsheets generated. It provides a summary of activities for a series of rural, daylight, complete samples in a District. Four such spreadsheets were prepared:

- Rural - daylight, Complete Survey
- Rural - daylight, Unidirectional
- Urban - daylight, Complete Survey
- Urban - daylight, Unidirectional

In column 1 of Table 14, the particular activity at the site is identified in the top quadrant of the table. These activities involve:

(1) Preparation for observations and videotaping

(2) Driving the site for videotaping, also with any continuous recording instrumentation that may be used

(3) Going to any discrete feature that may have been spotted to examine and rate the feature

(4) Allowance for turnaround maneuvers at the site

Column 2, top part of Table 14, gives the site class. The bottom part of the table explains what TxDOT classification is assigned to each of the four classes. Column 3, top, gives the distance to be traversed in videotaping/recording/rating. Column 4, top, gives the number of discrete samples assumed to be present in a given site. These assumptions are nothing more than guesses at this time. Column 5, top, gives the speed of traverse, 88.5 KMPH (55 MPH) in this case for a rural site.

Column 6 gives an estimate in minutes of how long it takes to perform each of the activities identified in Column 1. Column 7 shows the same information in decimal hours. The final column, top, provides the total hours spent at each class of site. They range from 0.24 hour (a little less than 15 minutes) for the simplest (but most numerous) site to almost an hour for a full-blown freeway site. It should be noted that this analysis was done months before the demonstration of rating activities was conducted. The time on site was 15 to 20 minutes.

Column 1, middle, provides an estimate of time required to go from one site to another, and then the total inter-site time in hours. It is assumed that it will take 15 minutes to go from one rural site to another, on average. Obviously, some sites may be just up the roadway, and others may be across the District. One of the challenges that must be faced is to develop a method of mapping the most efficient route from each selected site to another site. Although there are algorithms for "transportation" problems with only a few nodes, the number of nodes involved in surveying a District are way beyond the state-of-the-art in operations research.

The bottom part of Table 14 provides an analysis of the time to be spent on site for each class of site. The weights given in Column 6 are, of course, the proportion of total mileage in the State (rural or urban) that falls into that class. The sample number is apportioned by class according to these weights. The number of samples shown in Column 4, bottom, are fractional, but round up to an integer number in actuality.

Data reduction time at the District office after or between site visits are then estimated at the very bottom of this Table. If 4 areas or items of maintenance must be reduced from videotape or written records and it takes 5 minutes to reduce the area data from one site and make a rating, then it takes 20 minutes to do one sample. If there are 60 samples, then it will take 20 hours to perform data reduction.

Finally, all the time needed to accomplish these tasks is totaled at the bottom of Column 8. Assuming 6 hours of productive labor per 8-hour day, the final estimate of days in the District to obtain an "n" sample visit is obtained. A sensitivity analysis was performed in this spreadsheet to constrain the number of samples to a minimum based on available numbers of days that could be spent in a district in any given quarter (3 months) of the year. There are (allowing for vacations and holidays) an average of 20 working days per month. This means that there are 60 days per quarter available. A team of two LOS technicians must canvass four districts in that quarter. That means that 60/4 = 15 days are the maximum that can be allocated to a District. For the rural, full survey at every site (edges of all pavements and adjacent ROW examined), this analysis suggests that 98 samples can be collected.

The same analysis approach was used for the other three conditions. For the unidirectional approach (i.e., the two technicians traverse only 160 meters (0.1 mile) once from a bench mark, and rate what they can discern or record, then move on), the gain in number of samples that can thus be obtained is not dramatic (109 vs. 98 for rural, 83 vs. 75 for urban).

It should be remarked that there are a lot of unknowns and "slack" in these activity analyses. The travel time allowances are probably excessive, but may vary widely from, say, District 24 (El Paso) to District 20 (Beaumont). Seventy-five percent productivity (6 hrs/8 hr day) appears reasonable, especially for work that is largely over-the-road. Data reduction time allowance is also generous, since there are many unknowns at the time of this study about how long it may actually take to view videotape records, and rate items of maintenance.

In Fall, a special situation arises: nighttime surveys at sample sites for sign condition and reflectivity, delineators for condition and guidance, and object marker presence, condition, and retroreflectivity. If the sample size requirements are small enough, these surveys could be handled on an "overtime" basis, without special allowances. We will return to this consideration in the next section of this report.

11.4 SAMPLE SIZE REQUIREMENTS FOR STATISTICAL COMPARISONS BETWEEN DISTRICTS

Assuming that 98 sites can be sampled in rural districts and 75 sites in predominantly urban settings, what requirements for sample size arise from a consideration of statistical tests of significance for comparing any two districts of TxDOT? The first step in such a consideration is an estimate of the approximate proportion of a given item of maintenance that either will rate a "1" (desirable) or "3" (intolerable). The second step is to estimate how much change in that proportion will be considered important. Such estimates are obtained either from experience or from judgement prior to collecting data on actual conditions. Table 15 provides some judgement estimates of the proportion of each item of maintenance that could be expected to be at an intolerable level in any district, and then how much change in that status would be of management interest. For example, for ornamental plantings, only 0.05 (5 percent) are estimated to be dying or dead (intolerable), and a change of 3 percent should be detected by the sampling and tests of significance. Ten percent of pavement drainage might be intolerable, and again a 3 percent change is of interest.

The State of Virginia uses a standard equation for specifying sample size, given the two parameters of proportion and of change. The column labeled VaDOT provides the sample size required for a 95 percent level of confidence. Reasonably comparable results for n, the sample size, were obtained through the use of a slightly different technique outlined by Fleiss (32). With this technique, both the Type I error (risk of saying that districts are different when in fact they are the same) and the Type II error (risk of saying districts are the same when they really are different) can be set. This formulation is as follows:

$$n' = \frac{(c_{\alpha/2}\sqrt{2\overline{P}\overline{Q}} - c_{1-\beta}\sqrt{P_1Q_1 + P_2Q_2}\,)^2}{(P_2 - P_1)^2} \qquad (1)$$

Where

Where	n'	=	first approximation of sample size
	$c_{\alpha/2}$	=	value cutting off proportion $_{\alpha/2}$ upper tail of normal curve
	$c_{1-\beta}$	=	value cutting off the proportion 1-β in the upper tail and B in the lower tail of the normal curve
	$\overline{P}$	=	mean of one of the proportions of the two samples different by target change
	$\overline{Q}$	=	mean of the other of the proportions of the two samples different by target change

P_1 = Proportion expected in first population sampled, in this case proportion of ratings of 3

Q_1 = Other proportion expected in first population, in this case, proportion of 1's or 2's

P_2, Q_2 = Proportions for Population 2

and then a final correction for continuity given by:

$$n = n' + \frac{2}{/P_2 - P_1/} \quad (2)$$

where n = final sample needed for target change detection.

If the probability of a Type 1 error (α) is set at the conventional 0.05 and B is set at 0.20 (therefore a power ($1-\beta$) of 0.80), the sample sizes provided in Table 15 are generated. Some of them exceed the 98 (rural) and 75 (urban) that can be expected to be collected by a team of two technicians during a quarter in a District.

To gain some perspective into how such sample size requirements might look on a Statewide basis, Table 16 was developed. The analysis runs as follows:

In Spring, each rural district's sample sites are to surveyed for five different items. Urban areas are to be inspected for three items. In rural areas, for example, pavement edge drop-offs must be surveyed in the Spring. The work will be done during the day, with a sample requirement of 93 in each district. Dropoff is a continuous type of rating, i.e., an impression for rating is gained during the course of examining the entire segment of right-of-way. Any continuous type rural sample of an item that exceeds 98 cannot be accomplished in every District in Texas. Any continuous urban sample requirements that exceeds 75 similarly cannot be accomplished. Discrete (D) items of maintenance must be considered separately. These items, each sample being an encounter with such a feature or device, are estimated to occur twice in every 2-way undivided roadway sample, and maybe more often in more complex (but far less frequent) facilities. For this analysis, the assumption of two per continuous sample site is made. In Spring, for example, inlets on urban highways are to be judged. A sample size of 129 is needed. This is more than feasible under the assumption above, since up to 75 sites can be visited in a District, and 75 x 2 = 150.

What about the continuous sample items of maintenance sample needs that exceed either 98 (rural) or 75 (urban)? The assumptions about proportion of a "3" rating are no doubt subject to adjustment, but until more is known about the LOS in Texas for each item, the only feasible way to handle this is to adjust (upward) the target proportional difference that will be considered significant. Generally, a 0.01 increase in the proportional difference will bring the rural items within range; for urban items, 0.02 will be necessary. On the other hand, since the team will be surveying the sites anyway, some of the items of maintenance with lower-than-maximum sample size requirements can be inspected to a higher tolerance; i.e., smaller significant differences can be detected.

It appears that statistical tests of significance for proportions of "3" or "1" on individual items of maintenance can be obtained by six LOS technicians working with assistance from each District that they are surveying. As expectations are developed about the proportions of ratings in Districts, the sample size requirements can be adjusted to reflect such observed conditions.

11.5 ANALYSIS

By assuming that the proportions of number "1" and "3" ratings follow approximately a binomial probability distribution, hypotheses of no difference can be formulated for each element rated in the sample set obtained in two Districts. Then a series of pairwise comparisons can be performed in order to derive a rank ordering of Districts in Texas. For each comparison, a statistical test of significance is performed. The test of significance is a z test of the ratio of the difference between the two proportions of ratings in the two Districts and the estimated pooled standard deviation derived from these two proportions (33). If there is no difference between two Districts, they form a grouping. If another District differs (better or worse) from either of those first two, it goes into a different grouping. The process continues until all pairwise tests are performed, a very laborious process of 24 tests (24 x 23 x 22 x...x 1). The resulting groupings of Districts according to proportions of "1" or "3" form the rank order of performance on the particular element. This analysis must be done for each element. Districts can and probably will have different rankings in the State depending on which element forms the basis for the comparison.

11.6 RANK ORDERING SAMPLING REQUIREMENTS

Another less quantitative approach to comparing District performance should also be considered by TxDOT. This approach can also rank order Districts according to ratings for each item of maintenance (either proportion of "desirable" (1) ratings or "intolerable" (3) ratings).

The basic approach proposed for setting sample size is the Chi-square paradigm for analysis of proportions in a contingency table. There are three possible ratings for each item making up the Level of Service, and 24 Districts. Each item rated, for example, Pavement Encroachment gives rise to a Chi-square table that is 3 x 24:

Rating	District 1	2	3	4	24
1					
2					
3					

Cell entries in this matrix are enumerations or proportions of each rating level for a particular item in a District. For example, suppose Pavement Encroachment by vegetation is being rated in each District. In District 1, the technicians may have rated 75 per cent of the sites sampled "1" with regard to pavement encroachment, 25percent "2" and 0 percent "3." How many sites should be visited and rated? For Chi-square analysis of data in such a contingency table, there are several rules of thumb. One is that any "expected" cell number ought to be five or more. If the expectation is that ratings will be equally distributed in each District, a minimum number of samples would be 3 x 5 = 15. Since clearly some Districts will be much better than this, (and perhaps others much worse), it would be desirable to increase the sample size sufficient to assure that each District has enough ratings to allow some comparisons to be made. Accordingly, 20 ratings of 1, 2, and 3 would be expected as a "null hypothesis" for each District, and the sample size needed is 60. Such a sample size could be expected to allow reliable rank ordering among Districts.

Expected (E) values for the Chi-square analysis are generated by summing the cell row and column entries (O values), and then dividing by the total number of entries in the table. The overall extent that different Districts may depart from the "norm" for the state is then evaluated by calculating:

$$X^2 = \sum \sum \frac{O_{ij} - E_{ij}^2}{E_{ij}} \quad (3)$$

with (3-1) x (24-1) degrees of freedom. The expression:

$$\frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (4)$$

generated for each cell is an estimate of the contribution that cell makes to the overall magnitude of the chi-square statistic. This contribution estimate can form the basis of a rank order of the Districts with respect to the particular item of maintenance being evaluated. If a rank ordering from "best" to "worst" were to be desired by TxDOT, the contribution estimates for cells of rating 1 would be rank-ordered from 1 to 24. For the purpose of such ranking, the sign of the (O - E) difference in Equation 2 is retained. Ties are handled by averaging the ranks that the cells would have been assigned, had they not been tied, in the usual manner.

Ranking for each item of maintenance is then summed for each District for a composite rank ordering. The sums of ranks are themselves rank-ordered to arrive at this composite. In this way, Districts can be ranked across the State both on an individual item of inspection, and overall. It should be noted that data collected under the proportional tests of significance approach outlined above could also be analyzed by this Chi-square technique to rank order Districts across Texas.

Table 13. Mileage Breakdown by Class and Type

Mileage Breakdown by Class and Type						
	Subtotals				Totals	
Class	Rural	%	Urban	%		%
2-way	60751.00	.92	7464.00	.65	68215.92	.88
1-way	21.00	.00	448.00	.04	469.00	.01
Boulevard	2313.00	.03	1851.00	.16	4164.03	.05
Expwy No Serv Rd	415.00	.01	74.00	.01	489.01	.01
Expwy 1 Serv Rd	71.00	.00	41.00	.00	112.00	.00
Expwy 2 Serv Rd	83.00	.00	106.00	.01	189.00	.00
Frwy No Serv Rd	567.00	.01	260.00	.02	827.01	.01
Frwy 1 Serv Rd	476.00	.01	90.00	.01	566.01	.01
Frwy 2 Serv Rd	1443.00	.02	1194.00	.10	2637.02	.03
	66140.00		11528.00		77669.00	

Table 14. Highway Breakdown by Class and District

Highway Mileage Breakdown by Class and District													
CLASS:		2-way	1-way	Boulvd	Exp No	Exp 1	Exp 2	Fway N	Fway 1	Fway 2	Total	Rater	Miles/ra
DISTR	Office												
6	Odessa	2500	2	130	3	21	12	49	65	194	5032	1	1319
7	San Angelo	3399	2	95	23	5	5	86	41	30	2447	1	
24	El Paso	1496	19	109	10	3	2	79	56	57	2888	1	
8	Abilene	3102	8	81	54	4	23	3	7	164	2831	1	
4	Amarillo	3339	4	235	30	1	5	16	16	140	3447	2	1143
5	Lubbock	4441	0	401	55	2	8	1	1	123	3785	2	
25	Childress	2268	0	140	3	0	0	3	5	29	2376	2	
3	Wichita Fa	2569	8	114	22	11	5	25	7	71	1830	2	
15	San Antoni	4378	21	197	28	1	14	117	50	279	2610	3	1214
13	Yoakum	3259	3	69	64	17	13	31	26	41	3215	3	
16	Corpus	2489	9	247	6	0	4	12	18	89	3193	3	
21	Pharr	2658	26	118	57	2	8	1	1	115	3129	3	
2	Ft Worth	2657	10	224	15	6	15	59	24	205	3687	4	1566
18	Dallas	2852	22	704	5	0	18	148	48	310	3267	4	
23	Brownwood	2533	0	42	0	0	1	0	1	34	3627	4	
9	Waco	2947	9	61	3	2	10	28	7	125	5086	4	
12	Houston	2152	56	444	43	13	24	40	28	257	2987	5	1255
14	Austin	2980	19	153	1	1	4	16	7	85	4107	5	
17	Bryan	2755	7	68	6	15	4	6	77	46	3057	5	
20	Beaumont	2166	16	92	3	0	5	16	13	89	2400	5	
1	Paris	2918	8	85	6	0	3	3	3	103	2976	6	1235
10	Tyler	3349	4	189	1	0	0	36	24	24	3522	6	
11	Lufkin	2769	0	83	30	0	2	4	0	1	2874	6	
19	Atlanta	2155	3	104	0	0	4	46	41	23	2984	6	
Sum		68130	256	4185	467	105	189	823	565	2636	77356		
Mean		2839	11	174	19	4	8	34	24	110	3223		
SD		647	12	148	20	6	7	38	22	84	744		
Min		1496	0	42	0	0	0	0	0	1	1830		
Max		4441	56	704	64	21	24	148	77	310	5086		

Table 15. Sampling in a District

Exhibit II-3. Sampling in a District:			Rural, Daylight, Any Season				
Sampling Time Estimates			Complete Site Survey				
	Site						
Activity	Class	Distance	Number	Speed	Time	Time	Total
Class:	1				Min	Hrs	Hrs
Prep & Secure					10.00	.17	
Site Video		.20		55.00	.00	.00	
Discrete Rating			2.00		10.00	.03	
Turn around					2.00	.03	.24
Class:	2						
Prep & Secure					10.00	.17	
Site Video		.40		55.00	.01	.01	
Discrete Rating			4.00		20.00	.33	
Turn Around					4.00	.07	.57
Class:	3						
Prep & Secure					10.00	.17	
Site Video		.60		55.00	.01	.01	
Discrete Rating			6.00		30.00	.50	
Turn Around					6.00	.10	.78
Class:	4						
Prep & Secure					10.00	.17	
Site Video		.80		55.00	.01	.01	
Discrete Rating			8.00		40.00	.67	
Turn Around					8.00	.13	.98
Travel time to site:							
		15.00		55.00	16.36	.27	26.77
Facility:	Class	Base	No Samples/Distric		Weight		
2 way traffic	1	.24	87.40		.92		20.71
1 way traffic	1	.24	1.00		.00		.24
Boulevard	2	.57	2.85		.03		1.64
Expwy No service rd	2	.57	1.00		.01		.57
Expwy 1 service rd	3	.78	1.00		.00		.78
Expwy 2 service rd	4	.98	1.00		.00		.98
Frwy No service rd	4	.98	1.00		.01		.98
Frwy 1 service rd	3	.78	1.00		.01		.78
Frwy 2 service rd	4	.98	1.90		.02		1.86
				Sum	1.00		
Min Samples in District	=		95.00				
Total Samples Taken	=		98.15				55.31
Data Reduction:			No. Areas	t/Area			
Per sample			4.00	5.00	20.00	.33	
No. Samples					98.15		32.72
Total Time to survey 1 district							88.02
Days of work in District @				6.00	hrs/day		14.67

Table 16. Comparison of Sample Size Calculation by Required Detection Difference

Comparison of Sample Size Calculation						
By Required Detection Difference						
Item		Expected	Delta	VaDOT	Fleiss	
				n	n	
Orn. plants		.05	.03	201.29	161.29	
Pavmt drain		.10	.03	378.96	283.94	
Guardfence	.70*	.30	.04	495.29	366.58	
Traff Signal	.60*	.40	.04	564.62	419.89	
Veg encroach		.13	.05	172.72	134.78	
Safety strip veg		.10	.05	137.62	110.09	
Dropoff		.08	.05	112.64	92.63	
Curb drain		.11	.07	76.54	64.57	
Inlet drain	.70*	.30	.07	163.68	128.77	
Intersection veg		.15	.08	76.32	63.85	
Sparse turf		.15	.08	76.32	63.85	
Bare spots		.15	.08	76.32	63.85	
Mail box		.08	.08	44.11	40.53	
Luminaires		.10	.08	53.92	47.59	
Noxious weeds		.30	.10	80.44	67.51	
Signs		.14	.10	46.18	41.02	
Delineators		.16	.10	51.54	45.04	
Obj Mkrs		.13	.10	43.38	38.94	
RPMs		.23	.10	67.87	57.50	
Ditch drain		.25	.12	49.93	43.95	
Pave Marks		.45	.20	23.75	24.75	
Culvert drain		.33	.24	14.74	16.05	
Paint Lines		.40	.25	14.74	16.49	
Litter		.38	.32	8.84	10.96	
			Av	126.32	100.18	
			STD	144.77	105.77	
	*Use (1-Expected Proportion) for sample size estimate					

Table 17. Sample Requirements and Capabilities by Seasons

Exhibit II-8. Sample Requirements and Capabilities by Seasons						
Season	Type	Item	Time	Sample/ District	Sample Type	All Texas Distr.?
Spring	Rural	Pave Edge	Day	93	C	Yes
Spring	Rural	Woody Encroach	Day	135	C	No
Spring	Rural	Sparse Turf	Day	64	C	Yes
Spring	Rural	Noxious weeds	Day	68	C	Yes
Spring	Rural	Orn Plants	Day	161	C	No
Spring	Urban	Roadside Veg	Day	110	C	No
Spring	Urban	Orn Plants	Day	161	C	No
Spring	Urban	Inlets	Day	129	D	Probably
Summer	Rural	Intersect Veg	Day	64	C	Yes
Summer	Rural	Herb Encroach	Day	135	C	No
Summer	Rural	Roadside Litter	Day	11	C	Yes
Summer	Rural	Noxious weeds	Day	68	C	Yes
Summer	Urban	Intersect SD	Day	64	D	YES
Summer	Urban	Woody Encroach	Day	135	C	No
Summer	Urban	Roadside Litter	Day	11	C	Yes
Fall	Rural	Guardfence	Day	367	D	Difficult
Fall	Rural	Mailboxes	Day	41	D	Yes
Fall	Rural	Signs	Night	41	D	Yes
Fall	Rural	Traffic Signals	Day	420	D	Unkn.
Fall	Rural	Delineators	Night	45	C	Yes
Fall	Rural	Object Markers	Night	39	D	Yes
Fall	Urban	Pavement Markings	Day	25	C	Yes
Fall	Rural	Painted Lines	Day	17	C	Yes
Winter	Rural	Bare slopes	Day	64	C	Yes
Winter	Rural	Drainage Ditch	Day	44	D	Yes
Winter	Rural	Cross Culv Drain	Day	16	D	Yes
Winter	Rural	Cross Culv safety	Day	16	D	Yes
Winter	Rural	Parallel Culv drain	Day	16	D	Yes
Winter	Rural	Parallel Culv Safety	Day	16	D	Yes