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16. Abstract

An efficient and accurate inventory of a state highway agency's assets, along with the means to assess the condition of those assets and model their performance, is critical to enabling an agency to make informed investment decisions in a Transportation Asset Management (TAM) environment. Today, new technologies provide fast and improved ways to gather, process, and analyze data. The key is to identify and gather the most useful, reliable, cost-effect information and use it to make informed decisions for asset management.

Four key infrastructure areas have been identified as primary asset components; pavements, bridges, geotechnical features, and roadside appurtenances. Each area contains multiple categories and data elements important for sound decision making. Although some similarities exist in these four primary categories, the nature of data collection may differ, depending on the asset type. The, sheer number of data elements and the length of asset networks for pavements and roadside appurtenances render the automated highway speed data collection method a necessity rather than a luxury. However, the discrete nature of bridges and geotechnical features make the automated mobile data collection method on a network level unfeasible with today's technology.

Important issues in the collection process include precision, subjectivity and variability of the process itself, as well as speed, safety of the survey crew, proximity of the public, cost, etc. Although previous research has attempted to address these issues and determine the most appropriate method(s), the question remains as to which roadway data collection system is best for state highway agencies given real world constraints. This research set up a "sealed envelope" experiment wherein the identification, location, description, and quality of the asset data elements are known only to NCSU researchers. Vendors are informed of only the data necessary to perform their evaluation. To support this effort at 95-mile test course near Raleigh, North Carolina was identified, which contained a sampling of pavement, roadside, geotechnical and bridge elements. This document reports on the findings from the study.

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ASSET MANAGEMENT INVENTORY AND DATA COLLECTION

FINAL REPORT

(Report No. FHWA/NC/2008-15)

To North Carolina Department of Transportation
(Research Project No. HWY-2008-15)

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DISCLAIMER

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CHAPTER 1 INTRODUCTION AND OBJECTIVES

1.1. Introduction

An efficient and accurate inventory of a state highway agency's assets, along with the means to assess the condition of those assets and model their performance, is critical to enabling an agency to make informed investment decisions in a Transportation Asset Management (TAM) environment. Today, new technologies provide fast and improved ways to gather, process, and analyze data. The key is to identify and gather the information and assess how much of it is needed to make informed decisions that affect the assets' maintenance and rehabilitation. The data must be useful, reliable, cost-effective to obtain, and delivered in a timely fashion in a user-friendly format that can tie into existing management systems. In addition, the data must be defendable and repeatable so that users of this information have a high level of confidence in its overall effectiveness.

The Office of Asset Management at the NCDOT has identified four infrastructure areas as the primary asset components; these four areas are pavements, bridges, geotechnical features, and roadside appurtenances. In each area, the asset management database includes four categories of data: identification, location, description, and quality. That is, for each component, the database includes information to identify the asset and its location, to define and describe its features, and in several cases to explain how well it functions. Although the general requirements for these four data categories are basically the same for the four focal areas, the nature of data collection may differ, depending on the asset type. For example, data for pavements and roadside appurtenances can be collected at a highway speed, on a network level, using an automated data collection vehicle, whereas data for bridges and geotechnical features may not be collected in an automated fashion using current technologies and most likely will be collected for a specific structure at a time. The, sheer number of data elements and the length of asset networks for pavements and roadside appurtenances render the automated highway speed data collection method a necessity rather than a luxury. However, the discrete nature of bridges and geotechnical features make the automated mobile data collection method on a network level unfeasible with today's technology.

Mobile roadway data collection systems have existed for over fifteen years and have been in commercial service for over ten years. Many vendors now provide such data collection services. Indeed, a quick search of the literature and on-line sources reveals a huge variety of services and a wide range of van sensors. Location data can be collected via a Global Positioning System (GPS), Inertial Navigation System (INS), and Distance Measurement Indicator (DMI); and description and quality data can be collected via radar, laser, infrared, imaging, and other methods. Many systems rely on video collection in the field to be read later in the office by technicians, but the techniques and quality of this post-processing of data obviously vary widely as well.

Various issues in the asset data collection process include precision, subjectivity and variability of the process itself, as well as speed, safety of the survey crew, proximity of the public, cost, etc. Some previous researchers have attempted to sift through the maze of mobile systems and identify the best one(s). However, those previous attempts suffered from being too narrow in scope to be helpful to state highway agencies looking for an optimal automated asset data collection method and the definition of “best” is not unique. Thus, the question remains as to which roadway data collection system is best for state highway agencies.

One approach to evaluate these various equipment and technique issues is to set up a “sealed envelope” experiment wherein the identification, location, description, and quality of the asset data elements are known only to an independent evaluator, but the vendors participating in the evaluation are informed of only the data necessary to perform their evaluation. Such an experimental program has been initiated by the Federal Highway Administration (FHWA), and has resulted in the National Workshop on Highway Asset Inventory and Data Collection and this document which reports the findings from the data used in support of this workshop.

To support this effort, various asset data elements in each focal area have been identified by the focal groups that are composed of NCDOT engineers and the NCSU research team. The NCDOT Pavement Management Unit has identified a 95-mile test course located near Raleigh, North Carolina for data collection. This test course provides a wide range of roadway classifications, road geometry, pavement and shoulder types, conditions and types of data elements, terrain, and vegetation. In addition to these resources, an experimental design for the vendor testing and ground truth testing of the test sections is developed. The data from vendors are analyzed by the NCSU research team and compared against the ground truth measurements. This document presents the findings from the study.

1.2. Objectives

It is important to note that the effort reported here was in no way intended to identify the best or winning vendor from among those who agreed to participate. Instead, the purpose of this effort is to find the capabilities and limitations associated with automated surveys by comparing vendor and agency ratings of a representative test loop in North Carolina. The outcomes of this study and associated workshop are reported in this document so that agencies considering the use of automated surveys might have a resource from which to base the initial decision making process. The study team made every effort to keep the process as open and fair for all participating vendors, so that highway agencies interested in a certain set of elements could look at these results and make some distinctions among the vendors. However, the study team made no value judgments about which elements or which errors were more or less important. Instead, the role of the study team, and the intent of this report, was to describe as completely and accurately as possible the data which was collected, the analysis which was performed and the factual observations which were made. Where appropriate, interpretations of the results are made in the most general possible terms.

CHAPTER 2 PROJECT BACKGROUND

2.1. Test Road Description

The test road employed for this effort was a one-way (clockwise) 90-mile loop beginning and ending in Raleigh, NC. Figure 2.1 shows the road from the starting and ending point at the Poole Road and I-440 interchange (labeled as ‘A’ in Figure 2.1).

Figure 2.1. 90-mile test road located in central North Carolina.

The primary roadways along the course were:

- I-440: Inner freeway Beltline around Raleigh, NC
- I-40: Major interstate across NC
- Wade Avenue: Freeway extension between I-40 and I-440
- US-70/Glenwood Avenue: Primary arterial in Raleigh, NC
- I-540: Outer freeway bypass around Raleigh, NC
- US-1/Capital Boulevard: Primary arterial heading north from Raleigh, NC
- NC-98: Rural two-lane highway
- NC 39: Rural two-lane highway
- US-64/US-264: Important freeway heading to Eastern NC

This course can be driven at posted speeds in less than three hours. At slower data collection speeds, and including an urban street loop, the test road can easily be finished during part of a day. On the other hand, the study team intended the course to be long enough so that the vendors would treat it like any other inventory data collection project and vendors which ‘count every blade of grass’ would not receive special treatment. As a consequence the course offers a large variety of road characteristics. Specific diverse features include:

- Urban and rural: The course begins and ends in Raleigh, North Carolina. The course also travels through the middle of several small towns with typical "urban street" conditions, such as curbs, sidewalks, on-street parking, street lighting, and the like. The bulk of the course, like the bulk of the road mileage in the U.S., is in rural areas that have characteristics such as shoulder/ditch cross-sections and few driveways.
- Old and new: The test course includes several dozen miles of freeway and divided multilane arterial sections opened within the past two to ten years. These miles generally have been built with generous dimensions and some very wide right-of-ways. The bulk of the course has been open longer than ten years, however. The course includes some mileage of older urban freeway in need of rehabilitation and of older rural highway with dimensions that are now considered substandard.
- Multilane and two-lane: The course has sections of two-lane, four-lane, six-lane, and eight-lane highway, with the majority of the course consisting of two-lane highway. Except for very short segments, all of the multilane cross-sections have grassy medians. Most intersections have turn lanes, and several of the urban intersections have dual left turn lanes.
- Concrete and asphalt: The course includes both concrete and asphalt pavements. The concrete pavements are on some of the freeway segments, while all of the non-freeway segments have asphalt pavement.
- Intersections: The course runs through numerous signalized intersections and dozens of unsignalized intersections. The course contains only two stop signs.
- Interchanges: The course requires traversing seven interchanges, with ramps of various configurations and design speeds.
- Grades and curves: The course runs through terrain typical of the Piedmont region of North Carolina. That is, the terrain is rolling, but with no steep grades. Also, the course includes very few long tangent sections of road, but the curvature is generally moderate. The sharpest curves on the course have advisory speeds of around 25 mph.
- Vegetation: The course is lined primarily with deciduous trees that lose their leaves during November to March. Roadsides along the course have been cleared for at least ten feet laterally for the majority of the course, and longer on the multilane highways. Very few places on the course have a tree canopy or trees that block sight lines to any great extent.
- Imperfections: Obvious flaws and imperfections are evident throughout the course, especially on the older roadway sections. Pavement, signage, and marking quality are not good in some spots. Some guardrails and shoulders need maintenance.

2.2. Data Collection Overview

The general framework of this effort was to compare data collected on a sample of roadways by standard manual methods to data collected by mobile methods from a variety of vendors. The study team and NCDOT personnel made many key decisions while setting up this data collection. The guiding philosophy during all of that decision-making was to establish a comparison that was fair to both manual and mobile methods and to all of the vendors that chose to participate. The intention in this section of the report is to provide an overarching picture of the data collection process. Details specific to each group (pavements, bridges, geotechnical and roadside) are given later in this report.

Late in 2007 the study team began compiling lists of companies and agencies that might be interested in participating as vendors in this effort. The team sent email messages, circulated fliers at meetings, posted notices on the Expo web site, and made personal contacts. The study team sent letters to prospective vendors in late-2007 informing them of the proposed data collection schedule and encouraging them to set aside time for their van to visit North Carolina in late-spring and early-summer. Another letter in March provided more details, set a particular schedule for data collection activities, and set a deadline for vendors to register for a data collection visit.

Twelve companies made reservations for data collection. In the end, 11 of the 12 sent a vehicle to Raleigh, met with a representative of the study team, and at least began the data collection course. Vendor data collection began on May 13, 2008 and ended on July 2, 2008, so all vendor data collection occurred in summer-like conditions when the trees were full with leaves. All vendor data collection occurred in dry weather; temperatures ranged from about 70 degrees to well over 90 degrees. There were a couple of days during which two vendors drove the course, but the team scheduled those two vendors to begin at least 1.5 hours apart from each other so that each vendor operated independently. When a vendor was scheduled to begin data collection, at least one representative of the study team would meet them at the beginning of the course to hand them a catalog (also given in Appendix A of this report), describe the course, answer any questions the vendor had, and otherwise make sure that the data collection effort was as productive and fair as possible. Vendors were asked to phone a member of the study team upon completing the course; they generally reported that the directions were sufficient and that there were no serious weather, traffic, or construction issues in the way of successful data collection.

The catalog was posted on the Expo website a few days before the first vendor collected data (May 13, 2008) except that the map and directions for driving the course were not posted. The map and directions were given to each vendor when they arrived at the course and met the study team personnel. In this way, the vendors could not undertake special preparations just for this course. Also, the study team did not reveal the manual data collection sample sites until the workshop held on September 24-26, 2008, to insure that vendors gave no special attention to just those sample sites. In every other aspect of dealing with the vendors, though, the study team tried to be as open and accommodating as possible. Before and after the vendor visits, the team was available by phone and email to answer questions. Some vendors took advantage of this and asked the study team many questions before data collection and during data processing, while others did not.

The data collection catalog included details on each of the roadside variables of interest listed in Table 6.1. In particular, the catalog provided, for each variable:

- A description of the manual data collection method,
- The desired units, and
- An example desired data format.

The catalog also included definitions, pictures, and descriptions of conditions of interest for some roadside appurtenance variables, such as ‘low shoulder’, ‘blocked curb’, and ‘damaged barrier’. This information was copied from the *2006 NCDOT Maintenance Condition Assessment Manual*, which is the book that guides the current manual collection of those variables. Finally, the catalog included excerpts from the 2003 *Manual of Uniform Traffic Control Devices* and the 2004 *Policy on Geometric Design of Highways and Streets* to describe the sign types and curb types of interest, respectively. For pavements the catalog included a summarized list of data elements in the NCDOT and LTPP surveys. However, copies of the NCDOT survey manuals for both asphalt concrete and Portland cement concrete as well as copies of the LTPP survey guidelines were posted on the same website as the catalog.

Vendors were informed that the deadline for submitting data for this effort was August 1, 2008. Most of the vendors who submitted roadside data sent them on or before the deadline. A couple vendors asked for extensions to the deadline for a few days for various reasons; these extensions were granted and those data were included in the analysis. The study team asked the vendors for data in Excel or Access formats and all complied.

Vendors submitting data for the Expo were asked to sign a form that transferred ownership of the data to the NCDOT, and all vendors did so. Thus, the data on which the results are based are the property of the NCDOT and in the public sector; there is no copyright on those data and anyone may use them. A summary of the participating vendors and the surveys that they participated in is given in Table 2.1.

Table 2.1. Summary of Participating Vendors

Vendor	Pavements	Bridges	Geotechnical Features	Roadside Appurtenances
Geo-3D		X		X
Mandli Communications, Inc.	X			
NAVTEQ Corp.				X
Pathway Services, Inc.	X			X
Precision Scan, LLC				X
Roadware Group, Inc.	X			X
Terrametrix		X		
Yotta DCL				X

The study team is grateful to these vendors for making the effort to travel to Raleigh, drive the course, and process the data. Appendix B contains contact information for all of these vendors.

CHAPTER 3 PAVEMENTS

3.1. Introduction

Quantification of pavement distress and performance is a critical step in proper management of the highway infrastructure. In North Carolina, these items have been traditionally tracked using shoulder driven surveys performed by NCDOT personnel. The automated survey, an alternative to these so-called manual surveys, has gained national and international popularity in the last 10-15 years. The automated survey involves driving an instrumented vehicle along a path and recording various pavement distresses such as cracking, rutting, etc. These automated pavement distress surveys offer a potential benefit over existing agency personnel initiated surveys in terms of accuracy, repeatability and lack of bias. However, before embarking on a strictly automated survey based data collection strategy it is important for the agency to determine the compatibility of existing survey protocols and results with those from automated methods.

In this study three such automated surveyors, Pathway Services, Mandli Communication and Fugro Roadware, have been compared with the existing NCDOT survey protocols. Vendors drove the test section only once, measured the necessary quantities and analyzed the data. Coincident with these vendor surveys, the NCDOT has gathered reference survey data for the two survey techniques using multiple survey teams and compiled a consensus sectional rating for both surveys. The vendors and NCDOT submitted their data to the NCSU researchers for an independent assessment and comparison of the survey results. In the following sections the results from these analyses are shown. In part one, results from the NCDOT survey procedure are shown; first for the AC sections and then for the PCC sections. The second part of this report discusses the results from the LTPP based survey for the AC sections and then for the PCC sections. Since there were no reference survey LTPP measurements for any PCC section, only the total counted distresses from each vendor are shown for this survey. After each of these sections, a brief summary of the key findings is given.

The final section of this chapter presents data from the vendors that were resubmitted after the workshop was held. The motivation behind having the vendors resubmit a portion of the data is given in detail later. In short, some of the definitions used for data elements in the NCDOT survey protocol are not conducive to automated survey processes. This situation is not uncommon in the field of automated surveys, since many agencies have had to compromise on very detailed and accurate data gathering at the network level due to time and budgetary limitations. Overcoming this situation requires close interaction (or so-called calibration) between the agency and vendor. For this project, time and budgetary constraints did not allow for such detailed interaction between the two parties, but a method to approximate the interaction was developed and the data resubmission was necessary to judge the effects of this process.

3.2. Data Collection

3.2.1. NCDOT Survey – Asphalt Concrete Sections

The NCDOT survey procedure involves slowly driving along the pavement shoulder at 10-15 mph and recording the severity and/or extent of specific distresses. A summary of these distresses is shown in Table 3.1 for the asphalt concrete, AC, pavements. In total, four different teams surveyed the test course with the exception of a short repave section between mile markers 290 and 291 on I-40. Only three teams surveyed this section. After receiving the individual team reports NCDOT personnel compiled a consensus rating for each section. This rating was not necessarily the average of the survey teams' results and instead involved applying engineering judgment to the individual surveys.

Table 3.1. Summary of Items Included in NCDOT Asphalt Concrete Survey [NCDOT 2008a]

<table>
<tr><th>Data Element</th><th>Rating Type</th></tr>
<tr><td colspan="2">Travel Path Elements</td></tr>
<tr><td>Fatigue Cracking</td><td>Percentage by severity[a]</td></tr>
<tr><td>Transverse Cracking</td><td rowspan="7">N, L, M, S[a]</td></tr>
<tr><td>Rutting</td></tr>
<tr><td>Raveling[b]</td></tr>
<tr><td>Oxidation</td></tr>
<tr><td>Bleeding</td></tr>
<tr><td>Ride Quality</td></tr>
<tr><td>Patching</td></tr>
<tr><td>Pavement Width[c]</td><td>Feet</td></tr>
<tr><td>Number of Lanes[c]</td><td>Number</td></tr>
<tr><td colspan="2">Shoulder Elements[c]</td></tr>
<tr><td>Shoulder Type</td><td>P, U[d]</td></tr>
<tr><td>Shoulder Width</td><td>Feet</td></tr>
<tr><td>Curb and Gutter</td><td>Yes or No</td></tr>
</table>

[a] None, Light, Moderate, Severe
[b] Only reported on BST or Slurry Seals
[c] Not recorded in this study
[d] Paved or Unpaved

In fairness to the vendor measured values there are potential logic errors in comparing the results of this survey procedure to vendor measured values for certain distresses such as rut depth or ride quality. In these cases vendors have the capabilities to make very precise, repeatable and accurate measurements of quantified values. The NCDOT's reference survey data though are quite subjective. For example, rut depth is not actually measured; instead it is qualitatively estimated from the windshield survey and ride quality is based on the surveyor's visual inspection only. Replicating these types of subjective measures using automated techniques is not only very difficult, but it is also unnecessary because quantifiable values can be measured to better represent these distresses. While an agency is interested in gathering this kind of high quality data so that they can make better decisions, they must also be concerned with measurement compatibility. Pavement management systems require historical tracking to be most effective and a sudden change in the basis for a quantity has the potential to drastically change the rating for a given pavement and unnecessarily accelerate or delay maintenance. Because of this very practical concern, the research team has elected to compare the automated and NCDOT results for all of the quantities in the reference survey. Where appropriate the team has tried to make sure that the reader understands that differences between the two parties may reflect a potential error with the reference survey.

3.2.2. NCDOT Survey – Portland Cement Concrete Sections

The NCDOT Portland Cement Concrete (PCC) survey procedure involves slowly driving along the pavement shoulder at 10-15 mph and recording the severity and/or extent of specific distresses. A summary of the recorded distresses is shown in Table 3.2 for the PCC pavements. In total, four different teams surveyed the test course with the exception of the two sections along I-440. Only three teams surveyed this section. After receiving the individual team reports NCDOT personnel compiled a consensus rating for each section. This rating was not necessarily the average of the survey teams' results and instead involved applying engineering judgment to the individual surveys. Since the PCC survey is more cumbersome, the NCDOT compiles data on only the first 0.2 miles of any given PCC section. None of the resubmitted sections were PCC pavements.

Table 3.2. Summary of Items Included in NCDOT Portland Cement Concrete Survey [NCDOT 2004]

Data Element	Rating Type
Travel Path Elements	
Joint Spacing[a]	Feet
Number of Lanes[a]	Number
Concrete Patches	
Asphalt Patches	
Pumping	Number of slabs or areas
Surface Wear	Percentage by severity[b]
Ride Quality	Percentage by severity[c]
Longitudinal Cracking	Number of slabs by severity[b]
Transverse Cracking	
Corner Break	
Spalling	
Joint Seal Damage	
Shoulder Elements	
Curb and Gutter[a]	Yes or No
Paved Type[d]	P, B, C[e]
Paved Width[d]	Feet
Unpaved Width[d]	
Paved Condition[d]	L, M, S[b]
Unpaved Condition[d]	
Shoulder Drop-off[d]	
Shoulder Lane Joint[d]	

[a] Not recorded in this study
[b] None, Light, Moderate, Severe
[c] Good, Fair, Poor
[d] Recorded by a single survey team
[e] Plant mixed, Bituminous Surface Treatment, Portland Cement Concrete

3.2.3. NCDOT Survey – Additional Data Elements

In addition to reporting the necessary NCDOT survey items the vendors were allowed to submit additional information that they had gathered along the survey path. The data elements submitted by each vendor that either exceeded the NCDOT requirements or were not recorded by the NCDOT as part of their reference survey gathering process are given in Table 3.3. It should be understood that this list is not a comprehensive list of what a given vendor is capable of, simply a list of the data elements that the vendors elected to include in their data submission and thus consumed a portion of the analysis time for that vendor.

Table 3.3. Summary of Additional Data Elements Submitted by each Vendor.

Vendor	Additional Data Elements
Pathway	IRI Macrotexture (ASTM E 1845) Surface Texture Lane Drop-off
Fugro Roadware	Number of Lanes Curb and Gutter
Mandli	IRI Survey Speed Rut Depth

3.2.4. LTPP Survey – Asphalt Concrete Sections

The LTPP protocol for the asphalt concrete survey involves measuring the data elements shown in Table 3.4 To take all of these measurements required approximately 4 hours per section, thus to save resources, all three survey teams rated the sections at the same time. Due to the time requirements only three sections were surveyed for reference survey data. The first two sections were along NC-98 and the third was along US-64. Note that for the purposes of this study the NCDOT has elected to make measurements in the standard imperial units (inch, foot, mile, etc.), which is not what the LTPP protocol suggests (Miller and Bellinger 2003). It should be kept in mind that the NCDOT personnel performing the LTPP survey protocol are not certified to perform the survey. They have read, and are familiar with the above cited reference, but do perform the survey on a regular basis.

3.2.5. LTPP Survey – Portland Cement Concrete Sections

The LTPP protocol for the Portland cement concrete survey involves measuring the data elements shown in Table 3.5. Since no reference survey data were gathered on any PCC sections the following sections only give descriptions of the distresses shown in Table 3.5. A summary of the vendor data is given by course subinterval in subsequent sections.

Table 3.4. Summary of Data Elements for LTPP-AC Survey.

Data Element	Rating Type
Cracking Elements	
Fatigue Cracking	Area in square feet by severity[a]
Block Cracking	
Edge Cracking	
Unsealed Long. Cracking (Wheel Path)	Length in feet by severity[a]
Sealed Long. Cracking (Wheel Path)	
Unsealed Long. Cracking (Non-Wheel Path)	
Sealed Long. Cracking (Non-Wheel Path)	
Transverse Cracking Count	Number
Unsealed Trans. Cracking Condition	Length in feet by severity[a]
Sealed Trans. Cracking Condition	
Patching and Pothole Elements	
Patch Count	Number by severity[a]
Patch Deterioration	Area in square feet by severity[a]
Pothole Count	Number
Pothole Deterioration	Area in square feet by severity[a]
Surface Deformation	
Rutting	Depth in inches (every 50 feet)
Shoving Count	Number
Shoving Extent	Area in square feet by severity[a]
Surface Defects	
Bleeding	Area in square feet
Polished Aggregate	
Raveling	
Miscellaneous Distresses	
Water Bleeding and Pumping Count	Number
Water Bleeding and Pumping Deterioration	Length in feet

[a] Low, Moderate, High

Table 3.5. Summary of Data Elements for LTPP-PCC Survey.

Data Element	Rating Type
Cracking Elements	
Corner Breaks Count	Number by severity[a]
Durability ("D") Cracking Count	Number of slabs by severity[a]
Durability ("D") Deterioration	Area in square feet by severity[a]
Unsealed Longitudinal Cracking	Length in feet by severity[a]
Sealed Longitudinal Cracking	
Transverse Cracking Count	Number by severity[a]
Unsealed Transverse Cracking	Length in feet by severity[a]
Sealed Transverse Cracking	
Joint Deficiencies	
Sealed Transverse Joint Seal	Yes or No
Sealed Transverse Joint Seal Count	Number by severity[a]
Sealed Longitudinal Joint Count	0, 1, or 2
Longitudinal Joint Seal Damage Extent	Length in feet
Spalling of Longitudinal Joints	Area in square feet by severity[a]
Spalling of Transverse Joints Count	Number by severity[a]
Spalling of Transverse Joints Extent	Area in square feet by severity[a]
Surface Defects	
Map Cracking Count	Number of areas affected
Map Cracking Extent	Area in square feet
Scaling Count	Number of areas affected
Scaling Extent	Area in square feet
Polished Aggregate	
Miscellaneous Distresses	
Blowups	Number
Faulting of Transverse Joints and Cracks	Distance in inches (every occurence)
Lane-to-Shoulder Drop-off	Distance in inches (every 50 feet)
Lane-to-Shoulder Separation	
AC Patch Count	Number by severity[a]
AC Patch Deterioration	Area in square feet by severity[a]
PCC Patch Count	Number by severity[a]
PCC Patch Deterioration	Area in square feet by severity[a]
Water Bleeding and Pumping Count	Number
Water Bleeding and Pumping Deterioration	Length in feet

[a] Low, Moderate, High

3.3. Data Analysis

3.3.1. NCDOT Survey

For this report the reference survey and vendor data are processed and graphed by distress and, if appropriate, severity level using bar graphs. To better facilitate the data presentation, the total AC pavement portion of the course is broken down into eight, 6 to 11 mile sub-intervals. For the same reason, the PCC pavement portion of the course is broken down into four, 5 to 8 mile sub-intervals. The NCDOT reference survey data are given in one mile increments. The Mandli and Pathway groups submitted data in tenth of a mile increments and Fugro Roadware submitted data in full mile increments. The basis for the NCDOT PCC survey is the first 0.2 mile segment while the basis for the NCDOT AC survey is the whole mile. The PCC survey only considers the first 0.2 mile segment due to time limitations. It should be mentioned that all vendors have the capabilities to submit data in increments of any distance desired. Fugro Roadware elected to make the final submission in terms of full mile increments since this is the basis that the NCDOT uses in their windshield surveys for AC pavements and since the survey forms are labeled by mile increments. Since Pathway elected to submit data by tenth mile increments for the entire test loop, including the PCC sections, two different values were computed on the PCC sections; one based on the NCDOT procedure of considering only the first two tenths of a mile for a section and a second based on the whole mile interval. Due to data acquisition issues, Mandli did not submit data for any of the PCC sections.

Survey data were coordinated with the reference survey data by first using the vendor submitted distances and reference survey measured distances. After this initial coordination a finer adjustment was made by using some clearly defined high and low distress areas. For the Mandli and Pathway groups the tenth mile data were averaged over the mile length. Note that due to data acquisition and time issues that Mandli has only submitted data for the I-540 and US-1 intervals.

For consistent reporting in the PCC sections, the distresses listed in Table 3.2 are shown as a percentage. As part of the submission process the vendors were required to submit the total number of counted slabs in addition to the number of slabs at different severity levels. In some cases the reported total number of slabs was less than the number of slabs with some counted distress. For example, it may be reported that for a section that there are 25 slabs, but for this same section it is also reported that there are 20 slabs with light distress and 10 slabs with moderate distress. In such cases the total number of reported slabs is used even though it may then be possible to report higher than 100% distress levels.

For the graphs, the consensus reference survey data are shown with error bars that represent the highest and lowest values reported by the individual survey teams. For the vendor datasets similar error bars represent the highest and lowest values found within the respective sections. Such error bars are found for the Mandli and Pathway groups, but since the Fugro Roadware group did not submit tenth of a mile data similar extreme bars are not shown. In the subsequent sections, the distress definitions are given as reported in the North Carolina survey manuals (NCDOT 2004 and 2008a).

3.3.2. LTPP Survey

Little processing was needed for the vendor submitted LTPP data. Due to time limitations and contractual obligations Mandli did not complete or submit the LTPP based survey data. Fugro Roadware submitted the data in 528 ft increments instead of the LTPP specified 500 ft intervals. However, after discussions with the vendor it was determined that Fugro is capable of producing the 500 ft interval data if needed, but that it is best to make this decision before the survey is performed to produce the data efficiently. Pathway initially submitted the data in 528 ft intervals, but was able to reanalyze the data into the 500 ft basis.

No vendor immediately submitted the LTPP segment sketch/schematic. Due to time limitations it was determined that the vendors would not be asked to submit these sketches/schematics. However, each has stated that with the collected data such sketches/schematics could be generated. Finally, both Pathway and Fugro Roadware were able to include GPS coordinates for the beginning and ending points of the sections. Mandli also has the capability. Note that while the vendors did not submit similar coordinates for the NCDOT survey they could do so. Since the coordinates of the vendor submitted data and the NCDOT reference survey data did not exactly agree some averaging was necessary. The reference survey sections were plotted on a map of the test course along with the vendor's GPS coordinates to identify the closest vendor sections. The two vendor sections that overlapped the reference survey data were averaged. In the subsequent graphs the extreme error bars on the vendor data represent the extremes found from either of these overlapping sections. In the following sections the distress and severity descriptions are taken directly from the most recent LTPP distress manual (Miller and Bellinger 2000).

3.4. NCDOT Asphalt Concrete Survey

3.4.1. Fatigue Cracking

3.4.1.1. Definition of Distress

Alligator cracking is a load associated structural failure. The failure can be either in the surface, base or sub-base. Permanent deformation (rutting) does not have to be present for there to be alligator cracking. Cracking first begins in the wheel path, usually as longitudinal cracking. Further stress creates an alligator pattern. If the surface is very flexible the longitudinal crack will become wider and an alligator pattern may not develop until severe distress sets in. The proper solution for both alligator and longitudinal cracking is the same since a structural failure is taking place in both cases. Alligator cracking also includes cracking along the pavement edge, e.g., edge cracking.

The NCDOT rating process includes four different levels of severity reported as a base 10 percentage, i.e., a rating of 10 would mean 100% for the given distress. The lowest rating is none and the other levels are defined thusly:

- **Light:** Longitudinal disconnected hairline cracks about 0.125 in wide running parallel to each other; initially may be only a single crack in the wheel path or edge of pavement but could also look like an alligator pattern.
- **Moderate:** Longitudinal cracks in wheel path(s) or edge of pavement forming an alligator pattern; cracks may be lightly spalled and are about 0.25 in wide.
- **Severe:** Cracking has progressed so that pieces appear loose with severely spalled edges; cracks are about 0.375 to 0.50 in wide or greater; potholes may be present.

3.4.1.2. Data Processing and Results

Fugro Roadware submitted their data in the same format as the NCDOT by mile increments and no additional processing was needed. Pathway's submitted data were given in percentage base 100 and required some easy conversion to base 10 percentages. Mandli submitted data in percentages based on a single travel lane being 50% of the total section. For divided highways NCDOT ranks the entire section based on the worst lane, e.g., the worst lane in the travel direction represents 100% of a divided highway. Both the Fugro Roadware and Pathway groups scanned and reported percentages only on a single travel direction on the two-lane rural sections

(NC-98 and NC-39). For the NCDOT shoulder survey these roads are rated based on both travel directions being 100%. Since Mandli did not report data on the two-lane highways, no conclusion can be made on this vendor's scanning of rural sections. Note that the vendors were instructed to drive in only a single lane and could thus not drive the two lanes without violating the given instructions.

After compiling the mile based fatigue cracking values for each vendor, the NCDOT cracking composite index was also computed for each section. This index is given in Equation (3.1) below.

$$Fatigue\ Composite = 1\left(\frac{\%\ Light}{10}\right) + 2\left(\frac{\%\ Moderate}{10}\right) + 3\left(\frac{\%\ Severe}{10}\right) \tag{3.1}$$

The fatigue cracking results are shown by severity and by sections in Figure 3.1 through Figure 3.16.

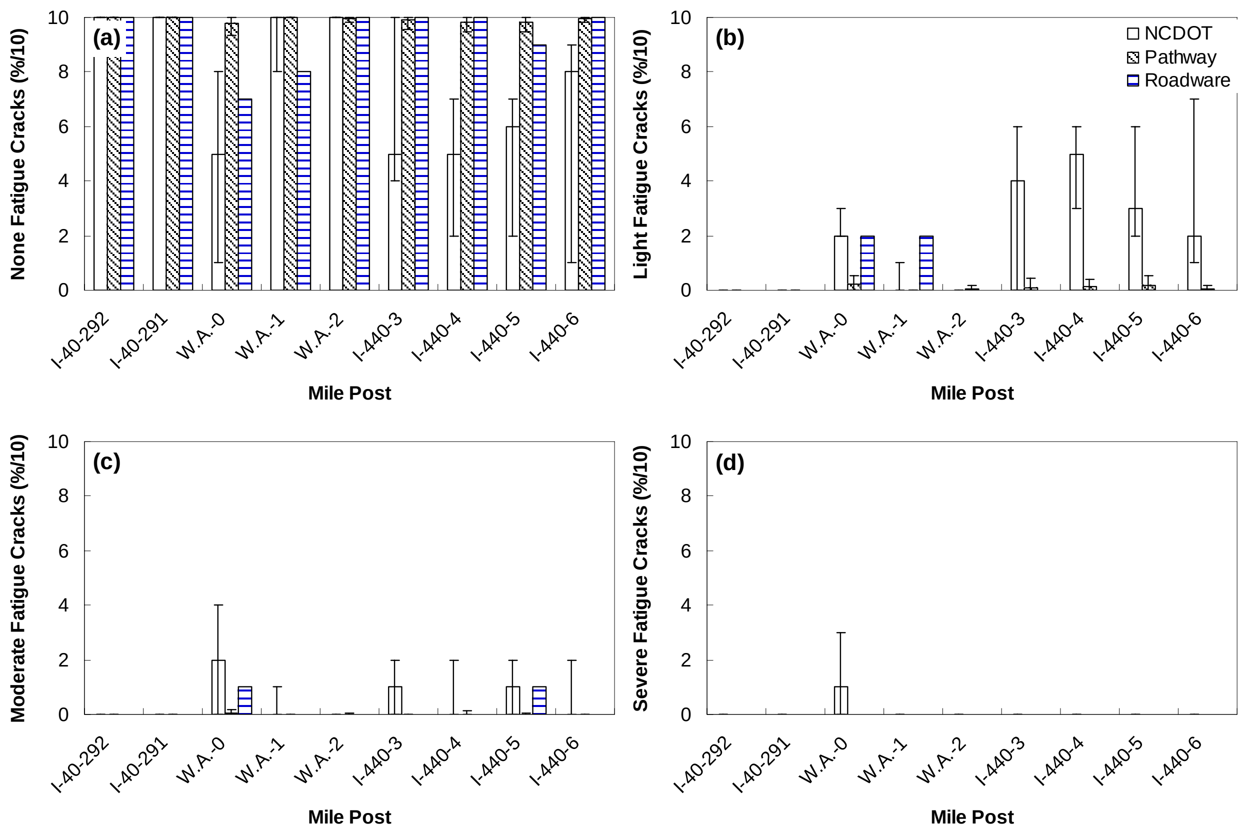


Figure 3.1. Fatigue cracking results for I-40, Wade Avenue, and I-440 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

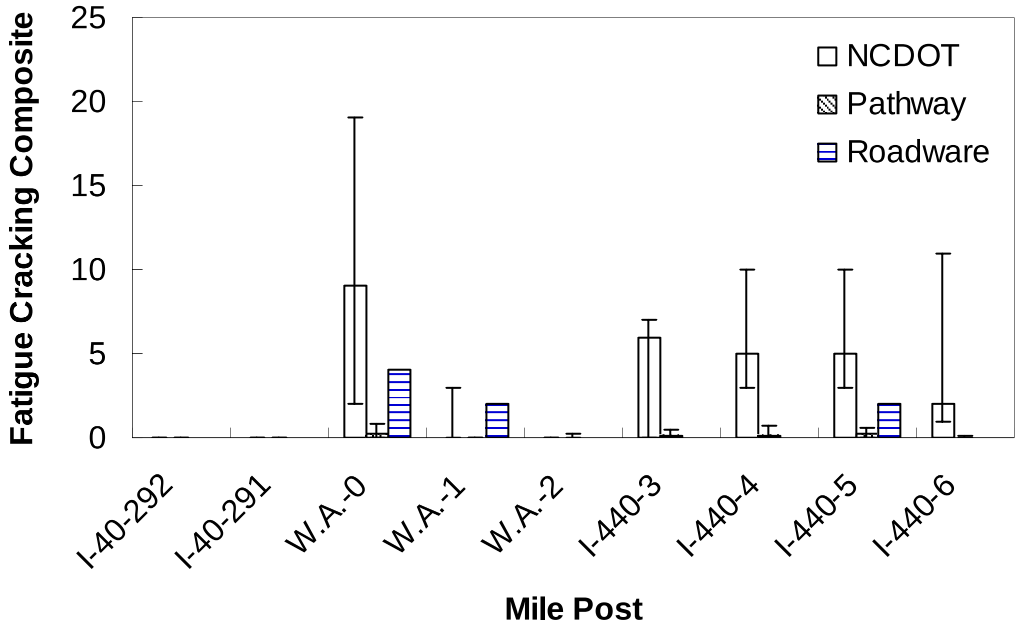


Figure 3.2. Fatigue cracking composite index for I-40, Wade Avenue, and I-440 sections.

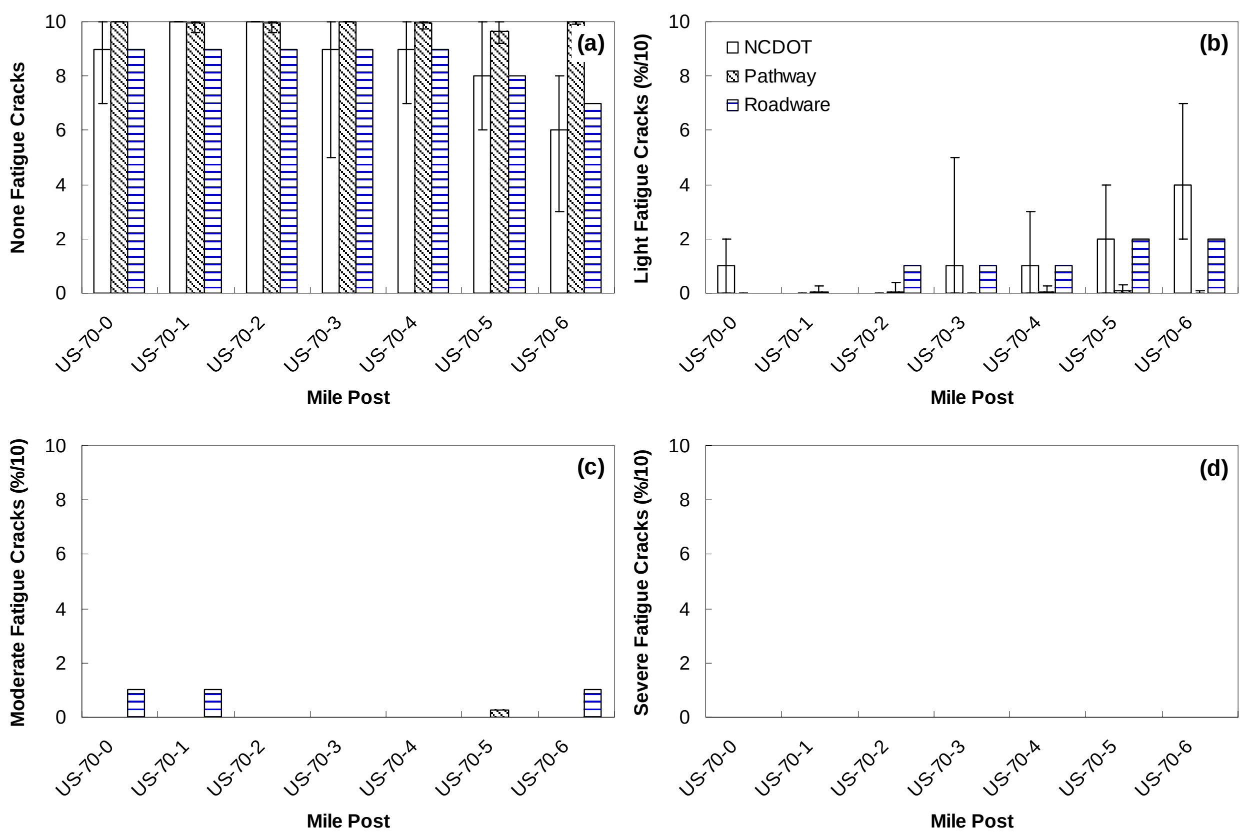


Figure 3.3. Fatigue cracking results for US-70 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

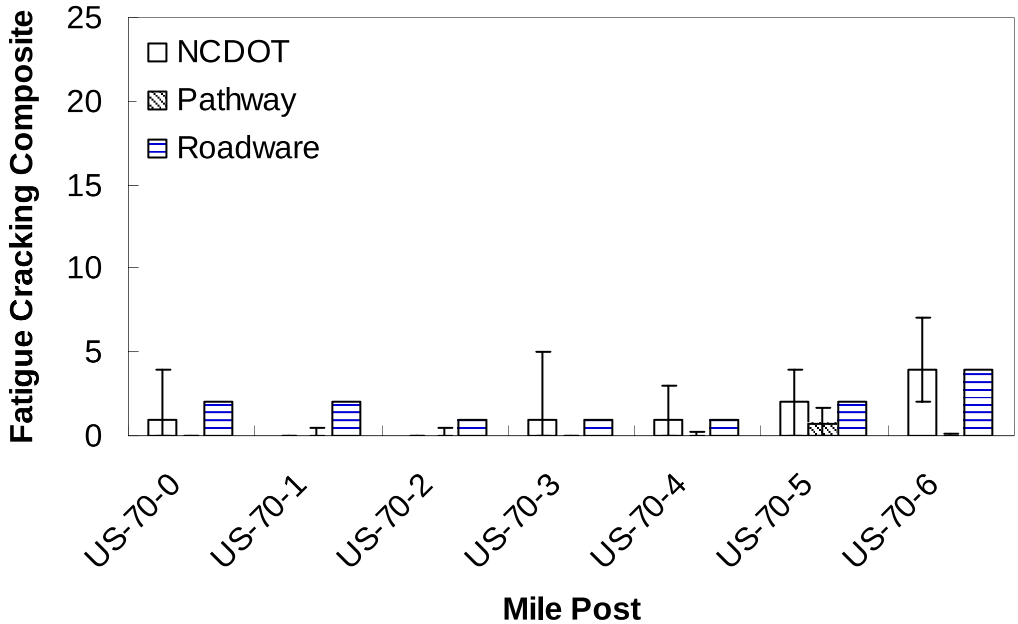


Figure 3.4. Fatigue cracking composite index for US-70 sections.

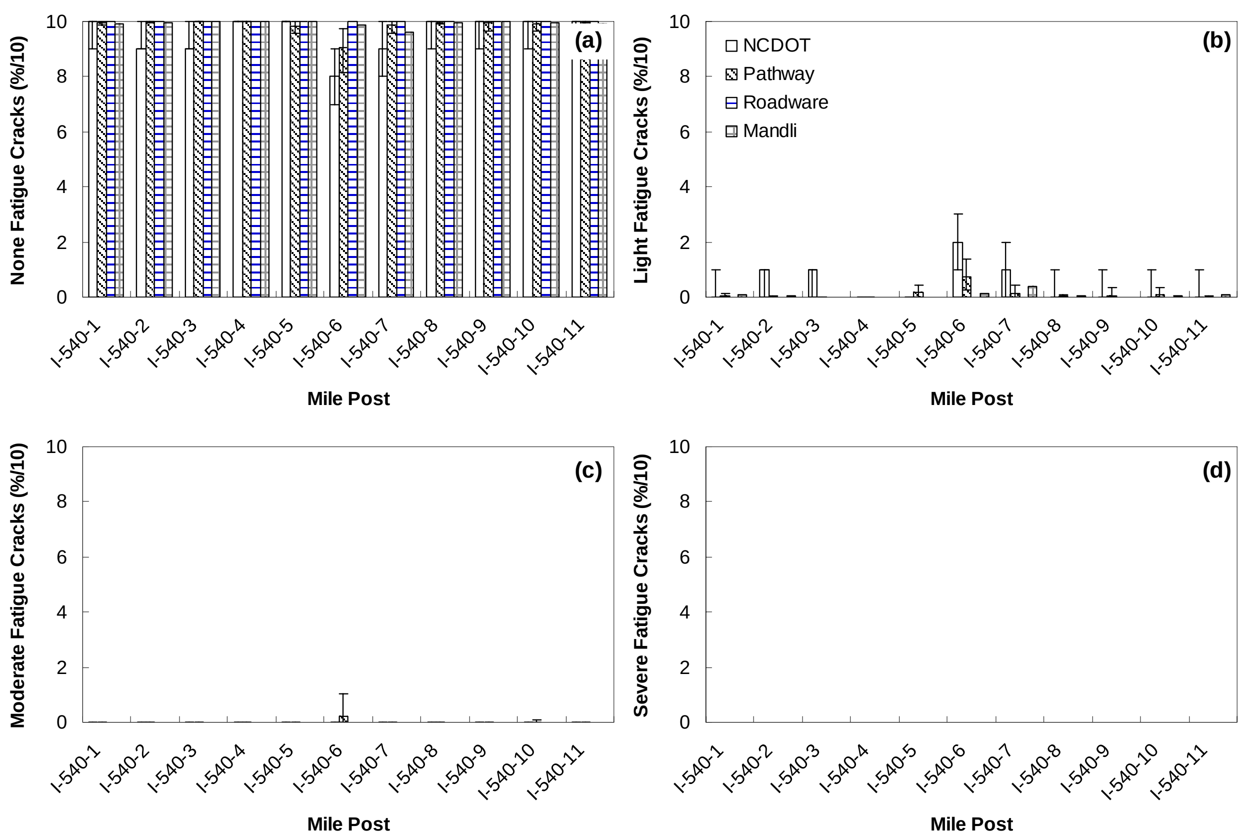


Figure 3.5. Fatigue cracking results for I-540 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

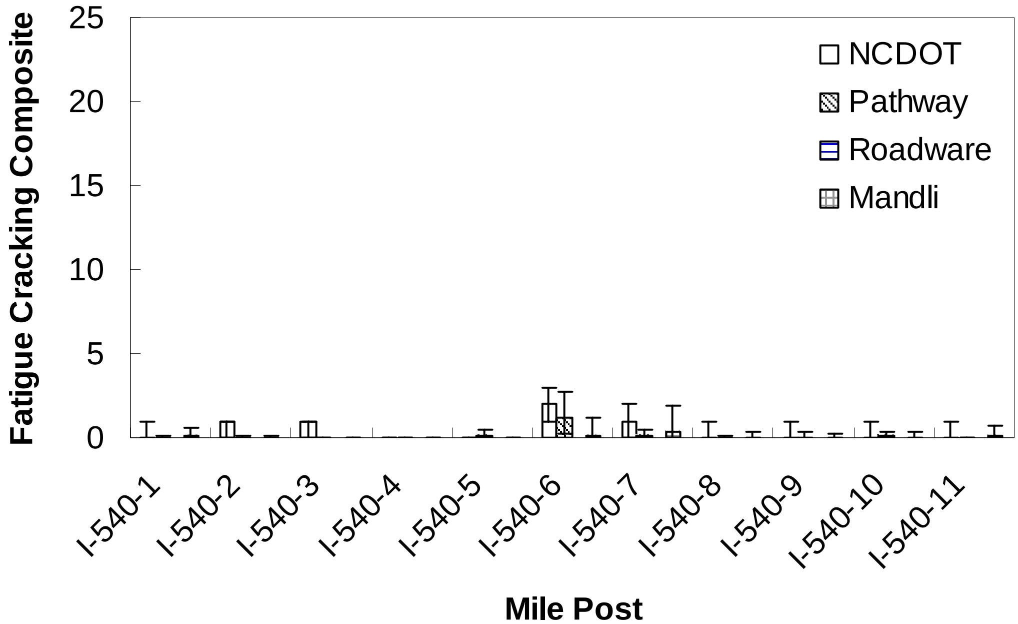


Figure 3.6. Fatigue cracking composite index for I-540 sections.

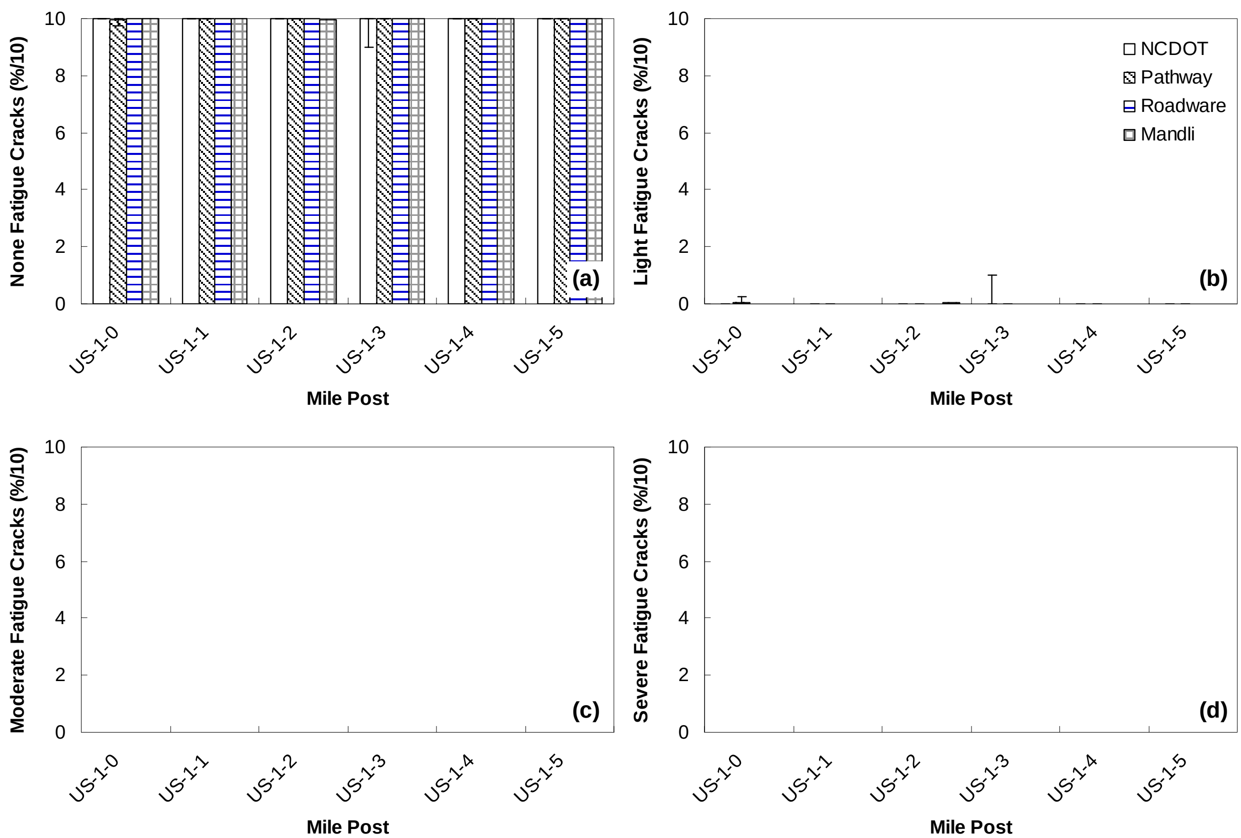


Figure 3.7. Fatigue cracking results for US-1 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

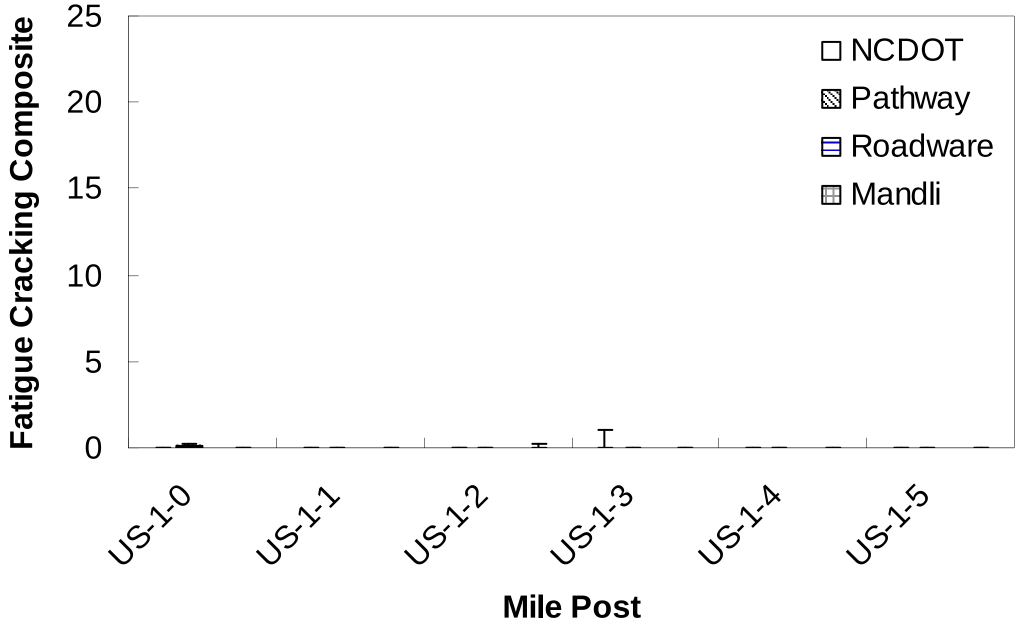


Figure 3.8. Fatigue cracking composite index for US-1 sections.

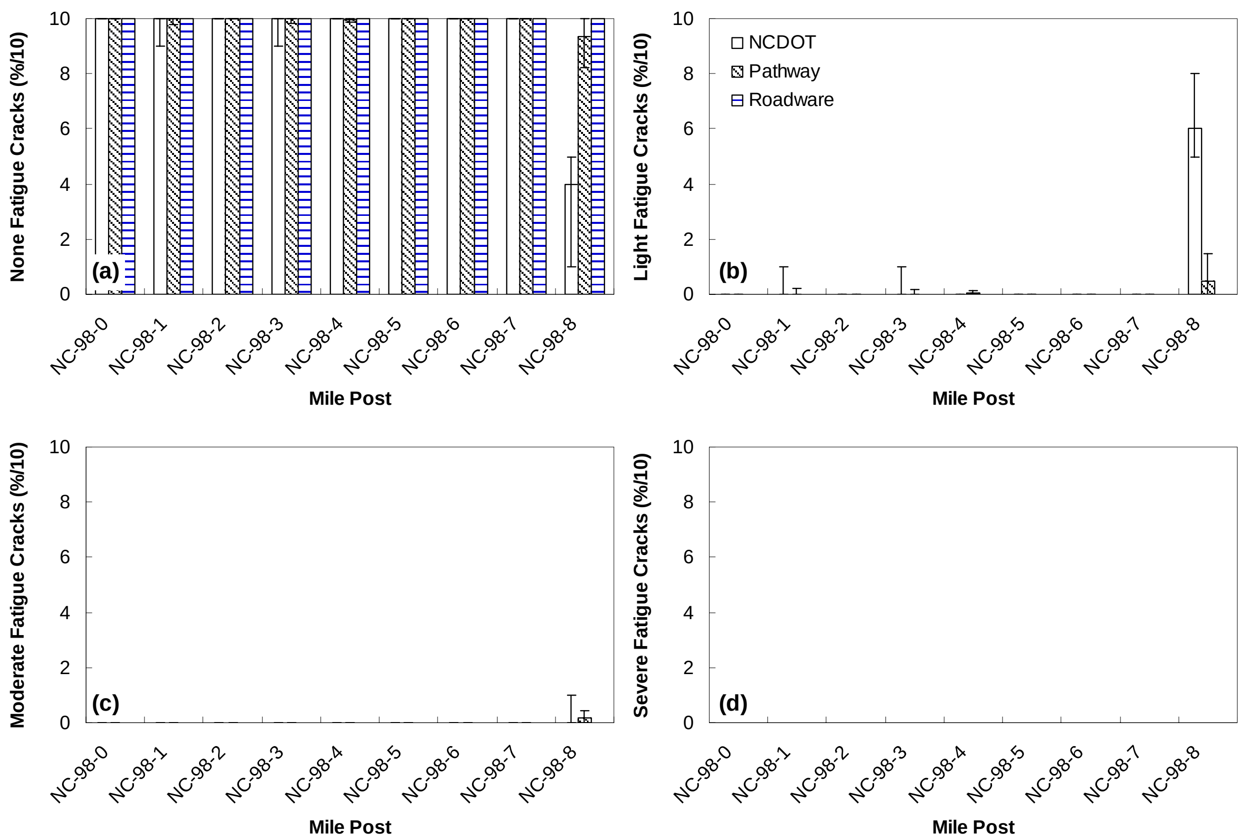


Figure 3.9. Fatigue cracking results for NC-98 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

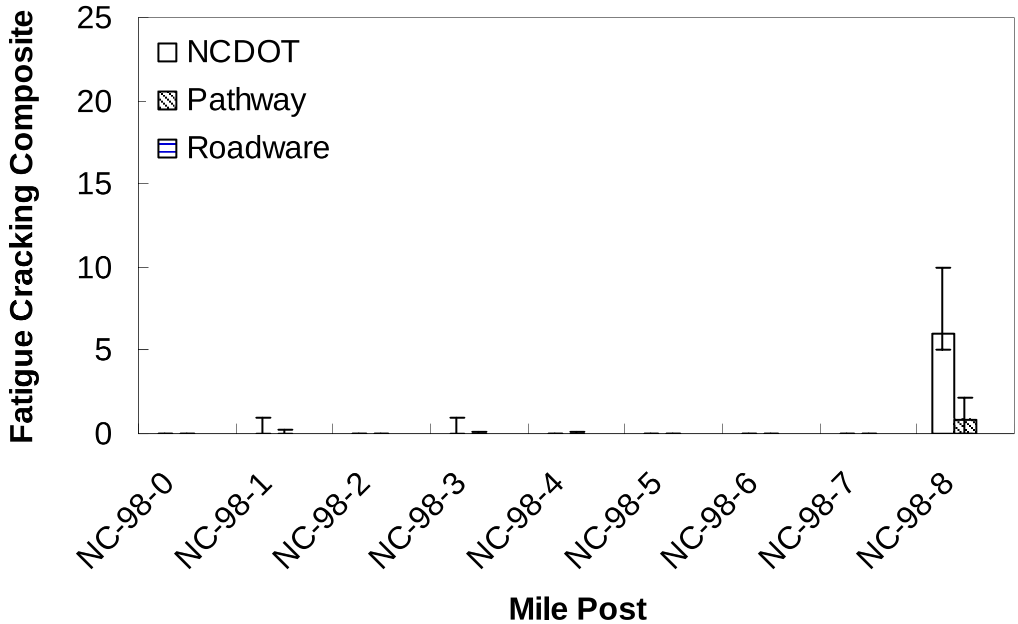


Figure 3.10. Fatigue cracking composite index for NC-98 (1) sections.

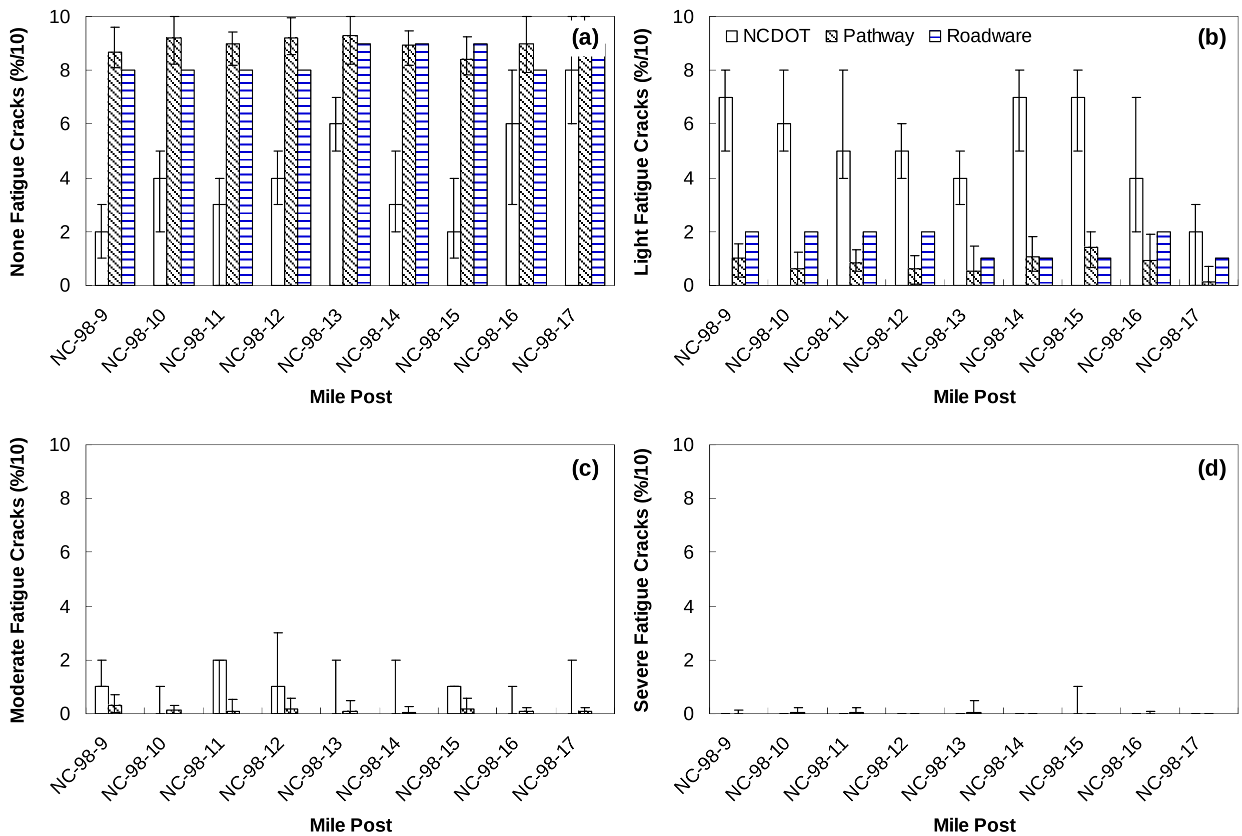


Figure 3.11. Fatigue cracking results for NC-98 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

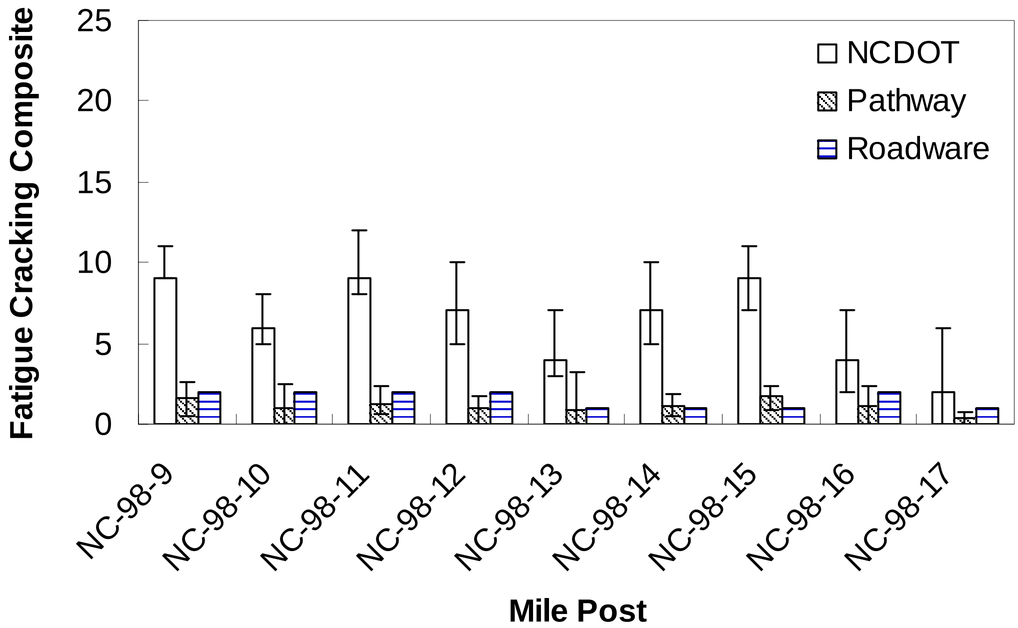


Figure 3.12. Fatigue cracking composite index for NC-98 (2) sections.

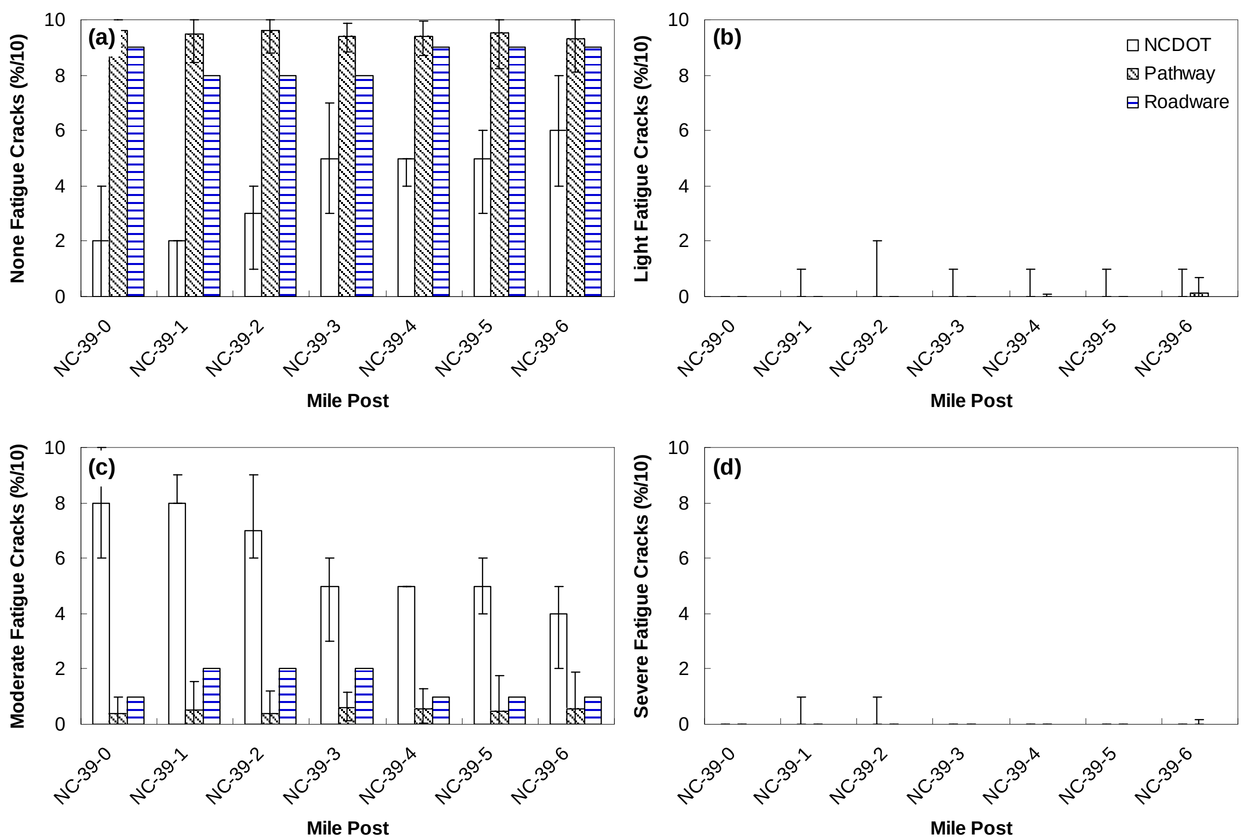


Figure 3.13. Fatigue cracking results for NC-39 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

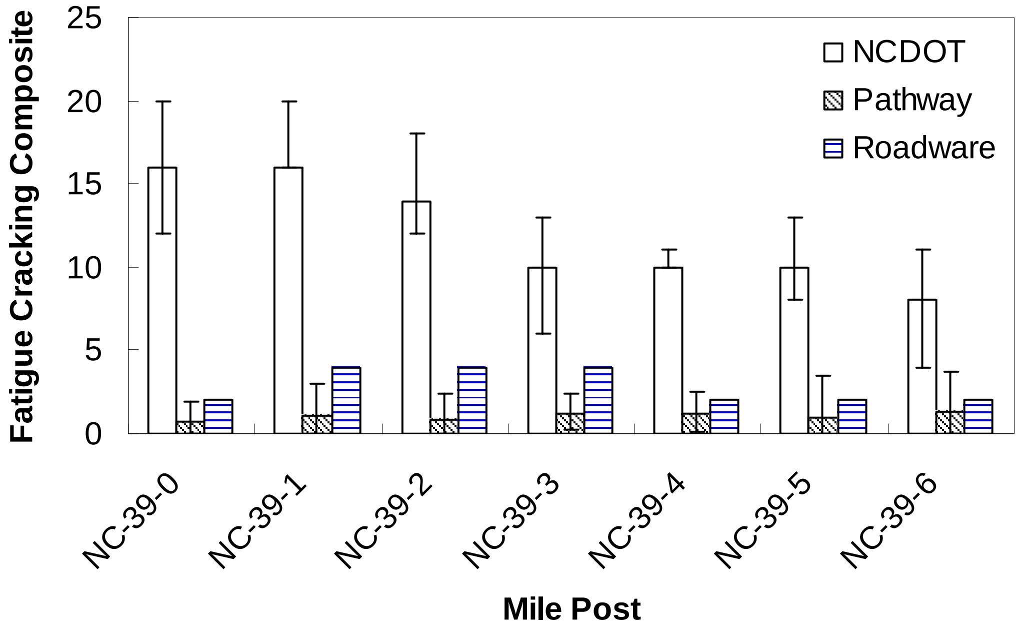


Figure 3.14. Fatigue cracking composite index for NC-39 sections.

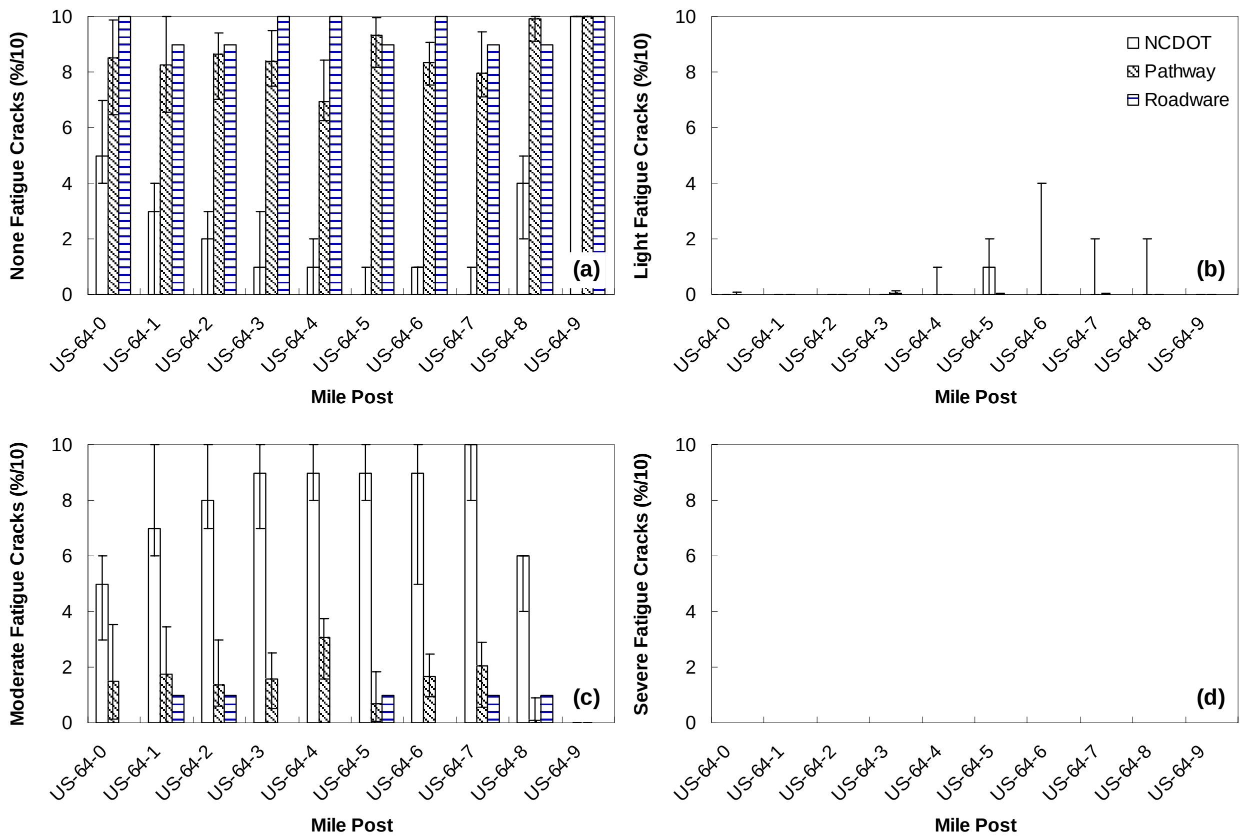


Figure 3.15. Fatigue cracking results for US-64 sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

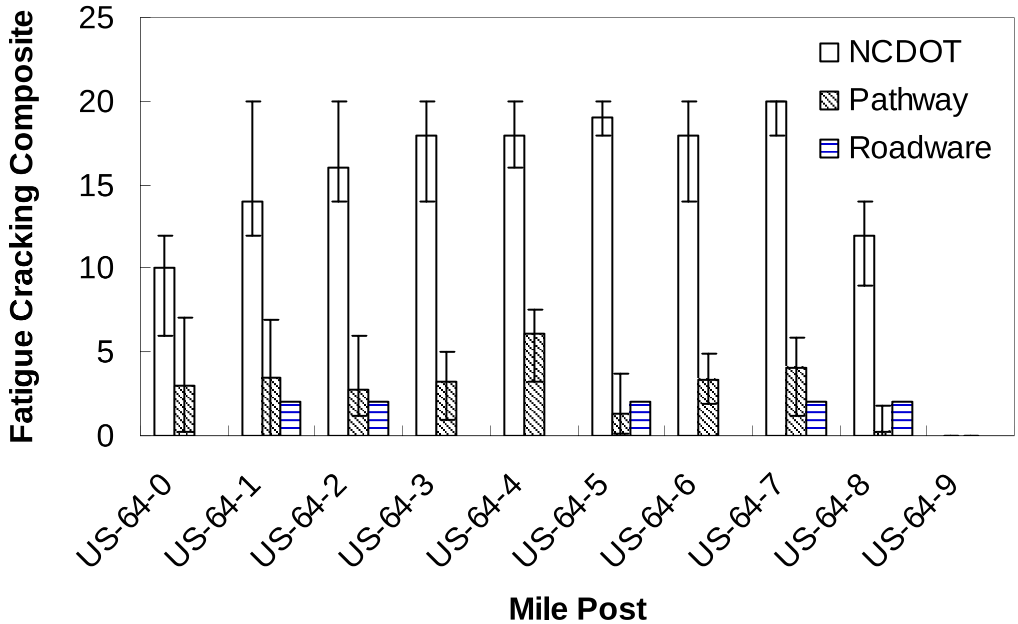


Figure 3.16. Fatigue cracking composite index for US-64 sections.

3.4.1.3. Discussion

I-40, Wade Avenue and I-440 sections

Reference survey Data

- Little to no fatigue cracking exists for the repaved section at I-40-292 and I-40-291.
- The beginning portion of Wade Avenue, mile marker 0, shows a mixture of light, moderate and severe fatigue cracking totaling approximately 50% of the total section length.
- For I-40 mile markers 3 to 6, there exists mostly light fatigue cracking with some moderate fatigue cracking at mile markers 3 and 5. One survey team also counted moderate fatigue cracking at mile markers 4 and 6.
- Except for Wade Avenue mile 0, no severe severity cracking is observed by any of the survey teams.

Pathway Services

- Both the average and the extreme observations total less than 0.5% fatigue cracking (light, moderate, severe) for all sections in this subinterval.
- No severe cracking is observed for any section.

Fugro Roadware

- Some light fatigue cracking, approximately 2%, is counted for Wade Avenue miles 0 and 1.
- Less than 1% moderate fatigue cracking is counted for Wade Avenue mile 0 and I-440 mile 5.
- No severe cracking is observed for any section.

US-70

Reference survey

- The consensus for most sections along this subinterval is that the total fatigue cracking constitutes 20% or less of the total length. US-70-6 is the exception and shows approximately 40%.
- Fatigue cracking that does exist in this section is entirely light severity cracking.
- No severe cracking is observed by any of the survey teams.

Pathway Services

- On the average fatigue cracking is counted for only one section, US-70-5. The cracking in this section is a combination of light severity (1%) and moderate severity (3%).
- At the extremes, 2% light fatigue cracking is counted at US-70-1, US 70-4 and US 70-5 and 1% is counted at US 70-6, 1% moderate fatigue cracking is counted at US-70-1.
- No severe cracking is counted.

Fugro Roadware

- For the first five miles of this subinterval fatigue cracking is counted on 10% of the total section; light for miles 2, 3 and 4 and moderate for miles 0 and 1.
- At miles 5 and 6, 20% light fatigue cracking is counted, an additional 10% moderate severity is counted for US-70-6.
- No severe cracking is counted.

I-540, US-1 and NC-98-0 to NC-98-7

Reference survey

- The consensus is that fatigue cracking exists only at I-540-2, I-540-3, I-540-6, and I-540-7. For each of these sections fatigue cracking constitutes at most 20% of the section (I-540-6).
- This reference survey cracking is all light in severity.
- No consensus fatigue cracking is observed for the US-1 sections.
- No moderate severity cracking is observed by any of the survey teams.
- No severe cracking is observed by any of the survey teams.

Pathway Services

- No cracking of any severity is observed for most sections along this subinterval. Exceptions exist at I-540-5 at 2% light severity cracking, I-540-6 with 7% light and 2% moderate severity, I-540-7, I-540-9, I-540-10, and US-1-0 with 1% light fatigue cracking.
- No severe cracking is counted.

Fugro Roadware

- No cracking of any severity is observed for most sections along this subinterval.

Mandli Communications

- No cracking of any severity is observed for most sections along this subinterval. Exceptions exist at I-540-7 at 4% light severity cracking and I-540-1, I-540-6, and I-540-11 with 1% light fatigue cracking.
- No severe cracking is counted.
- No observations are given for NC-98 sections.

NC-98-8 to NC-98-17

Reference survey

- The consensus for most sections in this interval is that light fatigue cracking exists for 40-60% of the sections.
- Consensus moderate fatigue cracking is also found at NC-98-9 (10%), NC-98-11 (20%), NC-98-12 (10%) and NC-98-15 (10%). Extreme moderate fatigue cracking is found at

NC-98-8 (10%), NC-98-10 (10%), NC-98-13 (20%), NC-98-16 (20%) and NC-98-17 (20%). Extreme severe fatigue cracking is observed at NC-98-15 (10%).

- The calculated fatigue composite index ranges from approximately 2.0 for NC-98-17 to 9.0 for NC-98-9, NC-98-11 and NC-98-15.

Pathway Services

- On the average fatigue cracking is counted on less than 20% of each section.
- The counted fatigue cracking is mostly light severity and is the greatest in extent for NC-98-15 at 14%.
- Some very slight moderate severity cracking, less than 3% and mostly less than 2%, is counted for all sections.
- Some very slight severe cracking is counted for NC-98-8 (2%), NC-98-11 (1%) and NC-98-13 (1%).
- The calculated fatigue composite index ranges from approximately 0.3 for NC-98-17 to 1.8 for NC-98-15.

Fugro Roadware

- On the average fatigue cracking is counted on approximately 20% of each section.
- The counted fatigue cracking is mostly light severity and is the greatest in extent for NC-98-9 to NC-98-12 and NC-98-16 at 20%.
- No moderate severity cracking is counted.
- No severe cracking is counted.
- The calculated fatigue composite index ranges from approximately 1.0 for NC-98-13, NC-98-14, NC-98-15 and NC-98-17 to 2.0 for the other sections.

NC-39 and US-64

Reference survey

- Fatigue cracking is observed for every section along this subinterval the majority of this consensus cracking is moderate in severity. The section at US-64-5 shows some light severity cracking (10%).
- For the subinterval along NC-39, the extent of the moderate severity cracking ranges from 80% on NC-39-0 to 40% on NC-39-6.
- For the subinterval along US-64, the extent of the moderate severity cracking ranges from 100% on US-64-7 to 50% on US-64-0.
- The calculated alligator composite index ranges from 8.0 at NC-39-6 to 20 at US-64-7.

Pathway Services

- Fatigue cracking is counted for every section along this subinterval, all of this counted cracking is moderate in severity.
- For the subinterval along NC-39, the extent of the moderate severity cracking ranges from 6% on NC-39-3 and NC-39-4 to 4% on NC-39-0 and NC-39-2.
- For the subinterval along US-64, the extent of the moderate severity cracking ranges from 31% on US-64-4 to 1% on US-64-8.
- The calculated alligator composite index ranges from 0.2 at US-64-8 to 6.1 at US-64-4.
- No severe cracking is counted for this subinterval.

Fugro Roadware

- Moderate severity fatigue cracking is counted for most sections along this subinterval with the exception of US-64-0, US-64-3, US-64-4, and US-64-6. For these sections no fatigue cracking is counted.

- For the subinterval along NC-39, the extent of the moderate severity cracking ranges from 10% on NC-39-0, NC-39-4, NC-39-5 and NC-39-6 to 20% on NC-39-1, NC-39-2 and NC-39-3.
- For the subinterval along US-64, the extent of the moderate severity cracking ranges from 0% to 10% on US-64-1, US-64-2, US-64-5, US-64-7 and US-64-8.
- The calculated alligator composite index ranges from 0.0 at US-64-0, US-64-3, US-64-4, and US-64-6 to 4.0 at NC-39-1, NC-39-2, and NC-39-3.
- No severe cracking is counted for this subinterval.

3.4.2. Transverse Cracking

3.4.2.1. Definition of Distress

For the NCDOT survey purposes transverse cracks include any cracking perpendicular to the primary cracking direction and block cracking. Block cracks divide the pavement up into roughly rectangular pieces. Block cracking is not load-associated. Cracks are generally caused by shrinkage of the asphalt concrete and daily temperature cycling. Wheel path loads can increase the severity of block cracking if water is allowed to penetrate into the cracks. It is therefore very important to seal these cracks to prevent water penetration into the base materials.

Transverse cracking also includes reflective cracking of plant mix resurfacing over concrete. The primary cause of reflective cracking is movement of the concrete slab beneath the PM resurfacing. This movement is due to thermal and moisture changes and faulting at the joints. Typically, the reflective joints are bulged above the riding surface such that the vehicle is riding over small bumps.

The NCDOT rating process assigns a single value, None, Light, Moderate or Severe, to represent transverse cracking over the entire section. The criteria used to determine this ranking is as follows:

Light: 0.50 or more of the section shows Light distress, OR A combination of distress conditions is present on 0.33 or more of the section with some Moderate distress.

Moderate: 0.50 or more of the section shows Moderate distress OR A combination of distress conditions is present on 0.33 or more of the section with some Severe distress.

Severe: 0.33 or more of the section shows Severe distress.

The definitions applied to the transverse cracking distress are:

Light: Cracks, usually only transverse, are less than 0.25 in wide and are not spalled; block pattern may not be visible yet; transverse cracks usually 10 to 20 ft apart. Cracks have little or no spalling and joints are usually not bumped up.

Moderate: Block pattern may be visible with blocks 10 square ft or greater present; cracks are 0.25 in to 0.50 in wide; cracks may or may not be spalled; transverse cracks usually 5 to 20 ft apart; joints may be bumped up 0.50 in over concrete.

Severe: Cracks may be severely spalled with smaller blocks 2 to 10 square ft present; cracks usually greater than 1/2 inch wide; transverse cracks may be 1 to 2 ft apart throughout portions of the surface; cracks may be bumped up more than 0.50 in.

3.4.2.2. Data Processing and Results

Processing involved averaging the Mandli and Pathway tenth of a mile data. Since Fugro Roadware submitted their data in the same format as the NCDOT mile increments no additional processing was needed. The transverse cracking results are shown by severity and by sections in Figure 3.17 through Figure 3.24.

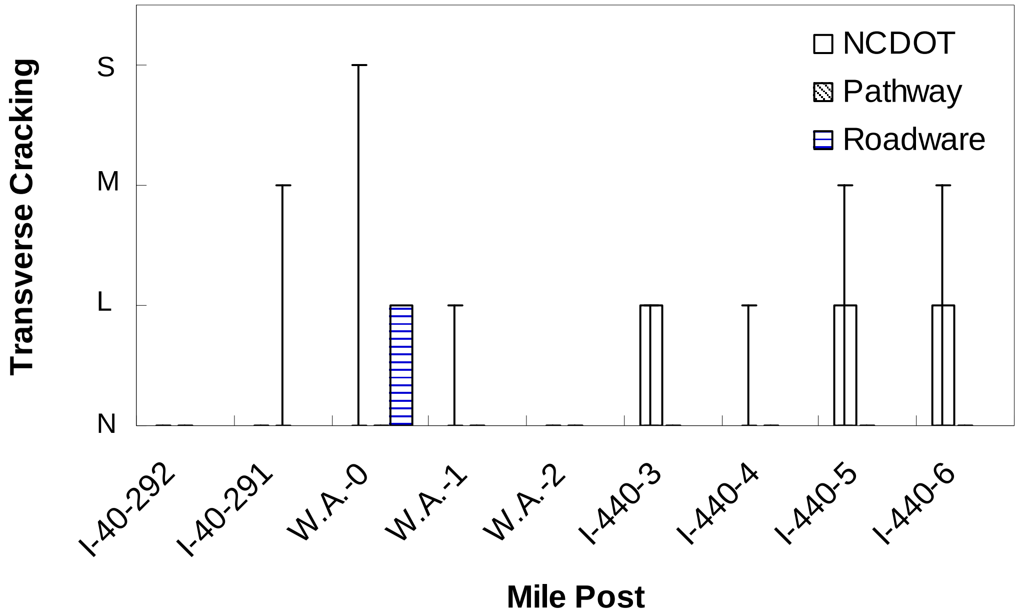


Figure 3.17. Transverse cracking rating for I-40, Wade Avenue, and I-440 sections.

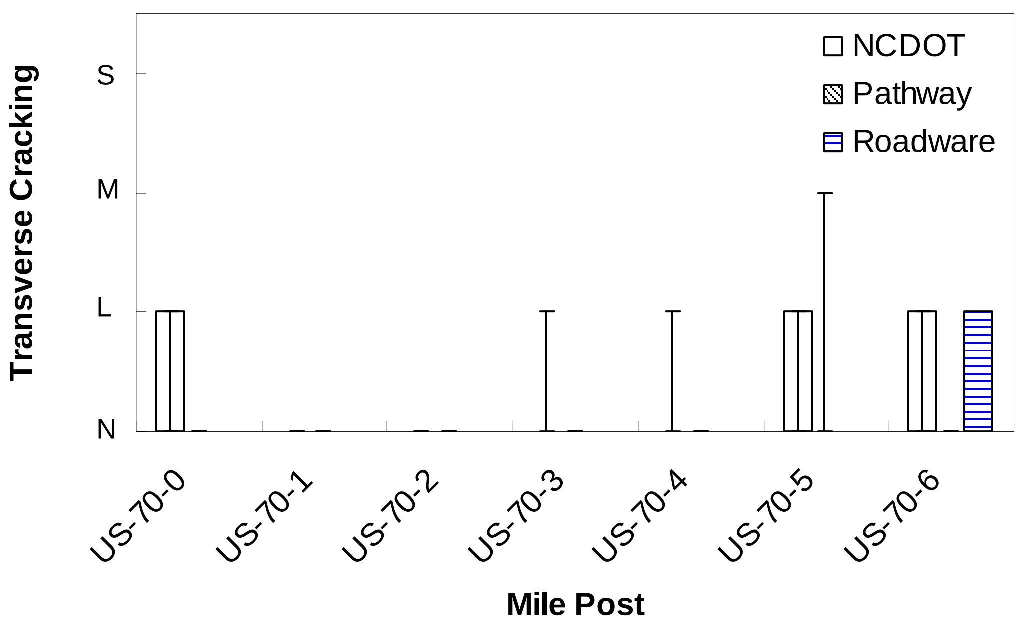


Figure 3.18. Transverse cracking rating for US-70 sections.

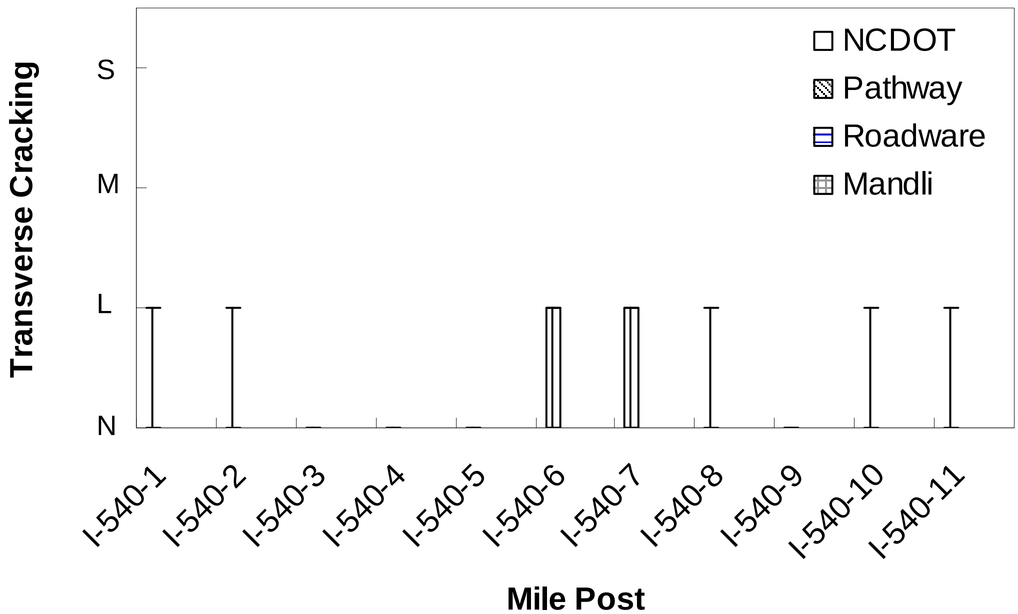


Figure 3.19. Transverse cracking rating for I-540 sections.

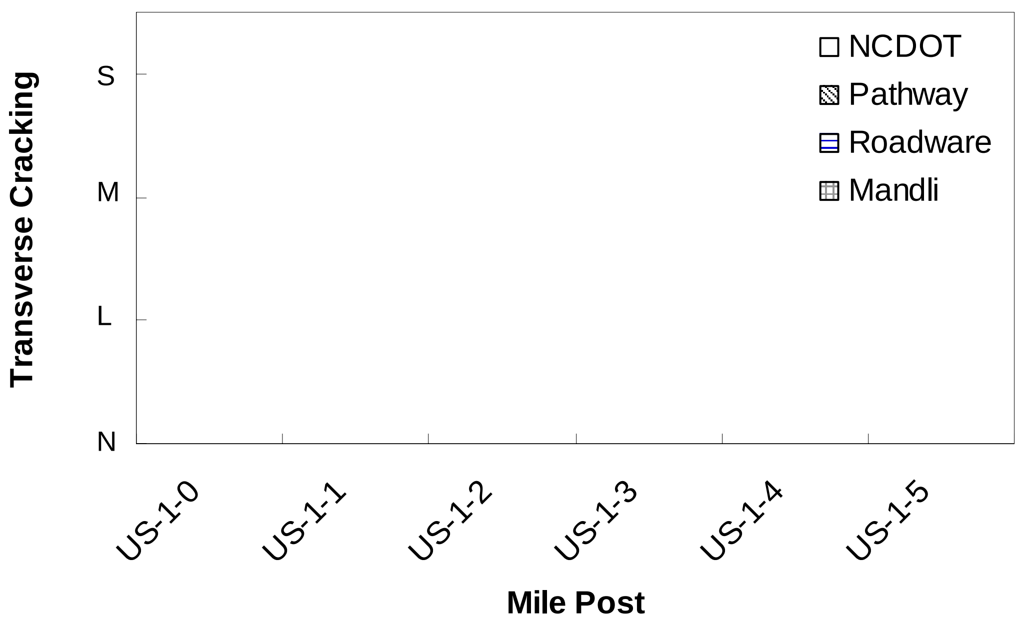


Figure 3.20. Transverse cracking rating for US-1 sections.

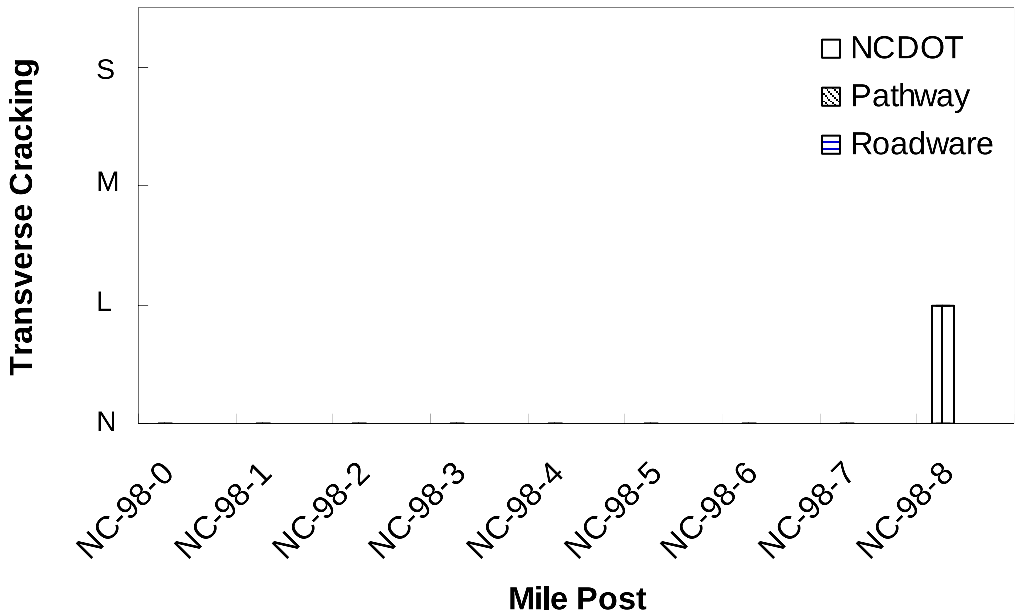


Figure 3.21. Transverse cracking rating for NC-98 (1) sections.

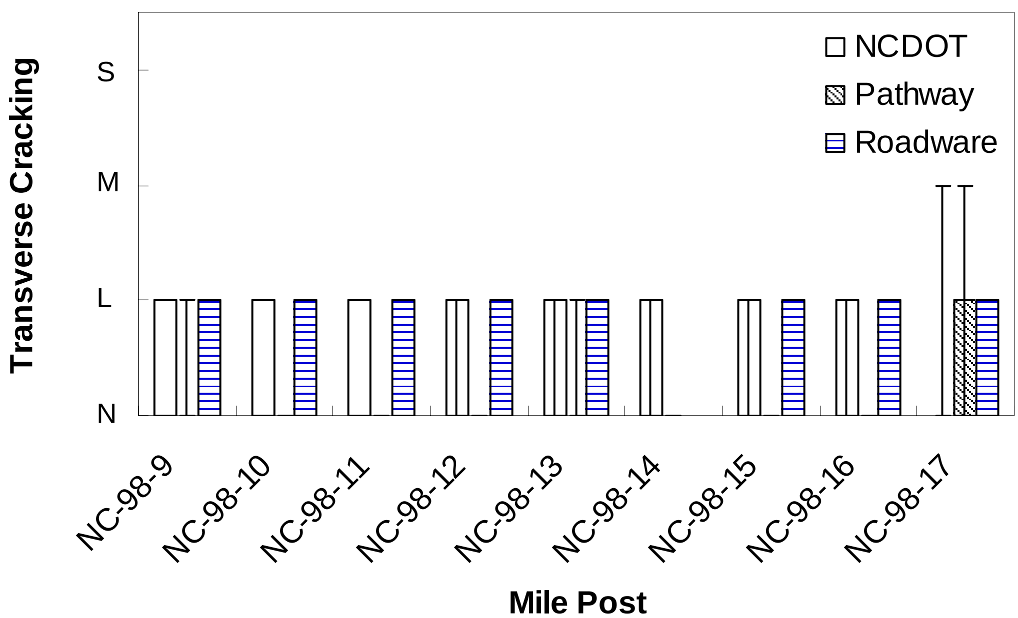


Figure 3.22. Transverse cracking rating for NC-98 (2) sections.

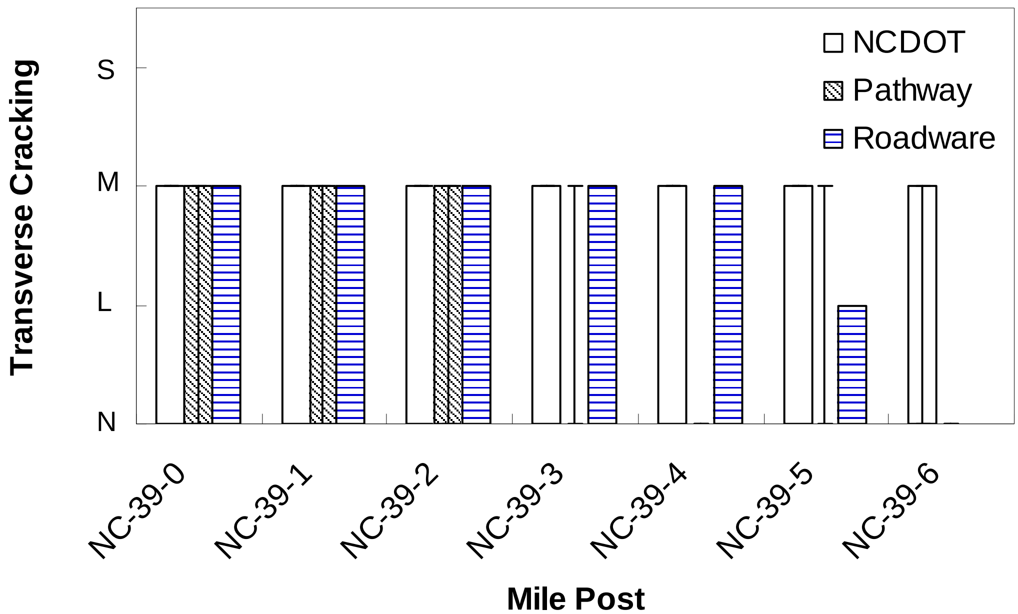


Figure 3.23. Transverse cracking rating for NC-39 sections.

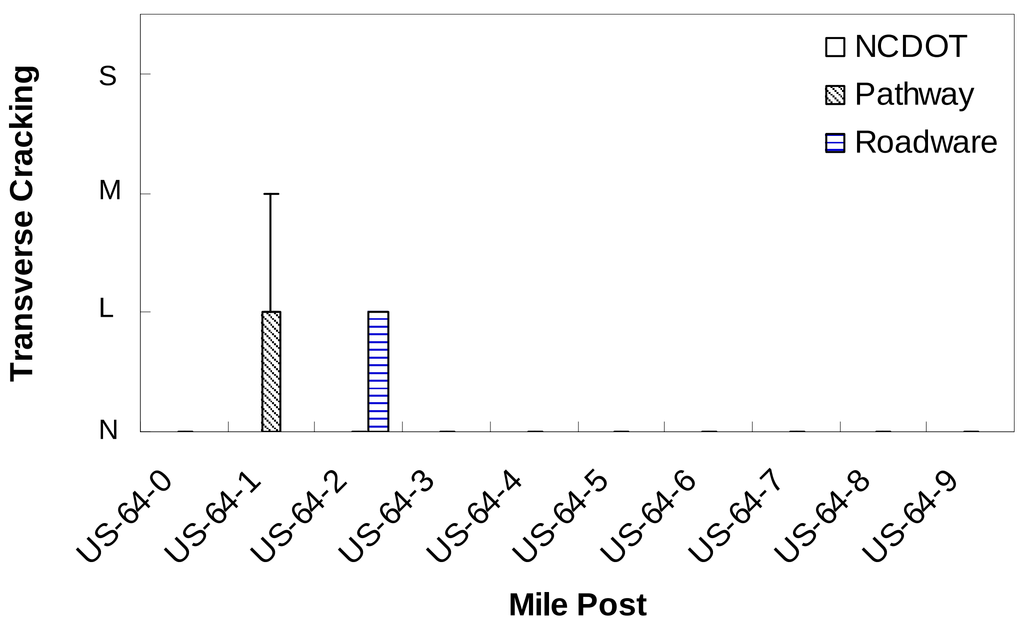


Figure 3.24. Transverse cracking rating for US-64 sections.

3.4.2.3. Discussion

Reference Survey

- Overall, when observed, the transverse cracking along the test course was light in severity.
- Transverse cracking does not appear to be a major distress for this test course.

- The highest transverse cracking was observed along NC-39 which showed moderate severity for all sections.
- No transverse cracking was observed for the I-40, Wade Avenue, US-1, NC-98-0 to NC-98-7 and US-64 subintervals.

Pathway Services

- Overall a small number of transverse cracks were counted.
- The highest transverse cracking was observed along the first three segments of NC-39 which show moderate transverse cracking.
- No transverse cracking was counted for the I-40, Wade Avenue, I-440, US-70, I-540, US-1, NC-98 (except NC-98-17), and US-64 (except US-64-1)

Fugro Roadware

- Overall transverse cracking was not rated as severe or highly extended.
- The highest transverse cracking was observed for the first 5 miles of NC-39 which all show moderate transverse cracks.
- No transverse cracks were counted for the I-40, I-440, US-70 (except at US-70-6), I-540, US-1, NC-98-0 to NC-98-8 and US-64 (except US-64-2) subintervals.

Mandli Communications

- No transverse cracking was counted for the I-540 and US-1 subintervals.

3.4.3. Rutting

3.4.3.1. Definition of Distress

A rut is a surface depression in the wheel path(s) or at the edge of pavement. Rutting comes from a pavement deformation in any of the pavement layers or in the subgrade, usually caused by consolidation or lateral movement of the materials due to traffic loads. Movement in the mix in hot weather or inadequate compaction during construction is the main cause of rutting.

The NCDOT rating process assigns a single value, None, Light, Moderate or Severe, to represent rutting over the entire section. The criteria used to determine this ranking is as follows:

Light: 0.50 or more of the section shows Light distress, OR A combination of distress conditions is present on 0.33 or more of the section with some Moderate distress.
Moderate: 0.50 or more of the section shows Moderate distress OR A combination of distress conditions is present on 0.33 or more of the section with some Severe distress.
Severe: 0.33 or more of the section shows Severe distress.

The definitions applied to the rutting distress are:

Light: Rutting 0.25 to less than 0.50 in deep.
Moderate: Rutting 0.50 to less than 1 in deep.
Severe: Rutting 1 in deep or greater.

3.4.3.2. Data Processing and Results

For this distress the Mandli and Pathway tenth of a mile data were averaged. In addition, Pathway's submitted data were by percentage and severity. Thus some additional averaging and application of the survey rules shown above were necessary. Since Fugro Roadware submitted their data in the same format as the NCDOT mile increments, no additional processing was needed. The rutting results are shown by severity and by sections in Figure 3.25 through Figure 3.32.

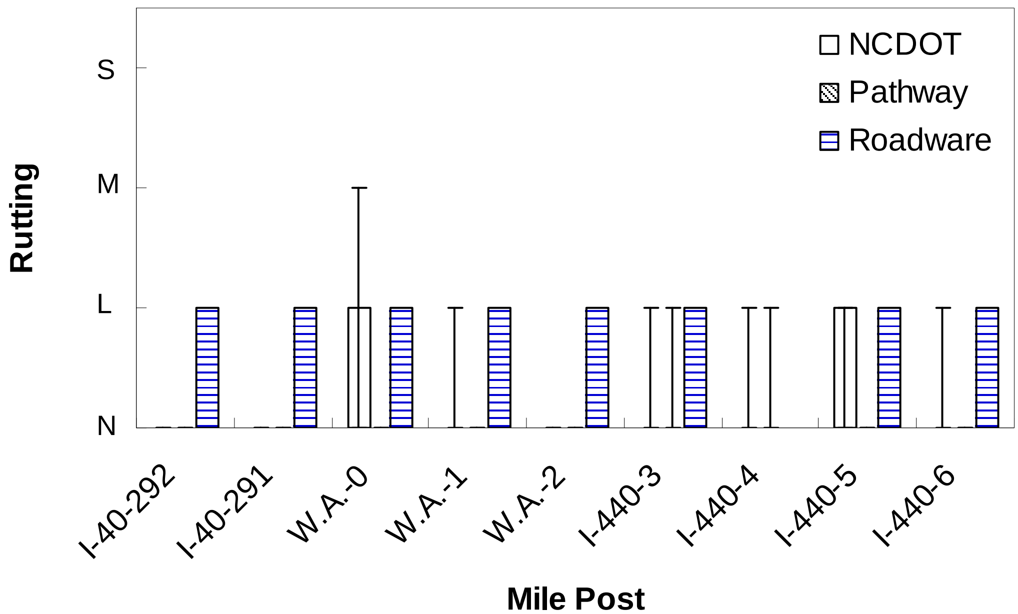


Figure 3.25. Rutting rating for I-40, Wade Avenue, and I-440 sections.

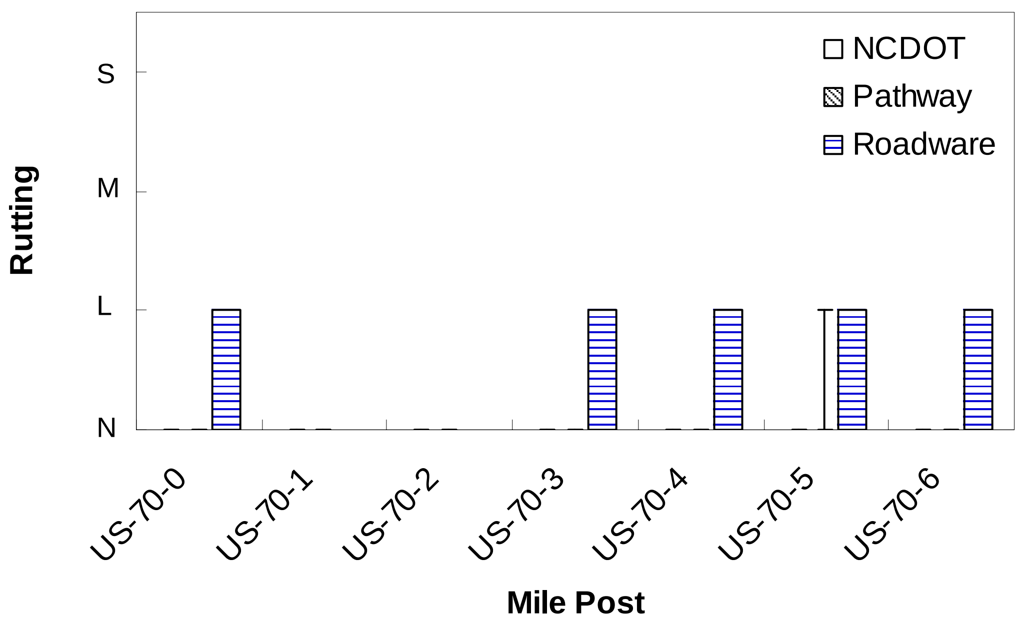


Figure 3.26. Rutting rating for US-70 sections.

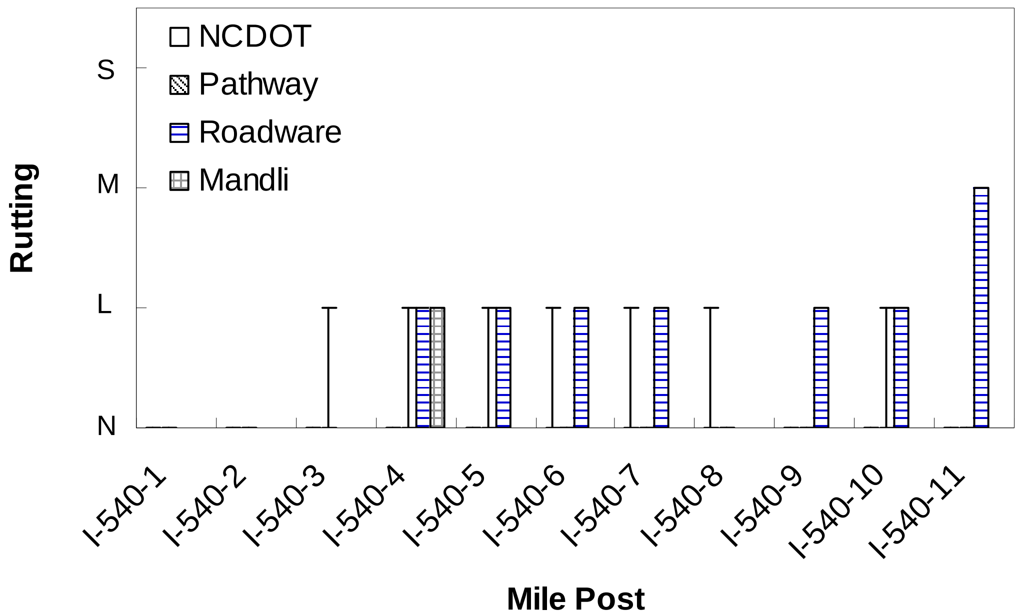


Figure 3.27. Rutting rating for I-540 sections.

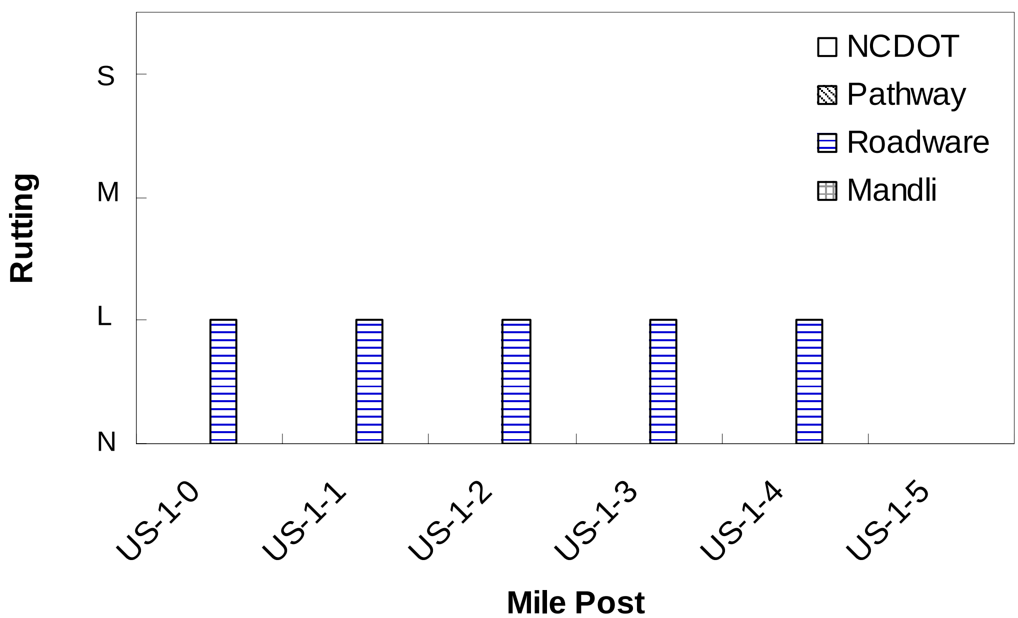


Figure 3.28. Rutting rating for US-1 sections.

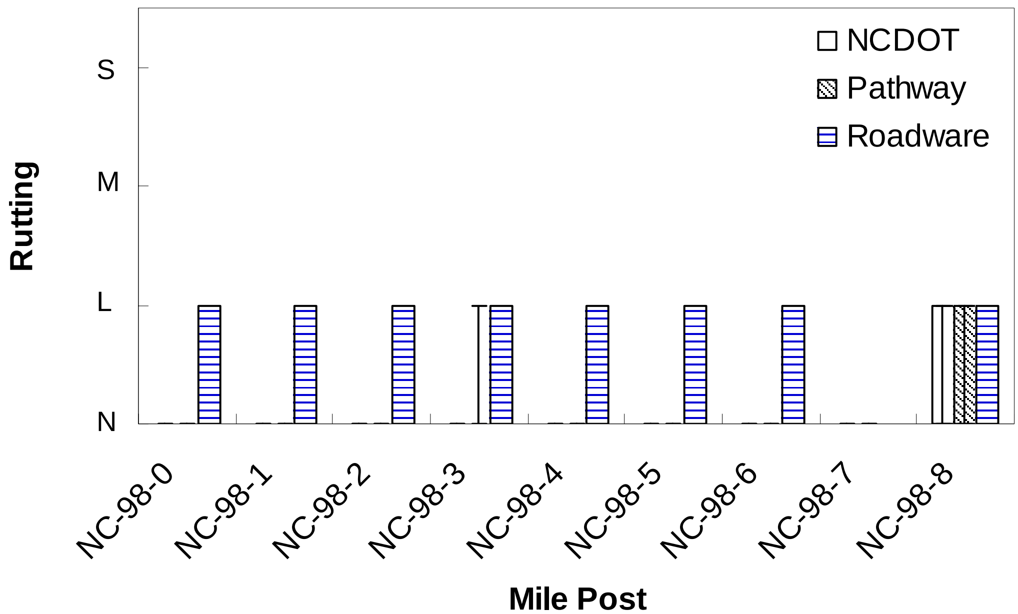


Figure 3.29. Rutting rating for NC-98 (1) sections.

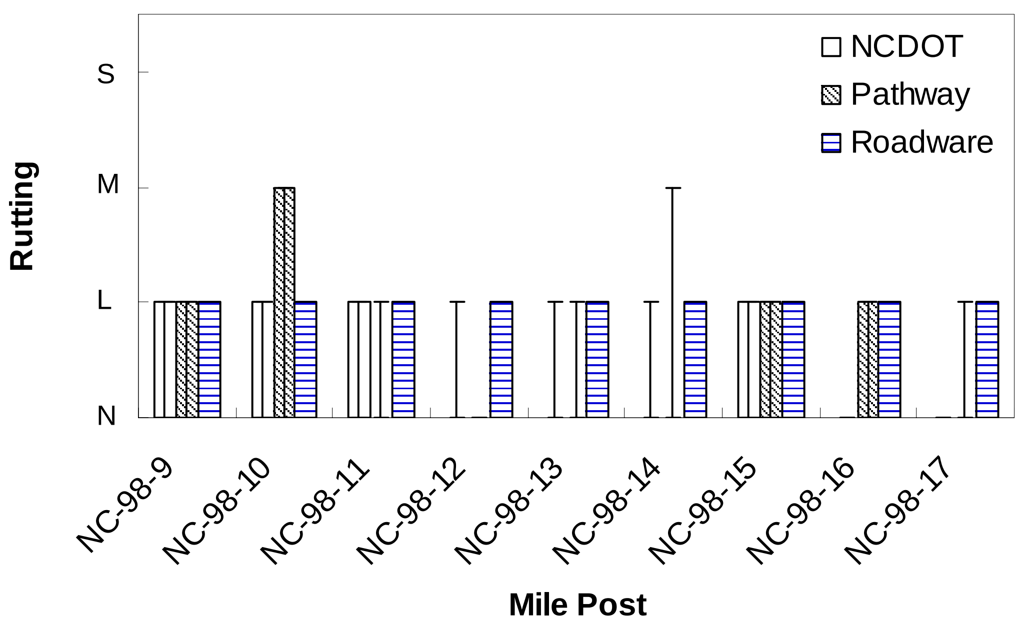


Figure 3.30. Rutting rating for NC-98 (2) sections.

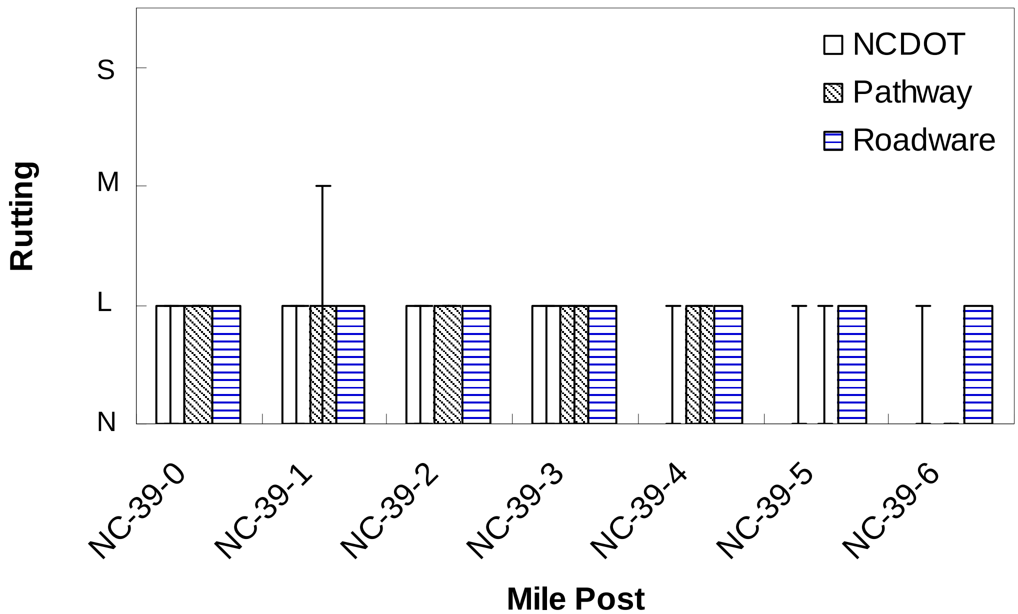


Figure 3.31. Rutting rating for NC-39 sections.

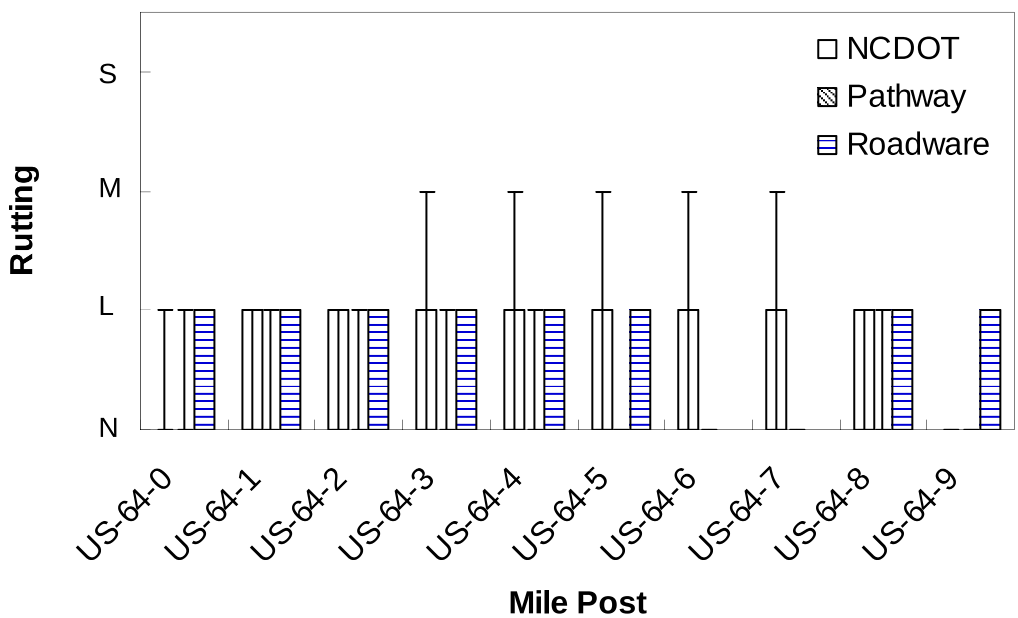


Figure 3.32. Rutting rating for US-64 sections.

3.4.3.3. Discussion

<u>Reference survey</u>

- Overall, when observed, the rutting along the test course was light in severity.
- Rutting does not appear to be a major distress for this test course.

- The most extensive rutting was observed along US-64 which showed moderate severity for all sections.
- No rutting was observed for the I-40, US-70, I-540, US-1, and NC-98-0 to NC-98-7.

Pathway Services

- Overall a small number of rutting was counted.
- The highest rutting was observed along the first five segments of NC-39 which all show light severity rutting. The section at NC-98-10 is the only one counted to show moderate rutting.
- No transverse cracking was counted for the I-40, Wade Avenue, I-440, US-70, I-540, US-1, NC-98-0 to NC-98-7, and US-64.

Fugro Roadware

- Overall rutting was rated as light along the test course.
- No section was counted as moderate or severe rutting.
- Rutting was counted in every subinterval.

Mandli Communications

- Of the surveyed sections, light rutting was counted only for I-540-4.

3.4.4. Ride Quality

3.4.4.1. Definition of Distress

Ride quality is what the general public perceives as the indicator of how well a road is holding up. Edge rutting, patching and localized dips significantly contribute to how the rater should look at ride quality. Ride quality is not to take into account rolling or mountainous terrain or curved alignment. These conditions would exist no matter if the pavement was smooth or rough.

Although this is a somewhat subjective distress, the NCDOT has attempted to develop quantitative ranking for this distress:

Light (Average): Pavement texture may cause minimum tire noise; isolated cases (up to 0.25 of the section) of bumps and dips; operating speed can be maintained safely.

Moderate (Slightly Rough): 0.25 to 0.50 of the section is uneven and bumpy with dips, rises, and ruts; pavement may be broken and cracked with a resulting increase in tire noise; slight difficulty in maintaining operating speed over section.

Severe (Rough): Greater than 0.50 of section is uneven and bumpy; rider is frequently jostled; rather large and frequent pavement failures and rough texture may be present causing a high increase in tire noise and jolts; operating speed cannot be maintained safely.

3.4.4.2. Data Processing and Results

Ride quality is a subjective measure as defined by the NCDOT, particularly considering that the survey data are taken from the shoulder. As a measurement all vendors have computed ride quality from the measured international roughness index (IRI) values. The criteria used differed by vendor and no reference survey IRI data were available. The values used by each vendor are summarized in Table 3.6. Note that Pathway only submitted IRI values for the two wheel paths. In accordance with NCDOT policy the highest (i.e., worst) IRI value was taken and used with the FHWA recommendations for IRI to ride quality conversion for interstate and national highway system pavements (FHWA 2000). As with the other distresses Fugro Roadware submitted their data in the same format as the NCDOT by mile increments and no additional processing was needed. Pathway's submitted data were in tenth mile increments and by IRI values. This required some additional averaging and application of the criteria shown in Table 3.6. The data submitted by Mandli required averaging only, since the data were already submitted in the appropriate light-moderate-severe format. The ride quality results are shown by severity and by sections in Figure 3.33 through Figure 3.40.

Table 3.6. Summary of Ride Quality to IRI Conversion Applied by Each Vendor

Vendor	IRI Range (in/mi)		
	Light	Moderate	Severe
NCDOT	No Accepted Method		
Fugro Roadware	< 150	150-300	> 300
Mandli	< 75	75-150	> 150
Pathway*	< 95	95-170	> 170

* taken from FHWA National Highway System recommendations

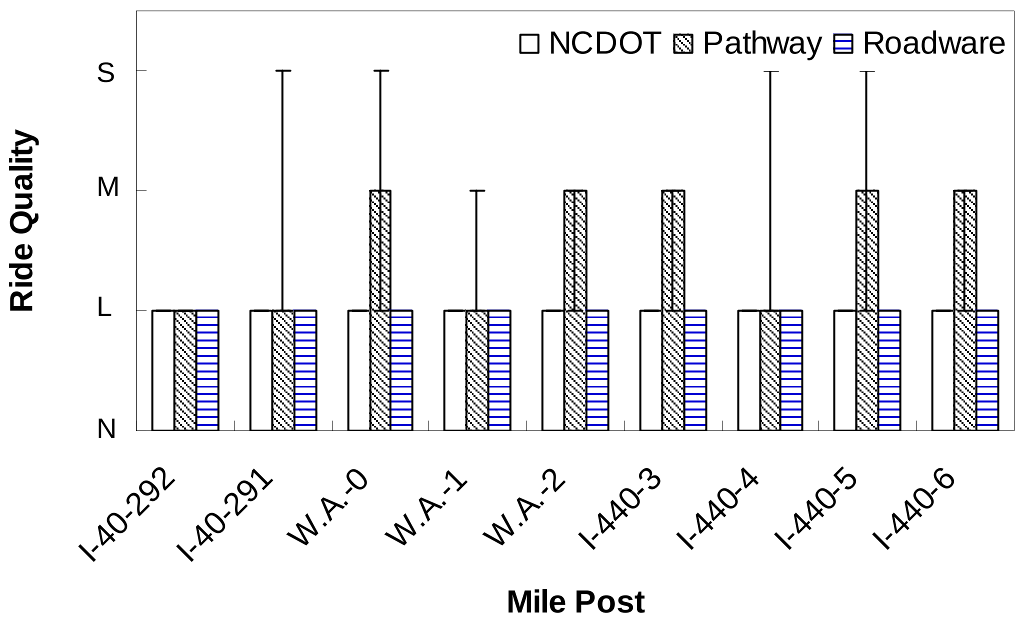


Figure 3.33. Ride quality rating for I-40, Wade Avenue, and I-440 sections.

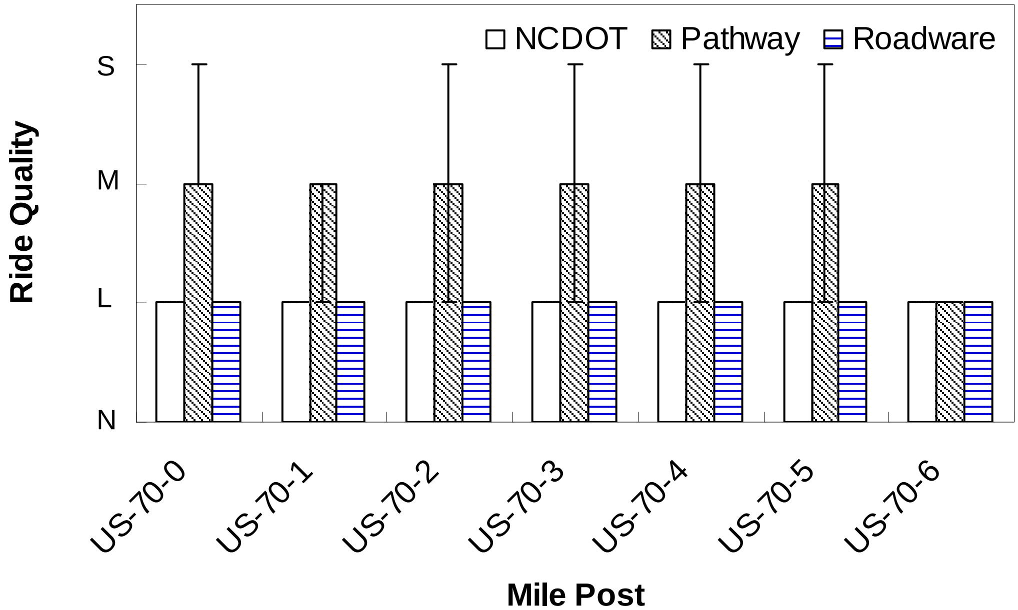


Figure 3.34. Ride quality rating for US-70 sections.

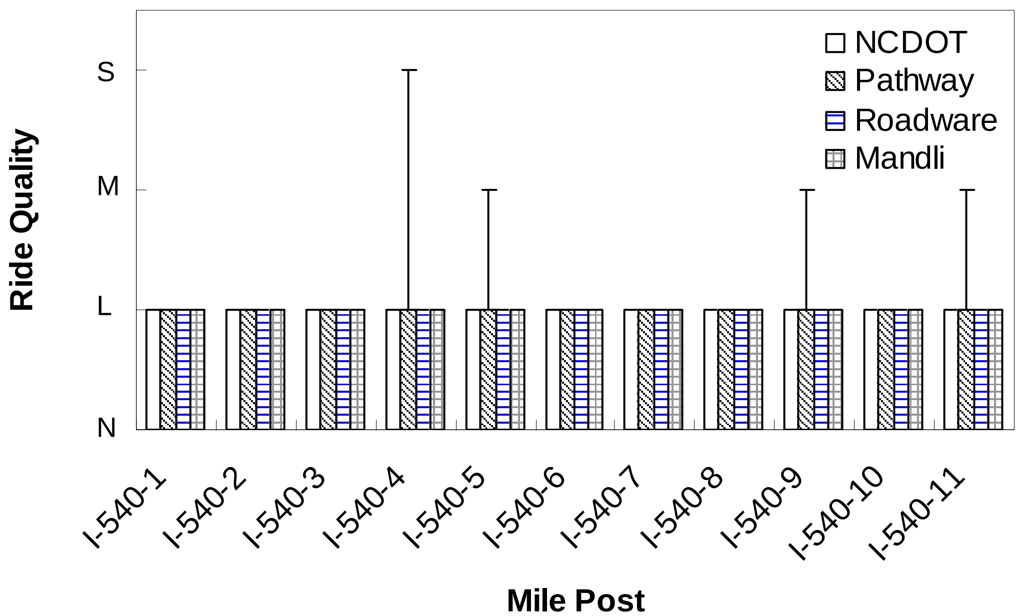


Figure 3.35. Ride quality rating for I-540 sections.

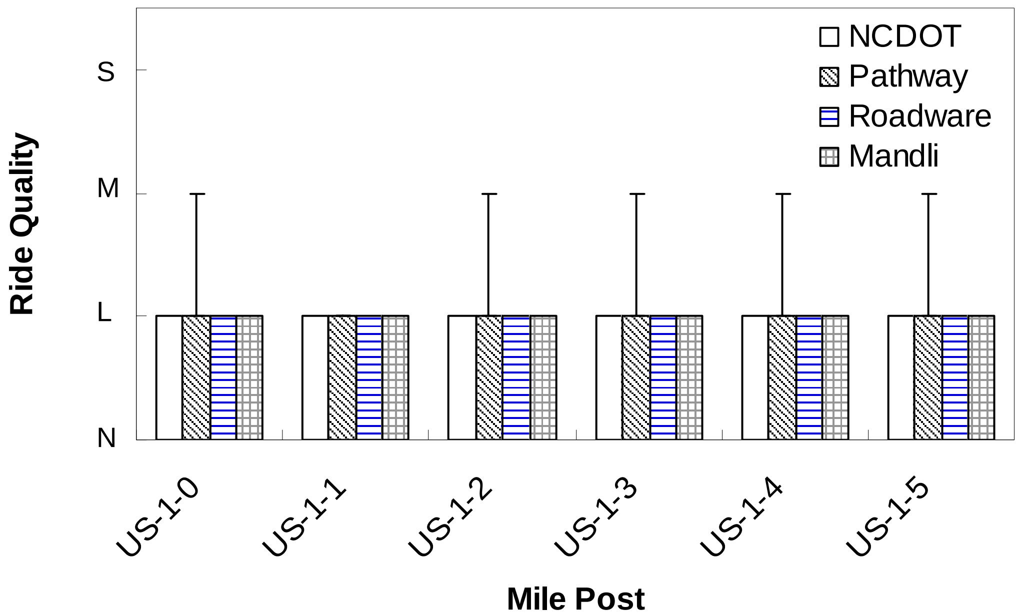


Figure 3.36. Ride quality rating for US-1 sections.

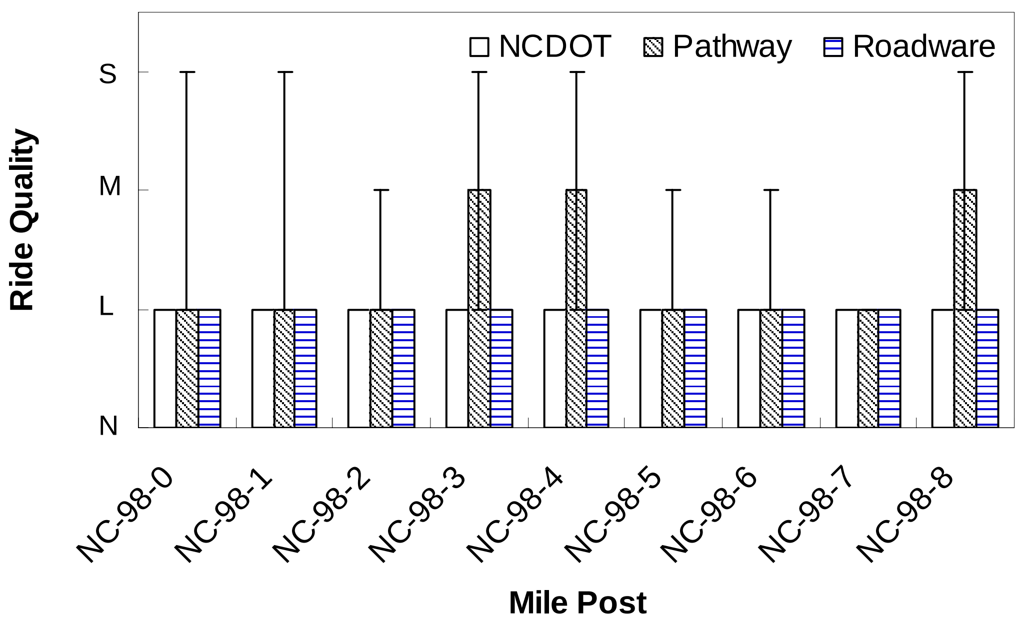


Figure 3.37. Ride quality rating for NC-98 (1) sections.

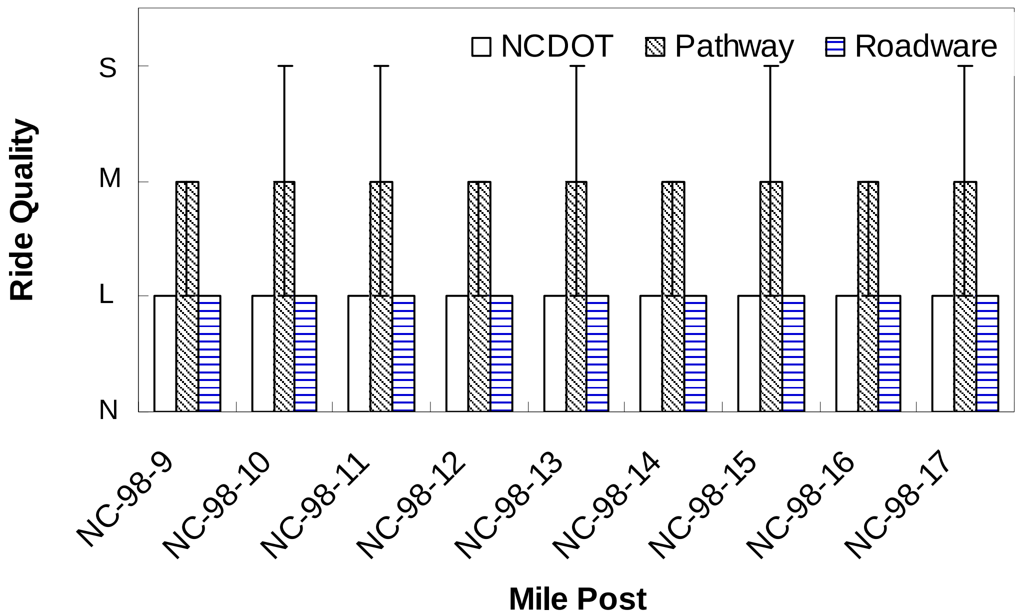


Figure 3.38. Ride quality rating for NC-98 (2) sections.

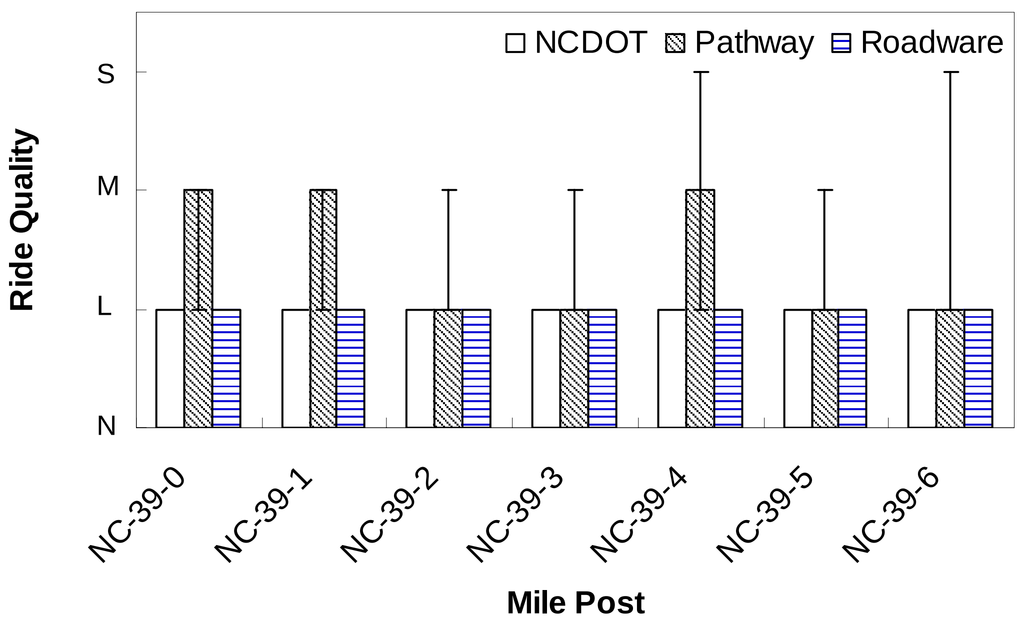


Figure 3.39. Ride quality rating for NC-39 sections.

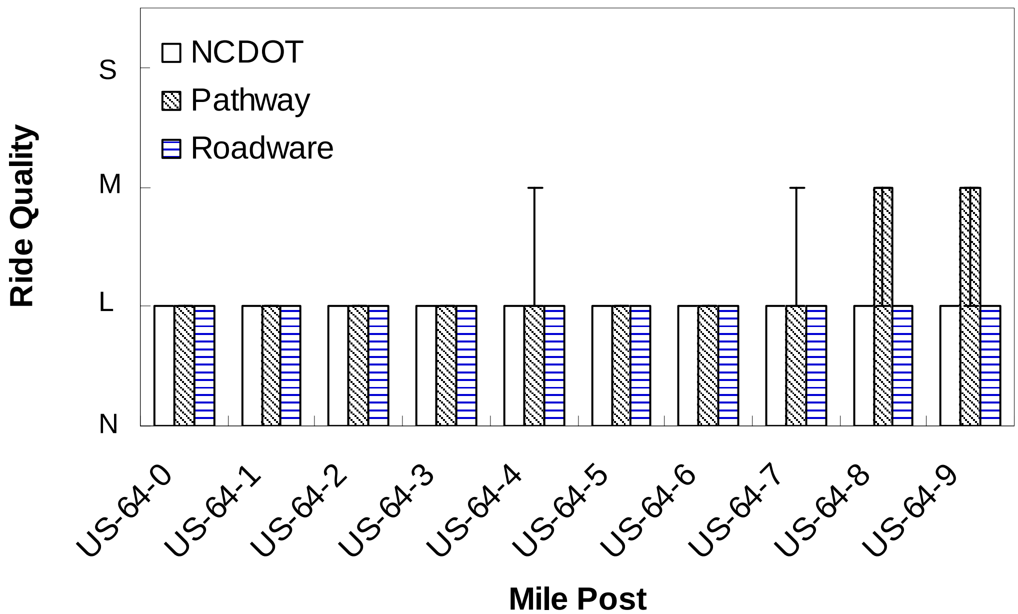


Figure 3.40. Ride quality rating for US-64 sections.

3.4.4.3. Discussion

Reference survey

- The ride quality rating for each section of the test course is light.

Pathway Services

- Overall the ride quality has been rated as either light or moderate with some extreme ratings of severe.
- Sections along I-40, I-540 and US-1 are universally light, sections along NC-98-8 to NC-98-17, US-70 (except US-70-6), are universally moderate.

Fugro Roadware

- The ride quality rating for each section of the test course is light.

Mandli Communications

- Of the surveyed sections, the ride quality for each section is rated as light.

3.4.5. Other Quantities

3.4.5.1. Definition of Distresses

Other quantities of interest in the NCDOT include raveling (only on slurry sealed and bituminous surface treatment pavements), oxidation (only on plant mixed pavements), bleeding and patching.

Raveling is the wearing away of the pavement surface caused by the dislodging of aggregate particles or loss of asphalt binder. Raveling is more common on AST or slurry surfaces than on plant mix surfaces, therefore, indicate raveling only on BST or Slurry surfaces. Raveling indicates either a hardening or poor application of asphalt binder.

Like rutting and transverse cracking, raveling is assigned a single value, None, Light, Moderate or Severe, to represent raveling over the entire section. The criteria used to determine this ranking is as follows:

Light: 0.50 or more of the section shows Light distress, OR A combination of distress conditions is present on 0.33 or more of the section with some Moderate distress.
Moderate: 0.50 or more of the section shows Moderate distress OR A combination of distress conditions is present on 0.33 or more of the section with some Severe distress.
Severe: 0.33 or more of the section shows Severe distress.

The definitions applied to the raveling distress are:
Light: Aggregate loss is not great; small amounts of stripping may be detected; aggregate has started to wear away.
Moderate: Some stripping evident; random stripping with small areas (less than one square foot) or strips of aggregate broken away.
Severe: Stripping very evident; aggregate accumulations may be a problem; large sections (greater than one square foot) of stripping with aggregate layer broken away.

Oxidation (weathering) is the hardening and aging of the asphalt binder. The surface binder has worn away to expose coarse aggregate. This condition will normally be found on plant mix pavement, therefore, indicate oxidation on Plant Mix surfaces only. Weathering usually covers the entire surface.

For the NCDOT survey a single value is assigned to represent oxidation for the entire test section. For this distress only two potential ratings are given, none and severe. The definitions applied to this distress are as follows:
None: Oxidation is not present on the section.
Severe: Oxidation is present on the section.

Bleeding is a film of bituminous material on the pavement surface that creates a shiny, reflective surface. Bleeding is caused by excess asphalt cement in the mix and/or low air void content. During hot weather the asphalt fills the voids of the mix and then expands out onto the surface of the pavement. The process is not reversible during cold weather, thus asphalt binder will accumulate on the surface.

No attempt has been made to define various levels of severity. Bleeding should be recognized when it is extensive enough to create a uniform coating in the wheel path(s).

For this distress the NCDOT ranks the pavement into one of four categories; none, light, moderate or severe depending on the extent of the bleeding:
Light: Condition is present on 10 to 25 percent of the section.
Moderate: Condition is present on 26 to 50 percent of the section.
Severe: Condition is present on greater than 50 percent of the section.

Patching is defined as any surface area of the existing pavement that indicates some type of maintenance repair has taken place. These patched areas may be Plant Mix or BST skin patches, edges, overlays or full depth patches. They may be in spot locations, along one or both edges, in the wheelpaths, across the entire surface for short distances, or a combination of any of these. In-kind treatments, such as plant mix edges on an existing plant mix surface, shall be considered as patches. Bridge approach tie-ins, intersection tie-ins, realignments, new signals or section widening and crack pouring shall not be considered as a type of patching to be measured. The quality and condition of the patch is not to be considered in evaluating patching. It does not matter if all the patches are alligator cracked, rutted or potholed. These conditions are measured in the other distresses. Patching is an indication of the amount of surface area that has received some type of maintenance repair that may or may not be holding up. The amount of patching shall be measured as a percentage of the total surface area. Be aware that a section must have at least 6 percent of the surface area to be marked as light. Do not assume that because there is some patching a light condition exists.

The NCDOT procedure ranking patching based on its extent as shown below:

Light: Condition is present on 6 to 15 percent of the section.
Moderate: Condition is present on 16 to 30 percent of the section.
Severe: Condition is present on more than 30 percent of the section.

3.4.5.2. Data Processing and Results

The distresses of raveling, oxidation, bleeding, and patching are combined here since these distresses were almost universally rated with *None* by the NCDOT. Raveling received a *None* rating from the NCDOT because there were no BST or slurry seals along the test course. Pathway did report some slight raveling along certain segments, but not to a high enough severity to register with the NCDOT criteria. Neither Mandli nor Roadware reported any raveling. For oxidation Mandli and Roadware reported a consistent *None* rating for the entire course; Pathway did not report any observation on oxidation; and the NCDOT consensus was that none of the sections showed oxidation. Neither the vendors nor NCDOT reported any bleeding along the surveyed path. Although some individual surveyors did report patching along the test path the consensus reference survey was that patching did not exist. Neither Mandli nor Fugro Roadware reported any patching. Pathway services reported some light patching at NC-98 mile marker 14.

3.4.6. Pavement Condition Rating

3.4.6.1. Definition of Pavement Condition Rating

For the NCDOT pavement management system the aforementioned distresses are combined into a single index function, the pavement condition rating (PCR). This index is defined in Equations (3.2) - (3.9).

$$PCR = 100 - A - T - Ru - Ra - B - P - O \tag{3.2}$$

Where;

A = alligator cracking deduct index, Equation (3.3),
T = transverse cracking deduct index, Equation (3.4),
Ru = rutting deduct index, Equation (3.5),
Ra = raveling deduct index, Equation (3.6),
B = bleeding deduct index, Equation (3.7),
P = patching deduct index, Equation (3.8), and
O = oxidation deduct index, Equation (3.9).

$$A = \begin{cases} 3.3 & \text{for distress } = L - \text{ 10\% to 90\%} \quad 1 \quad \text{for distress } = L - > 90\% \\ 7.5 & \text{for distress } = \text{M} - \text{ 10\% to 40\%} \quad 2 \quad \text{for distress } = \text{M} - > 40\% \\ 15 & \text{for distress } = \text{S} - \text{ 10\% to 20\%} \quad 3 \quad \text{for distress } = \text{S} - > 20\% \end{cases} \tag{3.3}$$

For the alligator distress a maximum of 30 points are deducted using the larger deduct points (3.3, 7.5 and 15). Once the 30 point threshold is reached the smaller deduct values are applied to the remaining fatigue cracking percentages.

$$T = \begin{cases} 5 & \text{for distress } = L \\ 15 & \text{for distress } = \text{M} \\ 30 & \text{for distress } = \text{S} \end{cases} \tag{3.4}$$

$$Ru = \begin{cases} 5 & \text{for distress } = L \\ 20 & \text{for distress } = \text{M} \\ 30 & \text{for distress } = \text{S} \end{cases} \tag{3.5}$$

$$Ra = \begin{cases} 2 & \text{for distress } = L \\ 5 & \text{for distress } = \text{M} \\ 15 & \text{for distress } = \text{S} \end{cases} \tag{3.6}$$

$$B = \begin{cases} 10 & \text{for distress } = L \\ 20 & \text{for distress } = \text{M} \\ 30 & \text{for distress } = \text{S} \end{cases} \tag{3.7}$$

$$P = \begin{cases} 5 & \text{for distress } = L \\ 10 & \text{for distress } = \text{M} \\ 20 & \text{for distress } = \text{S} \end{cases} \tag{3.8}$$

$$P = \begin{cases} 0 & \text{for distress } = \text{N} \\ 5 & \text{for distress } = \text{S} \end{cases} \tag{3.9}$$

3.4.6.2. Data Processing and Results

With every distress processed as mentioned above, Equations (3.2) - (3.9) were applied to each to determine the PCR values. The PCR results are shown by sections in Figure 3.41 through Figure 3.48. The error bars for the NCDOT series' represents the highest and lowest PCR values computed from the individual surveyor results. The error bars shown with Mandli and Pathway series represent the most and least distressed tenth mile increment within the given one mile segment. Since the Fugro Roadware group did not submit the tenth of a mile data, similar extreme bars are not shown. An overall line of equality summary showing the representative values for each section is given in Figure 3.49.

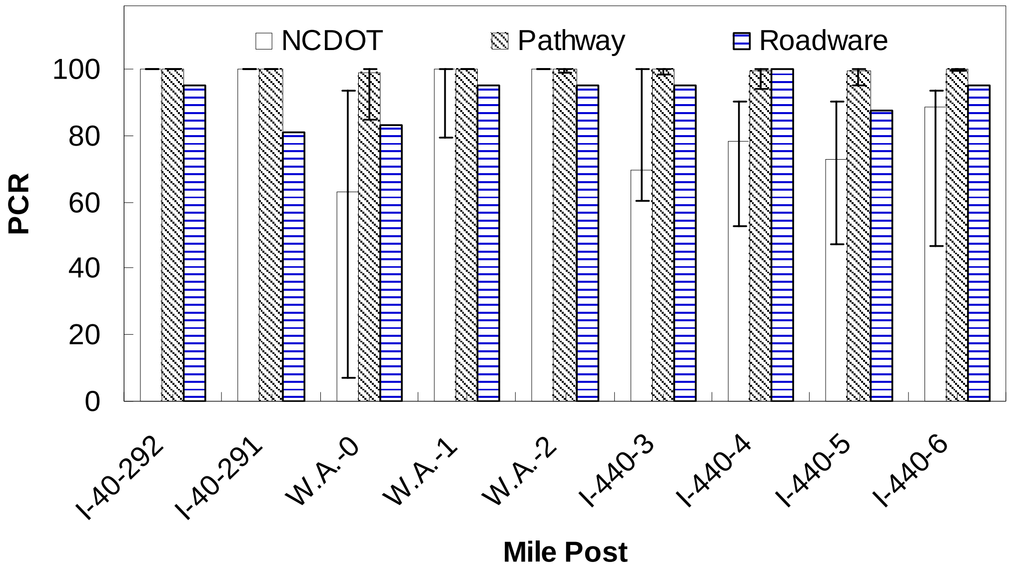


Figure 3.41. AC-PCR for I-40, Wade Avenue, and I-440 sections.

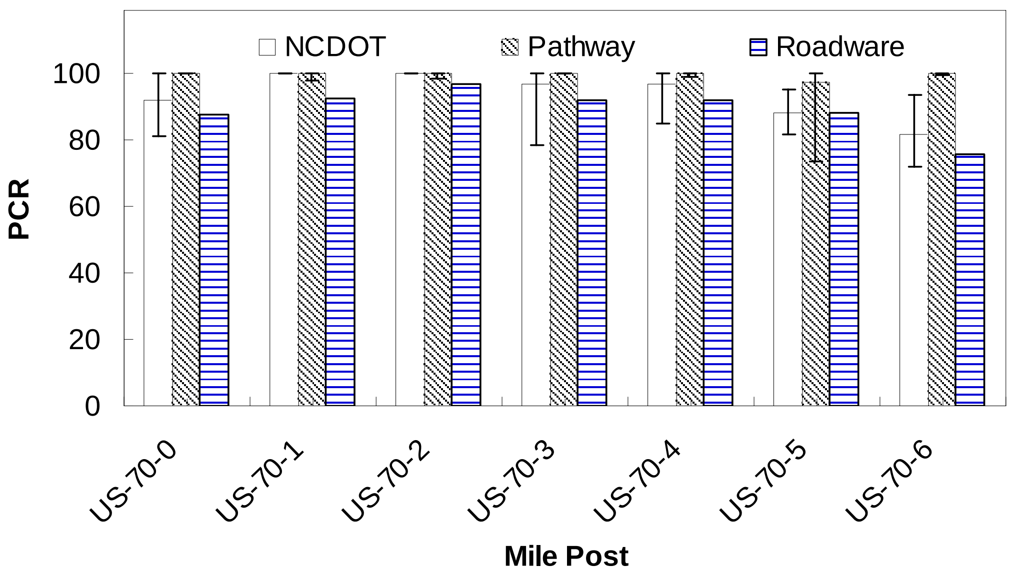


Figure 3.42. AC-PCR for US-70 sections.

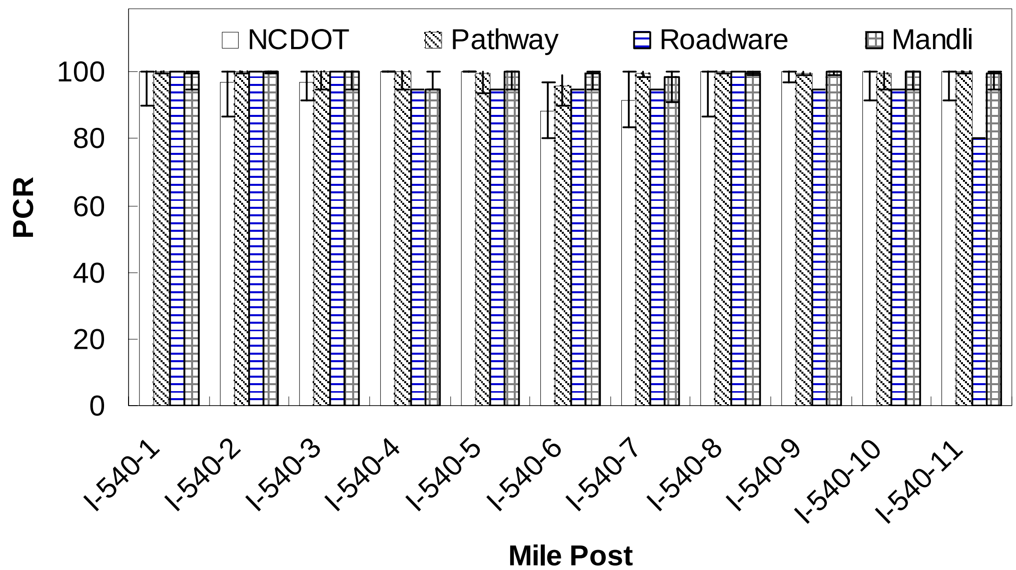


Figure 3.43. AC-PCR for I-540 sections.

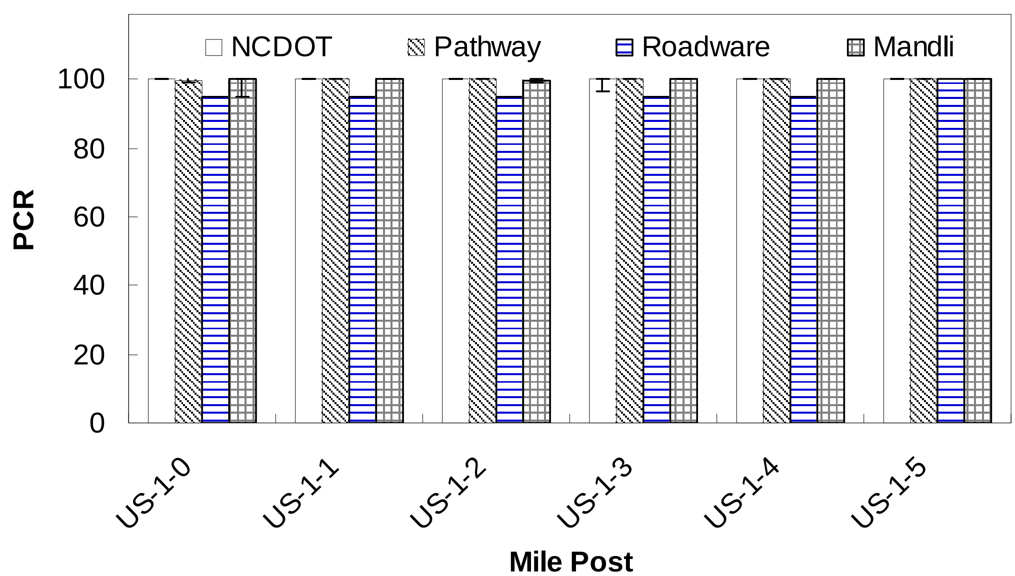


Figure 3.44. AC-PCR for US-1 sections.

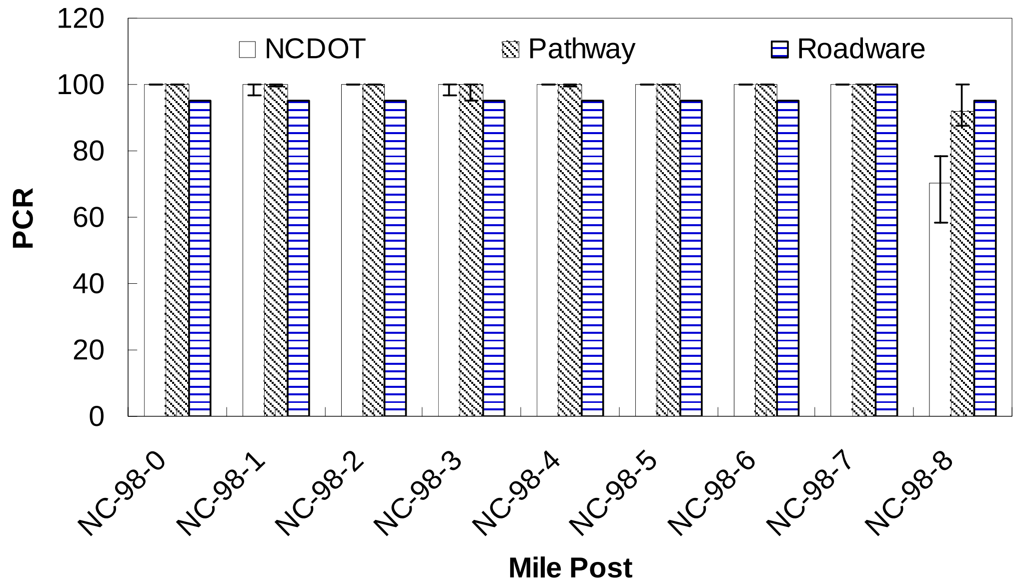


Figure 3.45. AC-PCR for NC-98 (1) sections.

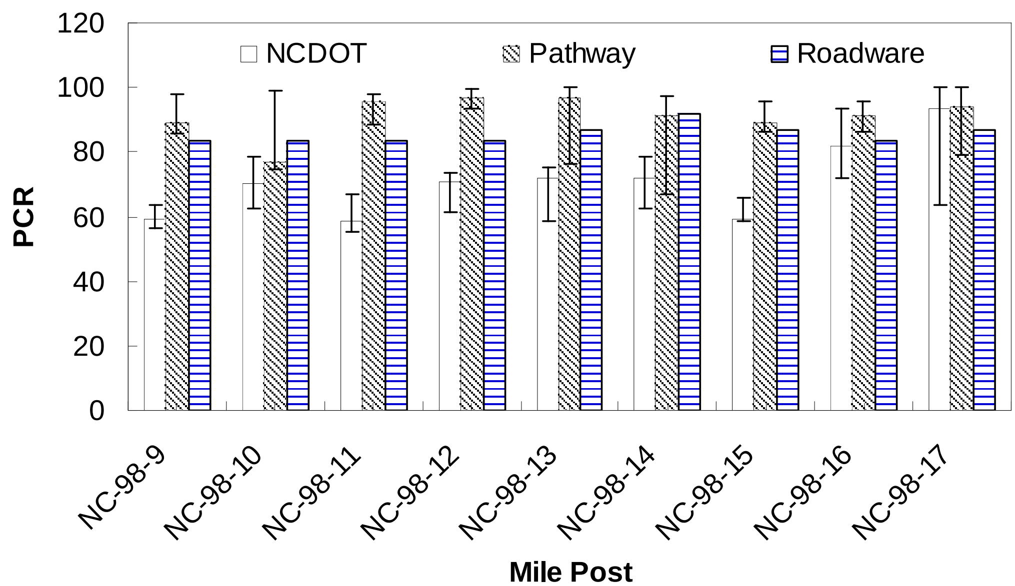


Figure 3.46. AC-PCR for NC-98 (2) sections.

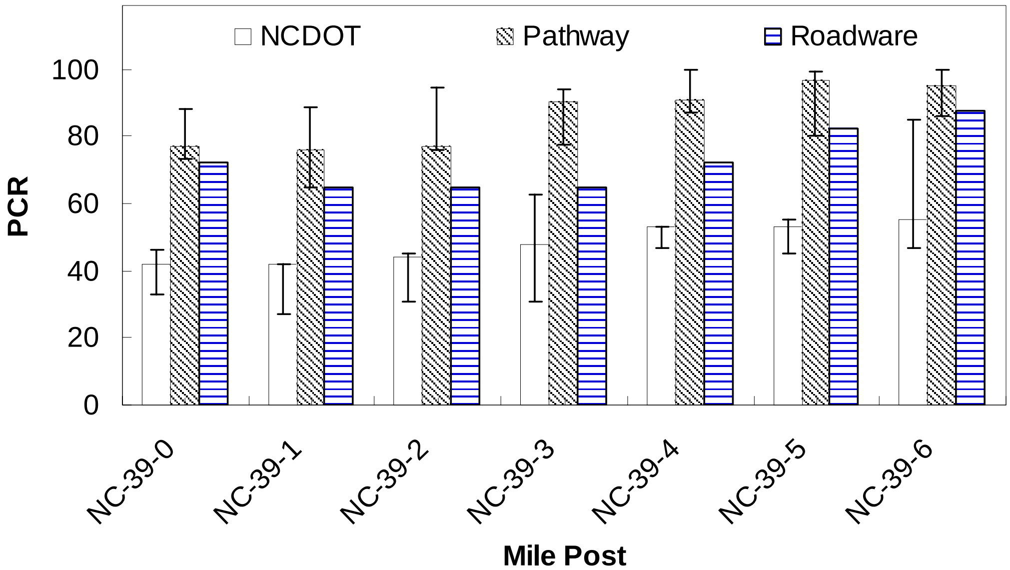


Figure 3.47. AC-PCR for NC-39 sections.

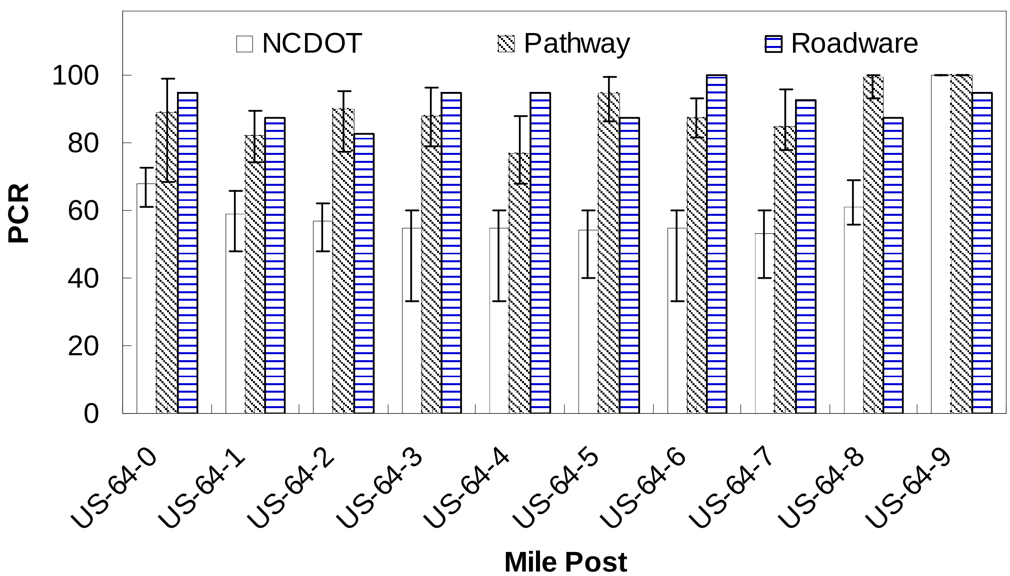


Figure 3.48. AC-PCR for US-64 sections.

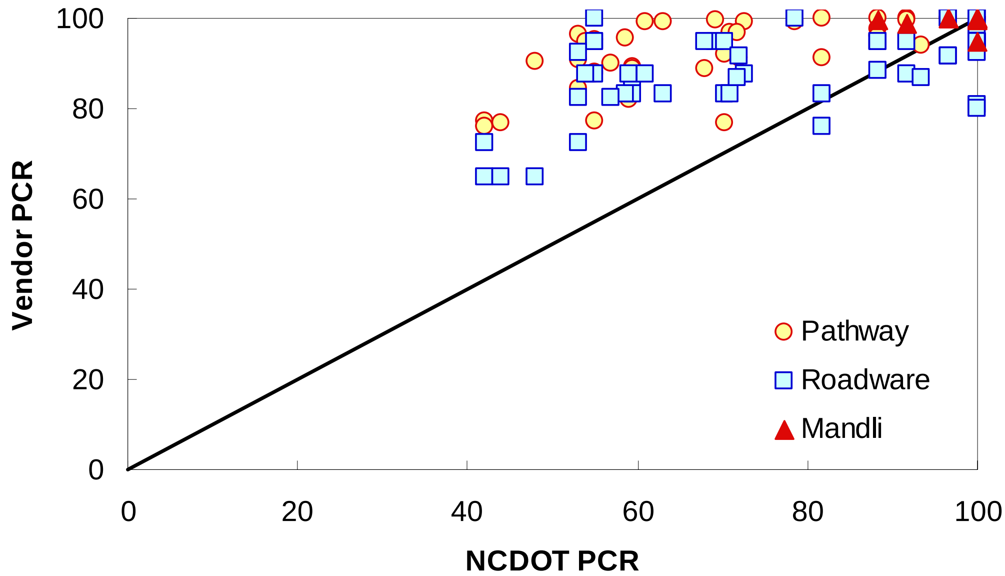


Figure 3.49. AC-PCR summary comparison for all sections.

3.4.6.3. Discussion

Reference survey

- Overall the sections along I-40, US-70, I-540, US-1, and NC-98-0 to NC-98-7 show high PCR values (greater than 80)
- Sections at Wade Avenue are also overall highly rated except the first section, sections along I-440 show moderate PCR values (60-80).
- In general, the sections along NC-98-8 to NC-98-17, NC-39 and US-64 show relatively low PCR values (below 60).
- The lowest PCR value is 42.0 which occurs at NC-39-0 and NC-39-1.

Pathway Services

- Overall the PCR values for the test course are high.
- Sections at I-40, Wade Avenue, I-440, US-70, I-540, US-1, and NC-98-0 to NC-98-7 all have PCR values greater than 95.
- Other sections have slightly lower PCR values.
- The lowest PCR rating is given at NC-39-1 where the rating is 76.0.

Fugro Roadware

- Overall the PCR values for the test course are high.
- Sections at I-40, Wade Avenue, I-440, US-70 (except US-70-6), I-540, US-1, NC-98 and US-64 all have PCR values greater than 80 with many greater than 90.
- The lowest PCR rating is given at NC-39-1, NC-39-2, and NC-39-3 where the rating is 65.0.

Mandli Communications

- Of the surveyed sections, the PCR is never less than 95.0.

3.4.7. NCDOT Asphalt Concrete Survey Summary

The following are the key observations made from the NCDOT asphalt concrete survey:

- Vendor predicted and reference survey measured fatigue cracking agrees well on sections with little fatigue cracking (I-40, US-70, I-540, US-1 and NC-98-0 to NC-98-7.
- Vendor data on sections with high concentration of fatigue cracking do not match the reference survey data well; specifically the vendor data tend to underestimate the reference survey fatigue cracking.
- The relative fatigue cracking trends observed with the reference survey data are not captured by the vendor data.
- The reference survey measured and vendor submitted transverse cracking severities do not match well on subintervals with sporadic and inconsistent cracking.
- Vendor and NCDOT surveys match well on subintervals that show consistent sectional transverse cracking.
- Overall Fugro Roadware shows a higher occurrence of light rutting relative to the reference survey survey.
- For the AC survey, IRI can be used to match the NCDOT ride quality definition of the relationship is properly calibrated.
- The ability of vendors to rate raveling, oxidation, bleeding or patching could not be completely assessed since slight and sporadic concentrations of these distresses were observed along the test course.
- Overall the AC-PCR computed from the vendor data was greater than that computed from the NCDOT reference survey survey.

3.5. NCDOT Portland Cement Concrete Survey

3.5.1. Patching

3.5.1.1. Definition of Distress

For the purposes of the NCDOT survey, a patch is defined as an area where a portion or all of the original concrete slab that has been removed and replaced with additional material after original construction. This additional material may be either AC or PCC and the survey process records the number of both types of patching materials within the test section.

3.5.1.2. Data Processing and Results

To fairly compare the NCDOT measured distress and the total mile based survey (i.e., the Fugro Roadware and one mile Pathway surveys) the total counted patches for the one mile were divided by five to give an average 0.2 mile increment patch number. Pathway did not distinguish between the concrete and asphalt patches. The total number of patches, both AC and PCC, are shown in Figure 3.50 through Figure 3.53. For consistent comparisons results are presented based on the number of patches per 0.2 mile increment. This means dividing the total number of patches counted for each mile increment of the Roadware and Pathway one mile based surveys by five.

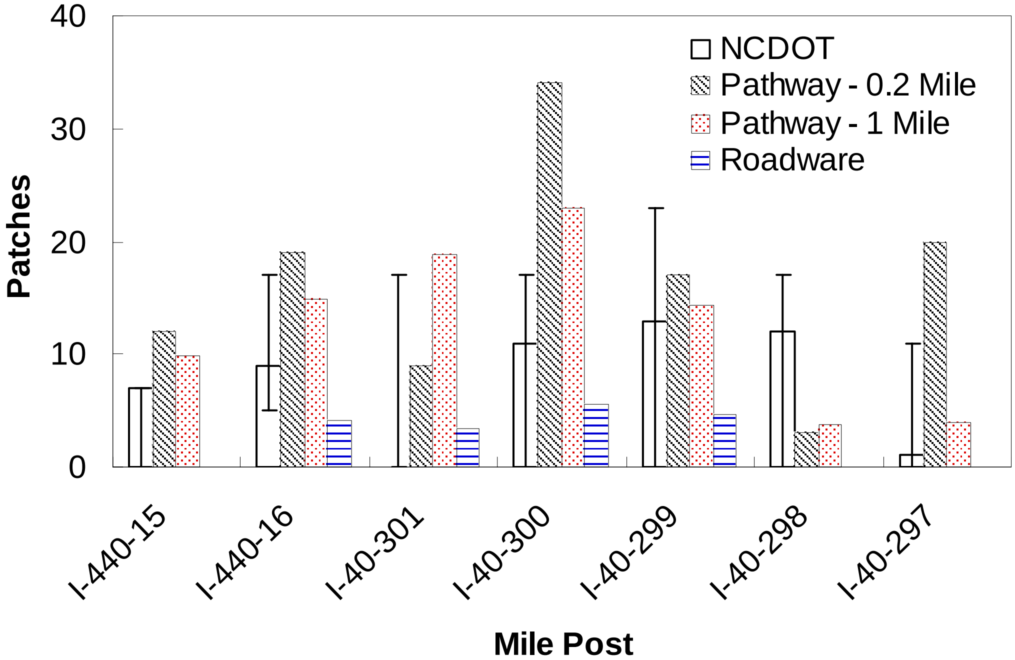


Figure 3.50. Patching for I-440/I-40 (1) sections.

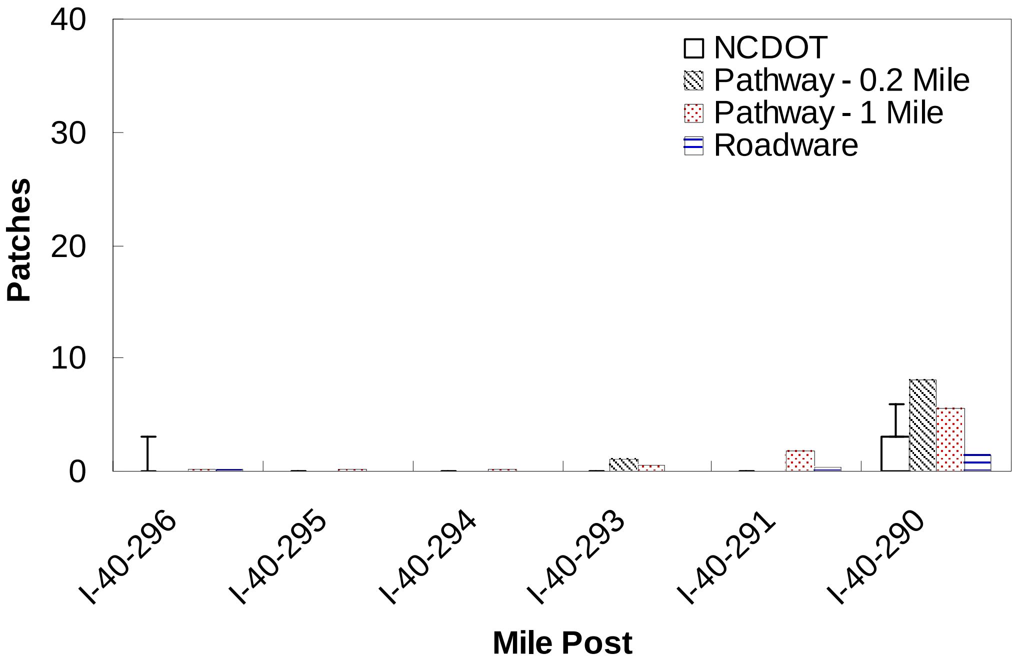


Figure 3.51. Patching for I-440/I-40 (2) sections.

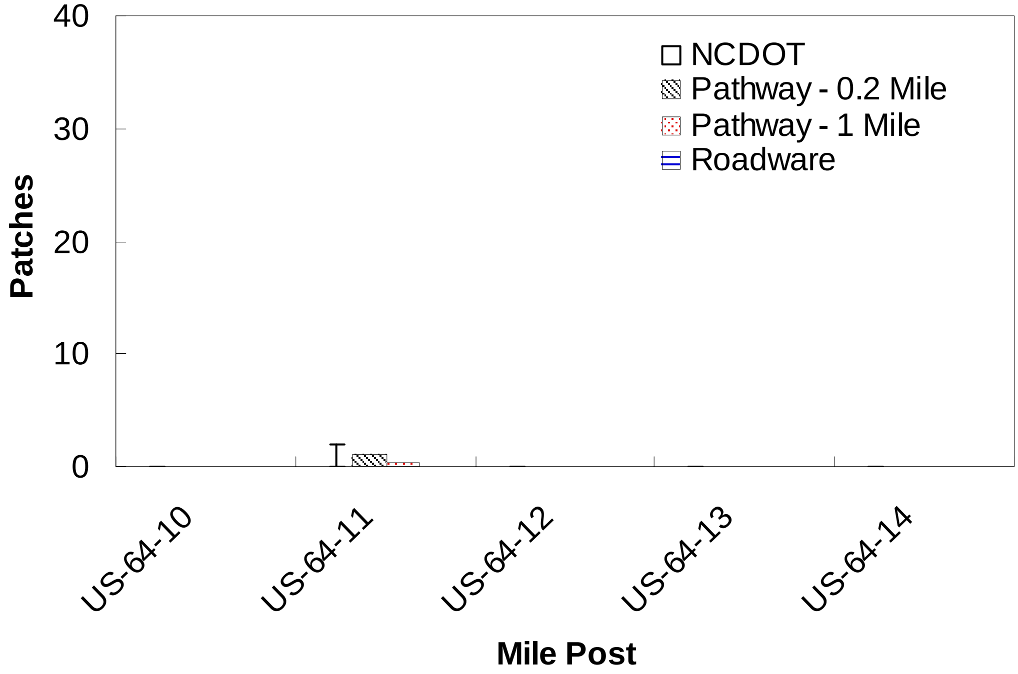


Figure 3.52. Patching for US-64 (1) sections.

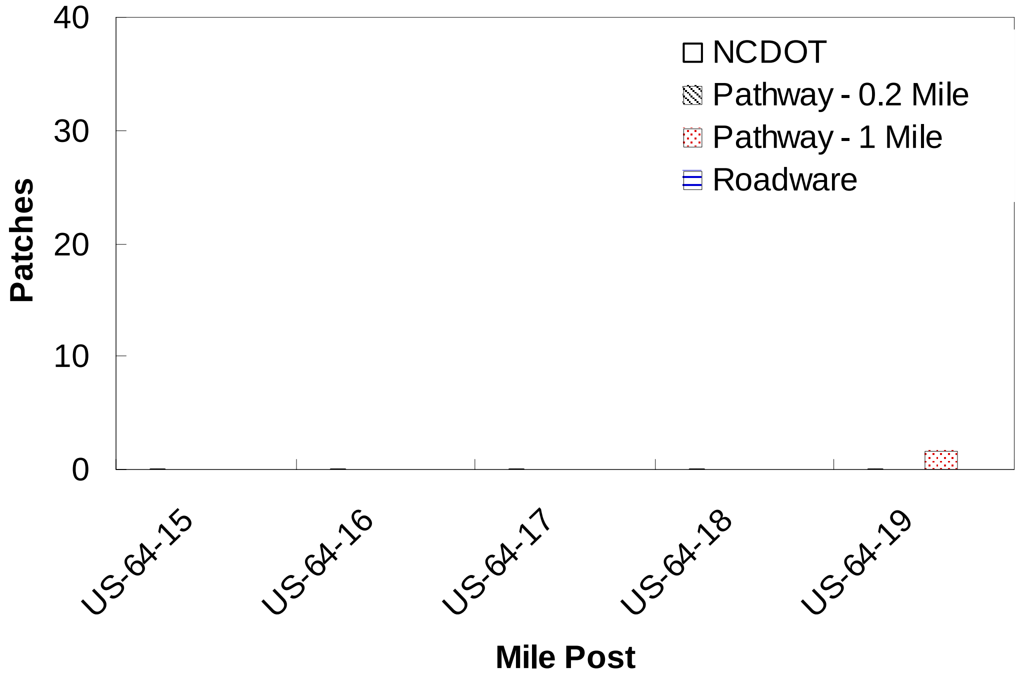


Figure 3.53. Patching for US-64 (2) sections.

3.5.1.3. Discussion

Reference survey

- Sections along I-440 and I-40 show some patching and on sections that do show patching the approximate average number is 10 patches.
- The highest concentration of patches occurs at I-40-299 with 13.
- No consensus patching is observed along US-64 although a single surveyor notes 2 patches at US-64-11.
- Most patching is asphalt based and not PCC based.
- Sections at Wade Avenue are also overall highly rated except the first section, sections

Pathway Services

- Sections along I-440 and I-40 show some patching. On sections that do show patching the approximate average number is 10-15 patches.
- The highest concentration of patches occurs at I-40-300 with 34.
- One patch is counted in the first 0.2 miles of US-64-11. Patching is also counted in the final 0.8 mile of the US-64-19.
- No differentiation is made between asphalt and concrete patches.

Fugro Roadware

- Sections along I-440 and I-40 show some patching. On sections that do show patching the approximate average number is 5 patches per 0.2 mile portion.
- The highest concentration of patches occurs at I-40-300 with 5.6.
- No patches are counted for the US-64 sections
- Patches are differentiated by the patching material, asphalt and concrete.

3.5.2. Pumping

3.5.2.1. Definition of Distress

For the NCDOT distress survey pumping is defined by the seeping or ejection of water from beneath the pavement through cracks or joints. Fine material may be present near joints or cracks staining the surface and there may also be depressions. The survey counts the number of pumped joints or pumping areas.

3.5.2.2. Data Processing and Results

Pathway's submitted data were in tenth mile increments and by a percentage instead of as a counted number of pumped areas. However, the Pathway data also showed that there was no pumping on any of the PCC sections. Since Fugro Roadware submitted their data in the same format as the NCDOT, with the exception that Fugro Roadware summarized the data in mile increments instead of the 0.2 mile increments measured by the NCDOT, no additional processing was needed. Overall there was very little pumping observed and reported for the PCC sections along the test course.

3.5.2.3. Discussion

Reference survey

- No pumping along the test course was reported.

Pathway Services

- No pumping of any kind was counted along the test course.

Fugro Roadware

- Slight pumping is counted at I-440-15 (13), I-40-299 (6) and I-40-295 (1).
- The location of the reported pumping along the surveyed mile is not reported so it cannot be determined if the NCDOT actually surveyed the pumped areas, i.e., they may occur in the final 0.8 miles of these sections.

3.5.3. Surface Wear

3.5.3.1. Definition of Distress

Surface wear is defined by a wearing away of the surface mortar and texture to expose coarse aggregates (polished). In addition small pieces of the pavement may have broken loose from the surface (popouts). This distress is rated as a percent area within four categories; none, light, moderate and severe which are defined below:

Light: Texture worn away with less than 25% of aggregate visible. Small popouts may be visible.

Moderate: Texture worn away showing 25% to 50% of aggregate. Small extensive popouts may be present.

Severe: Texture worn away showing more than 50% of aggregate. Large extensive popouts may be present.

3.5.3.2. Data Processing and Results

Pathway's submitted data were in tenth mile increments and was not separated by severity. However, the Pathway data showed that there was no surface wear on any of the PCC sections. Fugro Roadware submitted their data in the same format as the NCDOT with the exception that Fugro Roadware summarized the data in mile increments instead of the 0.2 mile increments measured by the NCDOT.

The surface wear results are shown in Figure 3.54 through Figure 3.57. Since most sections were dominated by a single severity level the individual percentages are not shown in these figures. Instead the qualitative ranking is shown. For sections which were rated approximately equally with two severity levels, the data are shown between the two nearest qualitative levels. For example, if a section were 50% light severity and 50% moderate severity then the bar for that section would be between the *L* and *M* levels in Figure 3.54 through Figure 3.57.

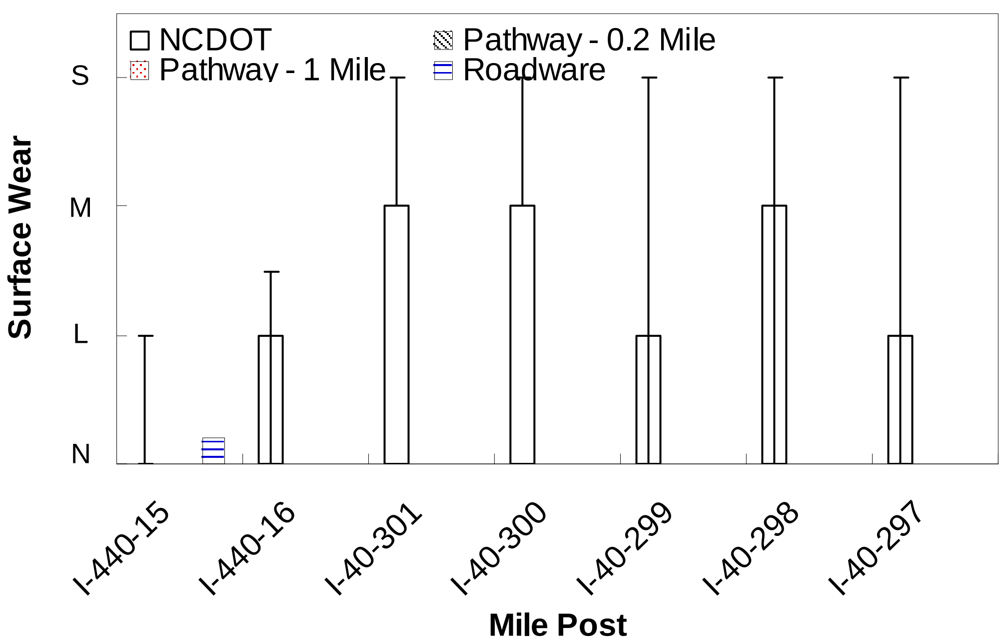


Figure 3.54. Surface wear for I-440/I-40 (1) sections.

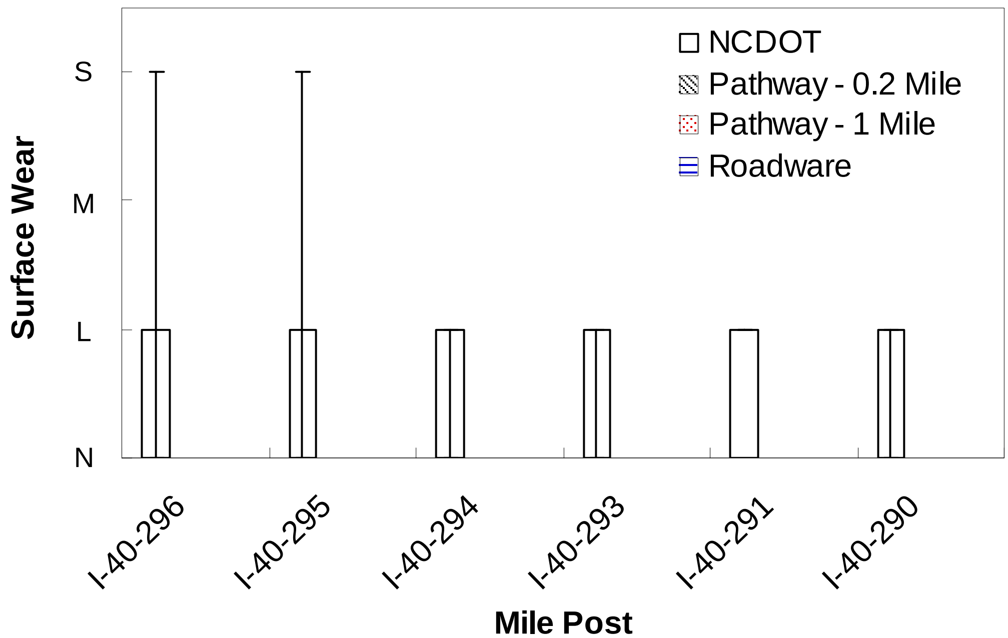


Figure 3.55. Surface wear for I-440/I-40 (2) sections.

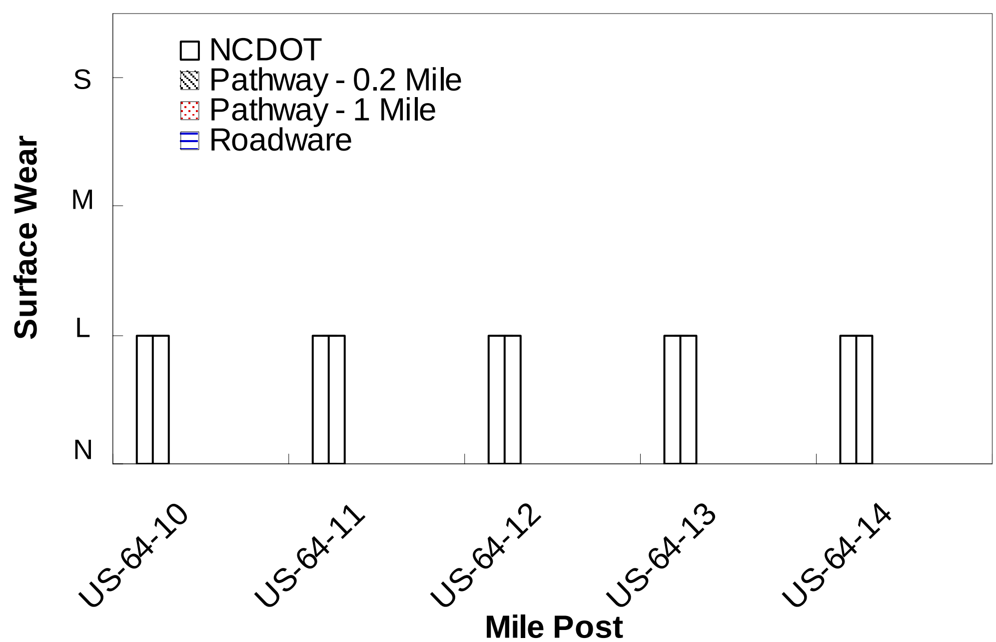


Figure 3.56. Surface wear for US-64 (1) sections.

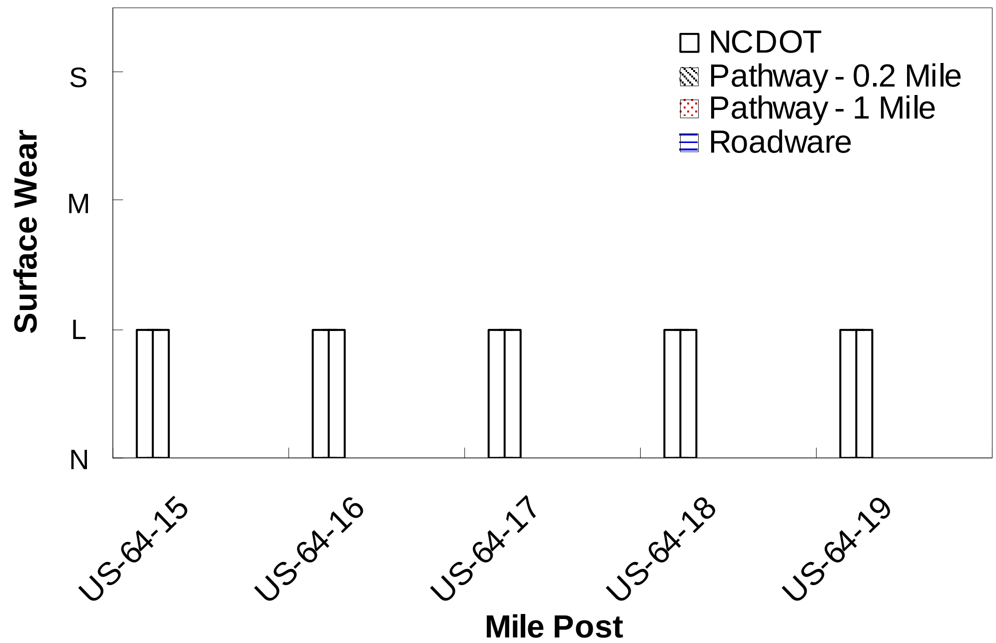


Figure 3.57. Surface wear for US-64 (2) sections.

3.5.3.3. Discussion

Reference survey

- All sections show either light or moderate surface wear.
- Sections with moderate surface wear lie along I-40 only.

Pathway Services

- Reports no surface wear for every section along the test course.

Fugro Roadware

- Reports no surface wear for every section along the test course except I-440-15 where a very slight amount of surface wear is reported.

3.5.4. Ride Quality

3.5.4.1. Definition of Distress

Ride quality is what the general public perceives as an indicator of how well a road is performing. The average operating speed is the speed at which most drivers would travel a section of road. This distress is rated as a percent area within three categories; light, moderate and severe which are defined below:

Light: Operating speed easy to maintain. A few bumps and dips (up to 25% of section). Joints are fairly smooth.

Moderate: Slightly difficult to maintain safe operating speed. Some joints appear to be faulted. Joints or cracks cause bumps and unevenness.

Severe: Difficult to maintain safe operating speed. Most joints severely faulted. Cracks cause unevenness and surface may be broken, cracked or worn away.

3.5.4.2. Data Processing and Results
Ride quality is a subjective measure as defined by the NCDOT, particularly considering that the survey data are taken from the shoulder. As a measurement all vendors have computed ride quality from the measured international roughness index (IRI) values. The criteria used differed by vendor and no reference survey IRI data were available. The values used by each vendor are summarized in Table 3.6. Note that Pathway only submitted IRI values for the two wheel paths. In accordance with NCDOT policy the highest (i.e., worst) IRI value was taken and used with the FHWA recommendations for IRI to ride quality conversion for interstate and national highway system pavements (Federal Highway Administration 2000). As with the other distresses Fugro Roadware submitted their data in the same format as the NCDOT by mile increments and no additional processing was needed. Pathway's submitted data were in tenth mile increments and by IRI values. This required some additional averaging and application of the criteria shown in Table 3.6.

The ride quality results are shown in Figure 3.58 through Figure 3.61. Since most sections were dominated by a single severity level the individual percentages are not shown in these figures. Instead the qualitative ranking is shown. For sections which were rated approximately equally with two severity levels, the data are shown between the two nearest qualitative levels. For example, if a section were 50% light severity and 50% moderate severity then the bar for that section would be between the *L* and *M* levels in Figure 3.58 through Figure 3.61.

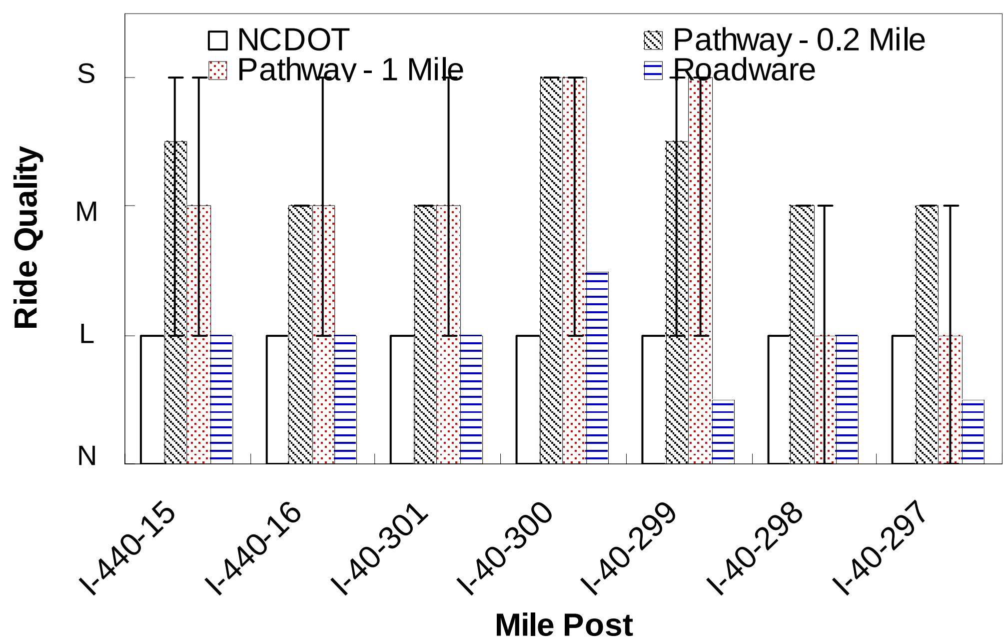


Figure 3.58. Ride Quality for I-440/I-40 (1) sections.

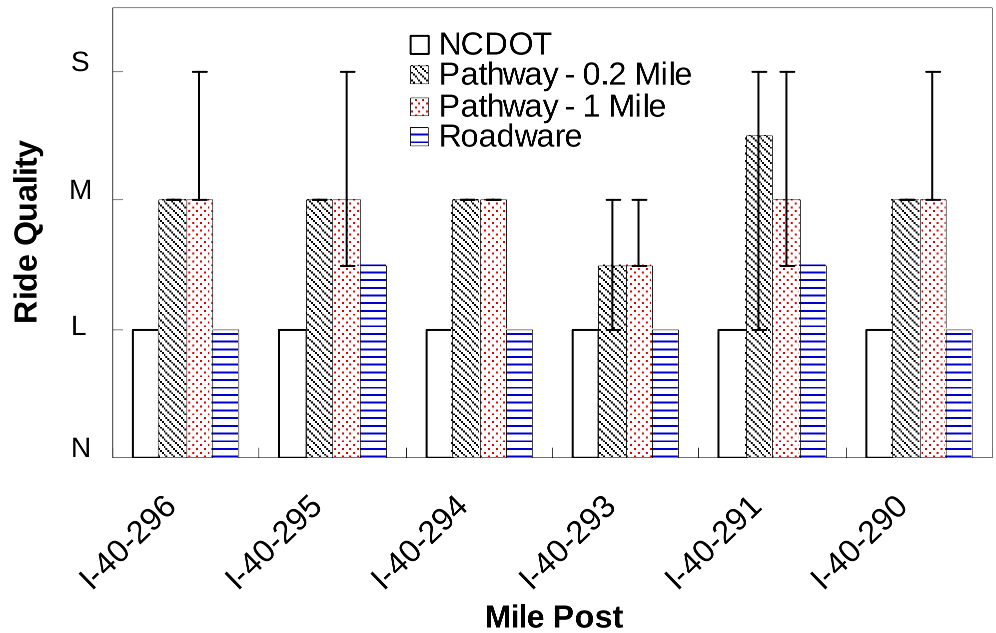


Figure 3.59. Ride Quality for I-440/I-40 (2) sections.

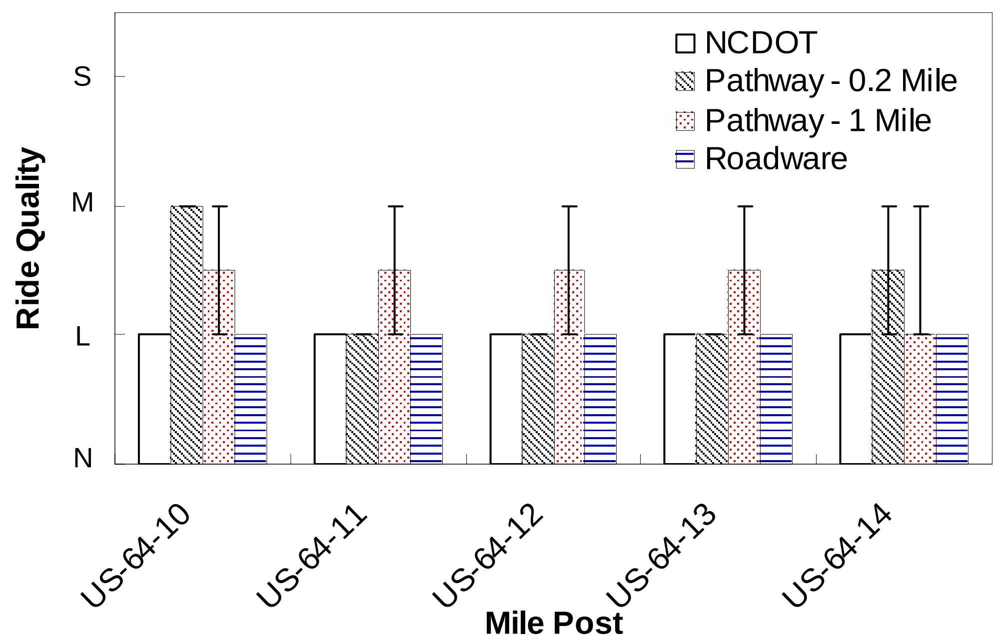


Figure 3.60. Ride Quality for US-64 (1) sections.

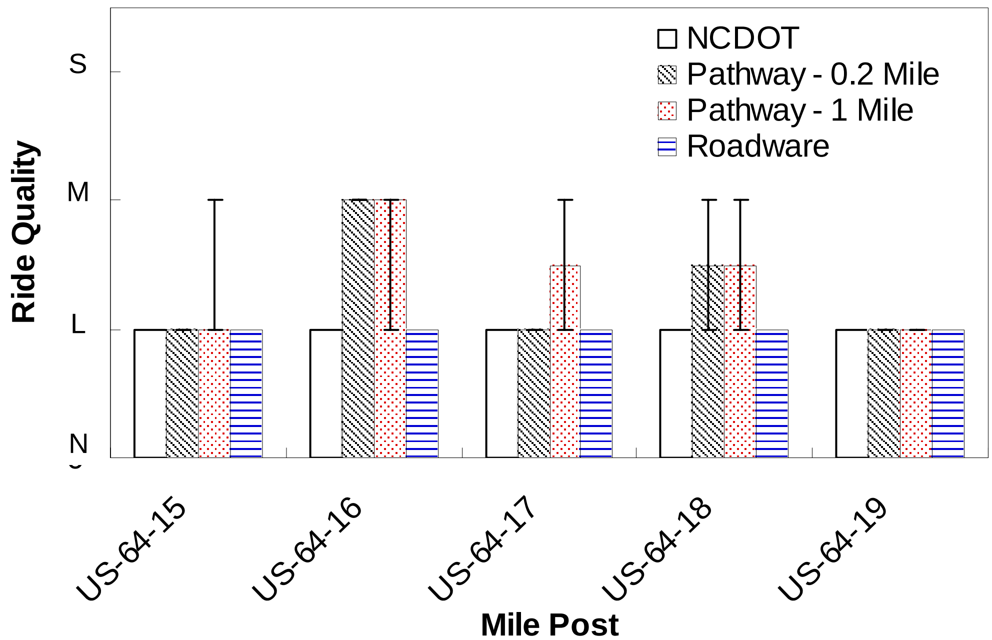


Figure 3.61. Ride Quality for US-64 (2) sections.

3.5.4.3. Discussion

Reference survey

- The ride quality rating for each section of the test course is light.

Pathway Services

- Overall the ride quality has been rated moderate to severe for the I-440 and I-40 sections.
- For the US-64 sections the ride quality has been rated as light to moderate with mostly light ratings.

Fugro Roadware

- Overall the ride quality has been rated light to moderate for the I-440 and I-40 sections.
- For the US-64 sections the ride quality has been rated as light for all sections.

3.5.5. Longitudinal Cracking

3.5.5.1. Definition of Distress

For the NCDOT survey process longitudinal cracks are defined as cracks that are predominantly parallel to the pavement centerline. This distress is rated by counting the number of slabs along the survey distance exhibiting one of four different severity levels; none, light, moderate and severe. The rating levels are:

Light: Crack widths less than 0.125 in, no spalling or faulting.

Moderate: Crack widths from 0.125 to 0.50 in, or with spalling less than 3 in, or faulting up to 0.50 in, may be sealed.

Severe: Crack widths greater than 0.50 in, or with spalling greater than 3 in, or faulting greater than 0.50 in.

3.5.5.2. Data Processing and Results

The longitudinal cracking results are shown in Figure 3.62 through Figure 3.65 by severity level. For consistent comparisons results are presented based on percentage instead of number of slabs.

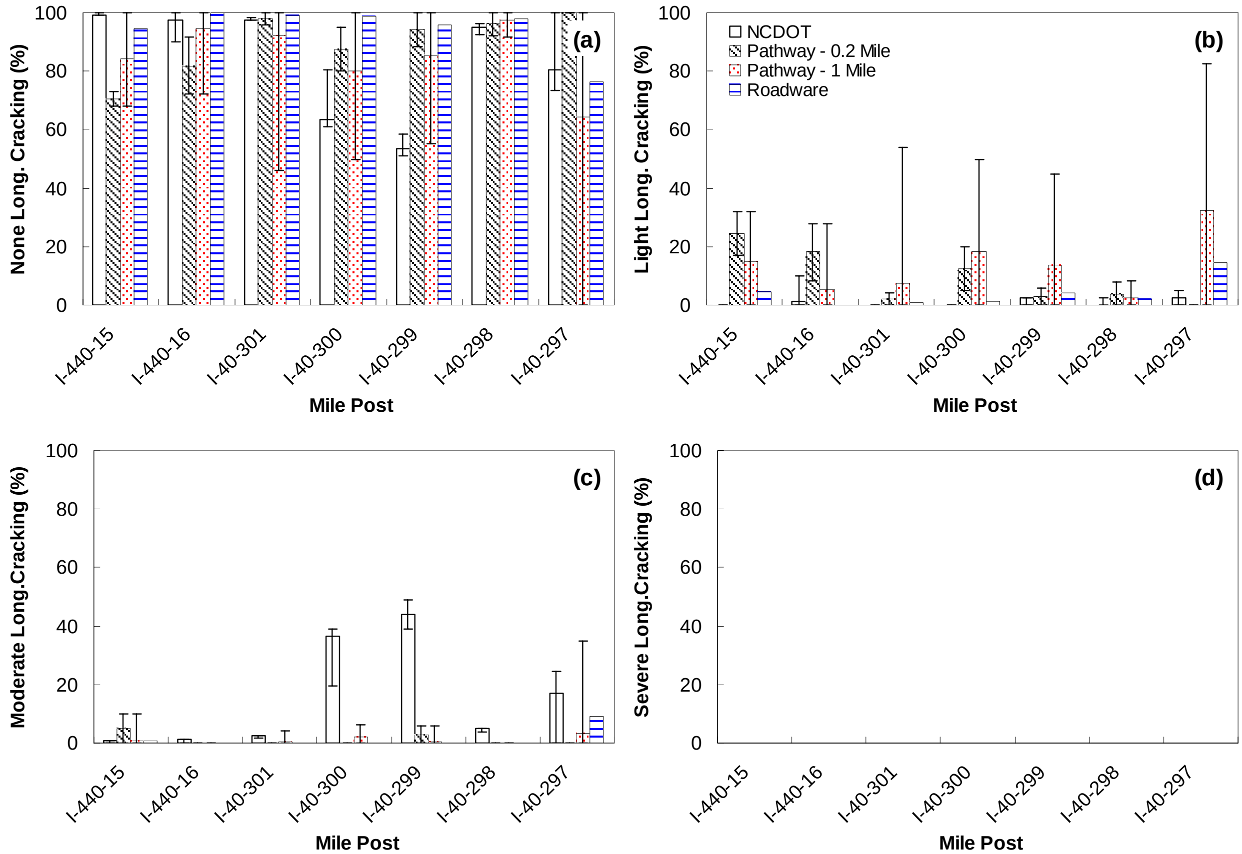


Figure 3.62. Longitudinal cracking for I-440/I-40 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

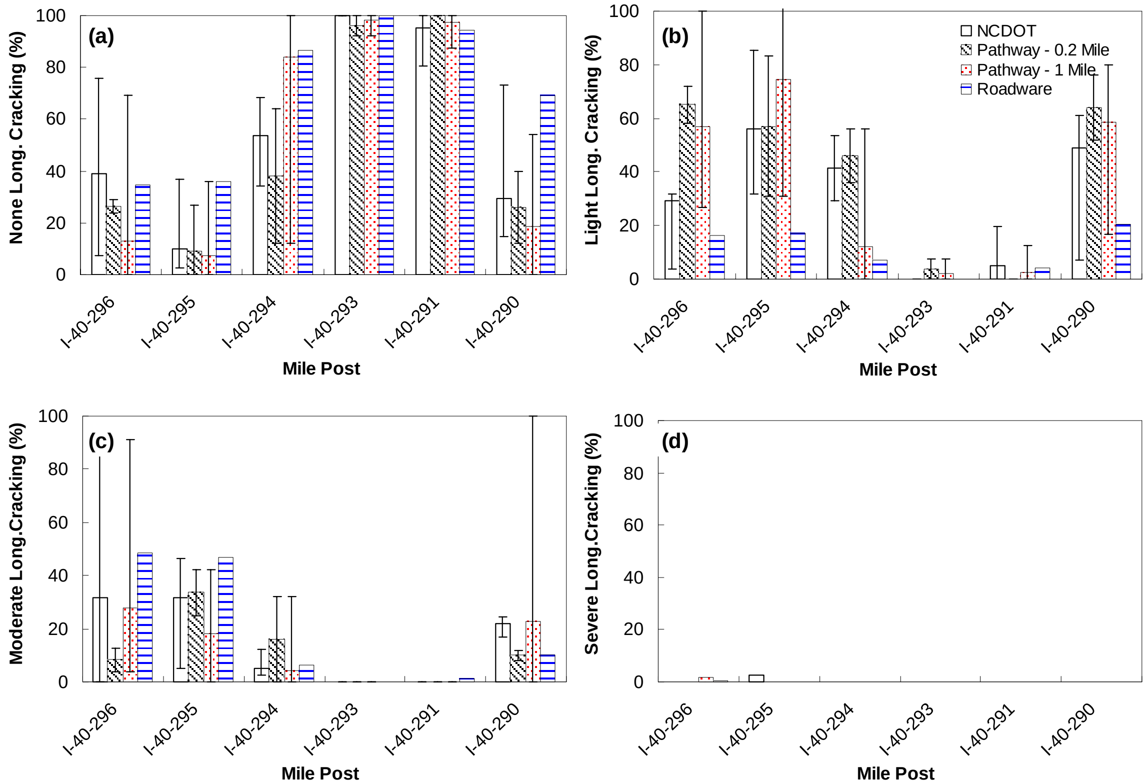


Figure 3.63. Longitudinal cracking for I-440/I-40 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

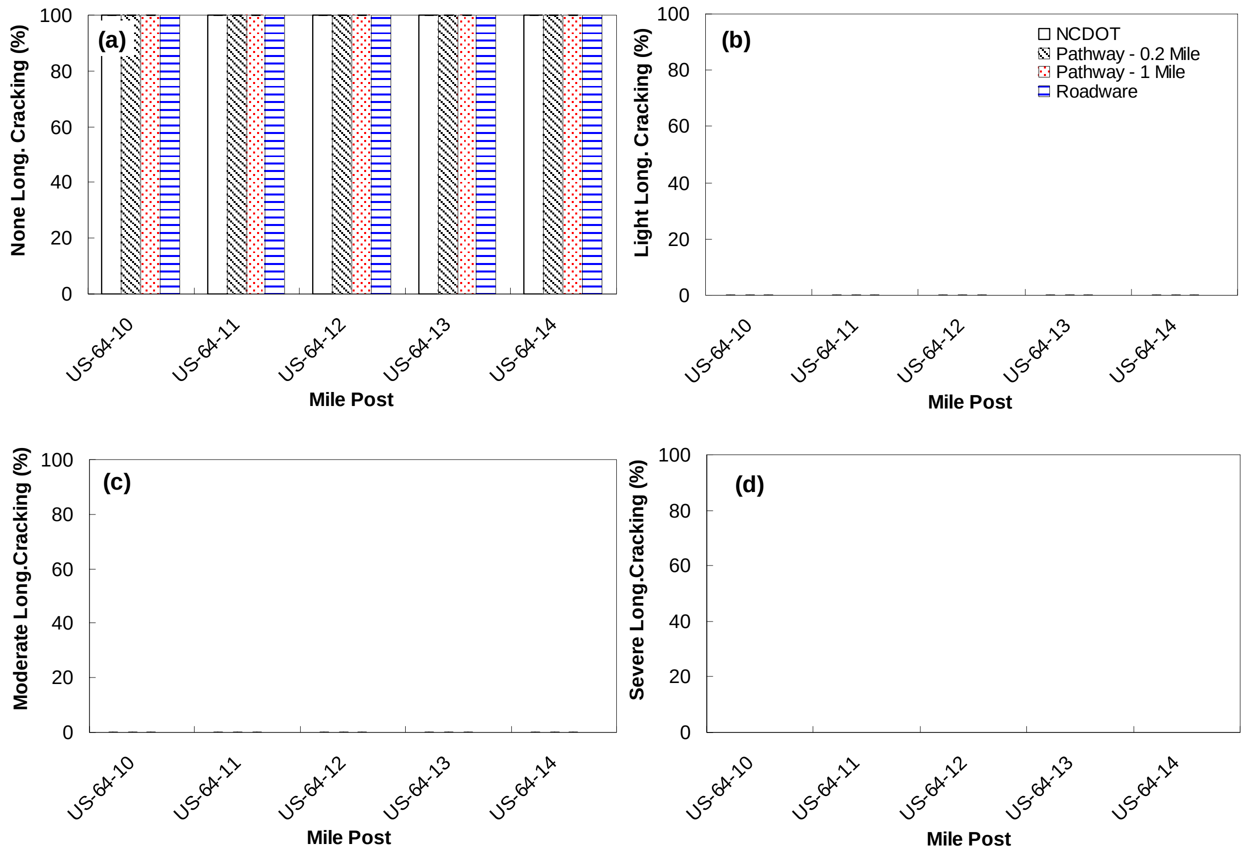


Figure 3.64. Longitudinal cracking for US-64 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

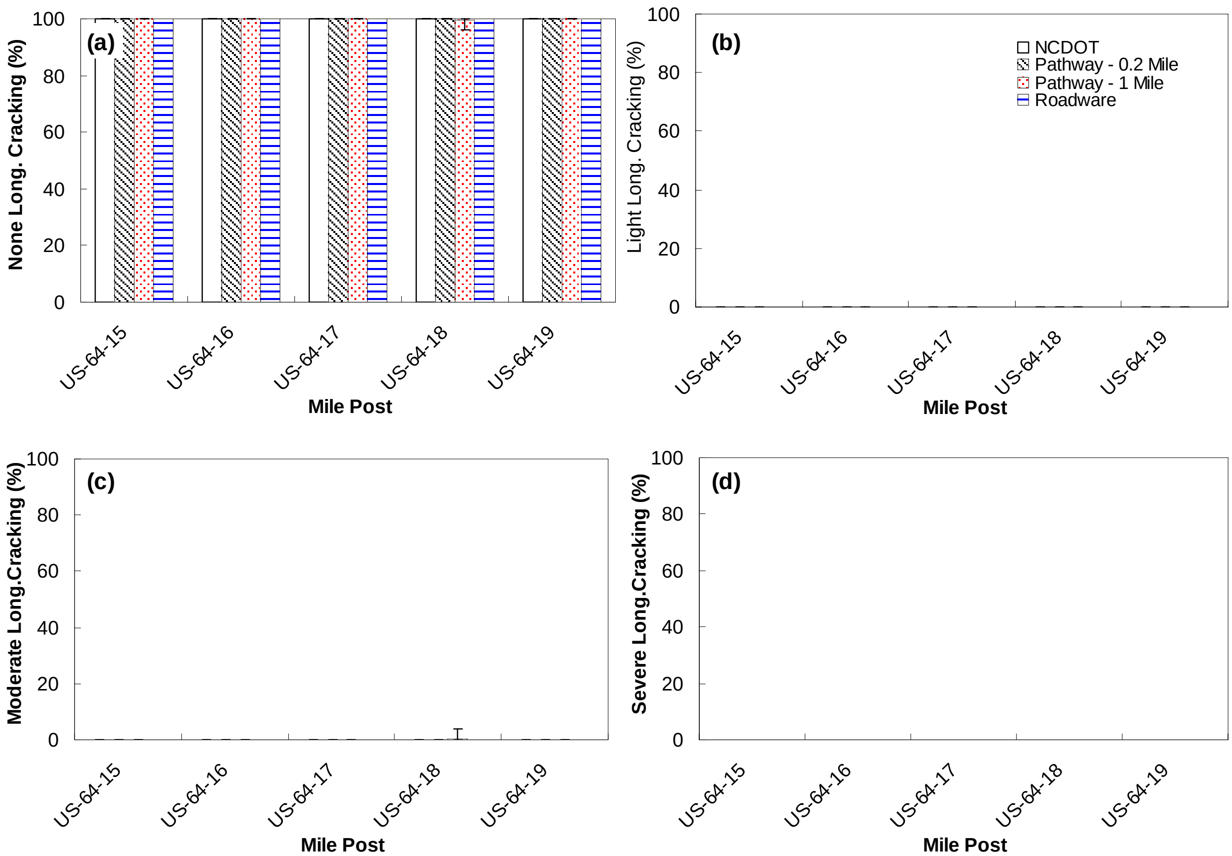


Figure 3.65. Longitudinal cracking for US-64 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

3.5.5.3. Discussion

Reference survey

- For the sub interval including I-440 and I-40-301 to I-40-297 the total amount of longitudinal cracking ranges from 0% at I-440-15 to approximately 45% at I-40-299.
- Sections showing some longitudinal cracking are at moderate severity.
- The most significant cracking in the test section is observed at I-40-296, I-40-295 and I-40-290 with 60%, 90% and 70% cracking.
- Most cracking in this section is light in severity although the three main distressed segments do show moderate severity and I-40-295 shows some severe distress.
- US-64 sections show no longitudinal cracking.

Pathway Services

- Overall the longitudinal cracking for the sub interval including I-440 and I-40-301 to I-40-297 has a low count of longitudinal cracking.
- The highest concentration of longitudinal cracking for this interval is counted at I-40-300 at approximately 20%, which is mostly counted as light severity.
- The most significant cracking in the test section is counted at I-40-296, I-40-295 and I-40-290 with 75%, 90% and 70% cracking.

- Most cracking in this section is counted as light in severity although the three main distressed segments do show moderate severity and over the final 0.8 mile increment I-40-296 shows some severe distress
- US-64 sections show no longitudinal cracking except at I-64-18 which shows some moderate fatigue cracking in the final 0.8 mile increment.

Fugro Roadware

- Overall the longitudinal cracking for the sub interval including I-440 and I-40-301 to I-40-297 has a low count of longitudinal cracking with
- The highest concentration in this interval is approximately 70% (20% light severity and 10% moderate severity) at I-40-297.
- The most significant cracking in the test section is counted at I-40-296, I-40-295 and I-40-290 with approximately 65%, 65% and 30% cracking.
- Most cracking in the most distressed sections is counted as moderate severity and I-40-296 shows some severe distress
- US-64 sections show no longitudinal cracking.

3.5.6. Transverse Cracking

3.5.6.1. Definition of Distress

For the NCDOT survey process transverse cracks are defined as cracks that are predominantly perpendicular to the pavement centerline. This distress is rated by counting the number of slabs along the survey distance exhibiting one of four different severity levels; none, light, moderate and severe. The rating levels are:

Light: Crack widths less than 0.125 in, no spalling or faulting.

Moderate: Crack widths from 0.125 to 0.50 in, or with spalling less than 3 in, or faulting up to 0.25 in, may be sealed.

Severe: Crack widths greater than 0.50 in, or with spalling greater than 3 in, or faulting greater than 0.25 in.

3.5.6.2. Data Processing and Results

The transverse cracking results are shown in Figure 3.66 through Figure 3.69 by severity level. For consistent comparisons results are presented based on percentage instead of number of slabs.

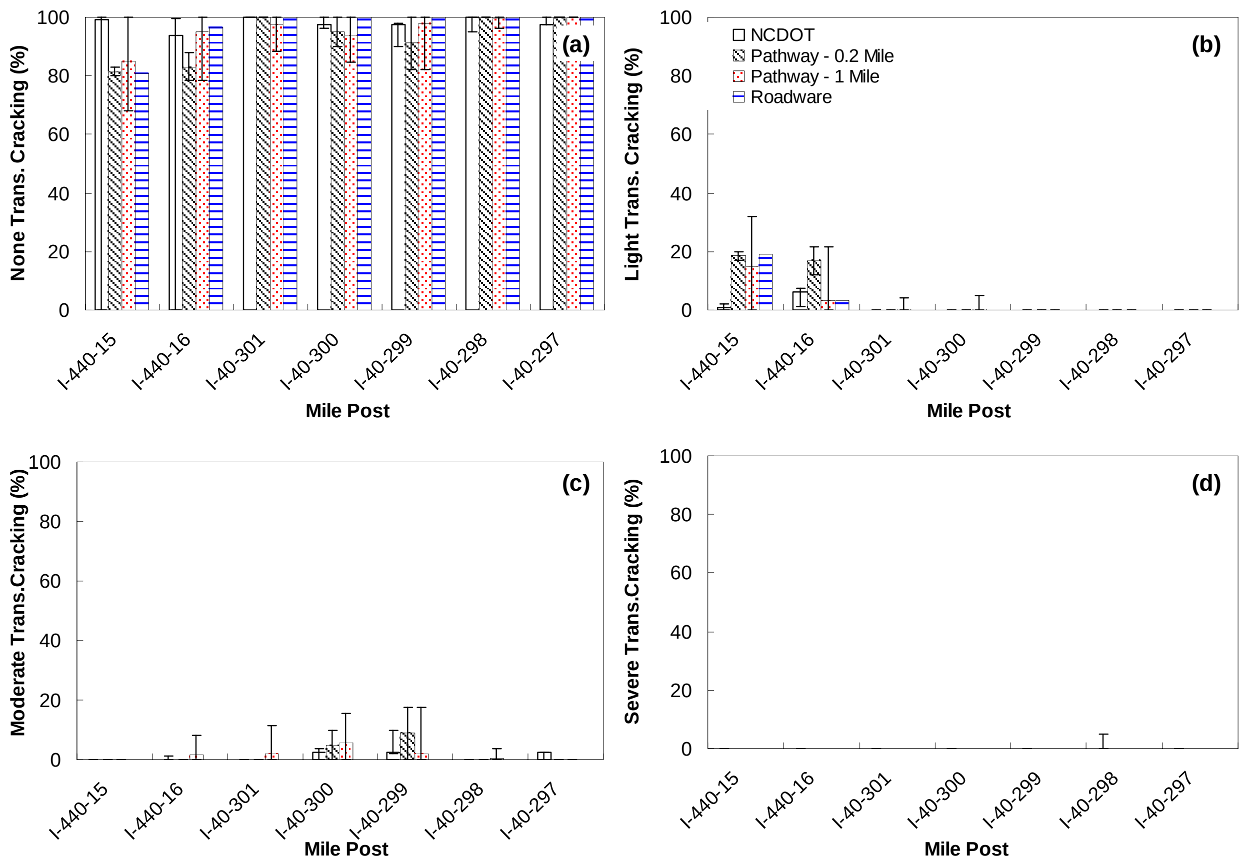


Figure 3.66. Transverse cracking for I-440/I-40 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

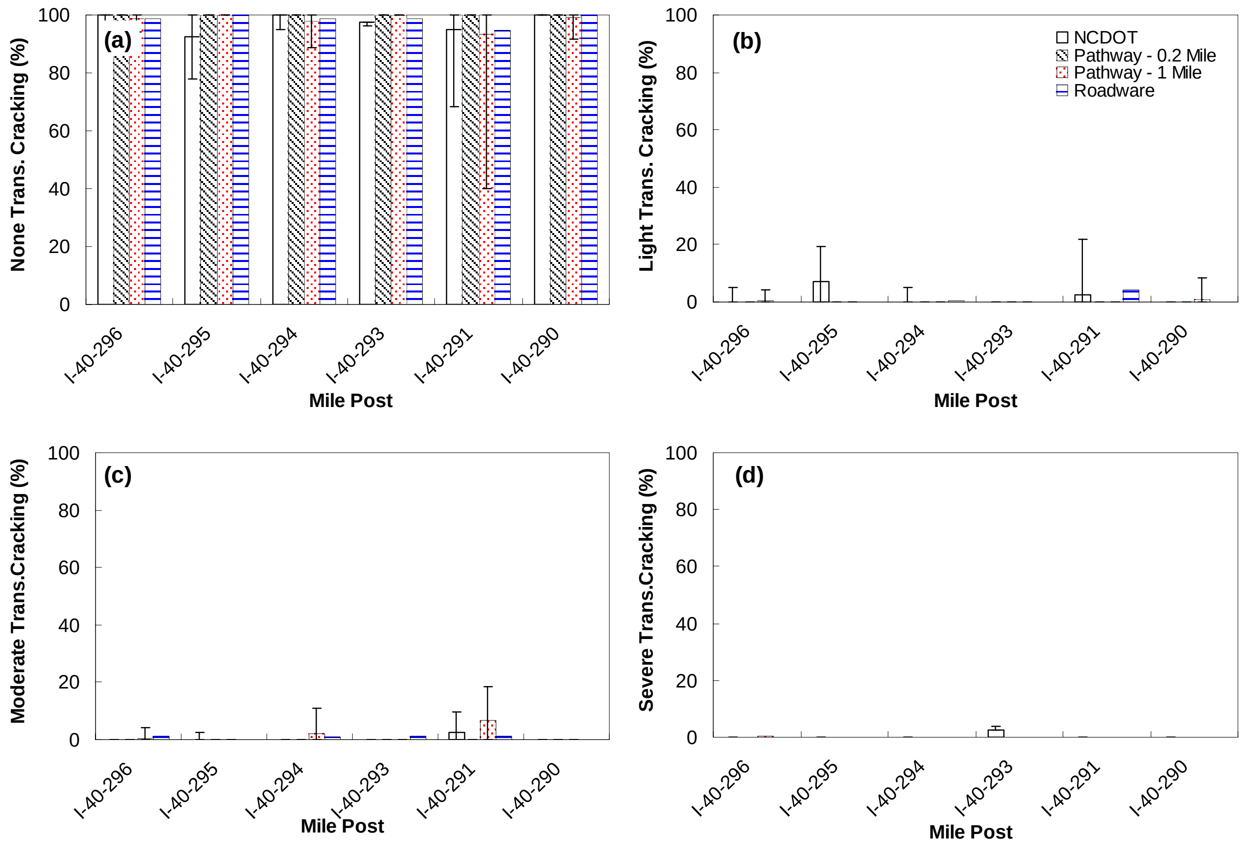


Figure 3.67. Transverse cracking for I-440/I-40 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

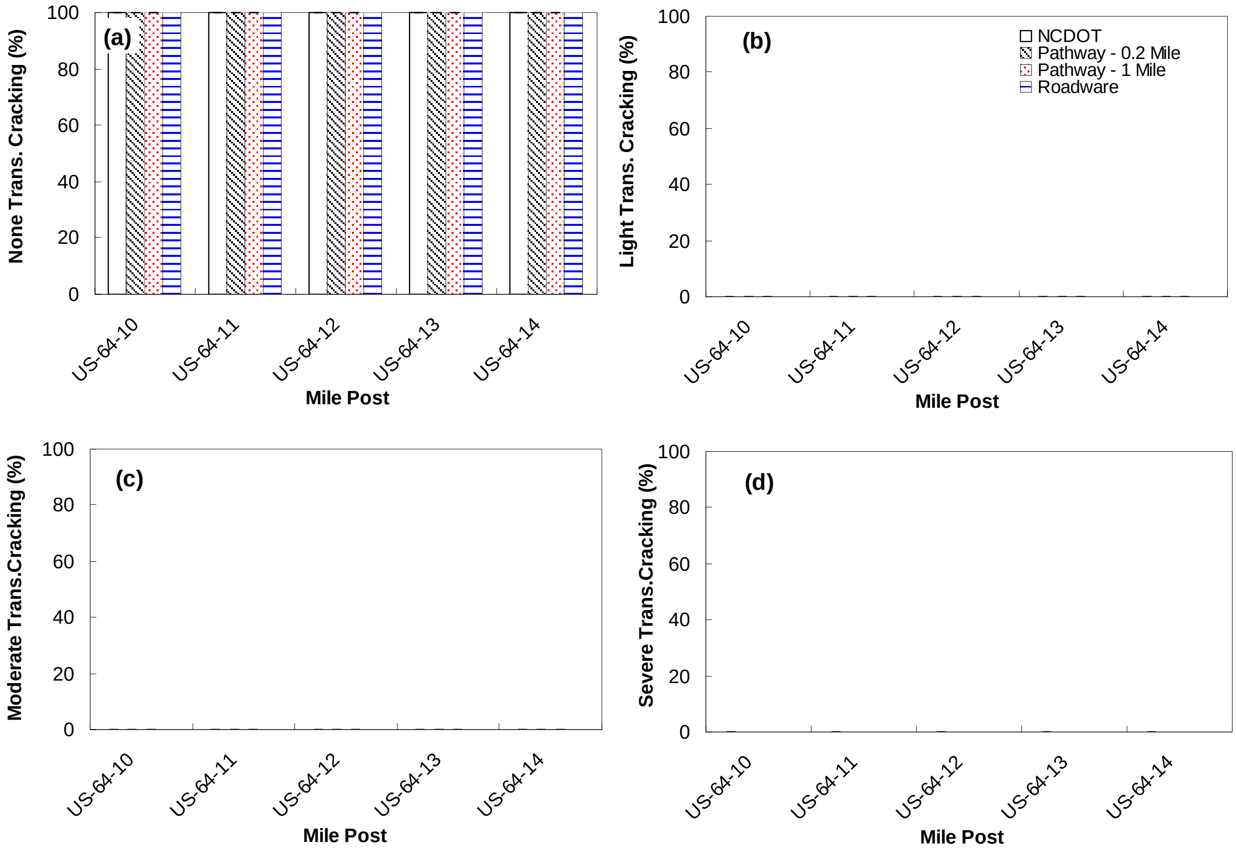


Figure 3.68. Transverse cracking for US-64 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

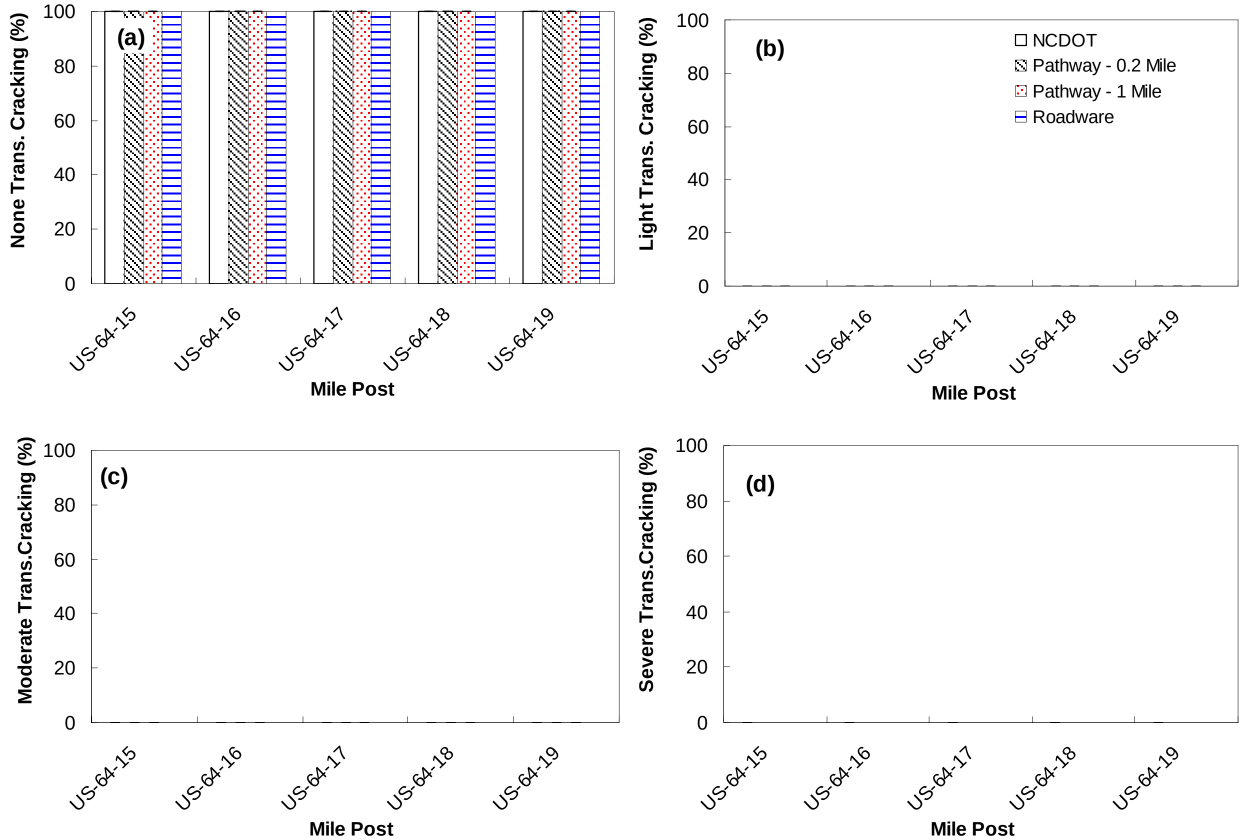


Figure 3.69. Transverse cracking for US-64 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

3.5.6.3. Discussion

Reference survey

- For the sub interval including I-440 and I-40 the total amount of transverse cracking ranges from 0% at I-440-15, I-40-301, I-40-298, I-40-297, I-40 296, I-40-294 and I-40-29-0 to approximately 5% at I-440-16 and I-40-295.
- Sections showing some transverse cracking are at light severity except I-40-300, I-40-299, and I-40-291 which have approximately 2% at moderate severity.
- Section I-40-293 shows some slight severe rated transverse cracking.
- US-64 sections show no transverse cracking.

Pathway Services

- Overall the transverse cracking for the sub interval including I-440 and I-40 has a low count of transverse cracking.
- The highest concentration of transverse cracking for this interval is 20% and consists of light severity cracking at I-440-15 and I-440-16.
- US-64 sections show no transverse cracking.

Fugro Roadware

- Overall the transverse cracking for the sub interval including I-440 and I-40 has a low count of transverse cracking.

- The highest concentration of transverse cracking for this interval is 20% and consists of light severity cracking at I-440-15.
- US-64 sections show no transverse cracking.

3.5.7. Corner Break

3.5.7.1. Definition of Distress

For the NCDOT survey process corner breaks occur when a portion of the slab is separated by a crack which intersects the adjacent transverse and longitudinal joints, at an approximately 45° angle. The length of the sides of the break ranges from 1 ft. to 1/2 the width of the slab, on each side of the corner. This distress is rated by counting the number of slabs along the survey distance exhibiting one of four different severity levels; none, light, moderate and severe. The rating levels are:

Light: Crack well sealed or hairline, no faulting or spalling, no break-up.

Moderate: Crack spalled at low to moderate severity, faulting less than 0.50 in, no pieces broken.

Severe: Crack spalled at moderate to severe severity, faulting greater than 0.50 in, broken into two or more pieces.

3.5.7.2. Data Processing and Results

The corner break results are shown in Figure 3.70 through Figure 3.73 by severity level. For consistent comparisons results are presented based on percentage instead of number of slabs.

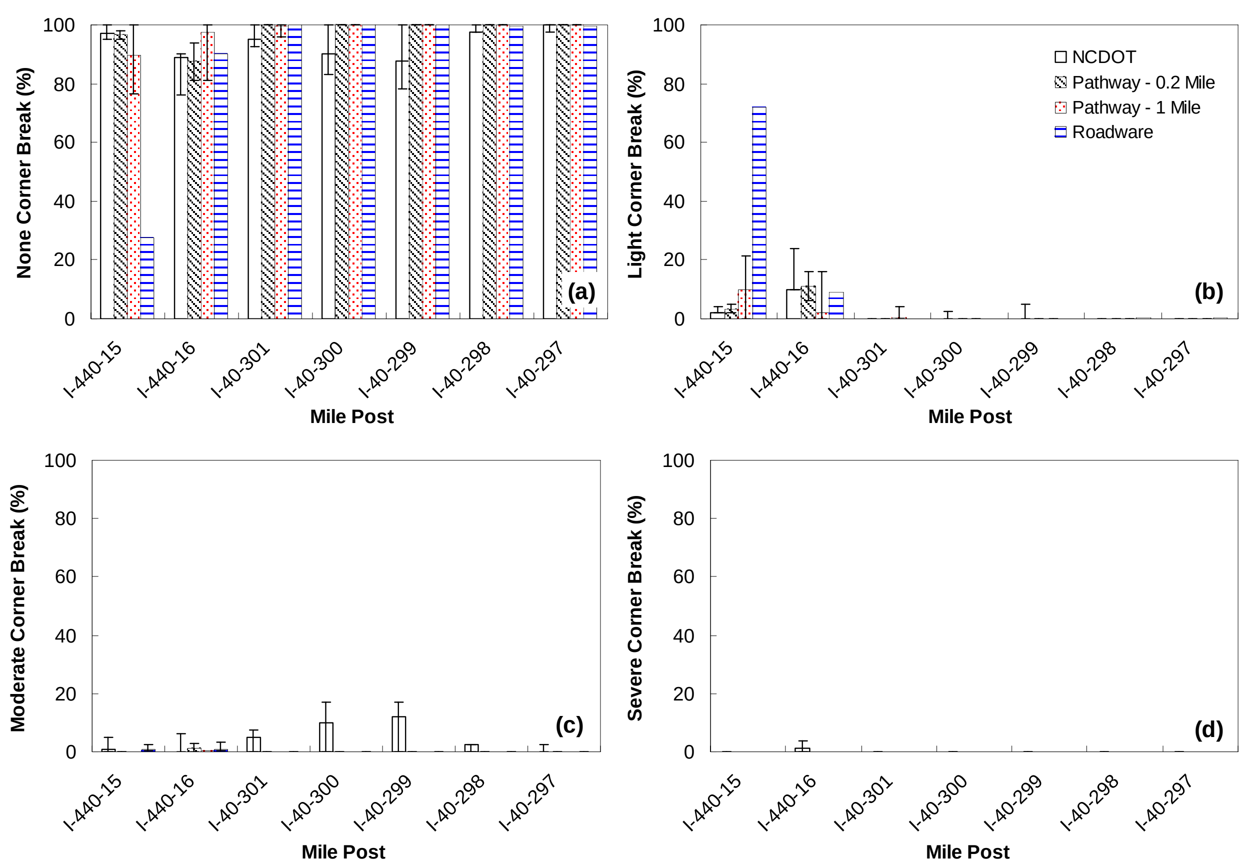


Figure 3.70. Corner break for I-440/I-40 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

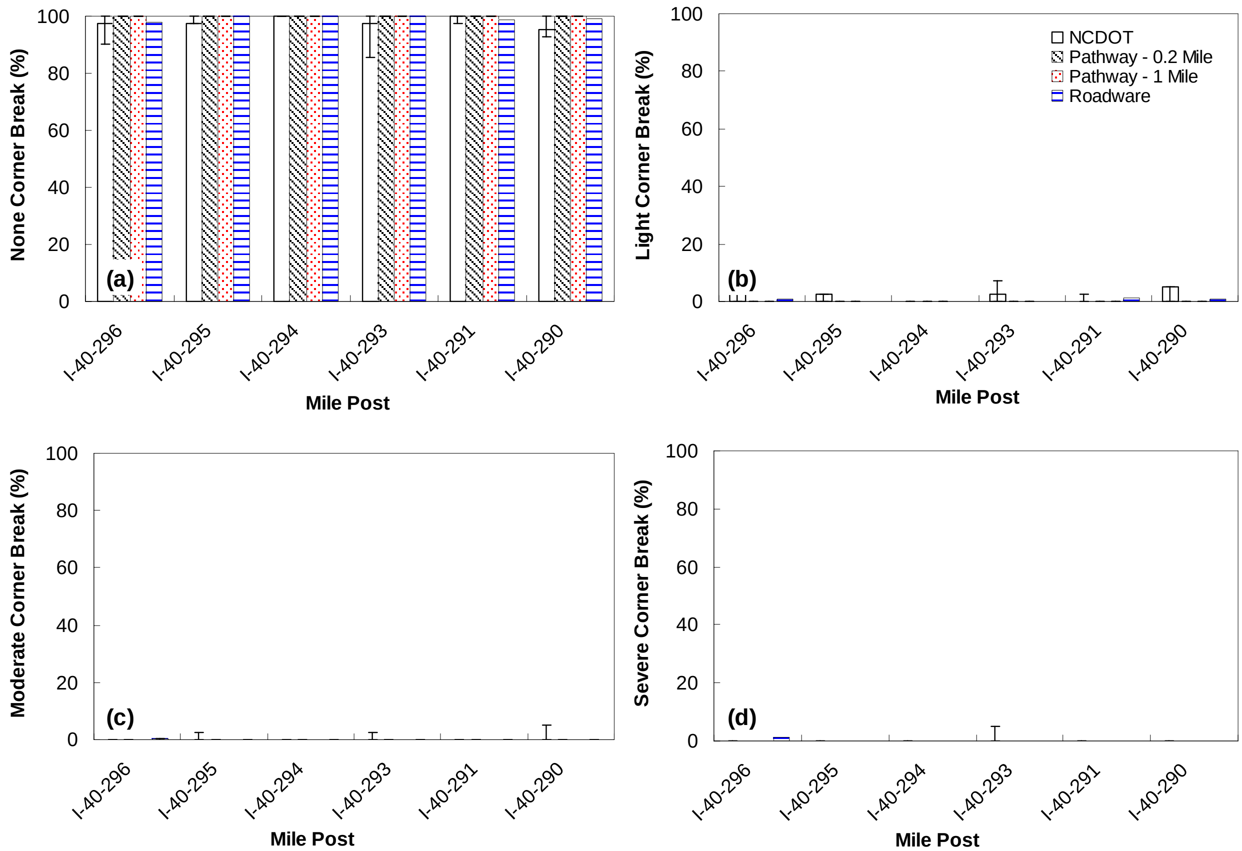


Figure 3.71. Corner break for I-440/I-40 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

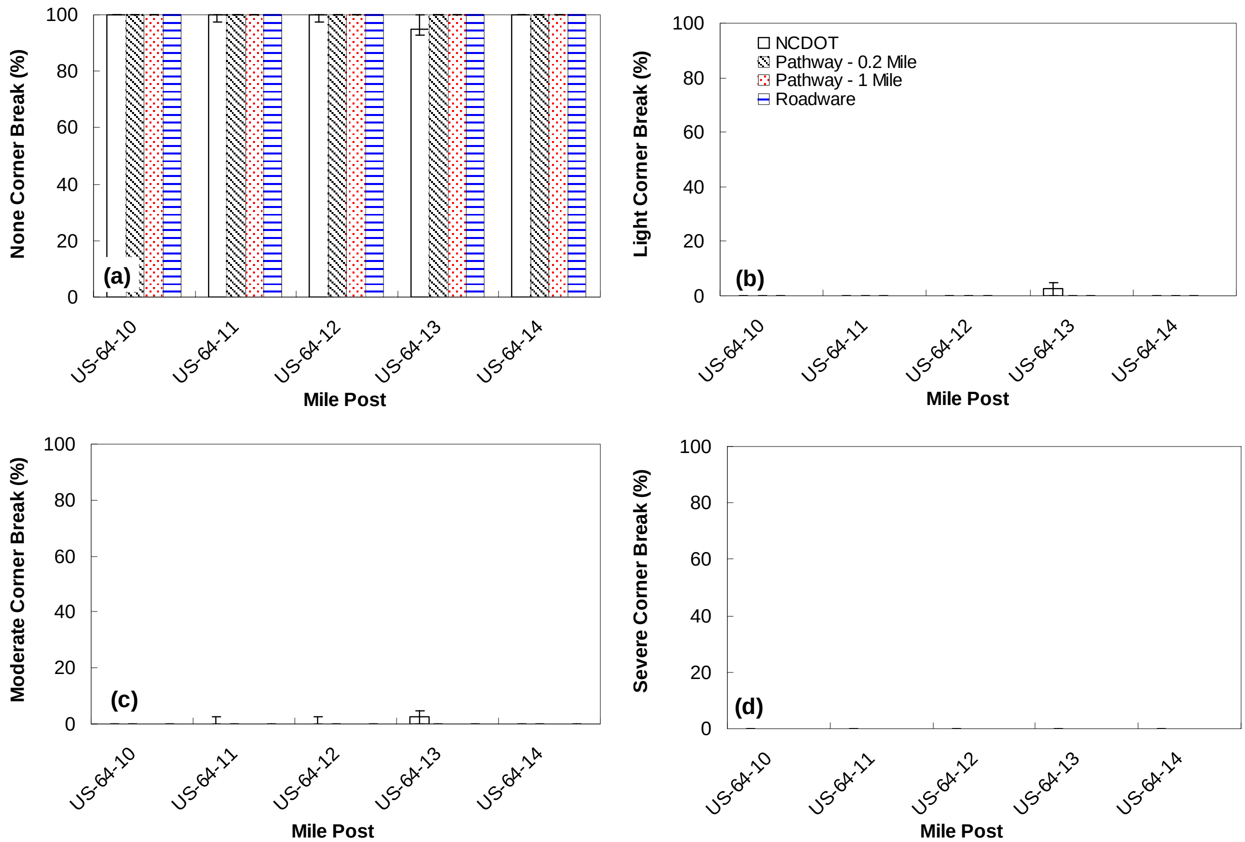


Figure 3.72. Corner break for US-64 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

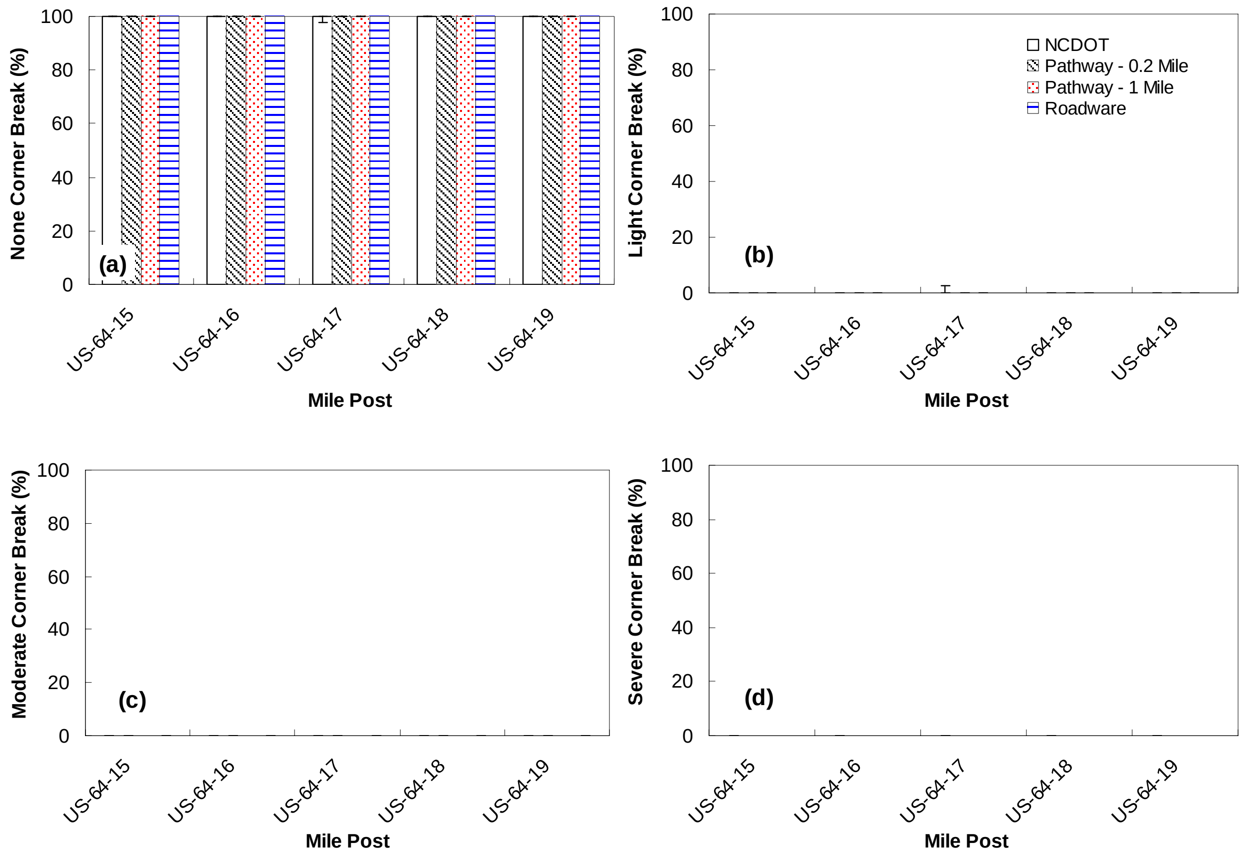


Figure 3.73. Corner break for US-64 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

3.5.7.3. Discussion

<u>Reference survey</u>

- The highest corner break content is at I-440-16, I-40-301, and I-40-300, 10-15%. For I-440-16 this is mostly light severity breaking but for the other two sections it is mostly moderate.
- Very slight light and moderate corner breaking (2% for both) is observed at US-64-13.

<u>Pathway Services</u>

- Overall little corner breaking is counted.
- The highest concentration of counted breakage is at I-440-16 and is approximately 15% light severity breakage.
- US-64 sections show no corner breaking.

<u>Fugro Roadware</u>

- Overall little corner breaking is counted except for I-440-15.
- The highest concentration of counted breakage is at I-440-16 and is approximately 70% light severity breakage. Other than this section, I-440-16 shows approximately 15% light severity breakage.
- US-64 sections show no corner breaking.

3.5.8. Spalling

3.5.8.1. Definition of Distress

For the NCDOT survey spalling is defined by cracking, breaking, or chipping of slab edges within 2 ft of a joint. This distress is rated by counting the number of slabs along the survey distance exhibiting one of four different severity levels; none, light, moderate and severe. The rating levels are:

Light: Spalls less than 3 in wide with loss of material, or spalls with no loss of material and no patching.

Moderate: Spalls from 3 to 6 in wide with loss of material.

Severe: Spalls greater than 6 in wide with loss of material.

3.5.8.2. Data Processing and Results

The spalling results are shown in Figure 3.74 through Figure 3.77 by severity level. For consistent comparisons results are presented based on percentage instead of number of slabs.

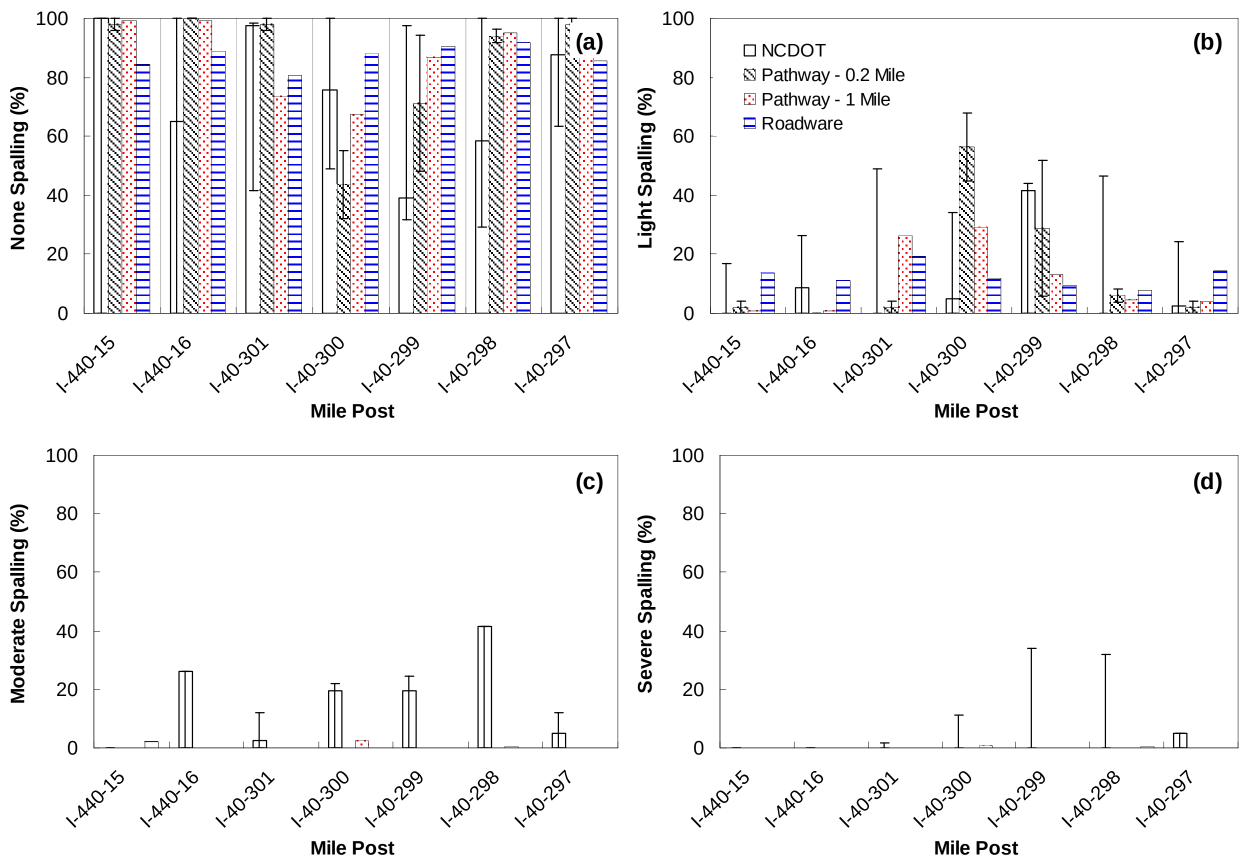


Figure 3.74. Spalling for I-440/I-40 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

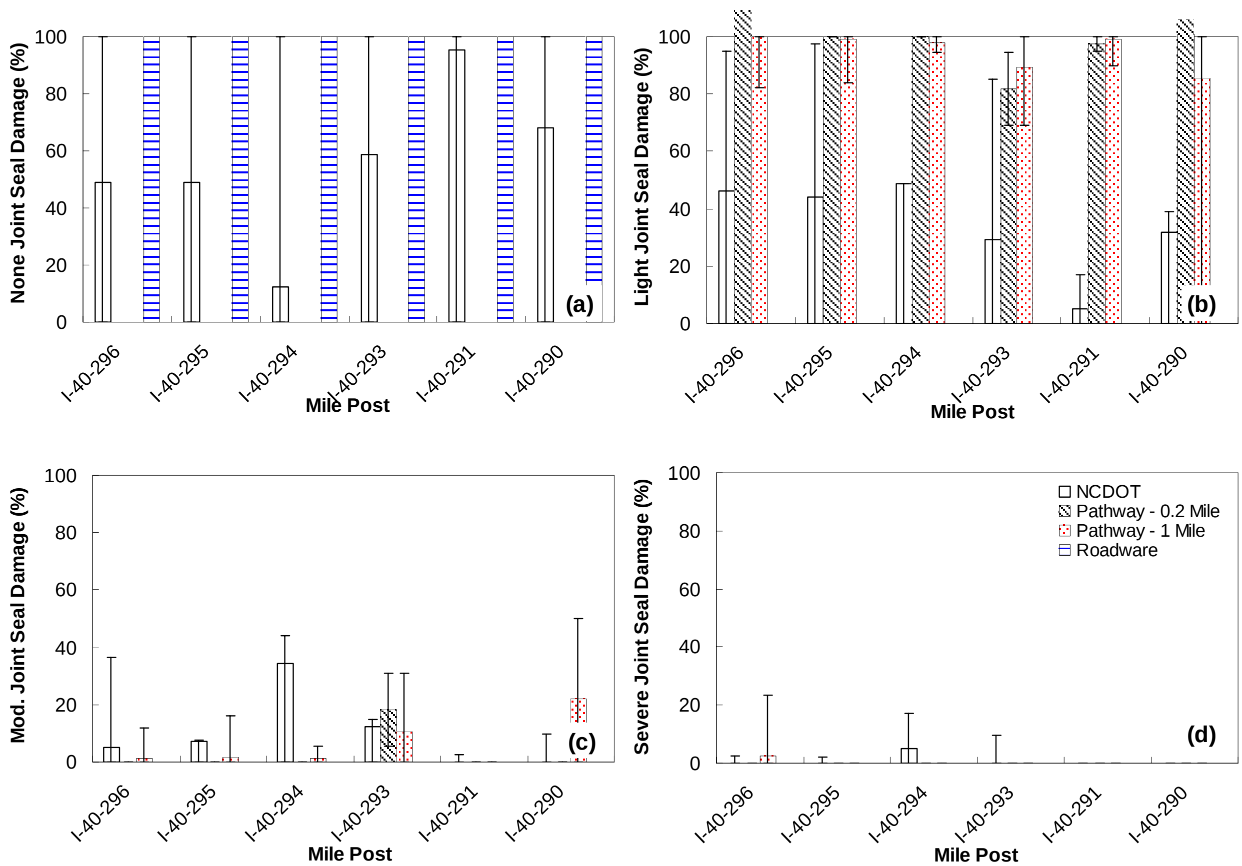


Figure 3.75. Spalling for I-440/I-40 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

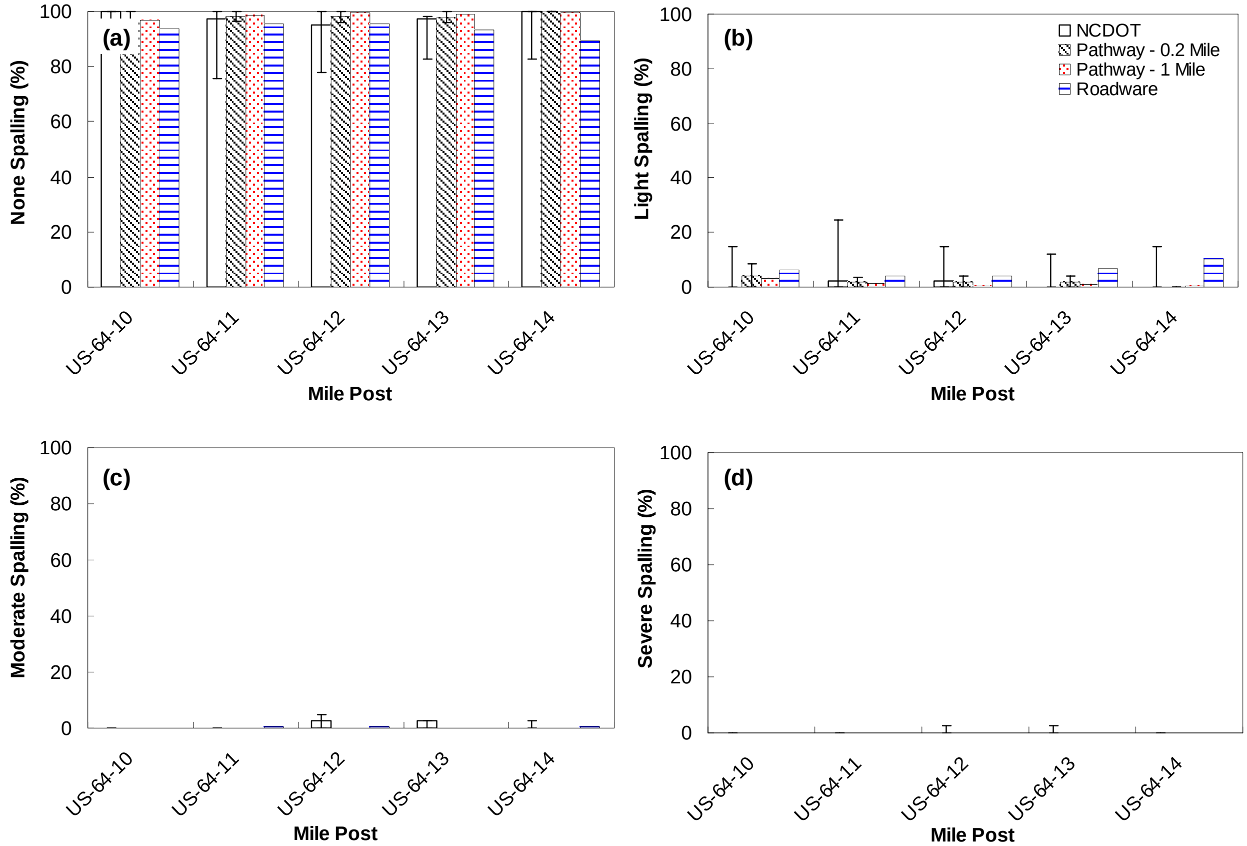


Figure 3.76. Spalling for US-64 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

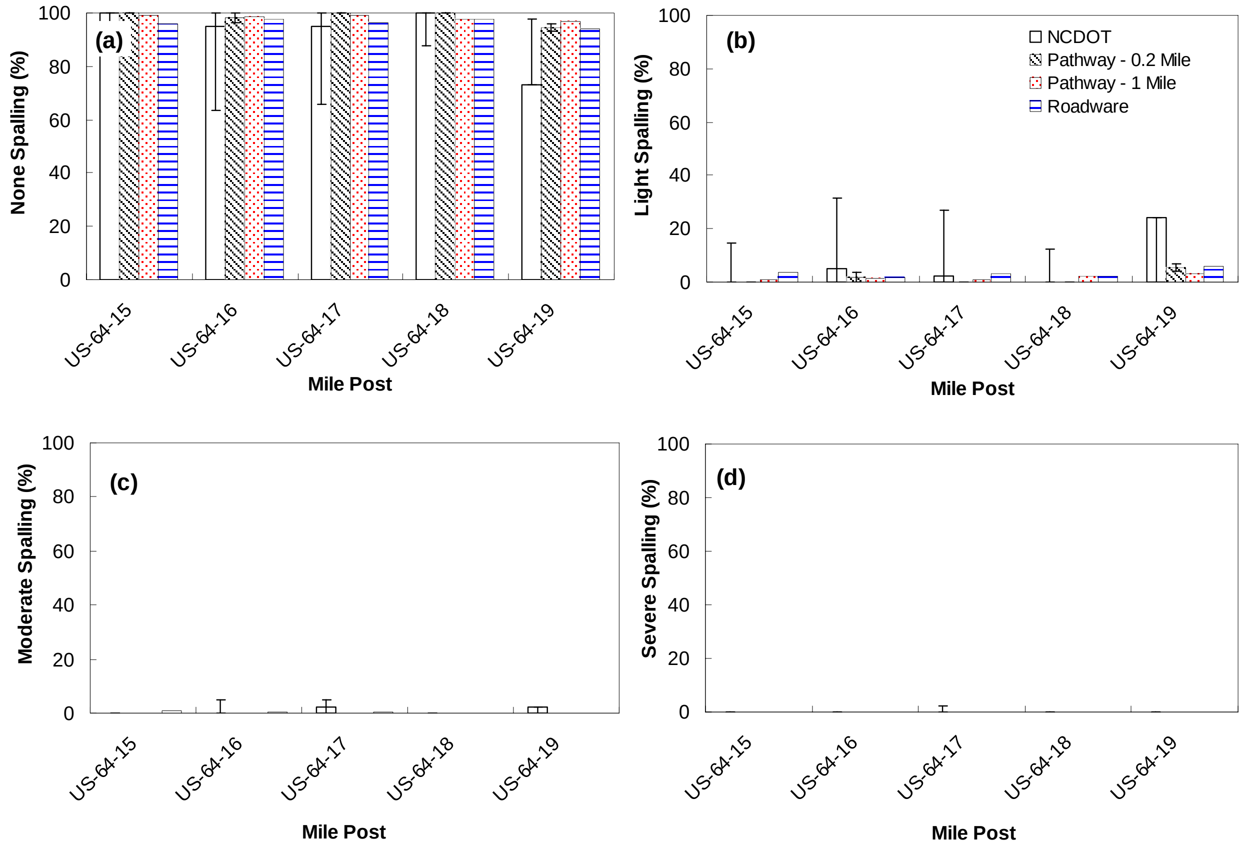


Figure 3.77. Spalling for US-64 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

3.5.8.3. Discussion

Reference survey

- The subinterval including I-440 and I-40 showed some substantial spalling.
- The highest spalling values were found at I-40-299 and were considered both moderate (20%) and light (40%). Other sections showed a mixture of moderate and light severity.
- The most heavily spalled US-64 section was US-64-19 at approximately 30% light severity spalling and 2% moderate severity spalling. All other US-64 sections show 5% or less spalling.

Pathway Services

- Some substantial spalling was counted for the subinterval including I-440 and I-40.
- The highest spalling values were found at I-40-300 where 60% light severity spalling was counted. No other section showed more than 30% spalling.
- Moderate spalling was counted only on I-40-296.
- All US-64 sections show 5% or less spalling.

Fugro Roadware

- Some spalling was counted for the subinterval including I-440 and I-40.
- The highest spalling values were found at I-40-301 and I-40-301 where roughly 30% light severity spalling was counted. No other section showed more than 25% spalling.
- Moderate spalling was counted on I-40-296, I-40-295, I-40-293, I-40-291 and I-40-290.

- All US-64 sections expect US-64-14 show 6% or less spalling. Section US-64-14 shows approximately 11% spalling (10% light and 1% moderate).

3.5.9. Joint Seal Damage

3.5.9.1. Definition of Distress

For the NCDOT survey process joint seal damage is defined as a condition which enables materials or water to infiltrate the joint. Also, includes extrusion, hardening, adhesive failure, cohesive failure or complete loss of sealant. This distress is rated by counting the number of joints along the survey distance exhibiting one of four different severity levels; none, light, moderate and severe. The rating levels are:

Light: Joint seal damage exists in less than 10% of the joint.
Moderate: Joint seal damage exists in 10% to 50% of the joint.
Severe: Joint seal damage exists in more than 50% of the joint.

3.5.10. Data Processing and Results

The joint seal damage results are shown in Figure 3.78 through Figure 3.81 by severity level. For consistent comparisons results are presented based on percentage instead of number of slabs.

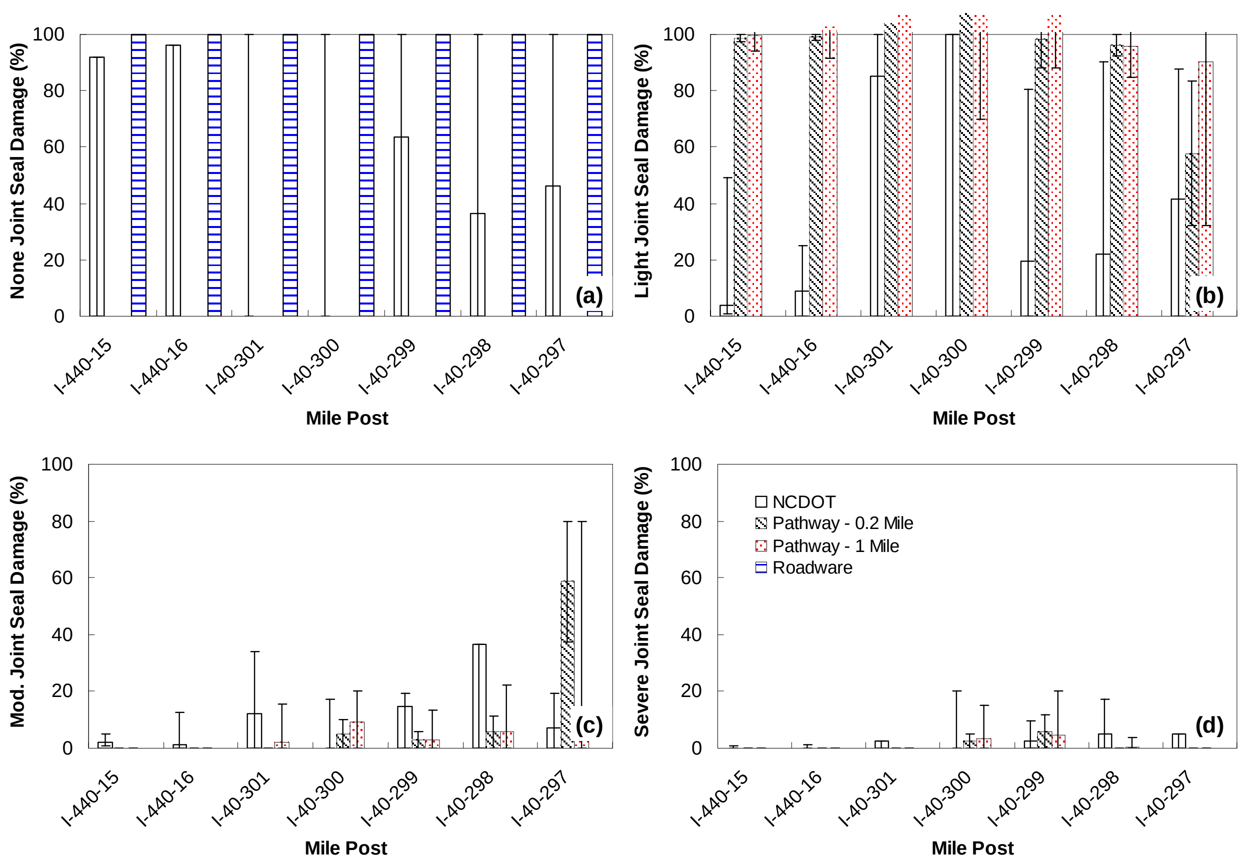


Figure 3.78. Joint seal damage for I-440/I-40 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

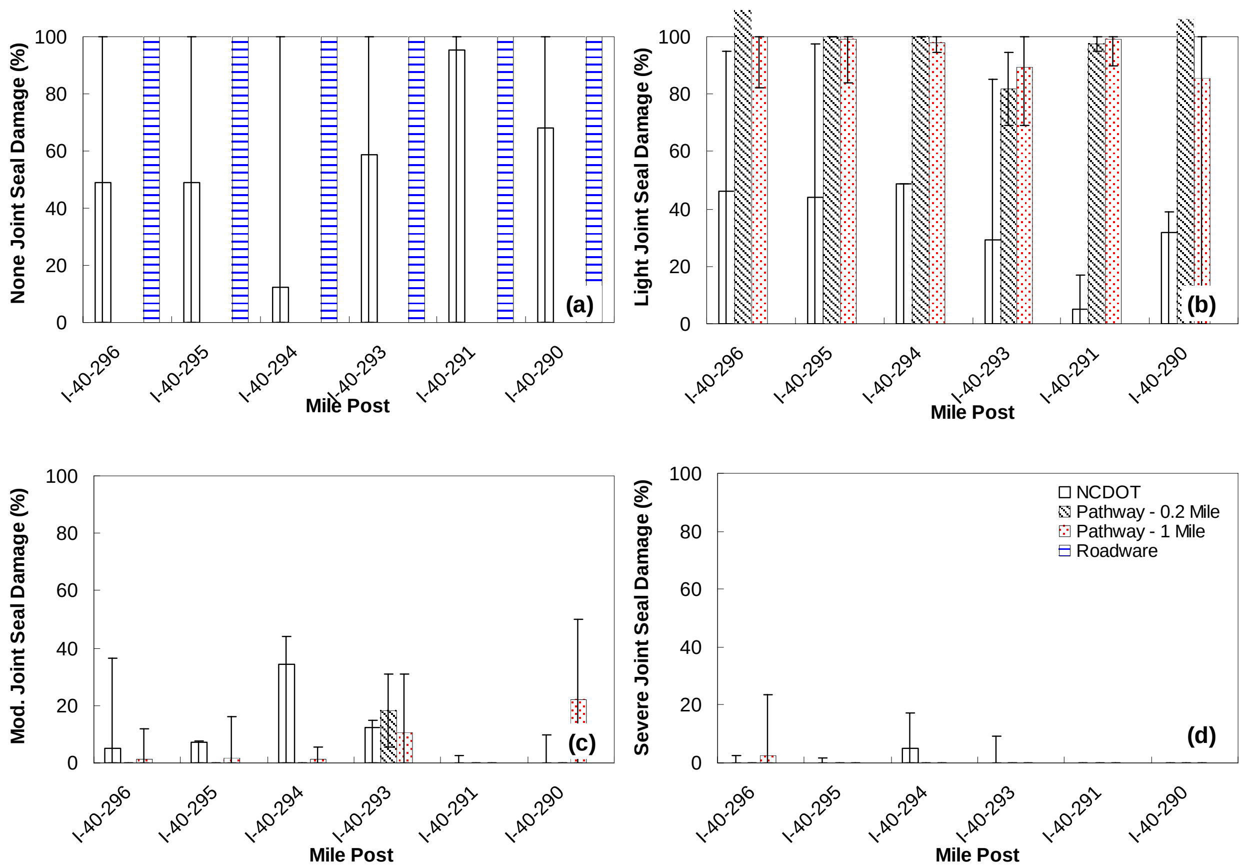


Figure 3.79. Joint seal damage for I-440/I-40 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

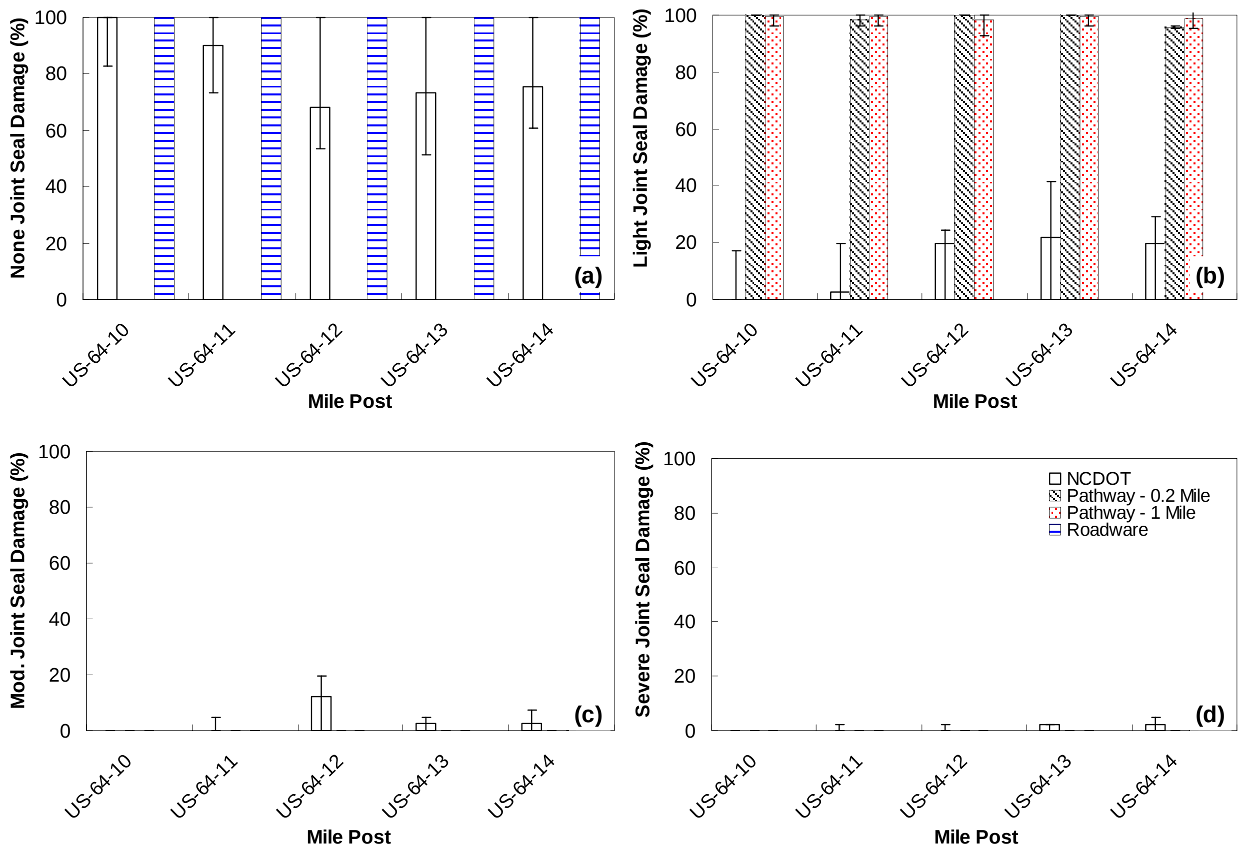


Figure 3.80. Joint seal damage for US-64 (1) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

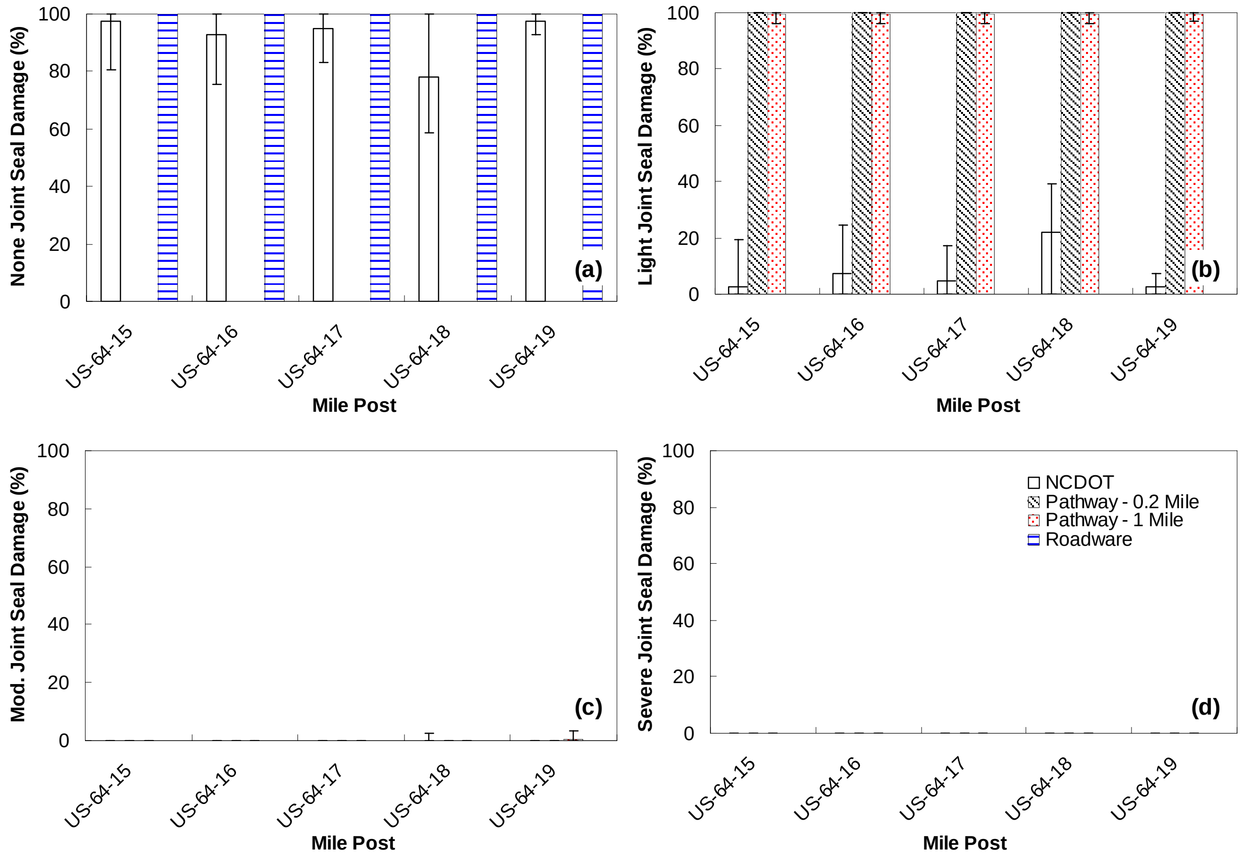


Figure 3.81. Joint seal damage for US-64 (2) sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

3.5.10.1. Discussion

Reference survey

- All sections in the subinterval including I-440 and I-40 show some joint seal damage.
- The highest joint seal damage is found at I-40-301 and I-40-300 with 100% mostly lightly distressed joint seal damage.
- The observed distress ranges from light to severe. The highest moderate damage occurs at 37% at I-40-298 while the highest severe joint seal damage is 5% occurring at I-40-298, I-40-297 and I-40-294.
- Overall the joint seals are less damaged for the US-64 subinterval with a maximum of approximately 40% at US-64-12.

Pathway Services

- All sections in the subinterval including I-440 and I-40 show 100% or more joint seal damage (due to the aforementioned analysis techniques it is possible to compute more than 100% damage).
- Most of the damage occurring is light severity except at I-40-297 where most approximately 60% is moderate damage. Some severe joint seal damage is also counted.
- Overall the joint seals are less damaged for the US-64 subinterval most joint seals in this interval received a rating of 100% lightly distressed.

Fugro Roadware

- All sections along the test course received a rating of 100% no joint seal damage.

3.5.11. Shoulder Condition

3.5.11.1. Definition of Distresses

The shoulder survey for PCC sections consists of four different components: 1) shoulder type, 2) shoulder width, 3) shoulder drop-off and 4) shoulder lane joint. The shoulder may consist of a combination of paved and unpaved materials. For the paved sections the shoulder is rated as either plant mixed asphalt (P), slurry seal (S), or PCC (C) shoulder. The widths of both the paved and unpaved shoulders are recorded. For sections with a paved shoulder, the unpaved width is defined as the clear distance from the edge of the shoulder to either the ditch or tree lines. In general this distance is 6-10 ft. Shoulders constructed of plant mixed materials, slurry seals or other bituminous surface treatments are rated as follows:

Light: Overall good condition, edge intact with no cracking.
Moderate: Acceptable condition; some cracking present up to 0.25 in wide, less than 0.50 in rutting, outside edge stable although may begin to break away in spots.
Severe: Unacceptable condition; cracking greater than 0.25 in, edge breaking away over a large part of section; rutting greater than 0.50 in.

Shoulders constructed of PCC are rated as follows:

Light: Shoulder condition basically in good shape with little or no problems; no cracking or faulting.
Moderate: Cracks 0.125 in wide or less’ light to moderate spalling, material is stable.
Severe: Cracks over 0.125 in wide, unstable material, faulting greater than 0.25 in.

Unpaved shoulders are rated as follows:

Light: Little or no erosion evident; thick vegetation cover.
Moderate: Thin vegetation with some bare spots; shallow erosion channel may be present.
Severe: Sparse vegetation; deep erosion channels, ruts greater than 1 in.

In addition to measuring the general shoulder condition, the shoulder to lane drop-off is rated as either; light, moderate or severe depending on the drop-off distance. This distance is the difference in elevation between edge of slab and outside shoulder. The ratings for this distress are as follows:

Light: Shoulder drop-off less than 0.25 in.
Moderate: Shoulder drop-off 0.25 to 0.50 in.
Severe: Shoulder drop-off greater than 0.50 in.

The final factor considered in the PCC shoulder condition is the lane to shoulder joint. For survey purposes this joint is examined for any widening of the joint between the edge of slab and outside shoulder. For shoulders constructed of plant mix, slurry seals or other bituminous surface treatments the criteria for severity are:

Light: Joint seal failure, less than 0.25 in opening between lane and shoulder.
Moderate: Joint seal failure, 0.25 in to 0.50 in opening between lane and shoulder.
Severe: Joint seal failure, over 0.50 in opening between lane and shoulder.

For shoulders constructed of PCC the severity criteria are:

Light: Joint seal failed at isolated locations.

Moderate: Joint seal failed 25% to 50% of the joint.
Severe: Joint seal failed over 50% of the joint.

3.5.11.2. Data Processing and Results

For this distress some additional post-processing was necessary with some of the vendor submitted data. Only a single surveyor rated the shoulder and thus no information regarding the variability of this portion of the reference survey data is available. Fugro Roadware submitted their data in the same format as the NCDOT with the exception that Fugro Roadware summarized the data in mile increments instead of the 0.2 mile increments measured by the NCDOT. This vendor also reported all of the quantities required for the survey, even those not reported in the reference survey data. Pathway's submitted data were in tenth mile increments and required averaging to compile into the single mile intervals. Pathway did not report any rating for the unpaved portion of the shoulder, nor did they report the lane to shoulder joint condition. Data were reported on the overall lane drop-off, but the reported numbers did not isolate the lane to shoulder drop-off only.

3.5.11.3. Discussion

Reference survey

- The paved and unpaved shoulder along I-40 mile marker 301 to mile marker 294 were moderately rated, all other shoulders are rated as lightly distressed
- The only section receiving a moderate drop-off rating was I-440 mile marker 16.

Pathway Services

- All shoulders are rated light except US-64-10 which is rated as moderate.

Fugro Roadware

- All shoulders and all components are rated as lightly distressed.

3.5.12. Pavement Condition Rating

3.5.12.1. Definition of Pavement Condition Rating

For the NCDOT pavement management system the above PCC distresses are combined into a single index function, the pavement condition rating (PCR). This index is defined in Equations (3.2) - (3.9).

$$PCR = 100 - C - Cb - J - S - D - P \tag{3.10}$$

Where;

C = cracking deduct index,
Cb = corner break deduct index,
J = joint seal damage deduct index,
S = spalling deduct index,
D = shoulder drop-off deduct index,
P = patching deduct index.

The general form of the C, Cb, J, and S deduct indices is as follows:

$$Deduct = L_{deduct} * \%\ Light + M_{deduct} * \%\ Moderate + S_{deduct} * \%\ Severe \tag{3.11}$$

Where;

L_{deduct} = deduct factor for light rating of given distress,
M_{deduct} = deduct factor for moderate rating of given distress,

S_{deduct} = deduct factor for severe rating of given distress,
% Light = percent of given distress rated as light,
% Moderate = percent of given distress rated as moderate,
% Severe = percent of given distress rated as severe.

The deduct factors for each of the distresses are shown in Equation (3.12) through (3.17).

$$C_{deduct} = \begin{cases} 0.20 & \text{for distress} = L - \text{ 0\% to 100\%} \\ 0.50 & \text{for distress} = \text{M} - \text{ 0\% to 60\%} \quad 0.10 \quad \text{for distress} = \text{M} - \ > 60\% \\ 0.75 & \text{for distress} = \text{S} - \text{ 0\% to 40\%} \quad 0.20 \quad \text{for distress} = \text{S} - \ > 40\% \end{cases} \tag{3.12}$$

$$Cb_{deduct} = \begin{cases} 0.10 & \text{for distress} = L - \text{ 0\% to 100\%} \\ 0.15 & \text{for distress} = \text{M} - \text{ 0\% to 100\%} \\ 0.375 & \text{for distress} = \text{S} - \text{ 0\% to 80\%} \quad 0.20 \quad \text{for distress} = \text{S} - \ > 80\% \end{cases} \tag{3.13}$$

$$J_{deduct} = \begin{cases} 0.10 & \text{for distress} = L - \text{ 0\% to 100\%} \\ 0.60 & \text{for distress} = \text{M} - \text{ 0\% to 50\%} \quad 0.10 \quad \text{for distress} = \text{M} - \ > 50\% \\ 1.00 & \text{for distress} = \text{S} - \text{ 0\% to 30\%} \quad 0.20 \quad \text{for distress} = \text{S} - \ > 30\% \end{cases} \tag{3.14}$$

$$S_{deduct} = \begin{cases} 0.15 & \text{for distress} = L - \text{ 0\% to 100\%} \\ 0.375 & \text{for distress} = \text{M} - \text{ 0\% to 80\%} \quad 0.10 \quad \text{for distress} = \text{M} - \ > 80\% \\ 0.50 & \text{for distress} = \text{S} - \text{ 0\% to 60\%} \quad 0.20 \quad \text{for distress} = \text{S} - \ > 60\% \end{cases} \tag{3.15}$$

$$D = \begin{cases} 5 & \text{for distress} = L \\ 15 & \text{for distress} = \text{M} \\ 25 & \text{for distress} = \text{S} \end{cases} \tag{3.16}$$

$$P = \begin{cases} 3.75 / patch & \text{for patch} \leq 8 \\ 1.00 / patch & \text{for patch} > 8 \end{cases} \tag{3.17}$$

3.5.12.2. Data Processing and Results

With every distress processed as mentioned above, Equations (3.10) - (3.17) were applied to each to determine the PCR values. The PCR results are shown by sections in Figure 3.82 through Figure 3.85.

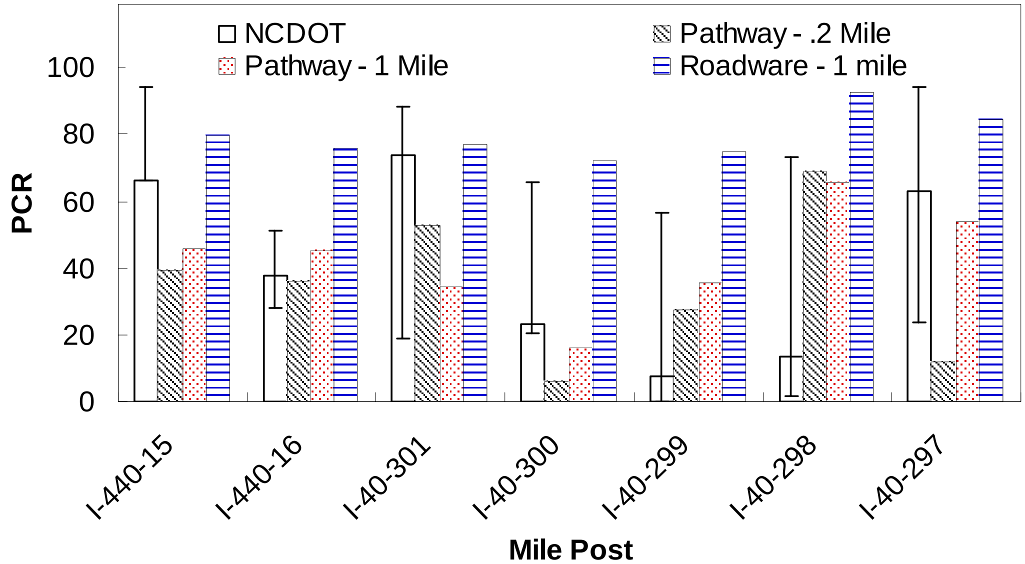


Figure 3.82. PCC-PCR for I-440/I-40 (1) sections.

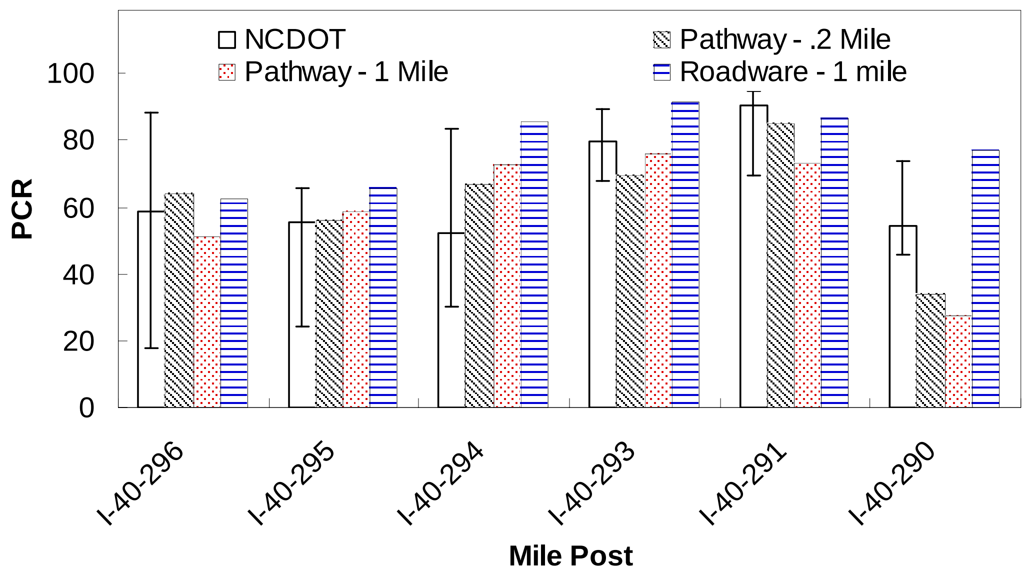


Figure 3.83. PCC-PCR for I-440/I-40 (2) sections.

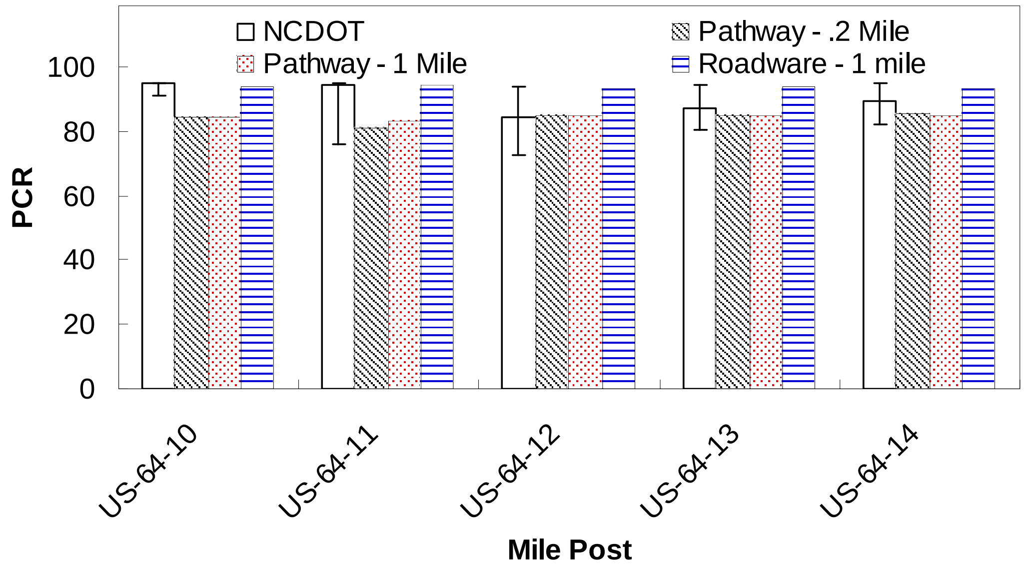


Figure 3.84. PCC-PCR for US-64 (1) sections.

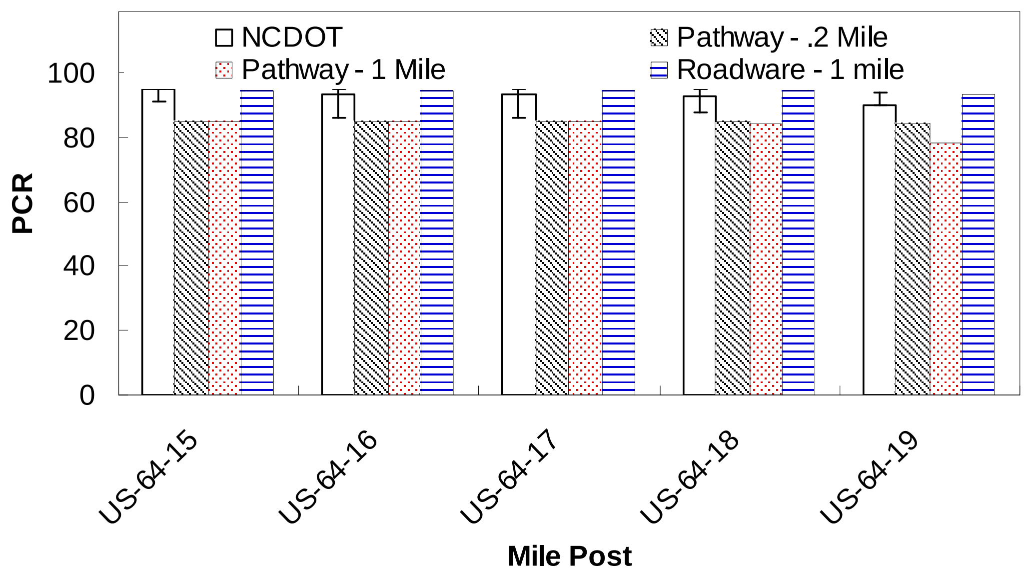


Figure 3.85. PCC-PCR for US-64 (2) sections.

3.5.12.3. Discussion

<u>Reference survey</u>

- Overall the sections along I-440 to I-40 show moderate (60-80) to severe (< 60) values.
- Sections between I-40 miles 300 and 298 show the lowest consensus PCR values which are between 10 and 20. The extreme PCR values in these sections are higher at 60-80.
- The sections immediately before and after the portion that was recently repaved with AC (I-40-293 and I-40-291) show the highest PCR values along this subinterval, 80-90.
- The US 64 sections show overall PCR values, > 85.

Pathway Services

- Overall the sections along I-440 to I-40 show moderate (60-80) to severe (< 60) values.
- Sections between I-40 miles 300 and 299 and mile 297 show the lowest PCR values which are between 10 and 20.
- The sections immediately before and after the portion that was recently repaved with AC (I-40-293 and I-40-291) show the highest PCR values along this subinterval, 70-80.
- The US 64 sections show overall PCR values, > 80.

Fugro Roadware

- Overall the sections along I-440 to I-40 show high moderate (70-80) to moderate (60-80) values.
- Sections between I-40 miles 296 and 295 show the lowest PCR values, approximately 65.
- The sections immediately before and after the portion that was recently repaved with AC (I-40-293 and I-40-291) and section I-40-98 show the highest PCR values along this subinterval at approximately 90.
- The US 64 sections show overall PCR values, > 90.

3.5.13. NCDOT Portland Cement Concrete Survey Summary

The following are the key observations made from the NCDOT Portland cement concrete survey:

- Pathway tends to overstate patching along the test course.
- Fugro Roadware tends to understate the patching along the test course.
- Vendors did not tend to report false negative pumping values.
- Vendor ratings for surface wear have a very poor match with the reference survey ratings.
- For the PCC survey, IRI based ride quality criteria do not match the NCDOT ride quality definition well.
- Vendor counted longitudinal cracking had an inconsistent comparison with the reference survey data, but vendor data reported only a very few false positives.
- The vendor counted values for transverse cracking and corner breaks was generally good, but overall neither was observed in large quantity along the test course.
- Overall the vendor counted and NCDOT measured spalling agree, with a slight difference in spalling severity by both vendors.
- Vendor counted joint seal damage had an overall poor, but inconsistent comparison with the reference survey data.
- High variability in the reference survey joint seal damage is observed.
- The overall vendor and reference survey shoulder ratings are similar, but for the test course the overall shoulder rating is good.
- Overall the vendor calculated and reference survey calculated PCC-PCR values agree although there is a lot of variability in the reference survey data.
- Some slight tendency to underestimate the consensus reference survey PCR value is observed with Pathway.
- Some slight tendency to underestimate the consensus reference survey PCR value is observed with Fugro Roadware.

3.6. LTPP Asphalt Concrete Survey

In the following sections the key components of the LTPP survey elements; cracking, patching and potholes, surface deformation, and surface defects, are discussed in detail. Comparisons are drawn between the vendor submitted data and the NCDOT reference surveys for three 500 foot sections. It is noted that the personnel who carried out the LTPP reference survey had no formal experience with the LTPP survey protocols. These surveyors are part of the NCDOT crews which routinely carry out the windshield surveys. The methodologies given in the LTPP Survey Handbook (Miller and Bellinger 2003) were followed as closely as possible by these personnel.

3.6.1. Cracking

3.6.1.1. Definition of Distresses

For the cracking elements in the AC-LTPP distress survey there are five different components; fatigue cracking, block cracking, edge cracking, longitudinal cracking, and transverse cracking. The first three components are reported by severity and area, which are defined for each in the following paragraphs. Fatigue cracks occur in areas subjected to repeated traffic loadings (wheel paths) and can be a series of interconnected cracks in the early stages of development. Higher degrees of severity show many-sided, sharp-angled pieces, usually less than 1.0 ft on the longest side, characteristically with a chicken wire/alligator pattern, in later stages. To be considered as a fatigue crack there must be a quantifiable area. Block cracking is a pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 1.1 ft^2 to 110 ft^2. Edge cracking applies only to pavements with unpaved shoulders. These cracks are typically crescent-shaped or fairly continuous cracks which intersect the pavement edge and are located within 2.0 ft of the pavement edge, adjacent to the shoulder. This cracking includes longitudinal cracks outside of the wheel path and within 2.0 ft of the pavement edge.

<u>Fatigue Cracking</u>

Low: An area of cracks with no or only a few connecting cracks; cracks are not spalled or sealed; pumping is not evident.

Moderate: An area of interconnected cracks forming a complete pattern; cracks may be slightly spalled; cracks may be sealed; pumping is not evident.

High: An area of moderately or severely spalled interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; pumping may be evident.

Note: If different severity levels existing within an area cannot be distinguished, rate the entire area at the highest severity present.

<u>Block Cracking</u>

Low: Cracks with a mean width ≤ 0.25 inch (in); or sealed cracks with sealant material in good condition and with a width that cannot be determined.

Moderate: Cracks with a mean width > 0.25 in and ≤ 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent low severity random cracking.

High: Cracks with a mean width > 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent moderate to high severity random cracking.

Note: If fatigue cracking exists within the block cracking area, the area of block cracking is reduced by the area of fatigue cracking.

Note: An occurrence should be at least 50 ft before rating as block cracking.

Edge Cracking

Low: Cracks with no breakup or loss of material.

Moderate: Cracks with some breakup and loss of material for up to 10 percent of the length of the affected portion of the pavement.

High: Cracks with considerable breakup and loss of material for more than 10 percent of the length of the affected portion of the pavement.

Note: The combined quantity of edge cracking cannot exceed the length of the section.

Longitudinal and transverse cracking are reported by length and severity. Longitudinal cracks are those cracks which are predominantly parallel to the pavement centerline and transverse cracks are those cracks which are predominantly perpendicular to the pavement centerline. For these cracking distresses the sealed and unsealed cracking are differentiated. Also for the longitudinal cracking the distress is separated by wheel path and non-wheel path locations. The definitions applied for the severity are:

Longitudinal Cracking

Low: A crack with a mean width ≤ 0.25 in; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Moderate: Any crack with a mean width > 0.25 in and ≤ 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent low severity random cracking.

High: Any crack with a mean width > 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent moderate to high severity random cracking.

Note: Any wheel path longitudinal crack that has associated random cracking is rated as fatigue cracking. Any wheel path longitudinal crack that meanders and has a quantifiable area is rated as fatigue cracking.

Transverse Cracking

Low: An unsealed crack with a mean width ≤ 0.25 in; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Moderate: Any crack with a mean width > 0.25 in and ≤ 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent low severity random cracking.

High: Any crack with a mean width > 0.75 in; or any crack with a mean width ≤ 0.75 in and adjacent moderate to high severity random cracking.

Note: The length recorded is the total length of the well-sealed crack and is assigned to the severity level of the crack. Record only when the sealant is in good condition for at least 90 percent of the length of the crack.

Note: If the transverse crack extends through an area of fatigue cracking, the length of the crack within the fatigue area is not counted. The crack is treated as a single transverse crack, but at a reduced length.

Note: Cracks less than 1.0 ft in length are not recorded.

3.6.1.2. Data Analysis and Results

Results from the AC-LTPP survey for the three reference survey sections are shown in Figure 3.86 through Figure 3.95. Note that sealed, non-wheel path longitudinal cracking is not shown since there was no consensus cracking observed and since only Fugro Roadware measured a small amount along the US-64 section. Also note that to compute an apparent area for the edge, longitudinal and transverse cracking a width of 0.98 ft (0.3 m) is assumed.

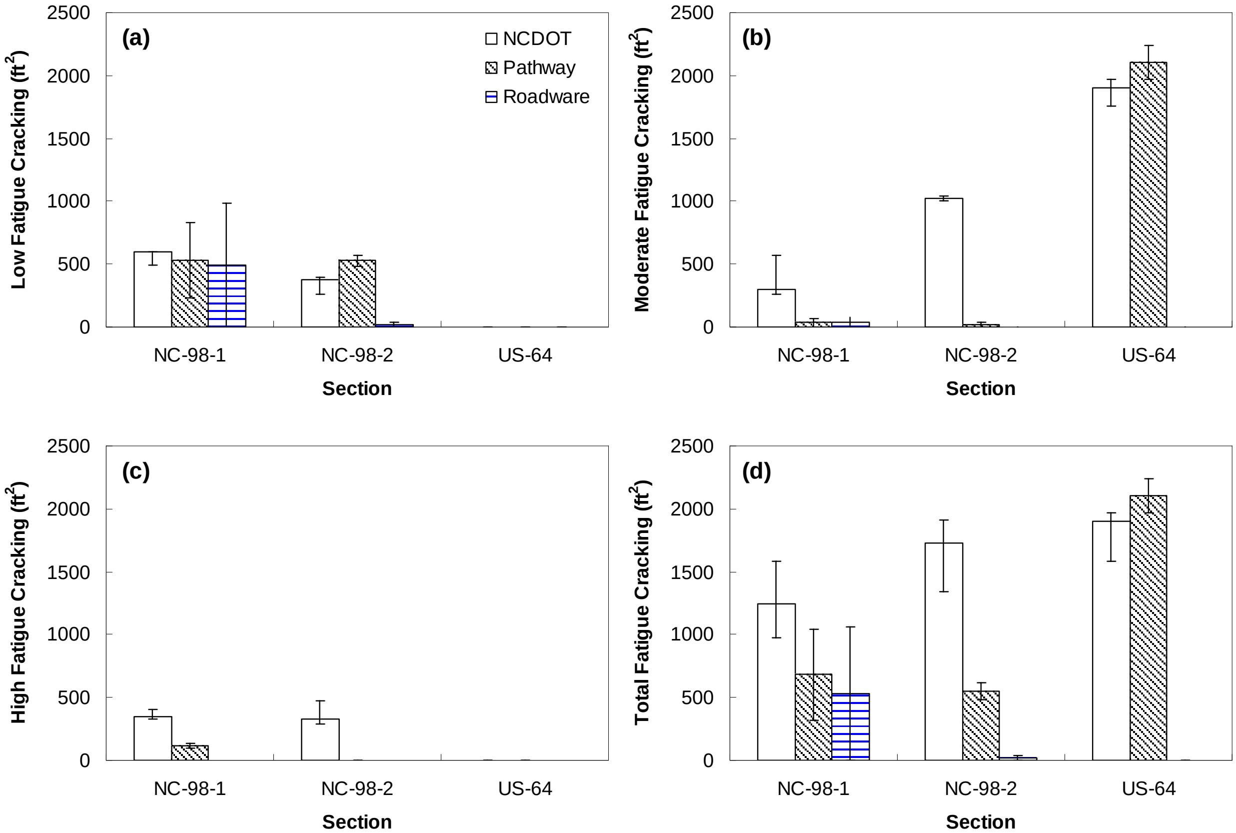


Figure 3.86. Fatigue cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

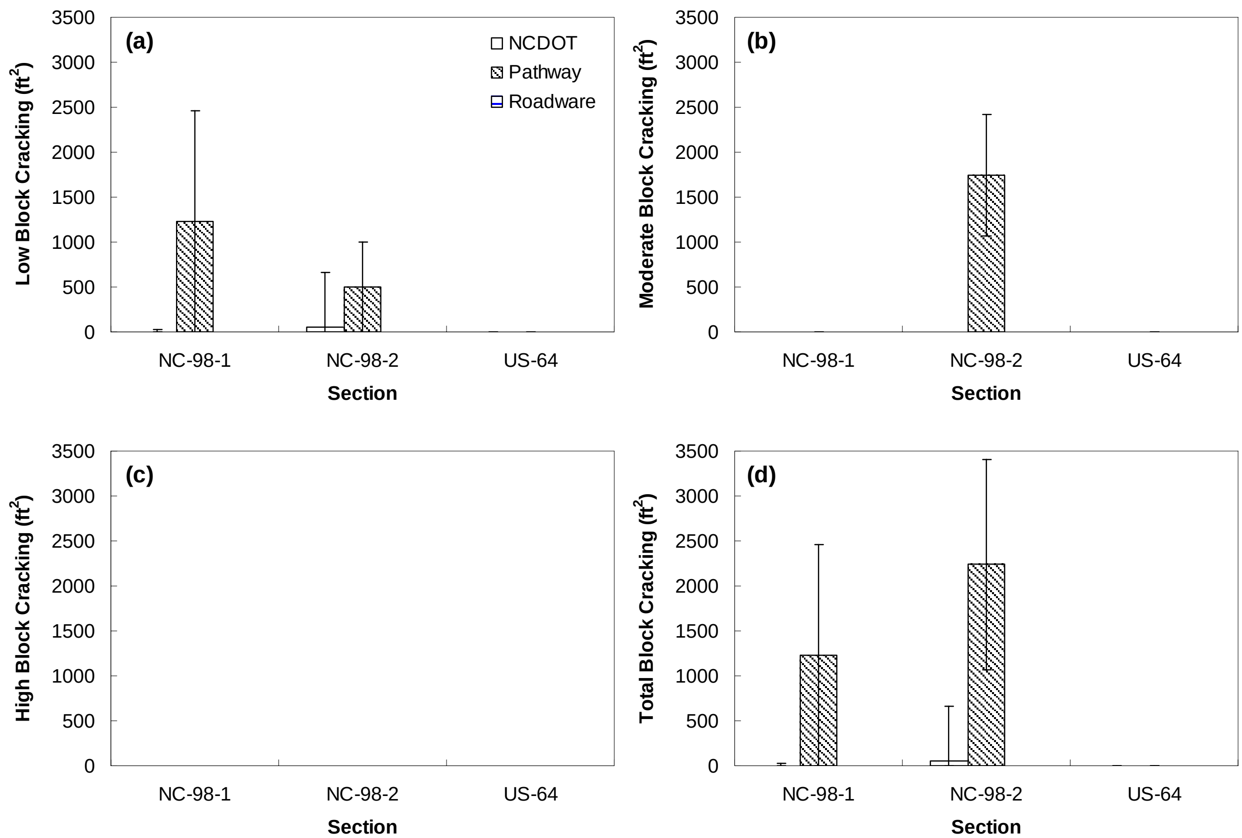


Figure 3.87. Block cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

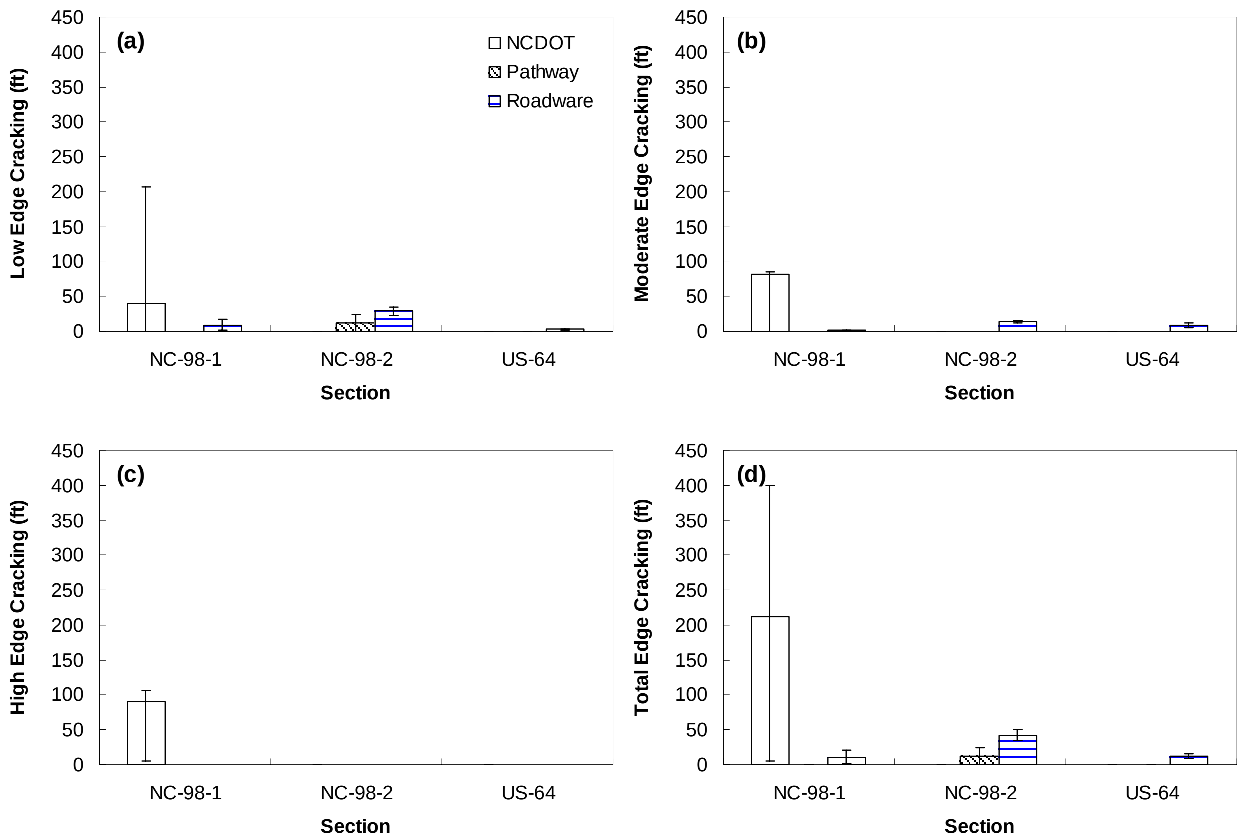


Figure 3.88. Edge cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

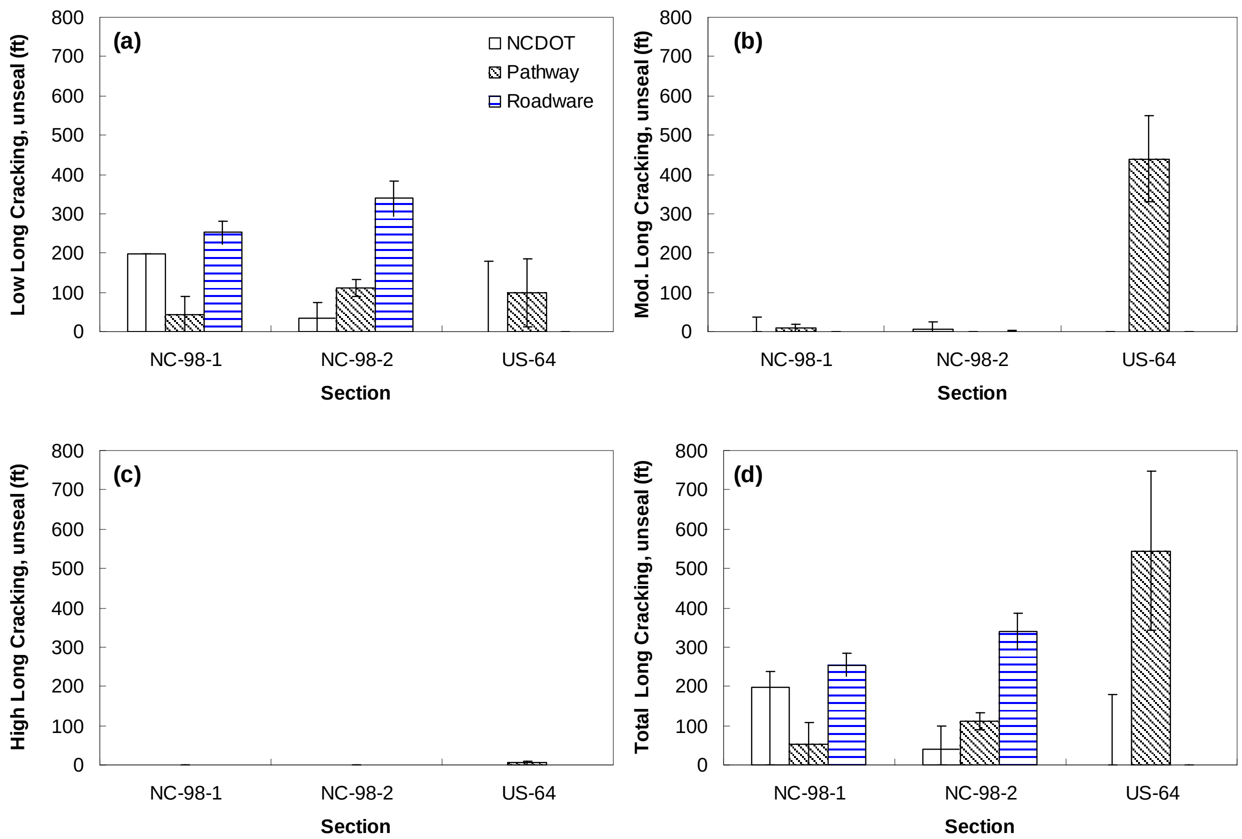


Figure 3.89. Unsealed wheel path only longitudinal cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

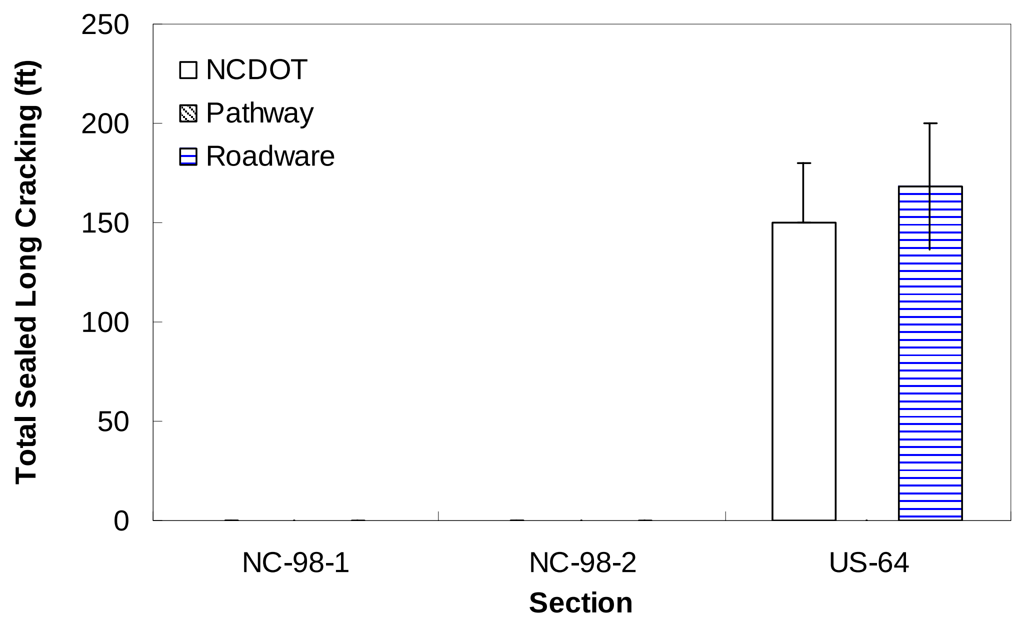


Figure 3.90. Total sealed wheel path only longitudinal cracking for three reference survey sections of AC-LTPP survey.

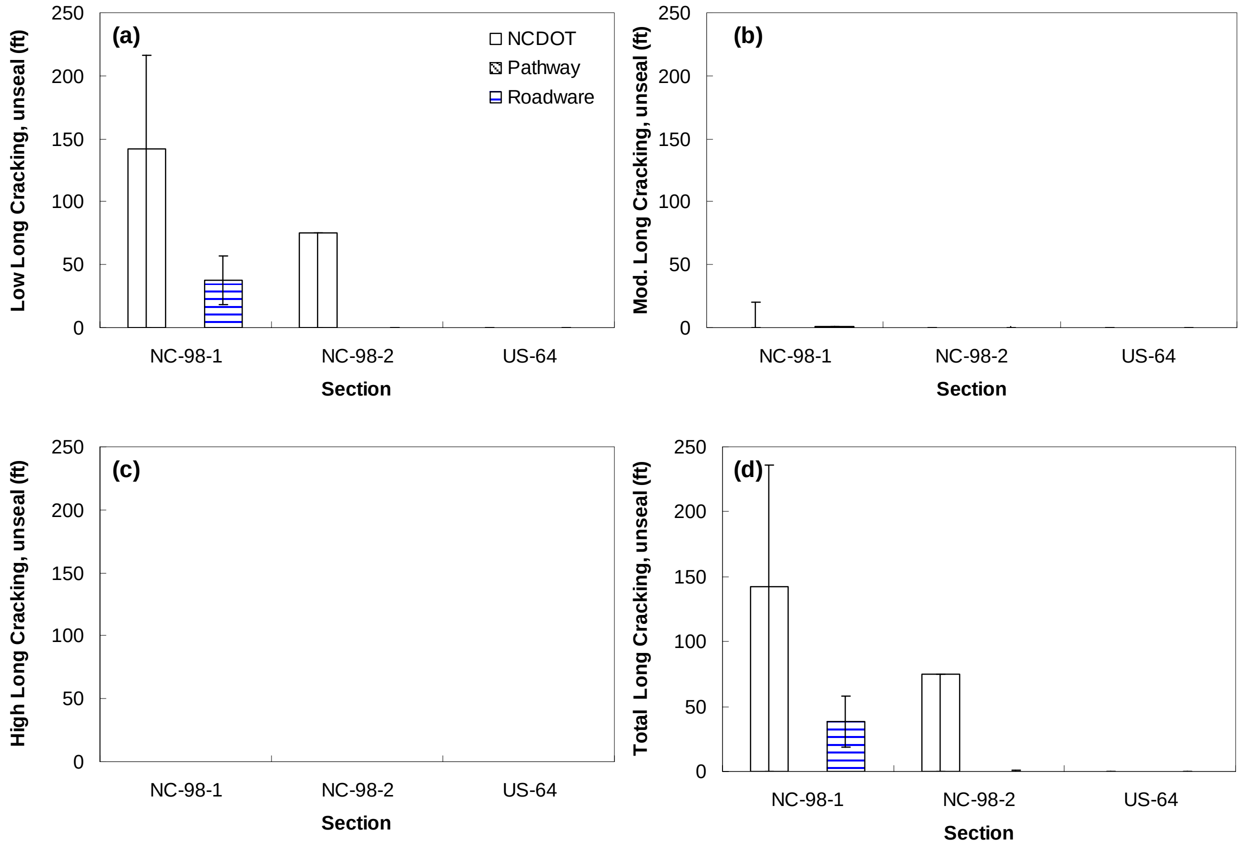


Figure 3.91. Unsealed non-wheel path only longitudinal cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

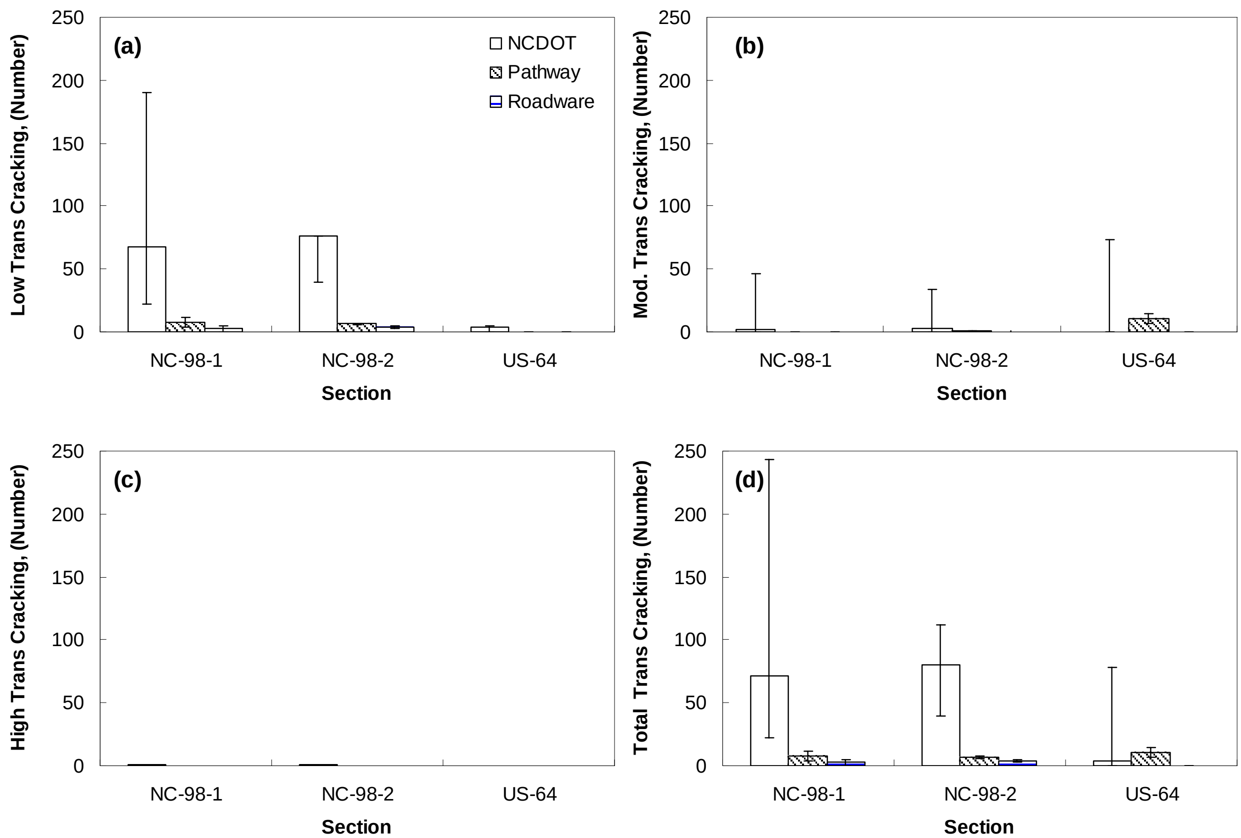


Figure 3.92. Transverse cracking counts for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

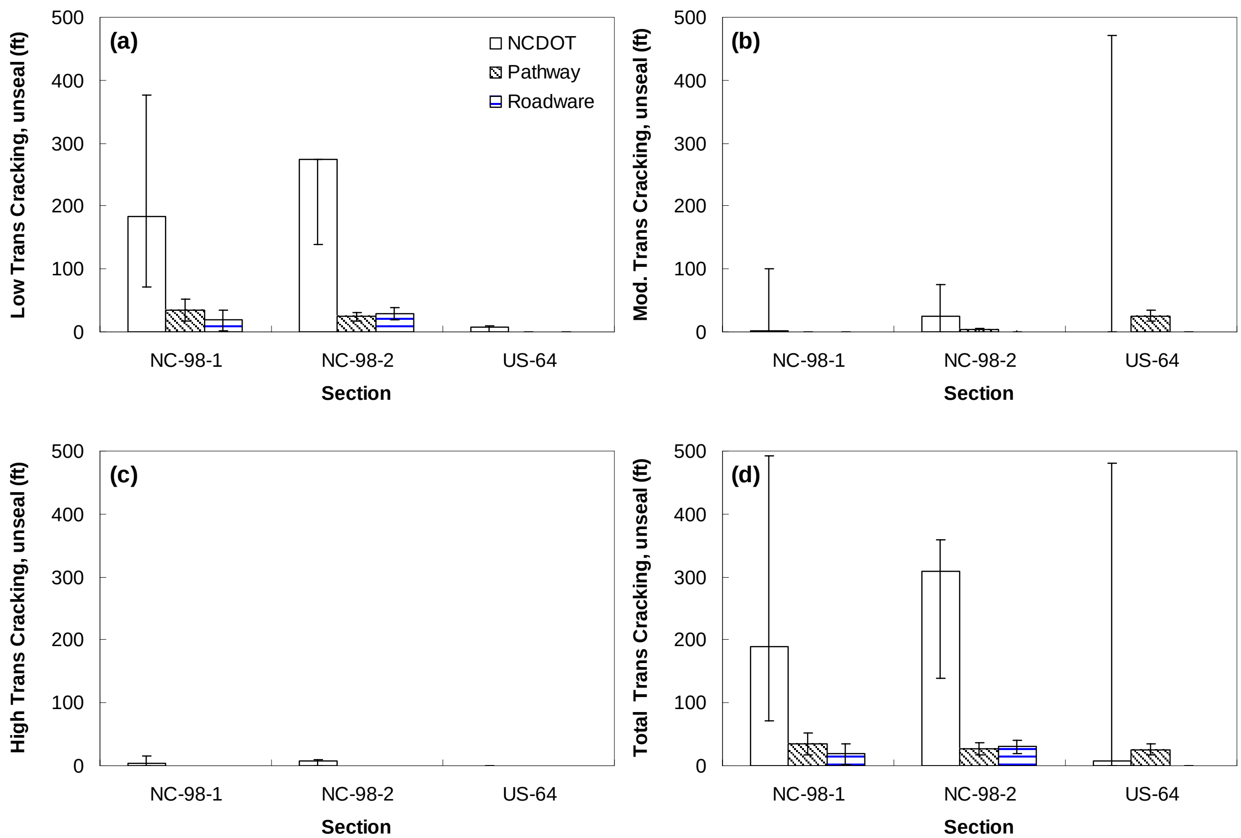


Figure 3.93. Unsealed transverse cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

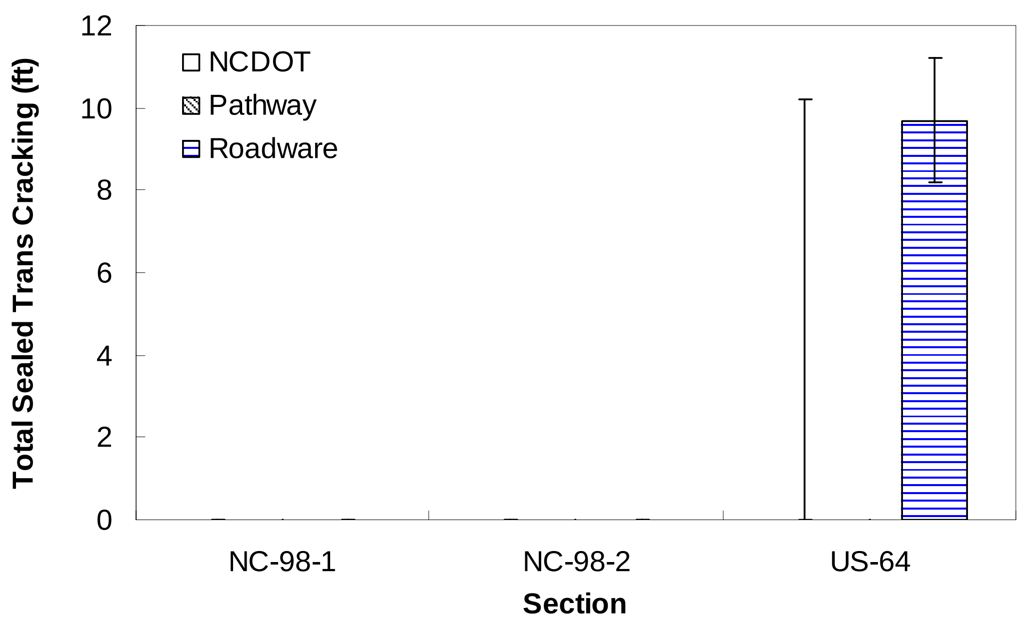


Figure 3.94. Total sealed transverse cracking for three reference survey sections of AC-LTPP survey.

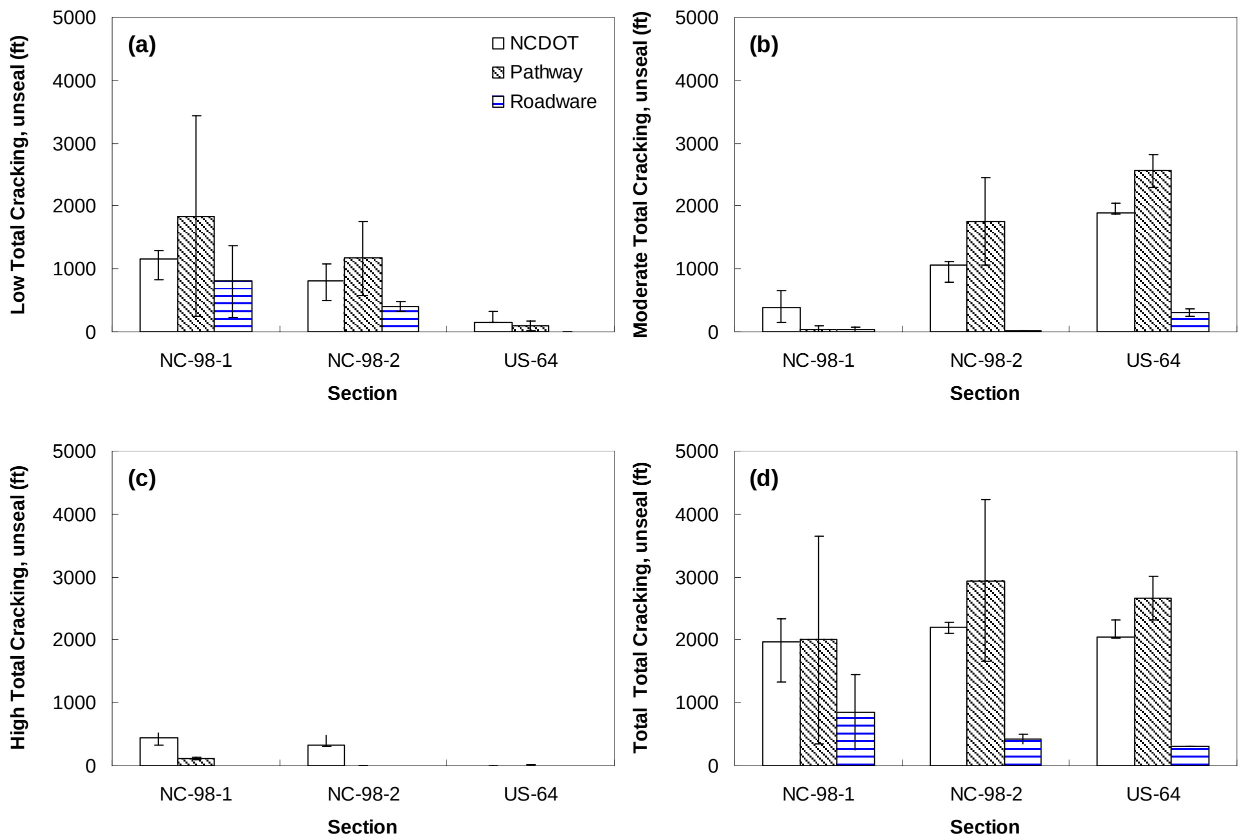


Figure 3.95. Total unsealed cracking ratings for three reference survey sections of AC-LTPP survey; (a) low, (b) moderate, (c) high, and (d) total.

3.6.1.3. Discussion

Reference survey

- All sections show some fatigue cracking.
- The US-64 test section shows the highest total concentration of fatigue cracking, this cracking is all moderate severity.
- The two NC-98 sections show almost equal low and high severity cracking, but NC-98-2 shows more moderate fatigue cracking.
- No notable block cracking is observed on any of the sections.
- An approximately equal mix of low, moderate and high severity edge cracking is observed on NC-98-1.
- The two NC-98 sections show almost entirely low severity wheel path longitudinal cracking with NC-98-1 showing the highest amount. No consensus longitudinal cracking is noted on US-64.
- Sealed longitudinal cracks are observed on the US-64 test section.
- Non-wheel path longitudinal cracking is observed on the NC-98 test sections.
- Notable transverse cracks are counted on the NC-98 test sections, but little is observed on the US-64 section.
- The greatest amount of overall cracking is observed in NC-98-2 followed by US-64 and then by NC-98-1.

- Total observed cracking is dominated by fatigue cracking.

Pathway

- Fatigue cracking is counted on all sections.
- The US-64 test section shows the highest total concentration of fatigue cracking, this cracking is all moderate severity.
- The two NC-98 sections show almost equal low severity cracking and almost no moderate severity cracking, some high severity cracking is counted on NC-98-1.
- Substantial block cracking is counted on the two NC-98 sections.
- A slight amount of edge cracking is counted on NC-98-2.
- Small amounts of low severity longitudinal cracking are counted on the three test sections.
- A relatively large amount of moderate severity longitudinal cracking is counted on the US-64 section.
- A small number/amount of transverse cracking is counted on every test section.
- The calculated total cracking is found to be the largest for NC-98-2 followed by US-64 and finally NC-98-1.
- The total counted cracking is dominated by block cracking.

Fugro Roadware

- Low severity fatigue cracking is counted on NC-98-1.
- A very slight amount of low severity fatigue cracking is counted on NC-98-1.
- No fatigue cracking is counted on the US-64 section.
- No notable block cracking is counted on any of the sections.
- Slight amounts of edge cracking are counted on every test section.
- Low severity wheel path longitudinal cracking is counted on both NC-98 test sections.
- Sealed longitudinal cracks are counted on the US-64 sections.
- Low severity non-wheel path longitudinal cracking is observed for NC-98-1.
- Small amounts of transverse cracking are counted on the two NC-98 test sections.
- No notable total cracking is counted for US-64.
- The total counted cracking is greatest for NC-98-1 followed by NC-98-2.
- The majority of counted cracking is longitudinal or fatigue.

3.6.2. Patching and Potholes

3.6.2.1. Definition of Distresses

For the patching and potholes element the AC-LTPP survey consists of four components; patch count by severity, patch deterioration by area and severity, pothole count by severity and pothole deterioration by area and severity. A patch is noted when a portion of the pavement surface, greater than 1.1 ft^2, has been removed and replaced or additional material has been applied to the pavement after original construction. A pothole is defined as a bowl-shaped hole of various sizes in the pavement surface with a minimum plan dimension of 6 in. The definitions used for the pothole and patching severities are:

Patching

Low: Patch has, at most, low severity distress of any type including rutting < 0.25 in; pumping is not evident.

Moderate: Patch has moderate severity distress of any type or rutting from 0.25 in to 0.50 in; pumping is not evident.

High: Patch has high severity distress of any type including rutting > 0.50 in, or the patch has additional different patch material within it; pumping may be evident.

Note: Any distress in the boundary of the patch is included in rating the patch. Rutting (settlement) may be at the perimeter or interior of the patch.

Pothole

Low: < 1.0 in deep.

Moderate: 1.0 in to 2.0 in deep.

High: > 1.0 in deep.

Note: Pothole depth is the maximum depth below pavement surface.

Note: If pothole occurs within an area of fatigue cracking the area of fatigue cracking is reduced by the area of the pothole.

3.6.2.2. Data Analysis and Results

No observations of note are made with regards to patching and pothole distresses. Neither the reference survey data nor the vendor data show significant values.

3.6.3. Surface Deformation

3.6.3.1. Definition of Distresses

The surface deformation element of the AC-LTPP survey consists of three components; rutting by depth by 50 ft increments, shoving count, and shoving extent in square feet but not by severity. A rut is a longitudinal surface depression in the wheel path. It may have associated transverse displacement. Shoving is a longitudinal displacement of a localized area of the pavement surface. It is generally caused by braking or accelerating vehicles, and is usually located on hills or curves, or at intersections. It also may have associated vertical displacement. Note that for the reference survey survey; rutting was measured using the tape measure and straight-edge method.

3.6.3.2. Data Analysis and Results

Results from the survey of rutting distress is shown in Figure 3.96(a) for the left wheel path and Figure 3.96(b) for the right wheel path. No observations of note are made with regards to shoving. Neither the reference survey data nor the vendor data show that this distress is present.

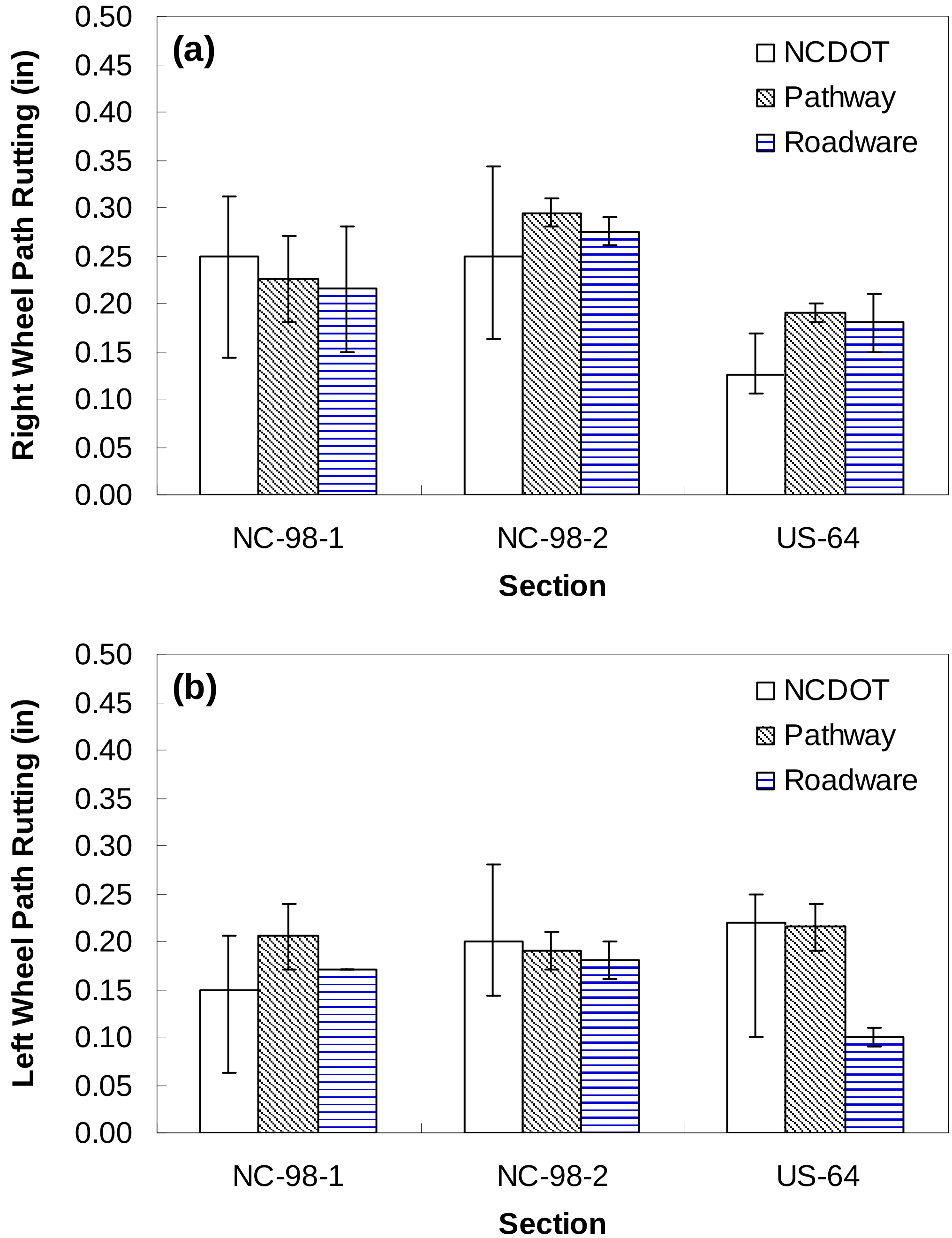


Figure 3.96. Rutting for three reference survey sections of AC-LTPP survey; (a) right wheel path and (b) left wheel path.

3.6.3.3. Discussion

Reference survey

- The average consensus left wheel path rutting is highest for US-64 (0.220), followed by NC-98-2 (0.200) and NC-98-1 (0.150).
- The average consensus right wheel path rutting is highest for the NC-98 sections (0.250) and the lowest for US-64 (0.125).

Pathway

- The average left wheel path rutting is highest for US-64 (0.215 in), followed by NC-98-1 (0.205 in) and NC-98-2 (0.190 in).
- The average right wheel path rutting is highest for the NC-98-2 section (0.295 in), followed by the NC-98-1 section (0.225 in) and the lowest for US-64 (0.190 in).

Fugro Roadware

- The average left wheel path rutting is highest for NC-98-2 (0.192 in), followed by NC-98-1 (0.171 in) and US-64 (0.087 in).
- The average right wheel path rutting is highest for the NC-98-2 section (0.293 in), followed by the NC-98-1 section (0.203 in) and the lowest for US-64 (0.150 in).

3.6.4. Surface Defects

3.6.4.1. Definition of Distresses

The surface defects element of the AC-LTPP survey consists of three components each measured by the extent of the distress in square feet. The three components for this element are; asphalt bleeding, polished aggregate and raveling. Bleeding is characterized by excess bituminous binder occurring on the pavement surface, usually found in the wheel paths. The distress may range from a surface discolored relative to the remainder of the pavement, to a surface that is losing surface texture because of excess asphalt, to a condition where the aggregate may be obscured by excess asphalt possibly with a shiny, glass-like, reflective surface that may be tacky to the touch. Polishing is noted when the surface binder is worn away to expose coarse aggregate. Raveling is the wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder. This distress ranges from the loss of fines to loss of some coarse aggregate and ultimately to a very rough and pitted surface with obvious loss of aggregate.

Preventative maintenance treatments (slurry seals, chip seals, fog seals, etc.) sometimes exhibit bleeding characteristics. These occurrences should be noted, but not rated as bleeding. Polished aggregate should not be rated on test sections that have received a preventive maintenance treatment that has covered the original pavement surface. Raveling should not be rated on chip seals.

3.6.4.2. Data Analysis and Results

Of the distresses constituting the surface defect element, only raveling was measured on the test sections and the results are summarized in Figure 3.97.

3.6.4.3. Discussion

Reference survey

- Raveling is observed only on the US-64 section

Pathway

- The highest raveling is observed on NC-98-1, followed by NC-98-2 and finally US_64.

Fugro Roadware

- A very slight amount of raveling is counted on NC-98-2.

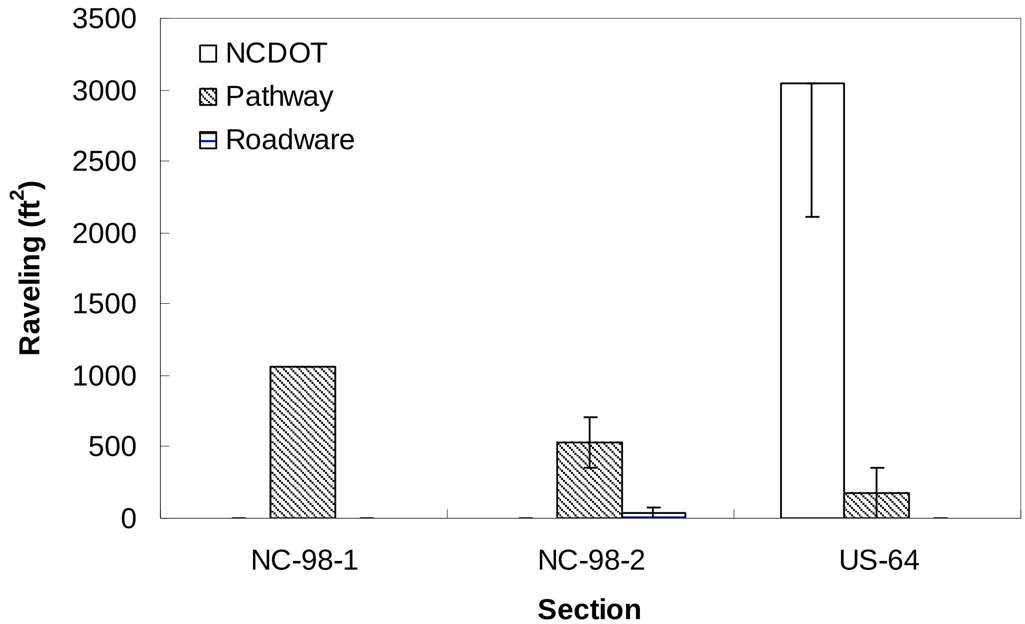


Figure 3.97. Raveling for three reference survey sections of AC-LTPP survey

3.6.5. Miscellaneous Distresses

3.6.5.1. Definition of Distresses

Two additional components are measured as part of the AC-LTPP survey and are combined under the generic term miscellaneous distress. These two components are number of sections where water bleeding and pumping occur at a length of greater than 3.28 ft and the length of water bleeding and pumping areas. Note that the total length of water bleeding and pumping cannot exceed the section length. These areas are characterized by the seeping or ejection of water from beneath the pavement through cracks. In some cases, detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

3.6.5.2. Data Analysis and Results

No observations of note are made with regards to water bleeding and pumping. Neither the reference survey data nor the vendor data any observed distress for the reference survey sections.

3.6.6. Course Summary

For completeness the vendor data have been compiled by course interval and are summarized in Table 3.7 for Pathway and Table 3.8 for Fugro Roadware. Elements not reported by the vendor are noted with a dash line. Also the elements in these tables represent the total observed distress except rutting which is the average over the entire subinterval.

Table 3.7. Summary of total AC-LTPP Survey for Pathway.

Data Element	Unit	I-40	Wade Ave.	I-440	US-70	I-540	US-1	NC-98	NC-39	US-64
Cracking Elements										
Fatigue Cracking	ft^2	0.0	1508.7	2593.9	2700.8	9425.0	392.6	57058.5	16338.7	91324.4
Block Cracking	ft^2	6093.5	0.0	0.0	18344.1	0.0	0.0	45158.9	194380.5	23655.8
Edge Cracking	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	467.9	534.7	0.0
Unsealed Long. Cracking (Wheel Path)	ft.	0.0	880.6	7950.4	12225.9	12835.6	3142.2	7394.2	4274.8	39482.3
Sealed Long. Cracking (Wheel Path)	ft.	--	--	--	--	--	--	--	--	--
Unsealed Long. Cracking (Non-Wheel Path)	ft.	--	--	--	--	--	--	--	--	--
Sealed Long. Cracking (Non-Wheel Path)	ft.	--	--	--	--	--	--	--	--	--
Transverse Cracking Count	No.	0.0	25.0	257.0	391.0	355.0	18.0	1731.0	1681.0	722.0
Unsealed Trans. Cracking Condition	ft.	0.0	110.2	1347.6	2085.4	2740.8	162.8	6898.8	6939.0	1672.9
Sealed Trans. Cracking Condition	ft.	--	--	--	--	--	--	--	--	--
Patching and Pothole Elements										
Patch Count	No.	0.0	2.0	1.0	7.0	0.0	2.0	61.0	3.0	6.0
Patch Deterioration	ft^2	0.0	75.0	3.7	198.1	0.0	32.8	3776.1	230.6	314.8
Pothol Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pothole Deterioration	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Deformation										
Rutting	in	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.3	0.2
Shoving Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shoving Extent	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Defects										
Bleeding	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polished Aggregate	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Raveling	ft^2	354.3	3879.2	4228.6	20805.2	2817.9	1057.6	31345.8	12355.2	7764.3
Miscellaneous Distresses										
Water Bleeding and Pumping Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Bleeding and Pumping Deterioration	ft.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.8. Summary of total AC-LTPP Survey for Fugro Roadware.

Data Element	Unit	I-40	Wade Ave.	I-440	US-70	I-540	US-1	NC-98	NC-39	US-64
Cracking Elements										
Fatigue Cracking	ft^2	2574.0	0.0	0.0	39.0	20.0	0.0	7247.5	3191.5	0.0
Block Cracking	ft^2	0.0	0.0	0.0	18418.9	0.0	0.0	0.0	0.0	0.0
Edge Cracking	ft^2	686.0	62.5	1363.3	8854.8	2038.5	782.5	2134.1	1145.5	2033.2
Unsealed Long. Cracking (Wheel Path)	ft.	1795.0	399.2	808.4	971.3	1953.7	1095.6	24923.3	0.0	61.0
Sealed Long. Cracking (Wheel Path)	ft.	0.0	0.0	0.0	0.0	0.0	0.0	108.4	17830.3	7427.2
Unsealed Long. Cracking (Non-Wheel Path)	ft.	687.4	456.0	2607.1	3301.0	4955.0	2728.4	6053.9	0.0	89.3
Sealed Long. Cracking (Non-Wheel Path)	ft.	0.0	0.0	0.0	0.0	0.0	0.0	62.0	3268.1	5129.5
Transverse Cracking Count	No.	2.0	1.0	17.0	103.0	49.0	6.0	402.0	0.0	0.0
Unsealed Trans. Cracking Condition	ft.	22.5	8.4	140.0	735.6	431.2	74.5	2619.0	0.0	3.0
Sealed Trans. Cracking Condition	ft.	0.0	0.0	0.0	0.0	0.0	0.0	146.7	6738.9	516.5
Patching and Pothole Elements										
Patch Count	No.	0.0	7.0	0.0	6.0	1.0	9.0	37.0	7.0	18.0
Patch Deterioration	ft^2	0.0	235.8	0.0	140.8	4.5	37.6	491.4	46.0	124.3
Pothol Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pothole Deterioration	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Deformation										
Rutting	in	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.1
Shoving Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shoving Extent	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Defects										
Bleeding	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polished Aggregate	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Raveling	ft^2	0.0	0.0	0.0	0.0	0.0	0.0	191.3	0.0	0.0
Miscellaneous Distresses										
Water Bleeding and Pumping Count	No.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Bleeding and Pumping Deterioration	ft.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3.6.7. LTPP Asphalt Concrete Survey Summary

The following are the key observations made from the LTPP asphalt concrete survey:

- The Fugro Roadware count of fatigue cracking is smaller than the reference survey measured fatigue cracking.
- The Pathway count of fatigue cracking is smaller than the reference survey measured fatigue cracking for the two NC-98 sections, but similar for the US-64 section.
- Overall the vendor data for edge cracking, longitudinal cracking and transverse cracking are smaller than the reference survey measured data.
- Pathway over counts the block cracking on the test sections.
- Overall the total cracking, at all severity levels, measured by NCDOT and Pathway matches well, with a slightly higher count from Pathway.
- The total cracking count from Fugro Roadware is smaller than the reference survey measured values.
- Overall, the rutting depths from the reference survey data and vendor data agree.
- The counted raveling distress does not match well with the vendor data.

3.7. LTPP Portland Cement Concrete Survey

3.7.1. Cracking

3.7.1.1. Definition of Distresses

For the cracking elements in the PCC-LTPP distress survey there are four different components; corner breaks, durability or “D” cracking, longitudinal cracking, and transverse cracking. Each of these distresses are reported by severity and extent in either number, length or the number of slabs showing the given distress. Corner breaks occur when a portion of the slab is separated by a crack, which intersects the adjacent transverse and longitudinal joints at an approximately 45° angle with the direction of traffic. The length of the sides of this break varies from approximately 1 ft to one-half the width of the slab on each side of the corner. Durability cracks are associated with closely spaced crescent-shaped hairline cracking pattern that occur adjacent to joints, cracks, or free edges; initiating in slab corners. These cracks are also characterized by dark coloring of the cracking pattern and surrounding area. Longitudinal cracks are those generally parallel to the travel direction while transverse cracks are those generally perpendicular to the travel direction. For these cracking distresses the sealed and unsealed cracking are differentiated. Also for the transverse cracking the number of transverse cracks is counted in addition to the length of cracking.

Corner Breaks

Low: Crack is not spalled for more than 10 percent of the length of the crack; there is no measurable faulting; and the corner piece is not broken into two or more pieces and has no loss of material and no patching.

Moderate: Crack is spalled at low severity for more than 10 percent of its total length; or faulting of crack or joint is < 0.5 in; and the corner piece is not broken into two or more pieces.

High: Crack is spalled at moderate to high severity for more than 10 percent of its total length; or faulting of the crack or joint is ≥ 0.5 in; or the corner piece is broken into two or more pieces or contains patch material. If the boundaries of the corner break are visible, then also rate as a high severity corner break.

Note: If different severity levels existing within an area cannot be distinguished, rate the entire area at the highest severity present.

Durability Cracking

Low: "D" cracks are tight, with no loose or missing pieces, and no patching is in the affected area.

Moderate: "D" cracks are well-defined, and some small pieces are loose or have been displaced.

High: "D" cracking has a well-developed pattern, with a significant amount of loose or missing material. Displaced pieces, up to 1.1 ft2, may have been patched.

Longitudinal Cracking

Low: Crack widths < 0.12 in, no spalling and no measurable faulting; or well-sealed and with a width that cannot be determined.

Moderate: Crack widths ≥ 0.12 in and < 0.5 in; or with spalling < 3.0 in; or faulting up to 0.5 in.

High: Crack widths ≥ 0.5 in; or with spalling ≥ 3 in; or faulting ≥ 0.5 in.

Transverse Cracking

Low: Crack widths < 0.12 in, no spalling and no measurable faulting; or well-sealed and the width cannot be determined.

Moderate: Crack widths ≥ 0.12 in and < 0.25 in; or with spalling < 3.0 in; or faulting up to 0.25 in.

High: Crack widths ≥ 0.25 in; or with spalling ≥ 3.0 in; or faulting ≥ 0.25 in.

3.7.1.2. Discussion

Pathway Services

- Submitted data did not include sealed crack lengths.

Fugro Roadware

- Did not separate sealed crack lengths by severity.

3.7.2. Joint Deficiencies

3.7.2.1. Definition of Distresses

Four specific joint deficiencies are quantified in the PCC-LTPP survey; transverse joint seal damage, longitudinal joint seal damage, longitudinal joint seal spalling, and transverse joint seal spalling. Joint seal damage (both longitudinal and transverse) is any condition which enables incompressible materials or water to infiltrate the joint from the surface. Typical types of joint seal damage are:

- Extrusion, hardening, adhesive failure (bonding), cohesive failure (splitting), or complete loss of sealant.
- Intrusion of foreign material in the joint.
- Weed growth in the joint.

For the survey it is noted whether or not the transverse joints are sealed and if they are the number at each severity level is also recorded. The severity level definitions are:

Transverse Joint Seal Damage

Low: Joint seal damage as described above exists over less than 10 percent of the joint.

Moderate: Joint seal damage as described above exists over 10-50 percent of the joint.
High: Joint seal damage as described above exists over more than 50 percent of the joint.

The number of sealed longitudinal joints are recorded along with the total sealed length, but not separated by severity. Only individual seals longer than approximately 3 ft are counted. Transverse and longitudinal joint spalling consists of cracking, breaking, chipping, or fraying of slab edges within approximately 1.0 ft of the face of the transverse joint. The area of spalling is recorded by the severity levels defined below. For longitudinal spalling the numbers of spalled joints are also recorded by severity.

Joint Spalling
Low: Spalls < 3 in wide, measured to the face of the joint, with loss of material, or spalls with no loss of material and no patching.
Moderate: Spalls 3 in to 6 in wide, measured to the face of the joint, with loss of material.
High: Spalls > 6 in wide, measured to the face of the joint, with loss of material or is broken into two or more pieces or contains patch material.

3.7.2.2. Discussion
Pathway Services
- Did not report the number of sealed longitudinal joints.

3.7.3. Surface Defects

For the PCC-LTPP survey three surface defects are identified; map cracking, scaling and polished aggregate. Map cracks are a series of cracks that extend only into the upper surface of the slab. Larger cracks frequently are oriented in the longitudinal direction of the pavement and are interconnected by finer transverse or random cracks. Scaling is the deterioration of the upper concrete slab surface, normally 0.12 in to 0.5 in, and may occur anywhere over the pavement. For both map cracking and scaling, the number of occurrences and area are recorded. Polished aggregates are noted when surface mortar and texturing are worn away to expose coarse aggregate. Diamond grinding also removes the surface mortar and texturing. However, this condition should not be recorded as polished aggregate, but instead, be noted by a comment. The area of polished aggregate is recorded.

3.7.4. Miscellaneous Distresses

3.7.4.1. Definition of Distresses
The PC-LTPP survey identifies six additional distresses; blowups, faulting of transverse joints and cracks, lane to shoulder drop-off, lane-to-shoulder separation, patching and water bleeding and pumping. Blowups occur when there is a localized upward movement of the pavement surface at transverse joints or cracks, and are often accompanied by shattering of the concrete in that area. The numbers of blowups are recorded in the survey. Transverse joint and crack faulting is the difference in elevation across a joint or crack. The elevation difference is recorded in inches with a positive value indicating that the approaching slab is higher than the departing slab and a negative value indicating that the approaching slab is lower. When other anomalies such as spalling interfere with the measurement it should be offset by no more than 1 ft. A null value should be entered when the anomaly does not allow measurement. The lane-to-shoulder drop-off

is the difference in elevation between the edge of a slab and the outside shoulder; typically occurs when the outside shoulder settles. The lane-to-shoulder separation is widening of the joint between the edge of the slab and the shoulder. Both this separation and the drop-off distance are measured regularly along the survey section. Note for the drop-off distance that if the shoulder is above the travel lane that a negative value is recorded. A patch is a portion, greater than 1.1 ft^2, where all or a portion of the original concrete slab has been removed and replaced, or additional material has been applied to the pavement after the original construction. Patches are counted by severity as either asphalt concrete or Portland cement concrete patches. In addition the area of each type of patch is recorded by severity.

<u>Patching</u>

Low: Patch has low severity distress of any type; and no measurable faulting or settlement; pumping is not evident.

Moderate: Patch has moderate severity distress of any type; or faulting or settlement up to 0.25 in; pumping is not evident.

High: Patch has a high severity distress of any type; or faulting or settlement ≥ 0.25 in; pumping may be evident.

Water bleeding and pumping are recorded by the number of occurrences, greater than 3.28 ft, and the length of water bleeding and pumping areas. Note that the total length of water bleeding and pumping cannot exceed the section length. These areas are characterized by the seeping or ejection of water from beneath the pavement through cracks. In some cases, detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

3.7.4.2. Discussion

<u>Pathway Services</u>

- Submitted the faulting of transverse joints and cracks as a representative 500 ft interval value.
- Did not submit lane-to-shoulder drop-off distance using the LTPP definition; instead submitted a total travel lane drop-off value.
- Lane-to-shoulder separation was reported as a representative value for every 500 ft interval.

<u>Fugro Roadware</u>

- Reported lane-to-shoulder drop-off, lane-to-shoulder separation in 26.4 ft intervals.

3.7.5. Course Summary

For completeness the vendor data have been compiled by course interval and is summarized in Table 3.9 for Pathway and Table 3.10 for Fugro Roadware. Elements not reported by the vendor are noted with a dash line. Also the elements in these tables represent the total observed distress over the entire subinterval.

Table 3.9. Summary of total PCC-LTPP Survey for Pathway.

Data Element	Units	I-440	I-40	US-64
Cracking Elements				
Corner Breaks Count	No.	91.0	2.0	0.0
Durability ("D") Cracking Count	No.	24.0	0.0	0.0
Durability ("D") Deterioration	ft^2	112.3	0.0	0.0
Unsealed Long. Cracking	ft.	700.6	13837.6	2.3
Sealed Long. Cracking	ft.	0.0	0.0	0.0
Trans. Cracking Count	No.	109.0	45.0	0.0
Unsealed Trans. Cracking	ft.	683.7	293.9	0.0
Sealed Trans. Cracking	ft.	0.0	0.0	0.0
Joint Deficiencies				
Sealed Trans. Joint Seal	Y/N	Y	Y	Y
Sealed Trans. Joint Seal Count	No.	701.0	2665.0	2287.0
Sealed Long. Joint Count	No.	--	--	--
Long. Joint Seal Damage Extent	ft.	9876.8	58203.3	51668.9
Spalling of Long. Joints	ft^2	32.7	2610.1	108.7
Spalling of Trans. Joints Count	ft.	1.0	133.0	16.0
Spalling of Trans. Joints Extent	ft^2	1.8	204.3	18.2
Surface Defects				
Map Cracking Count	No.	11.0	104.0	0.0
Map Cracking Extent	ft^2	44084.1	574705.1	0.0
Scaling Count	No.	0.0	0.0	0.0
Scaling Extent	ft^2	0.0	0.0	0.0
Polished Aggregate	ft^2	0.0	0.0	0.0
Miscellaneous Distresses				
Blowups	No.	0.0	0.0	0.0
Faulting of Trans. Joints and Cracks	in.	Reported as average of 500 ft		
Lane-to-Shoulder Drop-off	in.	--		
Lane-to-Shoulder Separation	in.	Reported as average of 500 ft		
AC Patch Count	No.	106.0	459.0	11.0
AC Patch Deterioration	ft^2	3419.0	7233.6	692.5
PCC Patch Count	No.	--	--	--
PCC Patch Deterioration	ft^2	--	--	--
Water Bleeding and Pumping Count	No.	1.0	0.0	0.0
Water Bleeding and Pumping Deterioration	ft.	0.0	0.0	0.0

Table 3.10. Summary of total PCC-LTPP Survey for Fugro Roadware.

Data Element	Units	I-440	I-40	US-64
Cracking Elements				
Corner Breaks Count	No.	235.0	11.0	2.0
Durability ("D") Cracking Count	No.	0.0	0.0	0.0
Durability ("D") Deterioration	ft^2	0.0	0.0	0.0
Unsealed Long. Cracking	ft.	180.0	7680.0	0.0
Sealed Long. Cracking	ft.	0.0	0.0	0.0
Trans. Cracking Count	No.	67.0	13.0	0.0
Unsealed Trans. Cracking	ft.	764.7	148.9	0.0
Sealed Trans. Cracking	ft.	0.0	0.0	0.0
Joint Deficiencies				
Sealed Trans. Joint Seal	Y/N	N	N	N
Sealed Trans. Joint Seal Count	No.	0.0	0.0	0.0
Sealed Long. Joint Count	No.	0.0	0.0	0.0
Long. Joint Seal Damage Extent	ft.	0.0	0.0	0.0
Spalling of Long. Joints	ft^2	0.0	0.0	0.0
Spalling of Trans. Joints Count	ft.	60.0	522.0	131.0
Spalling of Trans. Joints Extent	ft^2	690.9	5943.2	1485.4
Surface Defects				
Map Cracking Count	No.	50.0	472.0	0.0
Map Cracking Extent	ft^2	6458.6	38831.6	0.0
Scaling Count	No.	0.0	0.0	0.0
Scaling Extent	ft^2	0.0	0.0	0.0
Polished Aggregate	ft^2	0.0	0.0	0.0
Miscellaneous Distresses				
Blowups	No.	0.0	0.0	0.0
Faulting of Trans. Joints and Cracks	in.	Reported by occurrence		
Lane-to-Shoulder Drop-off	in.	Reported in 26.4 ft increments		
Lane-to-Shoulder Separation	in.			
AC Patch Count	No.	47.0	305.0	0.0
AC Patch Deterioration	ft^2	346.6	1721.5	0.0
PCC Patch Count	No.	0.0	13.0	17.0
PCC Patch Deterioration	ft^2	0.0	351.6	692.5
Water Bleeding and Pumping Count	No.	9.0	5.0	0.0
Water Bleeding and Pumping Deterioration	ft.	47.5	26.4	0.0

3.8. Survey Reanalysis

3.8.1. Motivation

After the initial workshop results were released, there were some concerns expressed by both vendors and NCDOT personnel regarding the agreement between the automated and reference surveys. Through the workshop process it was found that the vendors found some of the terms and definitions used by the NCDOT to be confusing. However, due to time constraints in data analysis these vendors were not able to fully clarify and discuss their concerns with NCDOT personnel. As a result there was a keen interest by both parties to have the vendors resubmit at least a portion of the data to NCSU for reanalysis.

Vendors can gather factual data, such as rut depth, photographs of a cracked pavement surface or IRI numbers with relative ease. It is quite a different process to analyze this data so that the outcomes are completely consistent with the techniques that an agency uses in gathering network level performance information. Using rut depth for example. The NCDOT protocol clearly defines a moderate rutting as a rut depth from 0.5 to 1 inch deep. However, from the windshield survey it may not be possible to differentiate between rut depths near the threshold values or even within a reasonable range. Further, tracking this average value visually over a one mile increment is a very difficult task. Vendors on the other hand have the capability to measure rut depths to a very high degree of accuracy and precision over any length of distance. Other quality indicators, such as ride quality or oxidation may be even more subjective.

This situation reflects more on a failure of the NCDOT survey protocols than the vendor capabilities. Nevertheless, for an agency to make the most effective use of automated distress data, that data must at least approximate the outcomes of their existing techniques. Failure to match this existing data can have an effect on the agencies pavement management system and decision making process for those affected sections. The calibration process to bring vendor and agency understanding and application of terms into agreement is an iterative one directly carried out between the vendor and agency personnel. Performing multiple iterations for each vendor was beyond the initial scope of this project. However, it was felt that at least approximating this complete process was important to accurately portray the capabilities of automated survey processes. To this end, the vendors have resubmitted a small portion of the total survey data.

3.8.2. Processing

Due to time and resource limitations the vendors were asked to resubmit data for only a very small portion of the total test section. Specifically the vendors were asked to make two data resubmissions; 1) redoing the LTPP analysis for the three reference survey sections and 2) redoing the NCDOT analysis with the full mile increments containing the LTPP reference survey sections. Figure 3.98 shows the approximate location of these three sections on the test track. Only Pathway Services and Fugro Roadware were asked to resubmit data, since these were the only vendors which originally submitted data for these sections.

All three sections are asphalt concrete and no resurvey by NCDOT personnel has been performed. Coordination of the vendor and reference surveys was accomplished by first identifying the approximate location of the beginning of the NCDOT survey using mapping software. The vendor submitted coordinates for their analysis sections were overlaid on top of this map and identified. The vendors were not explicitly told which NCDOT reference survey mile-marker their resubmission would be compared to. However, from the workshop the vendors did have available to them the results from the reference LTPP survey. Vendors were given explicit directions and data submission templates for the resubmission. The exact instruction letter sent to the vendors is given in Appendix D. For consistency with what has been presented above, the sections are denoted as NC-98-1, NC-98-2 and US-64 for LTPP survey purposes. For the NCDOT survey, the mile containing the first LTPP section corresponds to mile 11 along NC-

98 and is thus denoted as NC-98-11 for NCDOT survey comparisons. The second LTPP section is contained within the 15th mile of the NC-98 component and is denoted as NC-98-15. Finally, the US-64 LTPP section is contained in the mile 5 of the US-64 survey and is therefore denoted as US-64-5.

Figure 3.98. Location of data resubmission sections

For calibration purposes, the vendors provided NCSU and the NCDOT with copies of their viewing and analysis software and the images taken during the survey. NCDOT Pavement Management Unit personnel used this data to review the vendor rating scale and developed a set of comments. For example, if a vendor had counted a given distress as a fatigue crack, but if in practice the NCDOT would have counted that distress as a simple transverse crack; a note would be made and coordinated with the image or mile-marker where the observation was taken. These notes were compiled and submitted to the vendor for calibrating their distress ratings to better match the existing NCDOT survey protocols. After performing this calibration, the vendors then reanalyzed the targeted sections and submitted the results to NCSU for further data interpretation.

It is strongly emphasized here that the resubmission data set is substantially smaller than the full test road submission. For this reason extreme care must be made in interpreting the results, both favorably and negatively, shown in the following sections. The purpose here is to show with an extremely limited data set that through open communication and a willingness to find the best solution that the automated distress surveys can yield results that are closely in line with an agency's existing protocols. This process may likely require multiple iterations to arrive at a fully reasonable answer, but only a single iteration is performed here. Further, the fact that this calibration process is only checked on only a few short sections could call into question the statistical reasonableness of any final conclusions.

3.8.3. NCDOT Survey

3.8.3.1. Fatigue Cracking

According to NCDOT personnel fatigue cracking is the single most significant distress for North Carolina pavements. As a result this distress carries the most weight in the PCR deductions. Therefore, properly rating this single distress is important for coordinating automated and manual survey data. In the initial data submission, it appeared that the vendors had a sensitivity issue in identifying this distress. This hypothesis was supported by both the NCDOT and LTPP survey submissions. Further complicating matters is that this distress also includes edge and longitudinal cracking, which is somewhat different than what is typically considered.

The results from the original analysis are shown for these three sections in Figure 3.99 and Figure 3.100 using the same plotting rules as were used before. Results from the reanalysis of these three sections are shown in Figure 3.101 and Figure 3.102. From these figures it is clear that the process of even a single iteration has resulted in a better match of the automated and reference surveys. There still appears to be an issue with sensitivity, but the second survey has moved in the right direction.

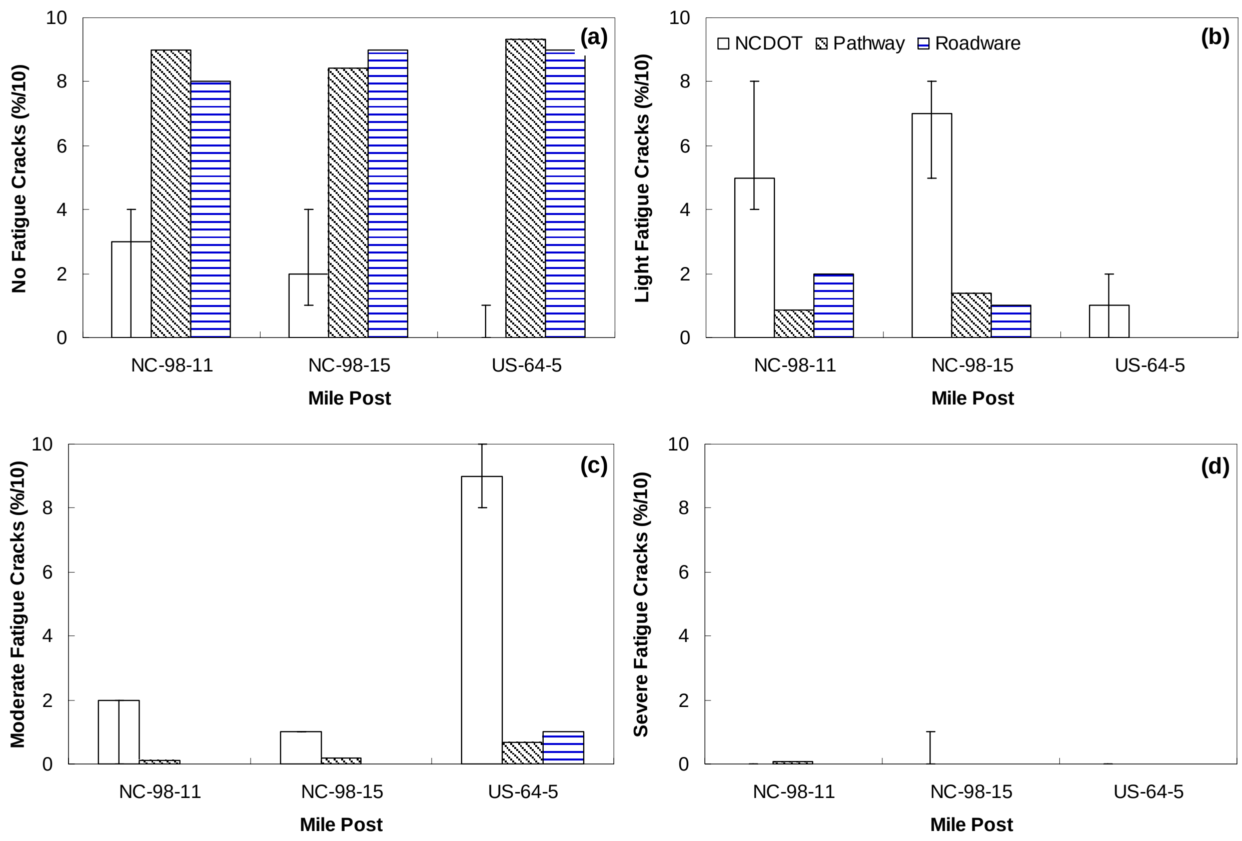


Figure 3.99. Fatigue cracking results for ***original analysis*** of resubmitted sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

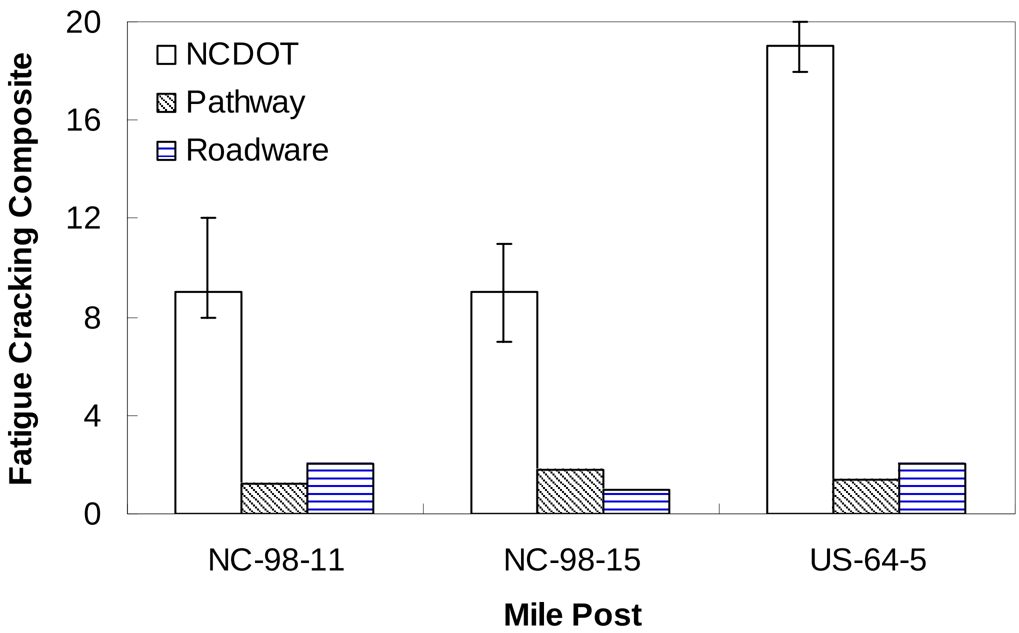


Figure 3.100. Fatigue cracking composite index for ***original analysis*** of resubmitted sections.

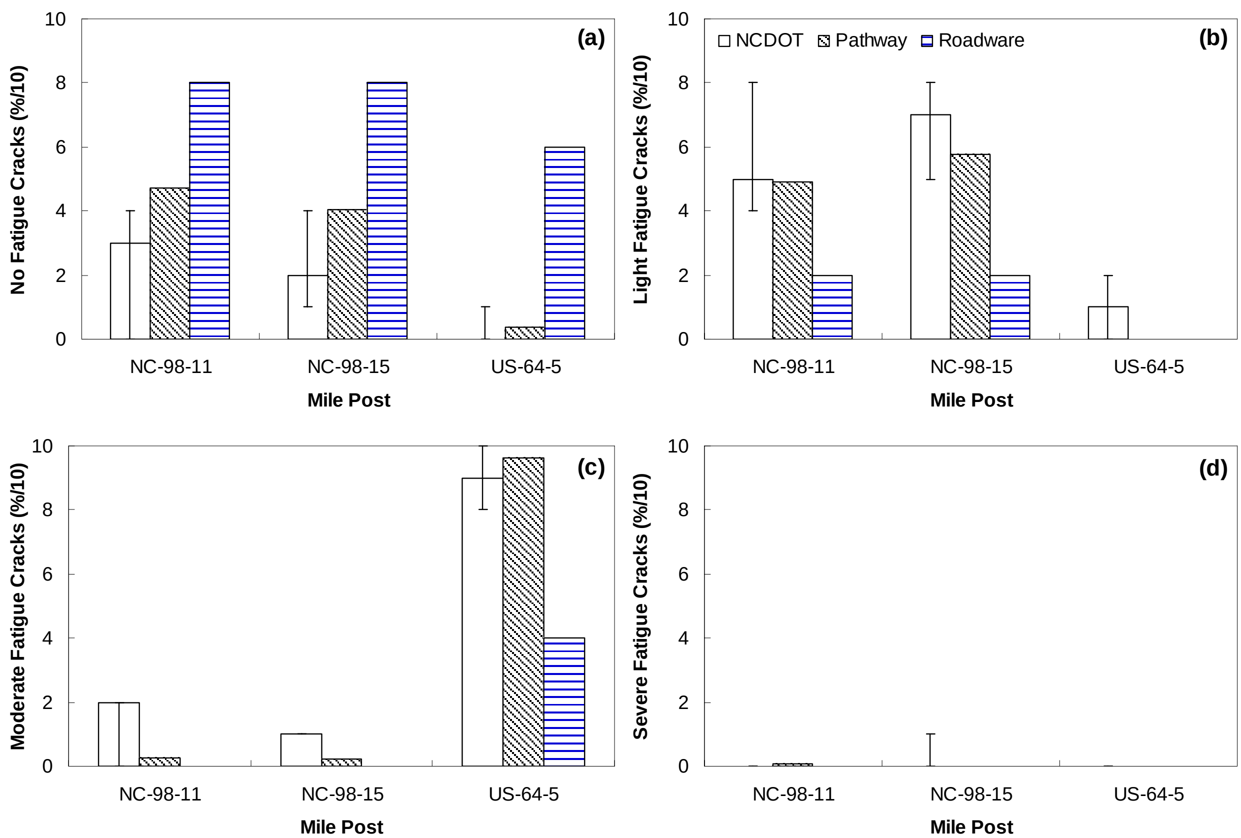


Figure 3.101. Fatigue cracking results for ***reanalysis*** of resubmitted sections; (a) none rating, (b) light rating, (c) moderate rating, and (d) severe rating.

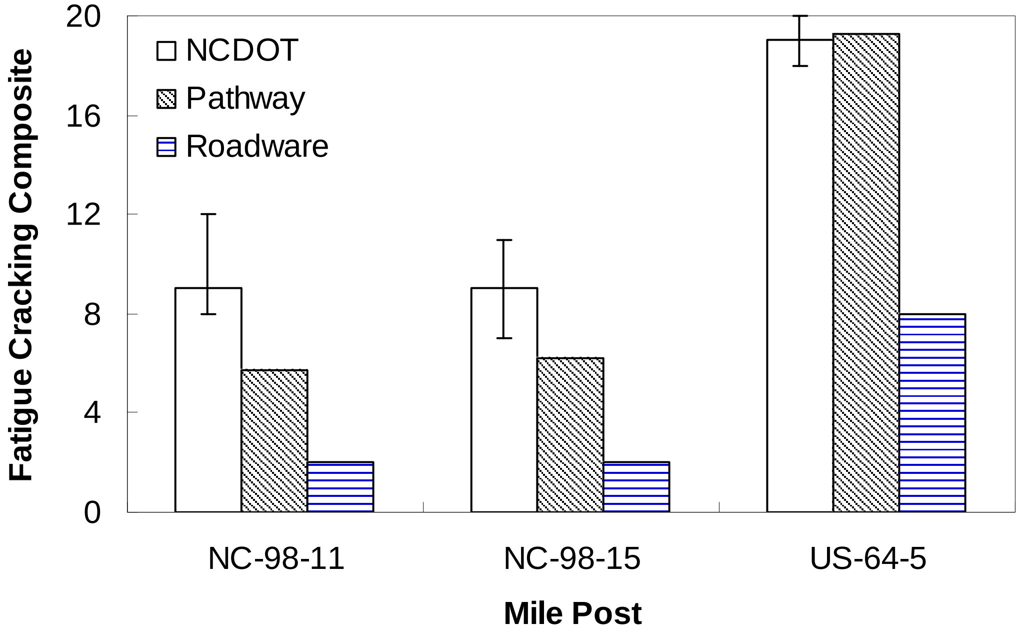


Figure 3.102. Fatigue cracking composite index for ***reanalysis*** of resubmitted sections.

3.8.3.2. Transverse Cracking

Transverse cracking along the three test sections is generally limited, which makes assessment of the vendor's capabilities questionable. When the vendors submitted the final results it was found that the original and resubmitted analysis were identical, shown in Figure 3.103. Since so little transverse cracking existed in these test sections, no conclusive findings regarding changes in the vendor's sensitivity can be drawn.

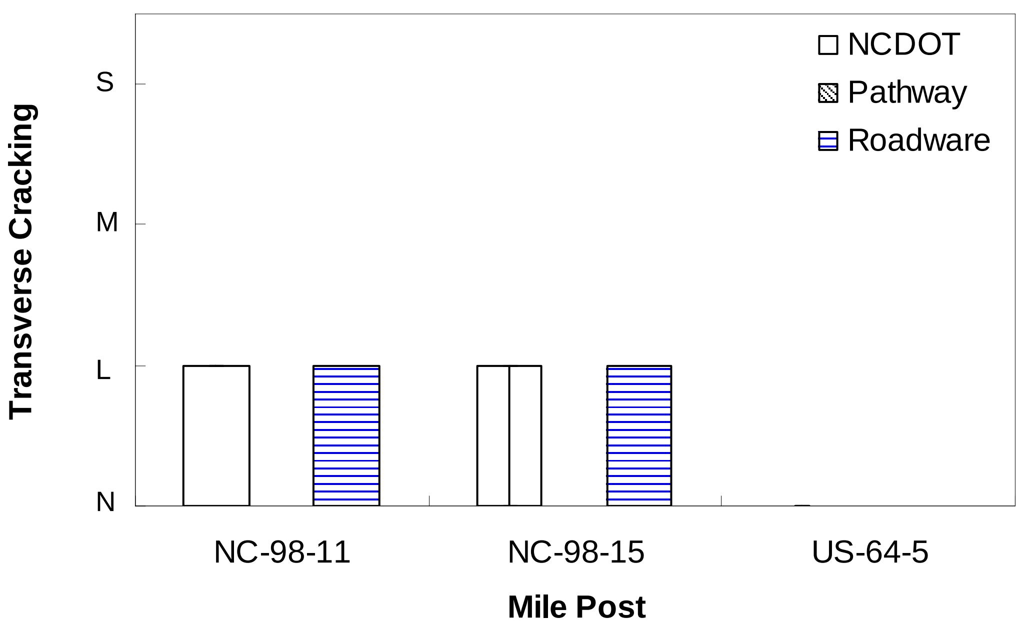


Figure 3.103. Transverse cracking rating for ***reanalysis*** of resubmitted sections.

3.8.3.3. Rutting

As it has been discussed earlier, rutting is a distress that automated distress surveys can determine with a relatively high degree of accuracy and precision. By comparison, the NCDOT survey procedure requires one to estimate the rut depth of the test section from the cabin of a moving vehicle. As a result of the major disconnect between these two protocols, one would expect the calibration of this distress to be highly variable since the subjective component of the NCDOT protocol would be smeared into any of the comparisons. Nevertheless, the vendors have performed recalibration of their data and have given reduced rutting ratings on the three test sections. The findings from the original submission are given in Figure 3.104 while the reanalyzed submission is given in Figure 3.105.

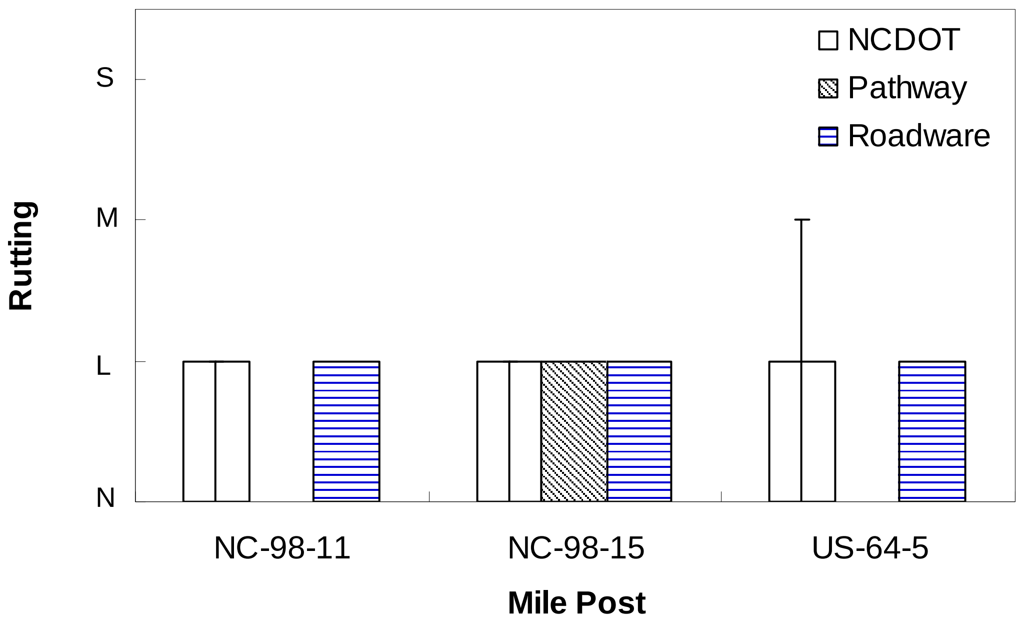


Figure 3.104. Rutting rating for ***original analysis*** of resubmitted sections.

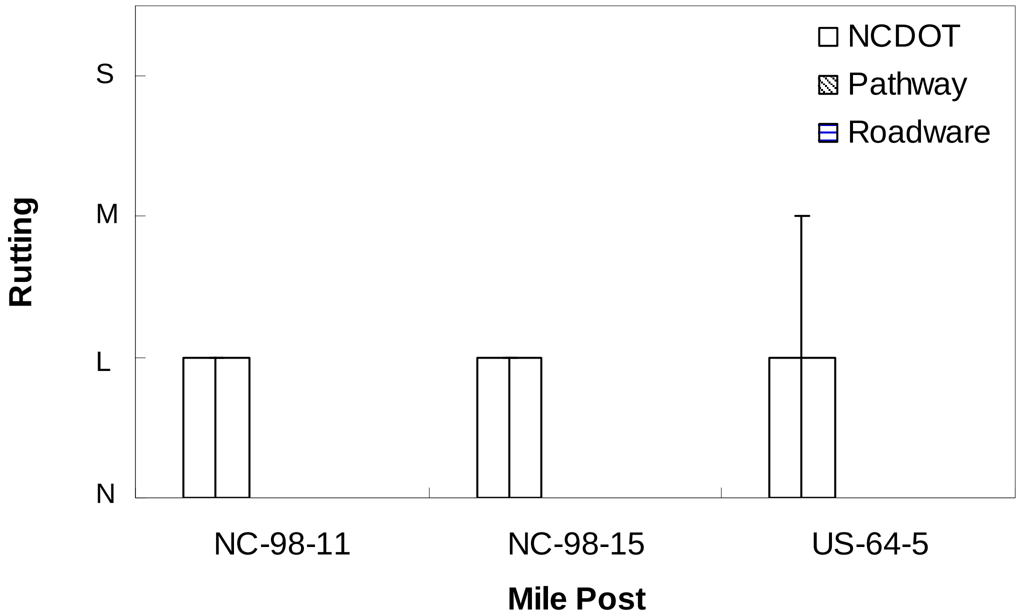


Figure 3.105. Rutting rating for ***reanalysis*** of resubmitted sections.

3.8.3.4. Ride Quality

A similar situation similar to that of rutting arises with the ride quality distress. The automated distress surveys have the capabilities of quantifying the ride quality accurately using the IRI values whereas the NCDOT relies on the subjective evaluation of ride quality by survey personnel. In the original data submission the vendors were not told an IRI to ride quality conversion standard to follow and as a result three different standards were followed (c.f. Table 3.6). For the data resubmission both Pathway Services and Fugro Roadware agreed to use the following conversion:

Low: 0 – 120 in/mi,
Moderate: 120 – 400 in/mi, and
Severe: above 400 in/mi.

The use of IRI over the subjective quantity used in the current NCDOT protocol has several advantages; particularly an overall reduction in year-to-year variation and a consistent level of comparison amongst pavements surveyed by different personnel. This latter issue is of particular importance since ride quality is a direct measure of user perception of pavement quality.

The results of the original data submission are shown in Figure 3.106. In this figure the IRI to ride quality conversions shown in Table 3.6 are used. Reanalyzed submission data is shown in Figure 3.107 and is found to have an overall better agreement with the NCDOT ratings. Keep in mind that the differences in ratings shown in Figure 3.106 and Figure 3.107 are a direct reflection of changes in the IRI to ride quality conversion noted above.

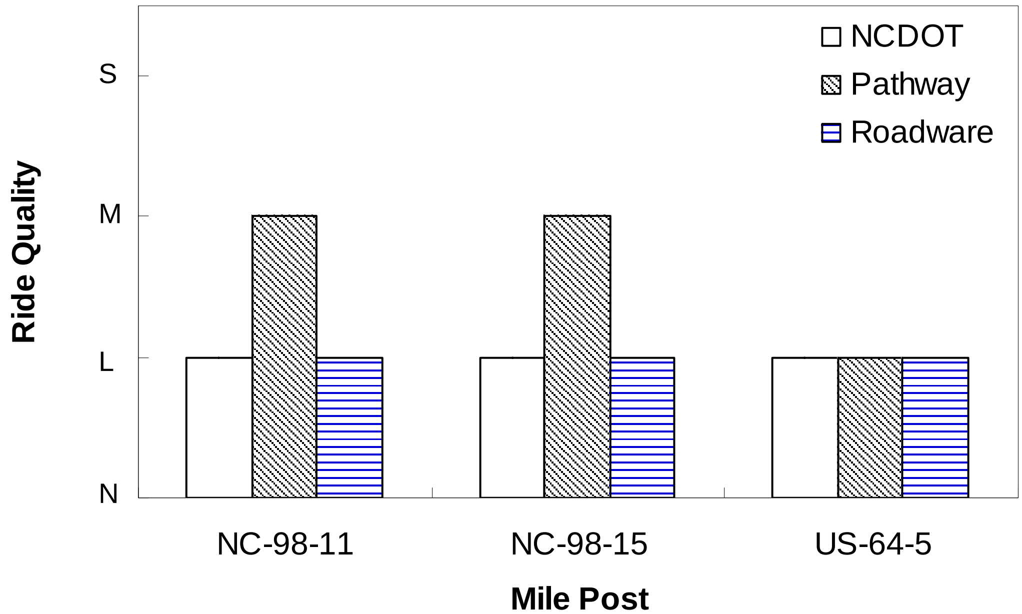


Figure 3.106. Ride quality rating for ***original analysis*** of resubmitted sections.

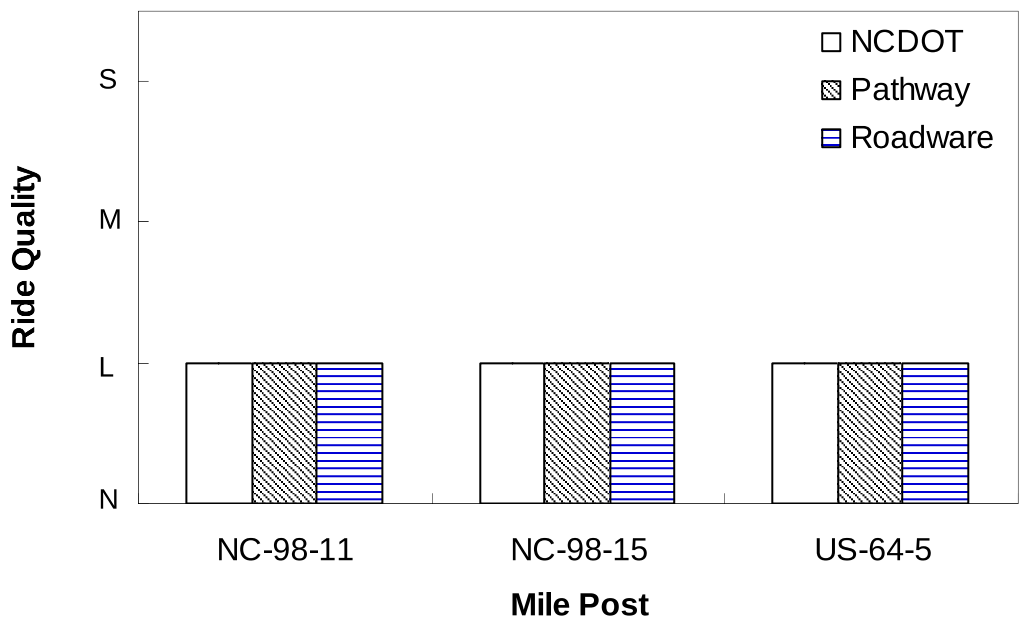
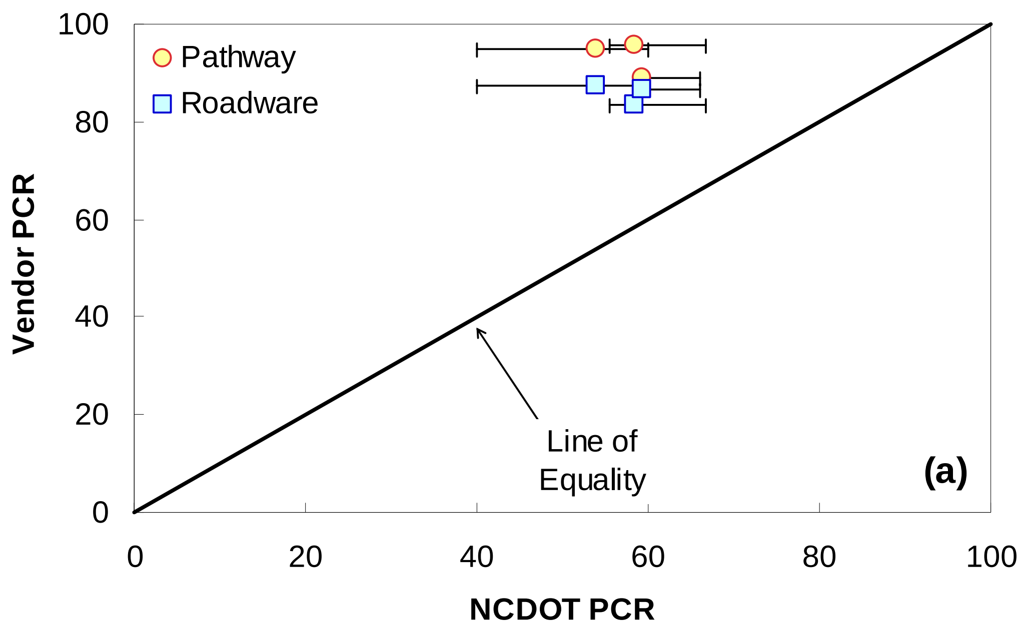


Figure 3.107. Ride quality for ***reanalysis*** of resubmitted sections.

3.8.3.5. Pavement Condition Rating

The critical index used by the NCDOT in network level decision making is the PCR value. The mathematical steps necessary to compute this parameter have been given above in Section 3.4.6. Results of this computation are shown for the three sections using a line of equality plot in Figure 3.108 for the original data submission and in Figure 3.109 for the reanalyzed submission. In both figures two plots are shown. The (a) plot shows the PCR ratings by vendor whereas the

(b) plot shows only the PCR deduct values for the fatigue cracking components, e.g., Equation (3.3). In both plots the horizontal error bars represent the variability from the NCDOT reference survey. Comparing the original and reanalyzed data submissions it is clear that the calibration process has greatly improved the agreement of PCR values between the automated and reference surveys. Particular improvement is made with the fatigue cracking deduct values indicating an improvement in the sensitivity of the vendor detection of fatigue cracking.



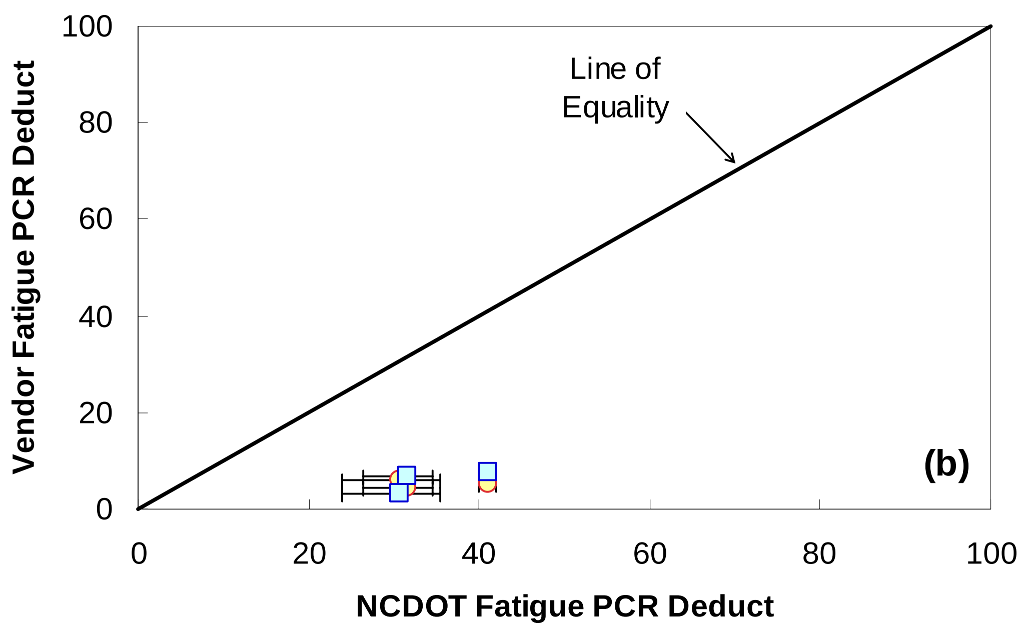


Figure 3.108. PCR for ***original analysis*** of resubmitted sections; (a) full PCR computation and (b) comparison of only fatigue deduct values.

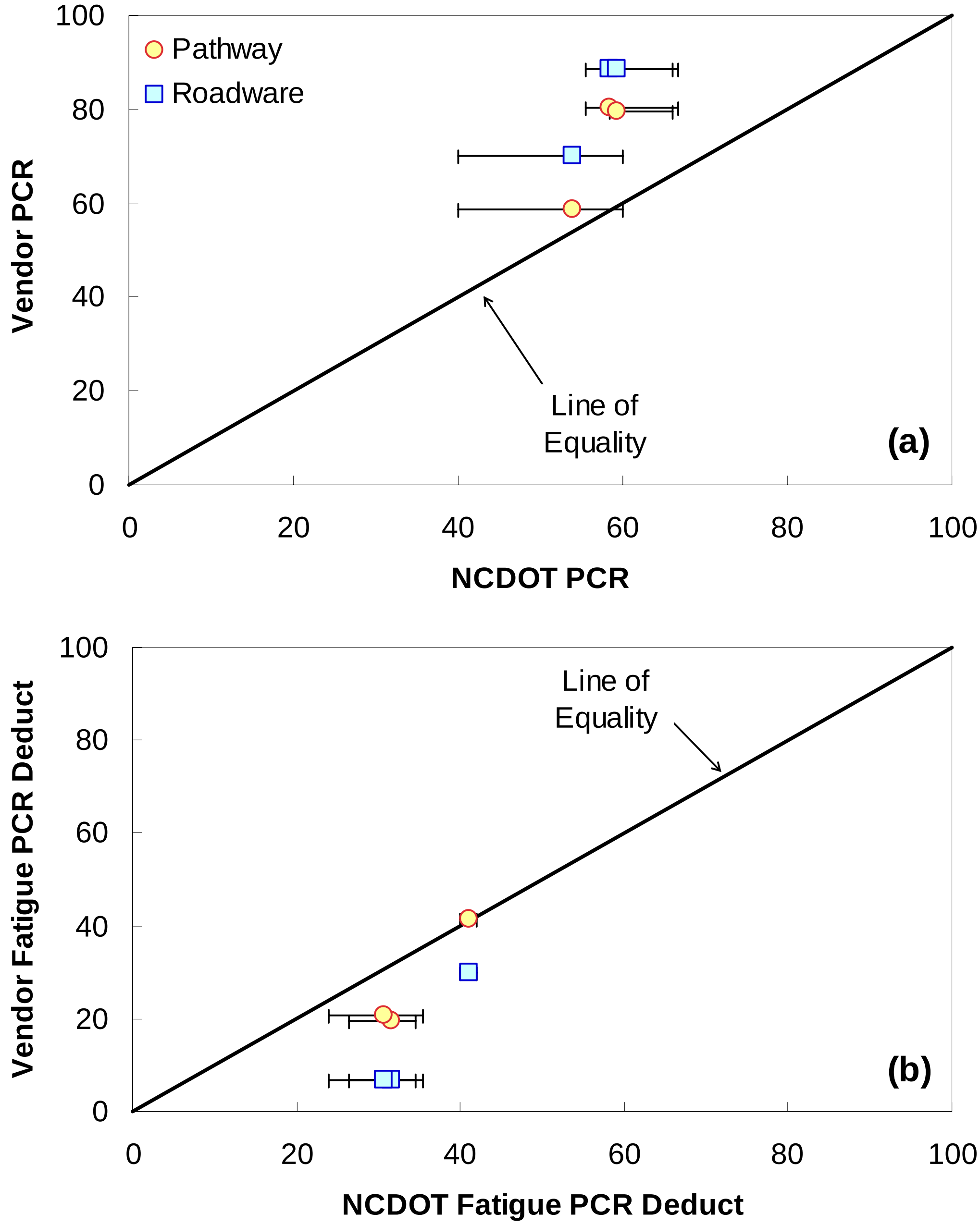


Figure 3.109. PCR for ***reanalysis*** of resubmitted sections; (a) full PCR computation and (b) comparison of only fatigue deduct values.

3.8.4. LTPP Survey

In addition to resubmitting data based on the NCDOT survey practice, vendors were also asked to resubmit the LTPP survey analysis. Both Pathway Services and Roadware obliged this request and resubmitted data. In the following sections the results from this survey resubmission for the main areas, cracking, patching and potholes, surface deformation, and surface defects, are processed and presented.

3.8.4.1. Cracking

The submitted data elements showing the most change in the resubmission process were those related to cracking. As was discussed earlier, the NCDOT personnel who performed the LTPP reference survey had very little training with the LTPP protocols. As a result these reference surveys reflect not a truly rigorous LTPP survey but a type of NCDOT-LTPP hybrid survey, and vendor calibration becomes an important step in matching results. Results of the data resubmission process are given below in Figure 3.110 through Figure 3.119. Readers should compare these figures with the original data submission values shown in Figure 3.86 through Figure 3.95. Through this process, it is found that in general the resubmitted values better match those of the NCDOT reference survey. In particular the resubmitted data shows better sensitivity towards cracking than the original data submission. It is also interesting to note that Pathways counts of block cracking changed significantly, but the amount of block cracking that was discounted in the reanalysis was not placed anywhere else, suggesting some definition differences still exist between the vendor and NCDOT on block and fatigue cracking. Similar issues may also exist with the Roadware analysis, but it is less clear. These findings suggest that more interaction between the vendors and NCDOT will likely bring the two surveys into better agreement.

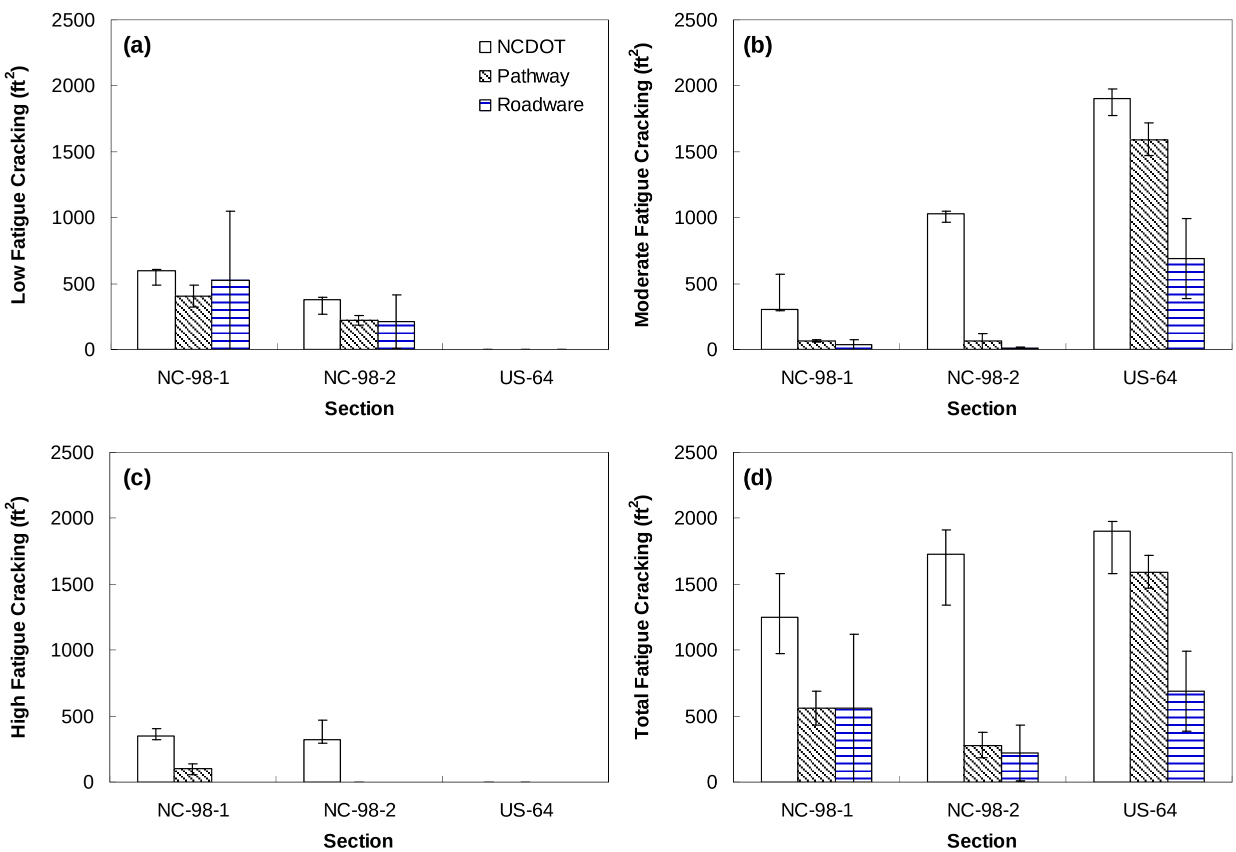


Figure 3.110. Fatigue cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

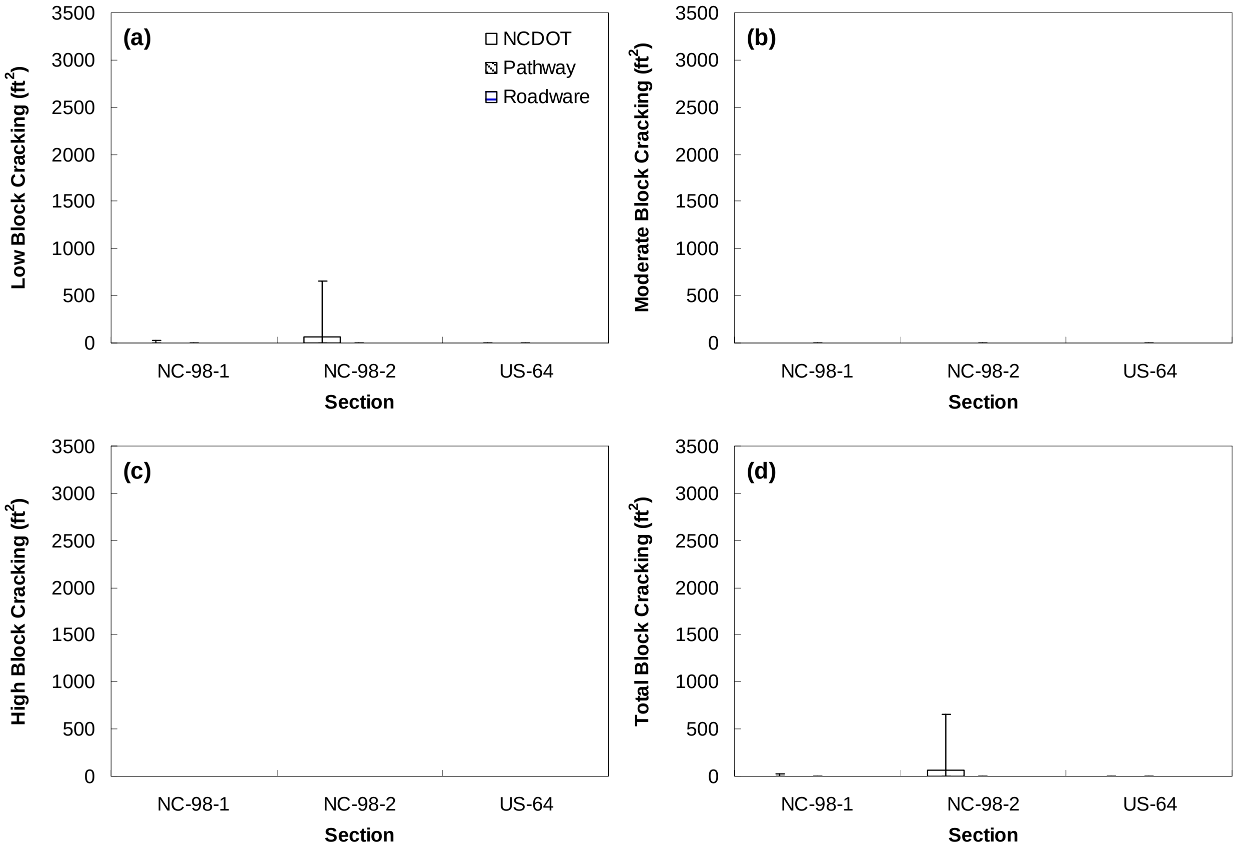


Figure 3.111. Block cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

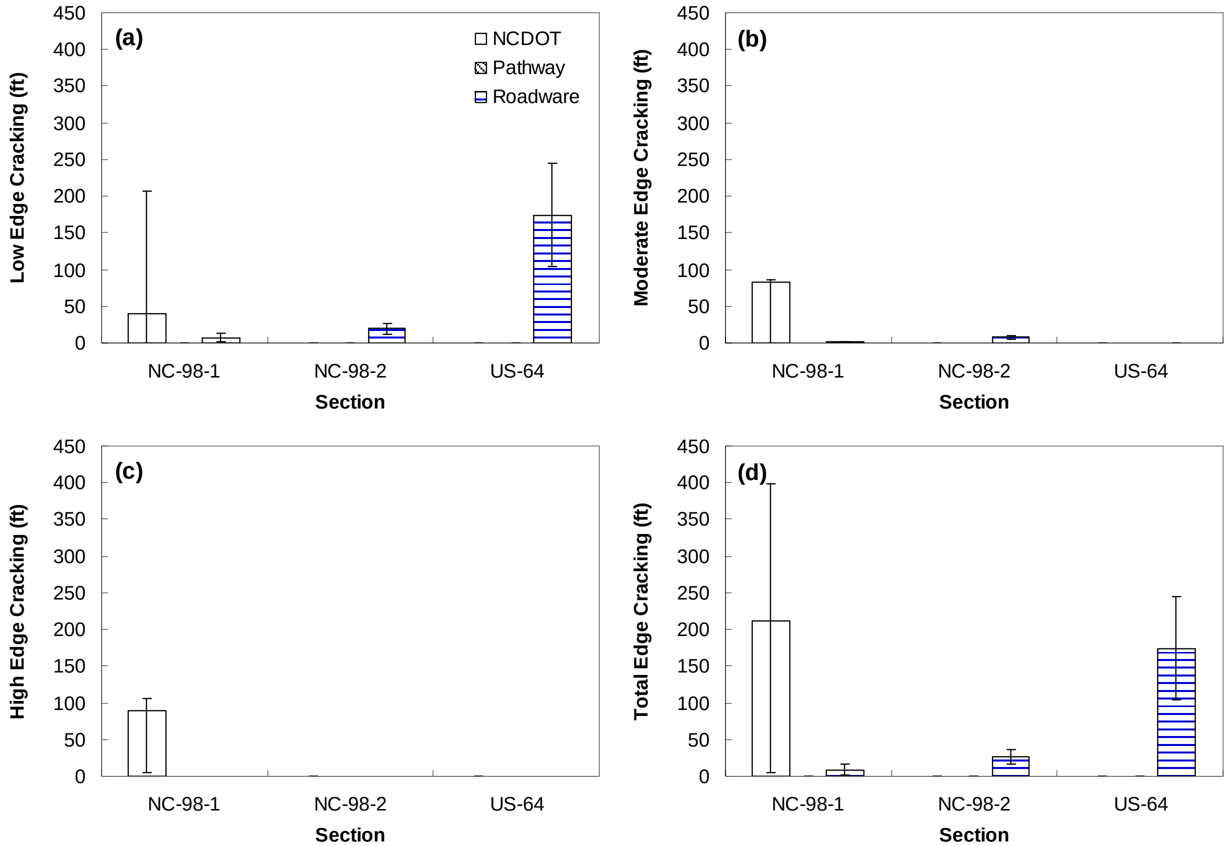


Figure 3.112. Edge cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

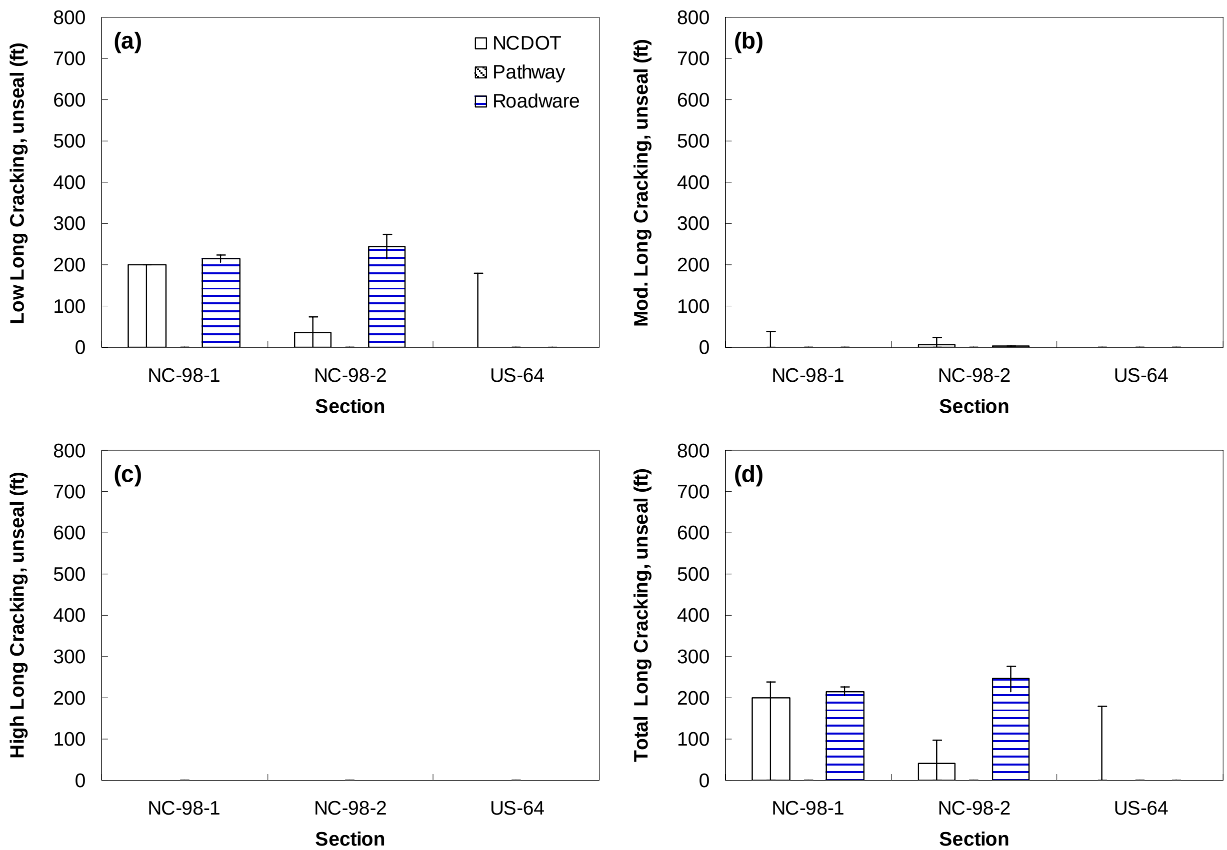


Figure 3.113. Unsealed wheel path only longitudinal cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

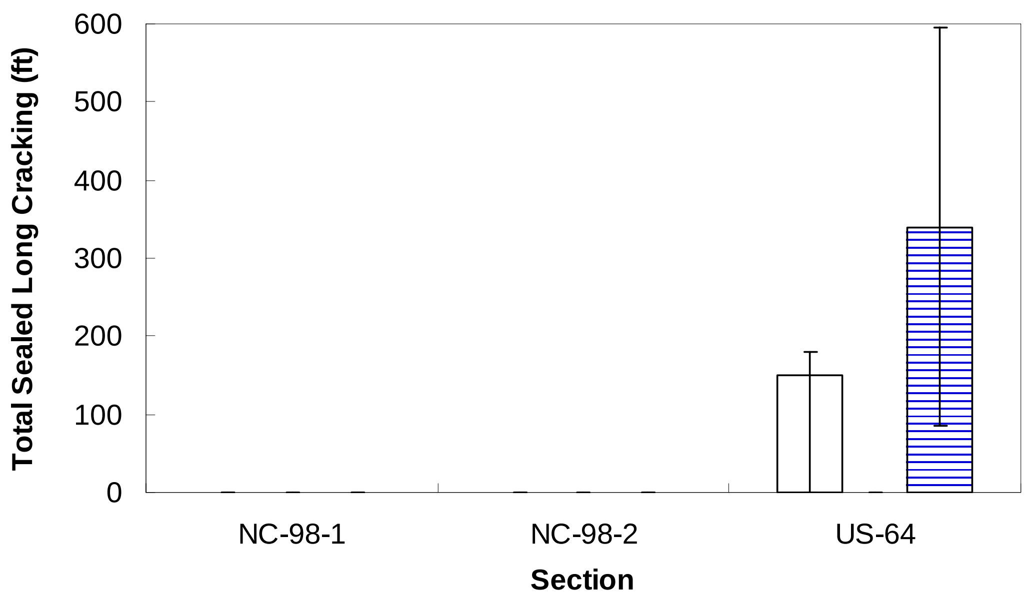


Figure 3.114. Total sealed wheel path only longitudinal cracking for ***reanalysis*** of LTTP survey sections.

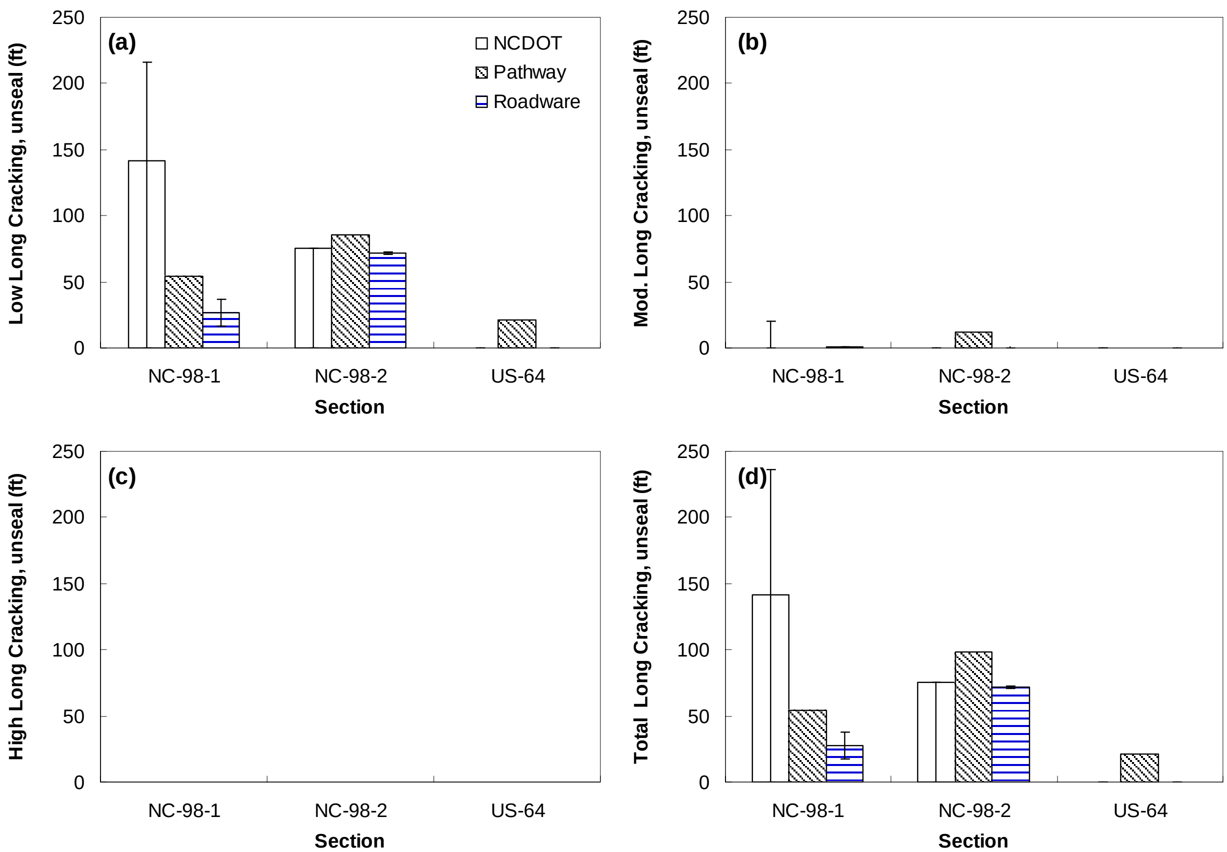


Figure 3.115. Unsealed non-wheel path only longitudinal cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

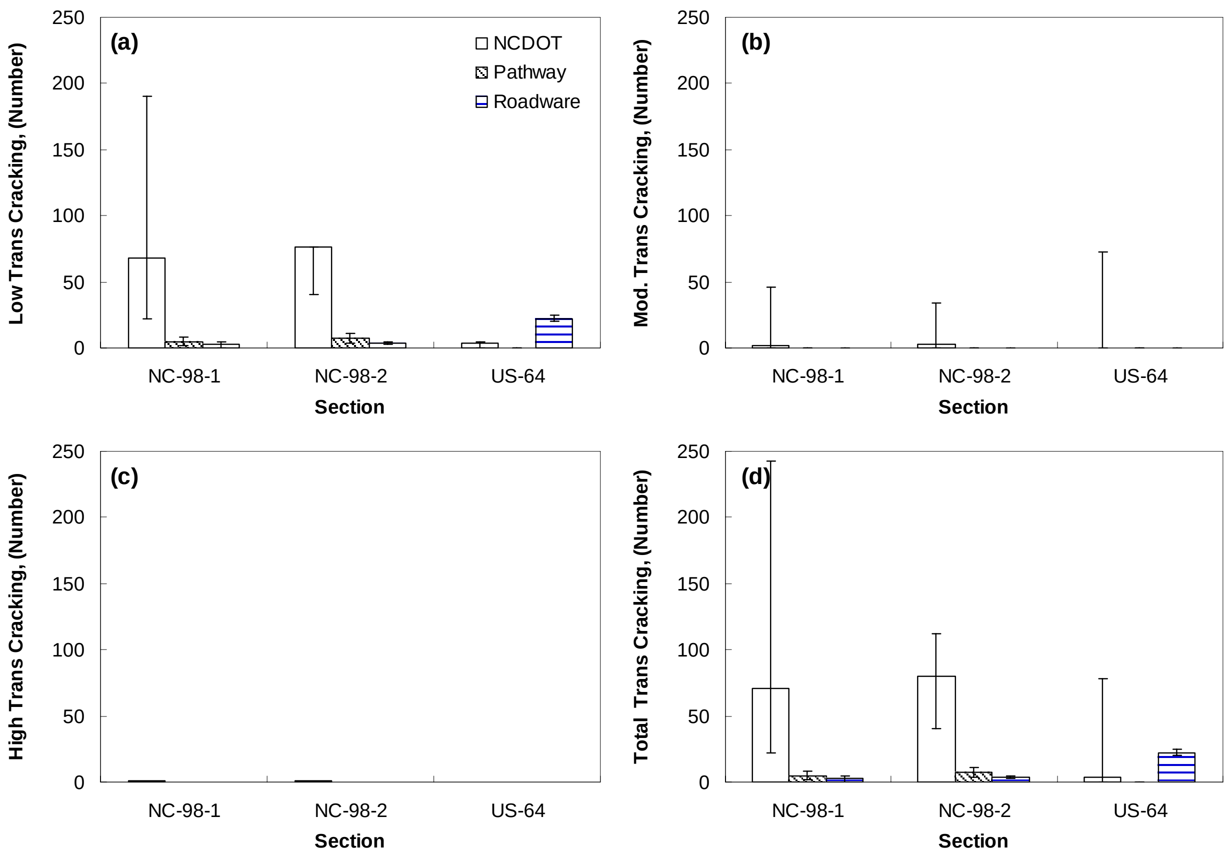


Figure 3.116. Transverse cracking counts for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

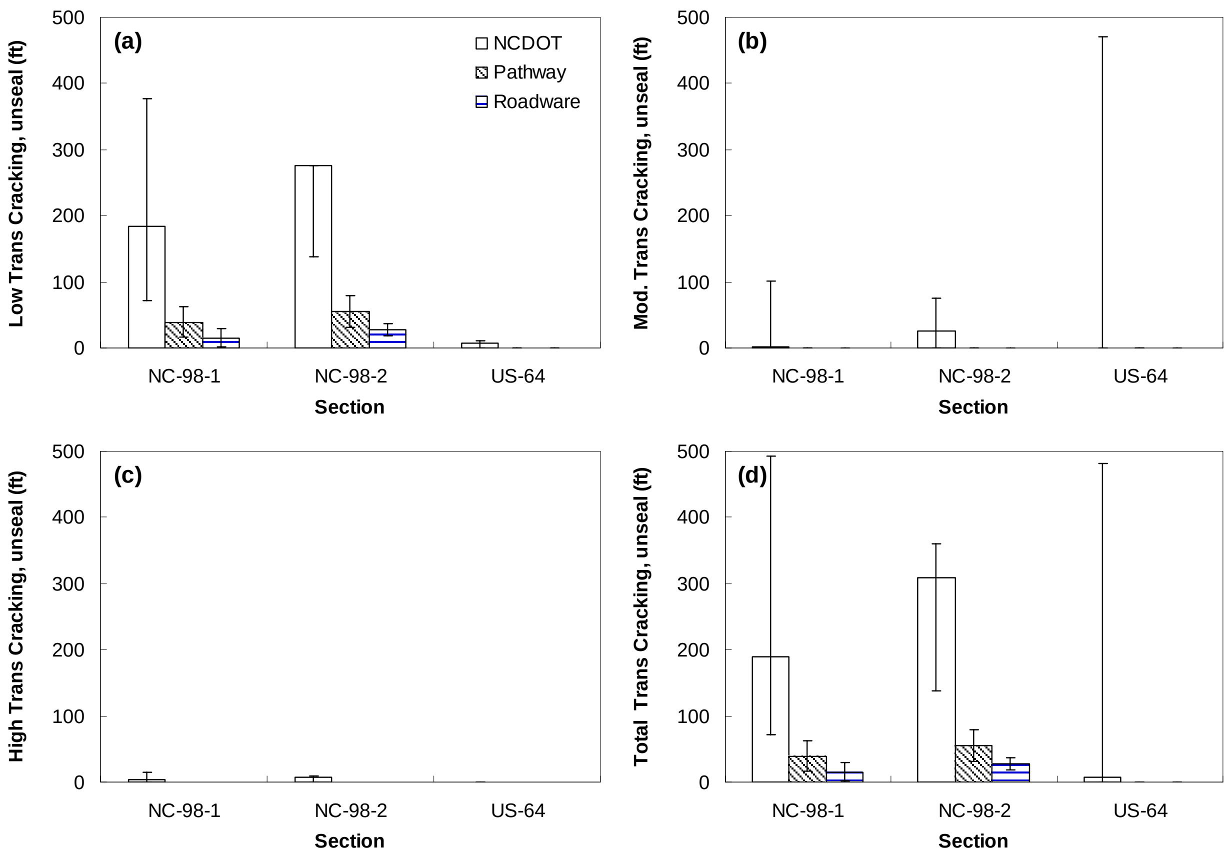


Figure 3.117. Unsealed transverse cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

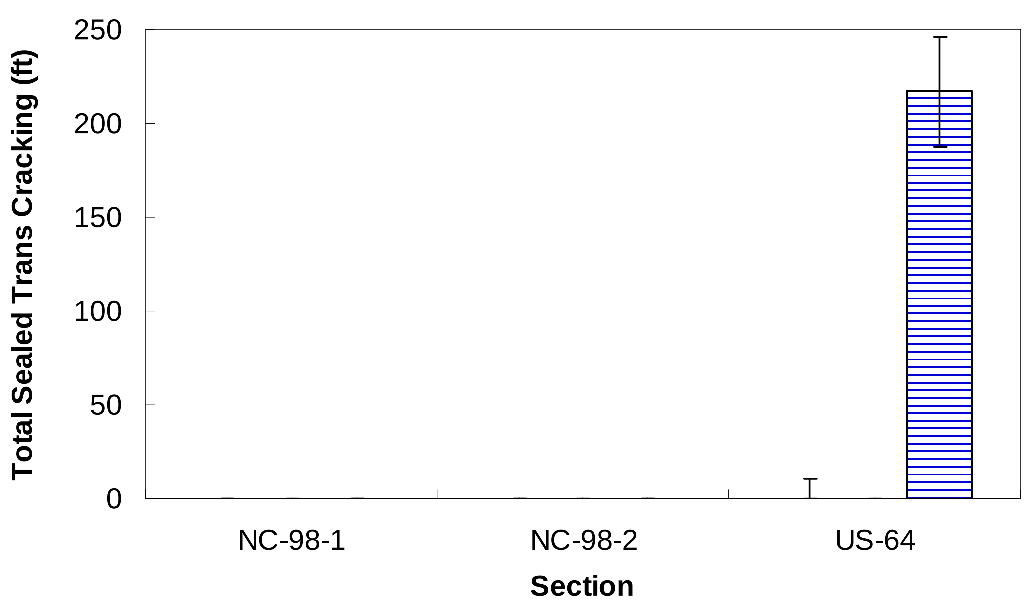


Figure 3.118. Total sealed transverse cracking for ***reanalysis*** of LTTP survey sections.

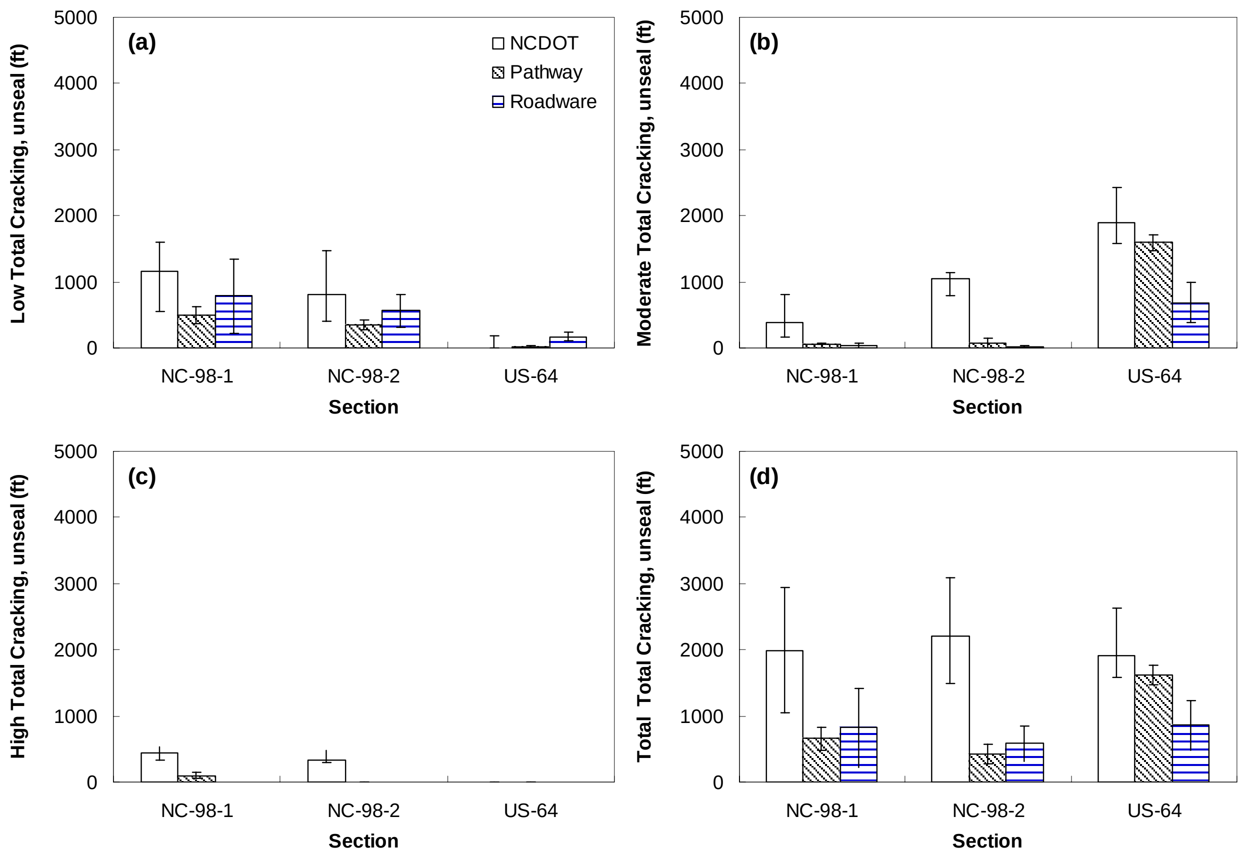


Figure 3.119. Total unsealed cracking ratings for ***reanalysis*** of LTTP survey sections; (a) low, (b) moderate, (c) high, and (d) total.

3.8.4.2. Other Distresses

In addition to cracking, vendors reprocessed the available photographs of the test road at the directed locations for other LTPP distress data including patching and potholes, rutting, shoving, asphalt bleeding, polished aggregate, raveling and IRI values. This last measurement is not part of the LTPP test protocol, but was requested from the vendors. No reference survey data is available for the IRI. The resubmitted data did not differ from the original submission and readers are directed to Sections 3.6.2, 3.6.3, and 3.6.4 for more details. Results from the submitted IRI values are shown in Figure 3.120 for the two vendors. The vendors actually submitted two set of IRI values, one for the right wheel path and one for the left wheel path. Since it cannot be guaranteed that the vendors traveled the exact same path or that either was exactly within the wheel paths, only the average values are shown. The ends of the error bars represent the values obtained for each wheel path.

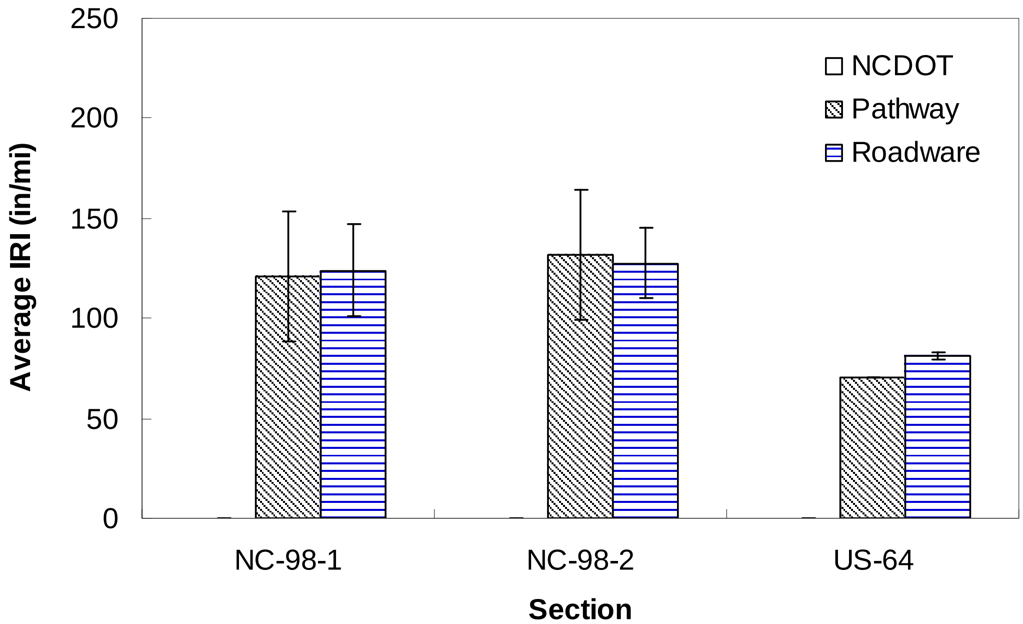


Figure 3.120. IRI ratings for ***reanalysis*** of LTTP survey sections.

3.9. Summary

For this project, three vendors drove the appointed test loop and submitted data on pavement distresses. Of these three, two were able to compile data for the entire test loop. Vendors were instructed to submit results following two different survey protocols, NCDOT and LTPP, for the entire test loop. For this process the vendors were provided with copies of the NCDOT survey manuals for AC and PCC pavements as well as the LTPP survey manual and instructed to follow those manuals to the best of their abilities. Coincident to these automated surveys, the NCDOT conducted its own reference survey using three to four teams of surveyors very familiar with the NCDOT procedure. NCDOT personnel also performed the LTPP survey protocol on three 500 foot sections of the test course, but were not as familiar with this protocol as they were with the NCDOT method.

Neither the vendors, nor the NCDOT were aware of the other survey results when each submitted their data. Researchers at NCSU reviewed both data submissions, compiled the results and presented these results as part of the workshop held in September of 2008 in Durham, North Carolina. The findings from this data submission have been summarized in the above sections, but the key findings were:

- Vendors tended to underreport cracking relative to the surveys by NCDOT personnel. Underreporting tends to be worst in AC pavements than it is in PCC pavements.
- Vendors can measure and report factual measurements, such as IRI and rut depth with a high degree of accuracy.
- The effect of errors in distress measurements may be amplified or reduced in network level pavement condition ratings.

- Differences between vendor reported and an agency reported value of a given distress can be related to errors in the agency survey protocol, the vendor analysis protocol or both.

Following the analysis of this initial survey, a second analysis was performed by the vendors. For this second analysis the vendor's supplied copies of their viewing software and NCDOT personnel reviewed portions of the total test loop and noted differences in distress interpretation. Unfortunately, time and resources did not allow NCDOT and vendor personnel to communicate face-to-face with one another. The notes complied by the NCDOT were supplied to the vendors, who reviewed them and used the knowledge gained to resurvey a small portion of the total test loop. Improvements in the overall agreement between the reference and reanalyzed automated surveys were observed. Differences still existed; however, it must be kept in mind that the resurveyed analysis represents a very small portion of the total test loop. Furthermore, the lack of one-on-one contact between the vendors and NCDOT may have kept the reanalysis from being as successful as possible. Nevertheless it is felt that since the single interaction resulted in better agreement, that multiple contacts between the two parties would likely improve this agreement even further.

Through this process attention was focused on the variability and accuracy of distress surveys, both automated and manual. Clear variability in the NCDOT manual surveys were observed, but since vendors drove the course only once this study could not assess the variability of automated distress surveys. However, finding that vendors can accurately measure some quantities, such as IRI and rut depth, indicates that with automated surveys the variability should be reduced for at least some distresses. This intuition could not be confirmed nor refuted in this study.

The second issue brought to the attention of the research team was the importance for an agency in deciding up front how they intend to use an automated distress survey. Analysis for this project was conducted assuming that an agency intends to include the results of these surveys directly into its existing pavement management system. Under this assumption, the initial analysis showed that an agency may expect some complications unless careful planning and an understanding of automated distress surveys are made. During the process that calibrates a vendor's interpretation of its survey results with the agency's interpretation, it is crucial that the two parties openly communicate. Simply providing an agency with the survey manual is not sufficient. These manuals may include precise definitions of certain distresses, but truly identifying when a given distress exists and/or distinguishing between two similar distresses is a subjective matter.

CHAPTER 4 BRIDGES

4.1. Introduction

Data collection for bridge inventory and condition assessment has many possibilities due to the complex nature of bridges as a highway feature. Perhaps somewhat unlike other areas, the inventory of bridge assessment data has been fairly extensive and growing for over 30 years under the Bridge Inspection Program and most states collect data far beyond the minimum requirements to support their Bridge Management Systems. However, enhanced methods of collecting inventory and condition assessment data is desirable to increase the completeness and quality of the data. Another high priority issue is the need for safety of the bridge inspectors as affected by traffic and during inspection of difficult to access locations on the bridge.

Bridges are complex to the extent that an approach of using a single data collection vehicle passing over or under a bridge cannot begin to fully inspect a bridge. Thus planning for the workshop presentations and exhibits allowed for a broad range of data collection technologies, updates on bridge assessment research, and new efforts in bridge management systems.

Typical bridge inspections primarily use visual inspection, ideally at arms length, supplemented by manual tools to collect inventory and condition data. When potential problems are identified, special inspections are made using various NDE devices. An extensive list of potential technologies was developed as examples for vendors who might have new advances to offer. Condition concerns included, but were not limited to, chloride content, alkali-silica reaction, corrosion, deck delamination, concrete cover, steel corrosion, fatigue cracking, voids, material deterioration, pile length, scour and underwater condition.

In planning for possible vendor demonstrations of new technologies for condition assessment, bridges with known deficiencies were needed. The NCDOT Bridge Management Unit reviewed the bridges located on the test loop and found that all were in relatively good condition and would not be good candidates for demonstrating new technologies. As a result, several bridges off the test lrack, but in the Raleigh vicinity were identified for the purpose such as the examples shown in Figure 4.1 through Figure 4.3.

As advanced preparation, the NCDOT Bridge Management Unit collected additional data on the bridge condition, particularly the deck condition for possible comparison to vendor technology data. However, in the end, the participating vendors' collection data were limited to the collection of bridge geometry data which could be demonstrated on the test loop. Presentations during the workshop covered a broader range of bridge assessment topics.

Figure 4.1. Bridge for SR 1010 over US 1 in Wake County.

Figure 4.2. Bridge steel superstructure and CIP concrete pier substructure.

Figure 4.3. Patched concrete deck of bridge.

4.2. Perspectives on Automated Bridge Survey

Six presentations were made during the bridge session of the workshop held in September. Each is documented in the workshop proceedings manual, but a brief summary follows.

4.2.1. Bridge Management: A National Perspective

Thomas D. Everett, PE, the Bridge Programs Team Leader for the Federal Highway Administration's Office of Bridge Technology, presented information on bridge management based on national policies, data and funding. Data was a main emphasis of his presentation, including the challenges related to the availability and usefulness of the National Bridge Inventory. Additional challenges included standardization among states and collection of more useful and comprehensive data. Mr. Everett talked briefly about performance reviews of the Federal Highway Administration's Highway Bridge Program and some of the areas where improvement has been suggested or mandated by the Government Accountability Office and the Office of the Inspector General. Then the involvement of Congress was discussed due to the potential for drastic changes in the current requirements, such as requiring risk-based prioritization, a performance plan and bridge management systems. In addition to these changes, another important change will revolve around the next authorization proposal which will center on reform. This new authorization will contain six major themes and eight core programs and it can be expected that bridge management will become much more important in the future.

4.2.2. Long-Term Bridge Performance Program

Andrew J. Foden, PhD, PE, Deputy Program Manager for the FHWA Long Term Bridge Performance Program presented information on the impact and expected outcome of this program. To illustrate the need for this program, Dr. Foden presented facts related to the country's infrastructure including usage, condition and economy. Then the approach and philosophy was explained including the definition of bridge performance which "encompasses how bridges function and behave under the complex and interrelated factors and stresses they are subject to day in and day out". Dr. Foden discussed in detail the goals and objectives of the research program which all center around further understanding of performance characteristics and addressing bridge deficiencies. The research project is designed with a 20 year timeline with the first 5 years being phase one and the remaining fifteen years being phase two. The program seeks to incorporate asset management into the bridge management system and develop objectives and strategies for asset management and life cycle analysis. The project team for this study is very diverse and experienced and seeks to develop new strategies to improve the current bridge maintenance and performance standards.

4.2.3. The Israeli Bridge Management System

Jim Edgerton and Pascal Laumet with AgileAssets provided a detailed case analysis on the implementation of a Road Maintenance Planning and Management system in Israel. The Israeli National Road Company employed AgileAssets to develop a maintenance planning and management program and Mr. Edgerton discussed the various challenges and capabilities of the system. The system is geared toward achieving several major goals -- the increased safety of the transportation network, extending the projected life of the given assets, improving the condition of the infrastructure by enabling better decision making and finally detailed cost benefit analysis. There were four major parts to the system including, pavement, bridge and safety management systems as well as a planning system. The software is totally integrated and web based and provides for asset inventory and inspection. The bridge module provides detailed analysis of inspection data and other bridge characteristics such as load limits and clearances. This data allows the software to analyze routes for oversized and overweight vehicles and provide the best choice based on hard data. The program stores all related data and empowers the user to create custom reports or to select from preloaded reports. Mr. Edgerton indicated the system is powerful and comprehensive and with sufficient data can be very helpful in managing maintenance procedures.

4.2.4. Bridge Health Monitoring

Eugenia K. Roman, PE, of Olson Engineering presented information on structural health monitoring and case examples from projects on which Olson Engineering is involved. In this forum, Mrs. Roman focused mainly on bridge monitoring, what information and methods are used to collect this data and how this data can be applied for asset management. According to Mrs. Roman structural health monitoring involves "qualitative global damage detection technology," instrumenting "structures to assess in-service dynamic response of a structure" and "long-term or periodic monitoring." Effective structural health monitoring systems require a broad range of sensors and accurate placement. In order to access the condition, it is important to establish a baseline of normal loading cycles. Data acquisition is accomplished through the use of specialized data acquisition systems that are all-weather and provide up to 32 channels for sensors. These systems can be used for a variety of reasons including understanding load response, early damage and fatigue detection, data for use in the design of retrofits or repairs, predicting the remaining service life and other such case specific needs. Mrs. Roman discussed several case studies as illustrations of how a structure health monitoring system can be customized for specific needs.

4.2.5. Advanced Technologies in Foundation Investigations

Steven Sibley, PE, serves as an engineer with the Louisiana Department of Transportation in Bridge Maintenance. His presentation centered on evaluating bridge pilings for scour susceptibility. The main concern identified and addressed by the presentation was the large number of bridges with unknown foundations. Mr. Sibley explained the new technology employed by the Louisiana DOT in determining foundation depth. Longstanding non destructive methods include parallel seismic, cross bore-hole logging and sonic echo / impulse response. These methods present significant challenges either in cost or space requirements. A new method was sought by LADOT, for which the company FDH-SE, Inc. offered dispersive wave propagation. This technology involvs placing sensors on bridge pilings and hitting the piles with a large hammer to send waves through the pile. The sensors would in turn provide data which can be analyzed to estimate the pile length and condition. LADOT set up several test sites for which pile lengths were known and had these piles tested with this new technology. The results showed the concrete and timber piles had reasonable error rates 2.66% and 4.92% respectively and all results came in below the actual length. Steel piles however returned inconsistent results but still were all lower than the actual lengths. Using the data Mr. Sibley stated that LADOT will analyze the scour susceptibility using tested pile lengths and in addition will use the data to select future testing sites.

4.2.6. Bridge Height Clearance Using Terrestrial LIDAR in Motion

Michael Frecks, PLS, is President of Terrametrix, specializing in 3D survey techniques. His presentation outlined the many advantages and new technology in the 3D in motion survey field.

Mr. Frecks' company uses multiple 2D LIDAR (**LI**ght **D**etection **A**nd **R**anging) systems mounted on a vehicle to produce 3D surveys that are dimensionally accurate. These surveys are conducted mainly on established roads and normally extend well beyond the limits of the road. Mr. Frecks described the method behind the data collection and explained that a survey of several miles can be conducted in a matter of days as opposed to weeks or months and much more information can be extracted from the resulting file. Mr. Frecks provided several 'fly overs' as an example of what can be done with the data as shown in Figure 4.4. The main interest in the data at the present is the ability to determine bridge height clearances based on the data that is collected. The file also integrates GPS data to accurately identify locations in GPS coordinates. Because this technology provides essentially the existing 'surface,' the bridge under deck can be analyzed and clearances taken at varying intervals. Mr. Frecks explained that there exists immense ability to extract whatever geospatial data may be needed from within the resulting survey files.

Figure 4.4. View resulting from dynamic multi-directional scanning

4.2.7. Live Fatigue Crack Data with the Electrochemical Fatigue Sensor (EFS)

Tyler Smithson, SE, PE, a structural engineer with Matech Corporation, made a presentation focusing on the importance of fatigue crack monitoring. Bridge failures present a real problem to state departments of transportation and one major concern is fatigue failure. Fatigue cracks are often found in bridge inspections and generally are repaired quickly and easily. However using visual methods does not allow for detection prior to an actual visible crack and in addition it is impossible for an inspector to know if the crack is propagating. Mr. Smithson discussed a relatively new technology for fatigue crack detection and monitoring called the Electrochemical Fatigue Sensor system. This system allows users to detect a non visible crack and determine if that crack is still active. This is accomplished by using two sensors placed on the crack or on an area prone to cracking. Data is collected and transferred to a computer program for analysis. The method also allows for verification of repairs. Mr. Smithson discussed several case studies where the system has been used by public agencies and presented data in support of the benefits of this system.

4.3. Data Collection

The bridge inventory contains bridge vertical clearance data for both the roadway served and the under-roadway at grade separations. Ideally, the vertical clearance is adequate with a margin of safety for passage of vehicles up to the legal limit of 13 feet and 6 inches as shown in Figure 4.5. Posting of the clearance is generally provided when less than 14 feet and 6 inches. Even when the clearance is greater than the legal limit, vehicles or loads exceeding the limit can cause damage to the bridge as shown in Figure 4.6 and Figure 4.7.

Figure 4.5. Bridge vertical clearance at grade separations.

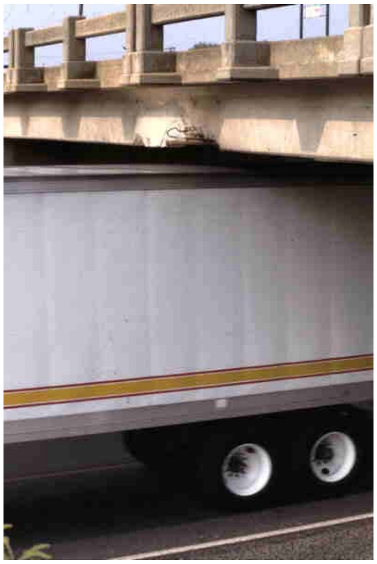


Figure 4.6. Vertical clearance for vehicles at grade separations.

Figure 4.7. Bridge damage due to vertical clearance deficiency collisions.

Two vendors participated in the test track data collection effort, Geo-3D and Terrametrix. Each provided vertical clearance data for a select number of bridges. The types of mobile data collection vehicles used are shown in Figure 4.8 and Figure 4.9. Each employs LIDAR for the survey process. After the basic field collection of position data, the data is reduced through extensive analysis to produce the required geometric results.

For bridge vertical clearances, the usual objective of the data reduction is to arrive at the measurement along multiple paths under the bridge or overhead sign that would define clearances for the width of the roadway. The scanning process records spatial data that could allow reduction of even the full undersurface of the superstructure. In the case of this demonstration, the vertical clearances along at least one path corresponding to a lane divider line were requested. The two responding vendors provided the clearances, but with slightly different approaches. Both approaches were helpful in understanding options and capabilities. Geo-3D provided clearances along a single lane divider line for each girder of the bridge. Terrametrix provided clearances for the first and last girder along three or more separate lane lines as shown by the example in Figure 4.10.

Figure 4.8. Geo-3D mobile data collection vehicle.

Figure 4.9. Terrametrix mobile data collection vehicle.

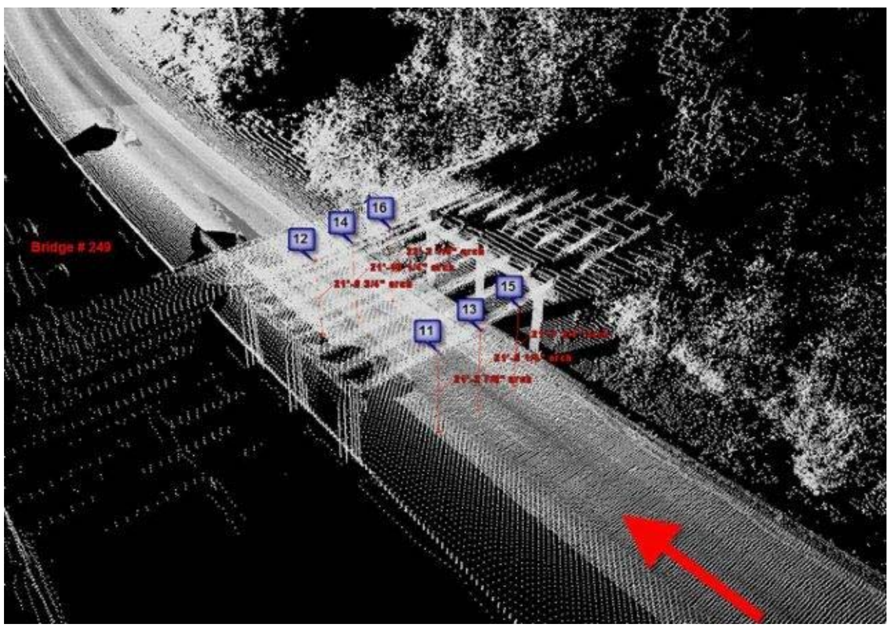


Figure 4.10. Bridge vertical clearance locations for first and last girder.

Reference survey data was gathered by the NCDOT. These personnel surveyed vertical clearances at the lane lines for the first and last girders of several bridges using a stationary LIDAR instrument as shown in Figure 4.11. In addition, existing data in the bridge inventory file was reviewed for comparison.

Figure 4.11. NCDOT special survey of vertical clearance at selected bridges.

4.4. Results

Vertical clearance data for several bridges at grade separations and overhead signs were submitted by the two vendors. The amount of data is not sufficient for statistical analysis, but general comparisons can be made by referencing the NCDOT special survey data and the existing vertical clearances listed in the bridge inventory file. Figure 4.12 illustrates some important relationships. The minimum vertical clearance (MVC) is a function of the longitudinal and transverse slopes of both the roadway below and the superstructure above. The concern for posting vertical clearance is the minimum value located at any point in the traffic lanes under the bridge or sign structure. This value does not necessarily represent the maximum possible clearance across the overhead elements total length. However, the maximum minimum vertical clearance (MMVC) in an identified lane does capture this height. The MMVC is important for routing permitted over-height vehicles and thus both MVC and MMVC are recorded in the inventory.

In the next few pages comparisons will be shown for three different physical locations along the test loop. The comparison will consist of a figure showing the actual location of each vendor's data collection as well as the reference survey data collection locations and a table summarizing the survey findings. Actual locations of vendor surveys are denoted on satellite images of the overhead element, gathered using the Google earth program. In these plots the location symbols for the three sets of data (NCDOT reference survey, Geo-3D, and Terrametrix) are the same and the key is given in Table 4.1. In all of the tables, height values are given by lane number. The convention followed for this report is as follows:

- Lane 1 is the pavement marking at the right of the rightmost lane at the roadway edge of the shoulder;
- Lane 2 corresponds to the lane markings at the right edge of the lane immediately to the left of lane number one;
- Lane 3 corresponds to the lane markings at the right edge of the lane immediately to the left of lane number two;

- Lane 4 (if available) corresponds to the lane markings at the right edge of the lane immediately to the left of lane number three;
- Lane 5 (if available) corresponds to the lane markings at the right edge of the lane immediately to the left of lane number three;
- Median corresponds to the pavement marking at the left edge of the left most lane.

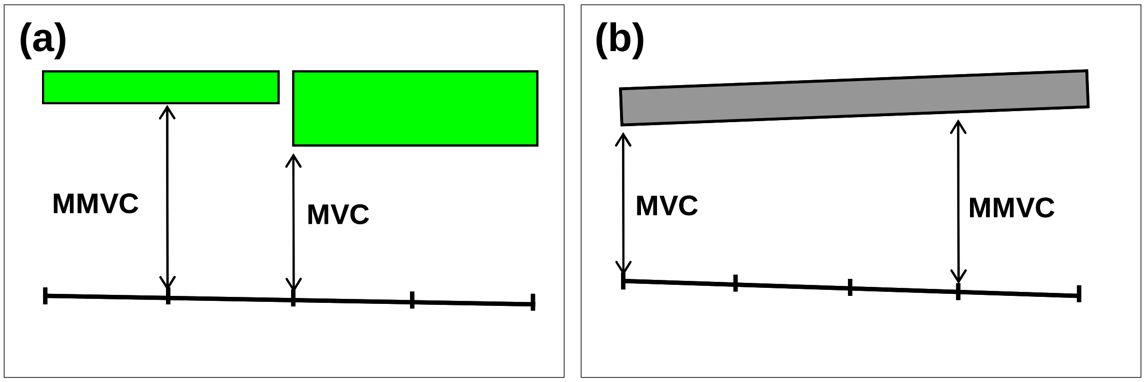


Figure 4.12. Schematic of minimum (MVC) and maximum-minimum (MMVC) vertical clearance for; (a) signs and (b) bridges.

Table 4.1. Vertical Clearance Location Symbols.

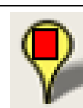
Symbol Legend	
	NCDOT Survey Locations
	Geo 3D Measurement Locations
	Terrametrix Measurement Locations

Table 4.2 lists the vertical clearance data from several sources for the Glen Eden Drive bridge over the north-bound lanes of I-440 in Raleigh, NC. Figure 4.13 and Figure 4.14 show the locations of the specific data points in plan plotted using the point longitudes and latitudes in Google Maps satellite view. The patterns of data collection from the NCDOT survey (first and last girder over lane markings), from Geo-3D (each girder along a single path) and from Terrametrix (first and last girder generally over three lane markings) are visible in Figure 4.13 and Figure 4.14. The presentation of the data in Table 4.2 is in a similar pattern to facilitate comparison. In general, there is a significant agreement among the data sources within one or two inches of variation.

Table 4.2. Glen Eden Drive Bridge Vertical Clearance Data Comparison.

Lane (Shoulder to Median)	Beginning (south)	< - - - - - - - - - - - - - - >						End (north)	
	DOT Survey	Terra-metrix	Geo-3D				Terra-metrix	DOT Survey	Insp. Rept.
	Vertical Clearance in Feet								
1	21.71	21.65	21.62	21.98	22.08	22.08	22.18	22.16	22.17
2	21.53	21.44					21.85	21.91	22.00
3	21.34	21.32					21.56	21.63	21.50
Median	21.32							21.57	21.42

Figure 4.13. Survey and Geo-3D measurment locations for Glen Eden Drive bridge.

Figure 4.14. Terrametrix measurement locations for Glen Eden Drive bridge.

Table 4.3 lists the vertical clearance data from several sources for the Lake Wheeler Road bridge over the west-bound lanes of I-440 in Raleigh, NC. Figure 4.15 and Figure 4.16 show the locations of the specific data points in plan. This bridge has a substantial skew and both the under roadway and the bridge deck have significant super-elevation variations. It should be noted that the inspection report clearances are for the first girder for Lane 1 but for the last girder for Lane 4 and an intermediate girder at the median marking. Thus, it can be interpreted that there is reasonable correspondence between the NCDOT survey data and the inspection report values. Some of the data collected in motion had reasonable agreement with the NCDOT survey values; however, in some other cases, the reduced clearances were off substantially. It is believed that the LIDAR scans in some cases may have been associated with the underside of the deck rather than the underside of the last girder.

Table 4.3. Lake Wheeler Road Bridge Vertical Clearance Data Comparison.

Lane (Shoulder to Median)	End (west) < - - - - - - - - - - - - - > Beginning (east)									
	DOT Survey	Terra-metrix	Geo-3D					Terra-metrix	DOT Survey	Insp. Rept.
	Vertical Clearance in Feet									
1	21.78								17.33	17.42
2	19.79	21.91	21.03	20.57	19.85	19.03	18.37	18.16	18.15	
3	19.88	22.27						19.13	18.29	
4	17.35	23.16						20.09	20.15	17.42
Median	17.52								21.12	17.00

Figure 4.15. Survey and Geo-3D measurement locations for Lake Wheeler Road bridge.

Figure 4.16. Terrametrix measurement locations for Lake Wheeler Road bridge.

Table 4.4 lists the vertical clearance data from the various sources for the South Saunders Street exit sign over the west-bound lanes of I-440. Figure 4.17 shows the locations of the specific data points. This sign structure has two signs mounted over the rightmost lanes with lower clearance than exists for the leftmost lanes with the structure only above. The clearances are further complicated at the signs with lower brackets under the signs at specific points to support sign lighting fixtures. Thus, there can be variations between the clearances to the brackets and the clearances to the lower edge of the sign. Since the data was often collected for the path along the pavement marking, these locations may not correspond to the brackets lower clearances. Thus, the differences in the measurements based of the various sources and locations can be reasonably understood. The inventory listing for the maximum-minimum clearance reasonably corresponds to the in-motion data values submitted. Nevertheless, it is apparent that the capability to reduce the data and obtain the clearance at the brackets will be important at overhead signs.

Table 4.4. South Saunders Street Exit Sign 81 Vertical Clearance Data Comparison.

Lane (Shoulder to Median)	Inspection Report	DOT Survey	Geo-3D	Terrametrix
	Vertical Clearance in Feet			
1				18.91
2		17.74		18.02
3	17.92	18.00	18.47	18.47
4		23.67		23.39
5	23.00[a]	23.34		23.01
Median				22.80

[a] Maximum-minimum clearance.

Figure 4.17. Measurement locations for South Saunders Street exit sign.

Table 4.5 lists the vertical clearance data from inspection reports and from Geo-3D for several additional bridges and sign structures on the test loop in the vicinity of Raleigh, NC. In comparing these values, it must be remembered that the Geo-3D data was taken along a single path and provides the clearances under a sign structure or under a series of girders. However, the inspection report clearances are at the location across all lanes where the clearance is the MVC or the MMVC within a lane. In most cases, the in-motion collected values are between the MVC and the MMVC which is reasonable. Two exceptions are the values determined for Sign 933 and for Bridge 348. These differences do not appear reasonable but could not be readily explained.

Table 4.5. Other Vertical Clearance Data Comparisons.

Structure	Inspection Report		Geo-3D
	Maximum Minimum	Minimum	Single lane
	Vertical Clearance in Feet		
Bridge 103 (Pedestrian Bridge)		25.00	24.64
			25.26
Sign 711 (Blue Ridge Rd.)	23.25	20.25	20.73
Sign 934 (Edwards Mill Rd.)	23.00	17.42	17.75
Sign 933 (Wade Ave.)		17.58	15.78
Bridge 549 (Blue Ridge Rd.)	17.25	17.17	17.62
			17.45
			17.22
			17.09
Bridge 580 (Cary Town Blvd.)	21.50	19.83	21.82
			21.23
			21.13
Bridge 348 (NC 54)	16.75	16.58	17.03
			17.78
			18.04
			17.85
Sign 712 (Lake Boone Tr.)		18.5	18.57

4.5. Summary

Overall, the data collected in-motion shows significant promise for these methods to be of benefit. There are some problems so that reliability remains an issue, particularly since the vertical clearance recorded and posted or used for permit routing could cause significant collision damage and injury if in error. Fortunately, the bridge inventory already contains values that can be used for comparison and to assist in identifying disparities. Since the implication for improved safety during inspections would be very positive if these methods become more reliable, their development should be supported by trial use.

CHAPTER 5 GEOTECHNICAL FEATURES

5.1. Introduction

Asset management is a relatively new concept in geotechnical engineering. In general, the nature of performance data, and response of structures within the realm of geotechnical engineering render the concept of asset management a valuable tool that, if effectively implemented, can lead to increased operation efficiency and cost control. The concept of asset management generally revolves around data collection and heuristic analyses to inform the decision making process. Within the realm of geotechnical engineering, two classes of assets can be considered: i) data collected during subsurface site investigation including subsurface stratigraphy describing lithology, and parameters describing soil properties that are evaluated through in situ as well as laboratory testing, and ii) Performance data collected by measurement of the infrastructure response with time during operating conditions, or a survey of the infrastructure condition. The Federal Highway Administration (1999) put forward a definition for asset management that define the term to generally mean operating the asset in a cost effective manner with maintenance and upgrades implemented in a systematic and optimized manner. The recognition of the need for an asset management system is emphasized more than ever given the ever increasing limited funds and increased demand for highway developed. An integrated asset management system that encompasses all structures typically owned and maintained by highway agencies is becoming a case of necessity to meet the demands of the 21st century. Given the large network of highway assets, automated data collection with a speed that can be tolerated by road traffic is the most preferred approach. It is however the case that technology is not yet advanced to the stage of performing data collection in such a manner for majority of geotechnical structures. Accordingly, the nature of data collection may differ, depending on the asset type.

In recognition of the gaps in our knowledge regarding management of state highway agency's assets, the North Carolina Department of Transportation spear headed the 2008 National Workshop on Highway Asset Management and Data Collection. The workshop effort was supported by the Federal Highway Administration, North Carolina State University, Transportation Research Board, United States Department of Transportation and American Association of State Highway Transportation Officials. The geotechnical asset management (GAM) focus of the workshop included four areas. These are unknown foundations, corrosion of buried metals, settlement of bridge approach slabs, and retaining walls inventory and profile measurements. These four areas were selected since they represent a myriad of challenges faced by departments of transportation across the nation and worldwide, and there have been innovative work performed for management of these assets. Two of areas, namely settlement of bridge approach slabs, and retaining walls inventory and condition assessment, provide the opportunity of data collection on a network level, while the other two areas, unknown foundations, and corrosion of buried metals, provide a demonstration of data collection on a project location level.

5.2. Geotechnical Asset Management (GAM)

In general, the presentation of geotechnical data collection and processing in the context of asset management systems is limited in literature. Sanford-Bernhardt et al (2003) presented a summary of highway components that can be considered as geotechnical assets. The asset categories in this case included those that are “exclusively geotechnical,” “partially geotechnical,” and “minimally geotechnical.” The type of assets listed in each category, and the reason for such listing are summarized in Table 5.1 by Sanford-Bernhardt et al (2003). The authors did not include site investigation data or parameters describing soil properties as an asset class. Sanford-Bernhardt et al (2003) made the point of geotechnical assets are sometimes indirectly included in single management systems (such as, for example, a pavement management system including descriptive condition of subgrade soils) and proposed a frame work to effectively incorporate geotechnical assets in an overall asset management system.

Table 5.1. Summary of Highway Components that may be Considered Geotechnical Assets [Sanford-Bernhardt et al. 2003]

Asset Function Category	Interaction with Other Assets	Asset	Purpose	Performance Objectives
Exclusively geotechnical	Indirect	Embankments and slopes	• To provide for gradual grade changes in vertical alignment	• Provide satisfactory support for roadway without intruding on pavement or other transportation structures
Partially geotechnical	Direct	Tunnels and Earth retaining Structures	• To retain earthen materials so that highway can be constructed in restricted right-of-way	• Satisfactorily retain earthen materials to prevent intrusion or damage to highway structures
		Culverts and Drainage Channels Foundations	• To provide control of surface waters • To transmit structural loads to supporting ground intruding on pavement or other transportation	• Prevent accumulation of water on pavement and prevent damage to highway structures from erosion • Satisfactorily support structure without excessive deformations

Raybould, (2003) linked earthworks asset management to risk management and emphasized the need for such a link as engineers seek the implementation of cost effective measures for management of infrastructure earthworks. Within the British system, Raybould, (2003) pointed out the nature of qualitative versus quantitative data and the use of such data for either strategic or tactical management system. Najafi (2008) presented a system for inventory and condition assessment of buried drainage infrastructure systems such as culverts. The authors presented their procedure in a format suitable for routine implementation by field operators.

Several recent papers, for example Ferreira (2005), Pagano et al (2006), and Harrison et al (2006), have emphasized the need for asset management systems that are integrated with lifecycle cost analysis for effective decision making and planning of transportation structures. However, asset management of geotechnical structures has not advanced to the level where life cycle analyses can be performed. This is mainly due to the lack of data collection protocols and the fragmented manner in which some of the relevant data are currently maintained, which renders the meaningful condition description of a given geotechnical structure challenging even in a qualitative manner. This leads to the inability to piece together components of asset management needed for life cycle cost analysis.

It is clear that the data must be defendable and repeatable so that users of the information can have a high level of confidence in its overall effectiveness. However, once data on the highway geotechnical structures are collected, asset management system components are possible to develop. At a minimum, such a system should include information management and querying system, condition assessment tools linked to specified performance levels, life cycle cost-benefit, and strategic policy development and implementation.

5.3. Data Collection

No vendors elected to participate in the data collection of geotechnical features. All data presented in this section of the report were gathered by NCSU personnel with help from the NCDOT.

5.4. Unknown Foundation

In general, the term "unknown foundations" has been used in geotechnical engineering to designate the status of foundation support elements for which records of type, dimensions, or depth of embedment are not available. This is generally the case for older structures, especially bridges, where continuous assessment of scour and prognosis of remaining service life are needed. Out of 580,000 bridges in the National Bridge Inventory data base by Federal Highway Administration, approximately 90,000 have been identified as having unknown foundations (Zayed et al. 2007). The NCDOT currently maintains 12,712 bridges across North Carolina, ranking our state as 13th in the nation for the highest number of state-maintained bridges (NCDOT 2008b). Approximately 5,000 bridges over water in North Carolina have been identified with some element of unknown foundations (FHWA 2008). Zayed et al. (2007) outlined the hierarchy of risk factors associated with unknown foundation as presented in Figure 5.1. It is however the case, with the advent of computerized data archiving, that the challenge of "unknown foundation" should be resolved in the near future as better and more efficient records keeping practices are implemented. On the other hand, the technology associated with defining unknown foundation is currently extended to provide condition assessment of the foundation elements. This is an aspect of importance especially for foundation supporting critical infrastructures (lifelines) in harsh environment.

Generally, focus has been placed on geophysical methods for estimating the depth or type of a foundation supporting a bridge. The reason of such a focus is the ability to assess the unknown foundation with a minimum disturbance to the site and with least requirement for accessibility. Geophysical methods may be used in combination with boreholes to access and target a specific depth or layer. The National Cooperative Highway Research Program NCHRP Projects 21-5 and 21-5(2) established benchmarks for determination of unknown bridge foundation. The assessed methods included the Parallel Seismic (PS), Sonic Echo/Impulse Response (SE/IR), Ultra seismic (US), Spectral Analysis of Surface Waves (SASW), Bending Wave (Short Kernel Method), Surface and Borehole Radar, Dynamic Foundation Response and Borehole Induction Field (IF) methods. A review of some of these techniques as they apply to unknown foundations has been given by Sack et al. (2004).

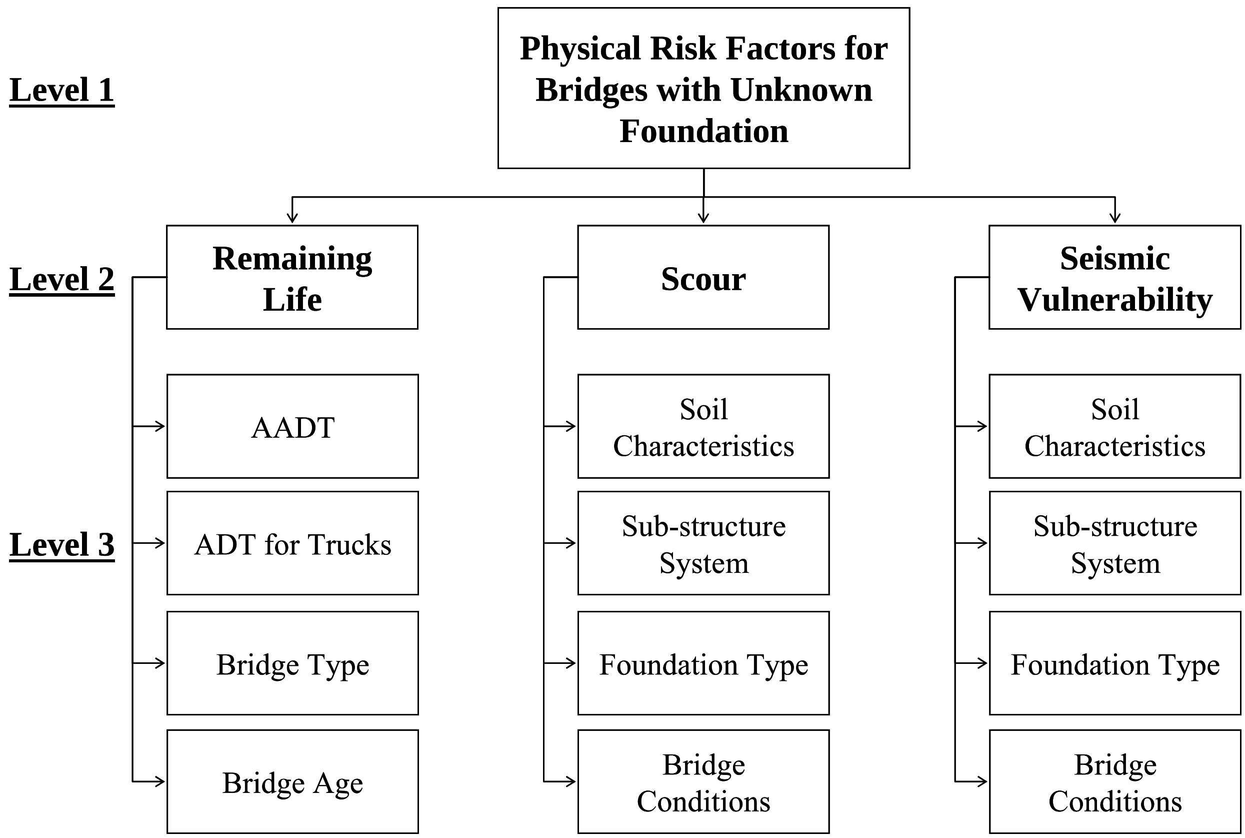


Figure 5.1. Hierarchy of physical risk parameters and their Factors (ADT =Average daily traffic and AADT =average annual daily traffic), [Zayed et al. 2007].

The alternative is to use invasive approaches that range from a simple probing technique to a comprehensive site work that includes trenching and several borings. The relatively simple probing approach utilizes a rod and hammer and attempt to identify the depth of refusal to penetration. The assumption then is a pile will most likely be terminated at the depth of refusal. The method can also be used to determine the width of a shallow foundation through probing over an area. Limitations to this approach are obvious. Probing is a labor intensive process, it is limited in its depth of exploration, and the data obtained from manually driving the rod and estimating its penetration resistance is highly subjective. On the other hand, the following geophysical approaches represent some of the most commonly reported in literature:

- Ground Penetrating Radar (GPR)
- Dispersive Wave
- Borehole geophysical methods
- Pulse-Echo

5.4.1. *Ground Penetrating Radar (GPR)*

Ground Penetrating Radar (GPR) uses electromagnetic waves to determine approximate distance to targets. Tallini et al. 2004 indicated that GPR single-frequency (1,600 to 600 MHz) and borehole (300 MHz) antennas may provide useful data on the characteristics of building foundation systems, whether shallow (grade beam and mat foundations) or deep (piles and micropiles). This method has also been used for assessment of pavement layers (e.g. Grote et al. 2005) and for finding subsurface geologic anomalies such as sinkholes (e.g Zisman et al. 2005). Stegman and Holt (2000) reported a case where GPR was mainly used to assess condition of a bridge abutment including reinforcing, thickness, and confirm the presence of a foundation support system. The use of GPR for unknown foundation is still in the process of development as the interpretation of data remains subjective. Emphasis in the deep foundation area has also been placed on Borehole GPR, albeit such application requires the drilling of a borehole.

5.4.2. *Dispersive Wave Method*

The dispersive wave method has been widely investigated by FDH Engineering and NC State University for the last decade. The method is used to calculate the length of the pile an is based on the premise that a seismic record would show three pulses: the first pulse is that which is propagated from the location of the impact to the gauge: the second pulse is that which is reflected from the tip (head, butt); and the third is that which is reflected from the toe of the pile. Based on the known distance between the gauge and the tip of the pile, and the time between the impact and the arrival of the second pulse, one can calculate the speed of propagation of the wave. Knowledge of the speed of travel of the pulse and the time elapsed between the arrival of the second and the third pulses at the gauge enables one to calculate the length of the pile. Douglas and Holt (1993) used analysis of bending waves in timber piles to estimate their length with reported accuracies of approximately + 10%. Holt (1998) shows the application of dispersive method to determine the length of both steel and concrete piles. The piles tested during the study had overall length ranging from 25 to 69 feet, with embedded length range from 20 to 62 feet. For the steel piles, the average percent error between the computed and recorded lengths was 12.5% (too short), with the majority of piles having -10% error or less. For concrete piles, the average percent error was 7.1%.

A method utilized by NCDOT is termed ‘short kernel method.’ In this method, one first does a Fourier analysis of the entire signal from which a Fourier spectrum is produced. The Fourier spectrum is a plot of the amplitudes versus frequencies of the various Fourier components. The spectrum supposedly gives an indication of the ‘predominant’ Fourier component; the frequency of that particular Fourier component is termed the predominant frequency of the signal. The kernel method then constructs a half sine pulse of the predominant frequency. An algorithm to move the kernel along the entire length of the signal is used to ‘detect’ the pulses. The method reliability is affected by signal noise such that the pulses may not be detected or a predominant frequency is not obvious. Furthermore, the shape of the pulse may be distorted beyond recognition due to dispersion.

5.4.3. *Pulse-Echo*

The pulse echo method offers an approach for creating electromagnetic (radar) pulse, with an ultrasonic or mechanical pulse (impact) is created at the surface, then use the reflection and backscatter signal from the internal structure to assess geometry and possible condition (Krause et al. 1997). A schematic illustrating the process is shown in Figure 5.2. The logic of the analysis is based on the classical wave equation.

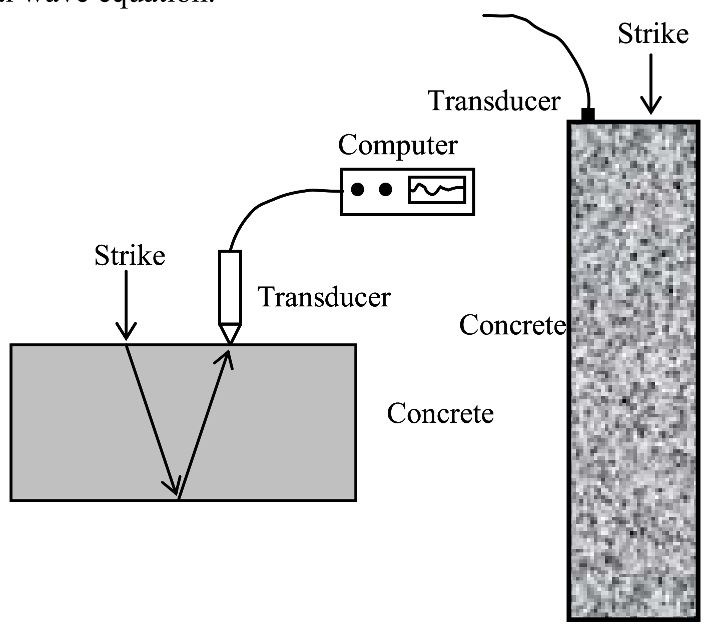


Figure 5.2. The pulse-echo method [LADOTD and FDC 2008].

Davis (1994) described use of sonic echo and parallel seismic methods for estimating pile length. In the sonic echo method, the head of the pile is impacted and the time for the reflected stress wave to reach an accelerometer, also mounted on the head of the pile, is measured. Davis reported several difficulties using this method including: (a) damping of the stress wave and multiple reflected waves made determination of the echo from the pile tip difficult; (b) delivering consistent direct impact to the side of the pile was difficult. Since the shape of the pulse invariably changes due to dispersion, it is often challenging to recognize the reflected pulses after some time is elapsed.

5.4.4. Borehole Seismic methods

The borehole methods require access from a borehole drilled close to the foundation system. The simplest borehole method, Parallel Seismic (PS) method, involves the hammer impacting at any part of the exposed structure that is connected to the foundation. A hydrophone or a three-component geophone is located in a nearby borehole and records the compression and/or shear waves traveling down the foundation. This method is applicable to concrete, wood, masonry and steel foundations. A setup of borehole method is presented in Figure 5.3 (a). Figure 5.3 (b) shows the hydrophone data obtained for the setup shown in Figure 5.3 (a). The idea is to measure the transit time from foundation to transducer. In Figure 5.3 (b) the slope of the upper line is indicative of the velocity of the tested foundation, and the second line is indicative of the velocity of the soil below the bottom of the foundation. The intersection of the two lines gives the depth of the foundation. The velocity of the concrete in the shaft in this case is 16,913 feet per second (5,155 m/s). A break in the graph occurs at a depth of 28 feet (8.5 m) indicating the depth of the shaft. A limitation of this method is the ability to set the borehole within 5 feet (1.5 m) of the foundation, which sometimes cannot be achieved.

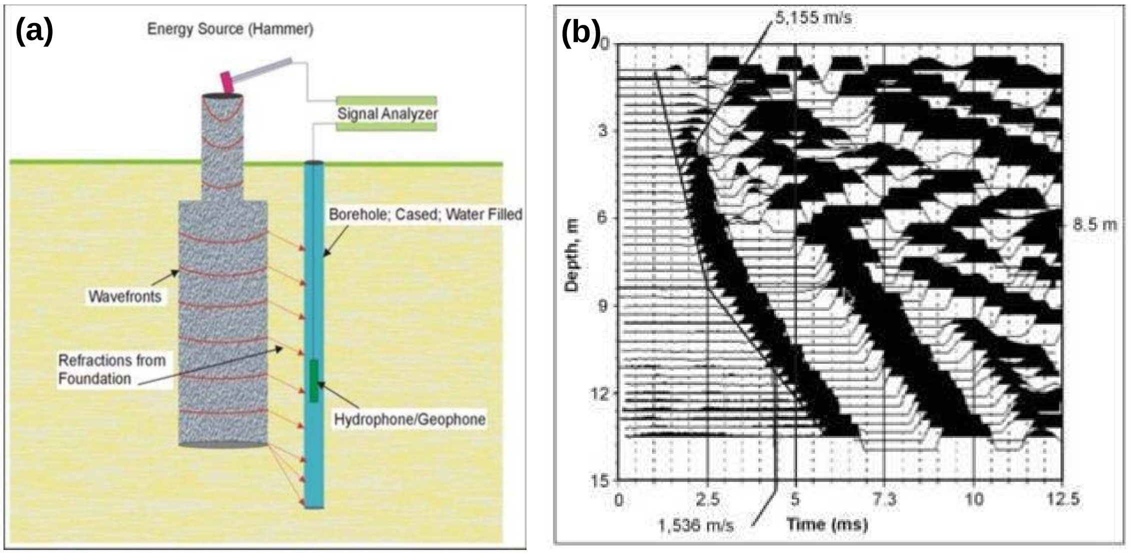


Figure 5.3. Borehole setup for unknown foundation determination by parallel seismic method: (a) parallel seismic survey setup and (b) parallel seismic data [USDOT 2008].

Sack et al. (2004) presented the approach of combining PS with a seismic Cone Penetrometer testing. The advantage is not only measurement of unknown foundation depth, but also soil properties of the subsurface profile. In addition, the use of the direct push approach replaces the need for drilling a borehole. Sack et al. (2004) indicated that this approach is one of the most accurate to estimate unknown foundation depth. Factors affecting accuracy of the results include distance from bore log to the foundation, the ability to extend the borehole below the foundation tip, and the extent of heterogeneity of the subsurface profile. Sack et al. (2004) indicated that for obtaining reliable results, a relatively high frequency source coupled with a sample rate of 50000-100,000 samples per second are needed to allow the capture of higher frequency waveforms.

5.4.5. Summary

From GAM perspective, the availability of reliable and accurate predictive tools to address the challenge of unknown foundation is of paramount importance in the present and near future. While such need may diminish with implementation of electronic record keeping, the approaches developed for evaluating unknown foundation are currently being extended to assess the condition of the foundation. Nonetheless, there is a need to verify existing methods using field testing on a large scale nationwide. With respect to analysis for prediction, there is a need for a more discriminating approach of signal processing, along with a detailed understanding of wave propagation through different foundation types and associated patterns of signals. The use of techniques such as wavelet analysis can lead to useful removal of noise from a signal and access information that may be obscured by other time-frequency methods such as Fourier analysis.

5.5. Corrosion of Metal Strips

Mechanically Stabilized Earth (MSE) structures utilize both metallic and polymeric reinforcing elements. While challenges with the use of polymeric elements may include issues such as creep, degradation due to hydrolysis, or installation damages, metallic elements suffer the issue of corrosion. Elias et al. (2001) reported that the majority of the MSE walls for permanent applications are constructed to date with galvanized steel reinforcements. The galvanized steel, either in strip or grid configuration (95% of applications according to Elias), is connected to a precast concrete facing. Aluminum alloys and stainless steel have been used for reinforcements mainly in France, but their use has been discontinued due to poor performance (Elias 1997). Corrosion of the tensile elements due to the chemical hardness of the soil-water is a major concern for the long term durability of MSE walls. The choice of backfill material and reinforcing material are two key issues to address in attempting to mitigate corrosion of MSE wall. In general, to address the issue of corrosion within the design life of the structure, the approach has been to increase the thickness of the reinforcement cross section such that performance limits are assured at the end of the design life (considering material loss due to corrosion during service life, AASHTO recommends 75 years for permanent structures, and 100 years for abutments (Raeburn et al. 2008).

Accordingly, assessing the corrosion state of metal strips reinforcing highway retaining structures is one of the important asset management tasks for departments of transportation across the country. Two NCHRP projects were initiated to assess practices and technology for investigating corrosion of metallic elements. These are NCHRP Project 24-13 “Recommended Practice for Evaluation of Metal Tensioned Systems in Geotechnical Engineers,” and NCHRP Project 24-28 “LRFD Metal Loss and Service-Life Strength Reduction Factors for Metal Reinforced Systems in Geotechnical Applications.” The second project implements findings from the first at more than 60 selected locations and aims at development of a performance database as well as studying the reliability of currently available metal loss models and service limit states used in the design of MSE and other earth reinforcement elements.

5.5.1. Backfill material

The California Department of Transportation (Caltrans) requires extensive measures for MSE walls construction in aggressive environmental condition. These include impermeable cap at or near ground surface above the soil reinforcement, surface runoff control measures, and use of geosynthetic materials over the backfill to decrease the effects of road salt and water on metallic reinforcement (Raeburn et al. 2008). Based on resistivity measurement, the corresponding relative level of corrosiveness, as defined by the FHWA (Elias 2000) is given in Table 5.2.

Table 5.2. Relationship between resistivity and corrosion [Elias 2000].

Aggressiveness	Resistivity (ohm-cm)
Very corrosive	< 700
Corrosive	700-2,000
Moderately corrosive	2,000-5,000
Mildly corrosive	5,000-10,000
Non-corrosive	> 10,000

Raeburn et al. (2008) also summarized controlling factors of corrosion rates as:

- Water content - soil water contains the salts and constitutes the electrolyte necessary for corrosion
- Soil resistivity, when measured at saturation, gives a figure related to the total amount of salts present in the soil

- pH (potential of hydrogen), that governs the solubility of corrosion by-products and thus the buildup of protective layers around the buried metal
- Chloride content – chloride is the most common aggressive salt
- Sulfate content

The requirement for backfill properties varies from state to state. Table 5.3 by Raeburn et al. (2008) summarized various State DOT requirements regarding backfill materials. There is a general agreement to limit organic content of the backfill soil since it increases corrosion due to microbial activity.

Table 5.3. Summary of Backfill Requirements for some DOTs [Raeburn et al. 2008].

State Name	PI or Φ	Resistivity, R (ohm-cm)	Chlorides (ppm)	Sulfates (ppm)	pH
(FHWA)	-	≥3000	≤100	≤200	5 to 10
California	PI ≤ 10	≥1500	<500	<2000	5.5 to 10
Florida	PI < 6	≥3000	≤100	≤200	5 to 10
Georgia	-	≥3000	≤100	≤200	6 to 9.5
New York	PI < 5	≥3000	≤100	≤200	-
Ohio	Φ > 34	≥3000	≤100	≤200	5 to 10 for steel reinf. 4.5 to 9 for geosyn. reinf.
Washington	-	≥5000 3000≤R< 5000	Waived ≤100	Waived ≤200	5 to 10 for steel reinf. 4.5 to 9 for geosyn. reinf.
Idaho	PI < 6	≥3000	Waived ≤100	Waived ≤200	4.5 to 9.5
Nevada	PI < 6	≥3000	≤100	≤200	5 to 10
Related Standards	ASTM D4318 for PI	AASHTO T-288-91	AASHTO T-291-91 or ASTM D-4327-88	AASHTO T-291-91 or ASTM D-4327-88	AASHTO T-289-91

The NCDOT restricts the type of backfill material to those only conducive to non-corrosive, or moderately corrosive, conditions during service life of the structure. On the other hand, another approach such as the one utilized by Caltrans allows a wider range of backfill materials, but compensates for such allowance by increasing the amount of sacrificial steel. This is an issue that requires further study in terms of lifecycle cost analysis as a part of GAM system.

5.5.2. Reinforcing material

Beckham et al. (2005) conducted a study on four MSE walls in Kentucky for evaluating the impact of corrosion and the condition of the walls. The study concluded that corrosion rates were consistent for uniform backfill. In 20 years old MSE walls, galvanized coated steel reinforcement elements embedded in large-sized, well-graded crushed limestone backfill resulted in corrosion rate lower than the AASHTO design standards. Loss rates recommended by AASHTO are presented in Table 5.4.

The advantages of galvanization were listed by Gladstone et al. (2006) as: (1) minimizing the surface irregularities and their contributions to corrosion, (2) lowering consumption rate of zinc compared to steel, and (3) "passivation" of steel due to zinc oxides which lowers the rate of steel consumption compared to non-galvanized steel.

Table 5.4. AASHTO Recommended Corrosion Rates for Design [Raeburn et al. 2008).

Material	Time/Corrosion extent	Rate of corrosion (μm/yr./side)
Zinc	2-years	15
Zinc	Corrosion to depletion	4
Carbon steel	Standard time	12

5.5.3. Corrosion Detection

Withiam et al. (2002) summarized methods available for condition assessment of corrosion state, and the suitability of the various methods for testing metal elements under tension. Both destructive and nondestructive techniques are available for corrosion detection with challenges exist with both types of inspection techniques. Corrosion potential monitoring can be used to determine metal phases as the reinforcement loses zinc, ultimately down to the carbon steel base (Elias 2000).

5.5.3.1. Destructive Technique

Measuring metal loss data from the exhumation of a wall is a common destructive technique for corrosion detection and measurement. Due to process of excavation while maintaining the integrity of the wall, this method is limited to reinforcement elements near the surface. Such a limitation may provide results that are not representative of the most corrosive area of the wall. Corrosion rates are established through weight loss and thickness measurements, and usually multiple measurements are made at different times to assess the effect of time on the rate of metal loss (Gladstone et al. 2006). The method is expensive since it is labor intensive, and requires caution in order to ensure that the stability of the wall will not be compromised during sampling.

5.5.3.2. Non-Destructive Techniques

Popular non-destructive methods for assessment of corrosion are polarization resistance measurements, linear polarization resistance (LPR) measurements, and coupon Testing and half-cell potential measurements of reinforcement. In polarization resistance measurements, composition and geometry of the surface of reinforcement should be known. The approach is based on converting the polarization resistance to a corrosion rate. For LPR, the potential is varied from "–5 to –20 mV" to "+5 to +20 mV) around the free corrosion potential while simultaneously measuring the applied current. Polarization resistance is determined from the slope current and potential. Since corrosion rates vary throughout the year, measurements should be taken during different seasons to attain an average corrosion rate for the structure (Gladstone et al. 2006).

5.5.3.3. Coupon Testing and half-cell potential measurements of reinforcement
Coupon testing and half-cell potential measurements of reinforcements are installed at regular intervals during MSE wall construction. The North Carolina Department of Transportation began installing this type of monitoring approach during construction in 1990s. Zinc bars and steel plate coupons were installed, and reinforcements were wired for half-cell potential measurements at each monitoring station along the wall. Withiam et al. (2002) provided details on corrosion measurement at several sites in North Carolina and California based on this approach.

5.5.4. Summary

It is clear that integration of corrosion measurements with time to asset management of metallic components of earth structure is needed. Withiam et al. (2002) provided a conceptual framework for integrating corrosion performance measurement within a database of mechanically stabilized walls. Such framework can be streamlined into a broader GAM system for comprehensive and economically reliable management of metallic reinforcement.

5.6. Retaining Walls

A scan of literature, however, clearly shows a lack of a structured and widely accepted system for management of walls as a highway asset. Retaining structures support many of the highway assets. As such, the development of an asset management system for retaining structures is an emerging concept. Anderson et al. (2008) developed a system for wall Inventory Program (WIP) to support effort underway in the National Park Service. The purpose of the system is to manage maintenance and replacement cost of earth retaining structures. An inventory system for retaining walls and sound barriers was presented by Hearn (2004). The system included information about location, age, type, dimensions, and condition of the wall. The authors presented the application of linking the inventory system with a maintenance management program. It is of interest to note that Robert et al. (2006) indicated that noise walls and other structures are now included in the "Pontis" bridge management system. This is a positive development as a GAM component (noise walls) is integrated into a broader highway asset management system. The development of a systematic means for condition assessment and cataloging of all highway retaining structures in a sustainable manner will represent a major contribution an asset management system.

5.6.1. Wall Data Collection

In conjunction with the conference activities, four retaining walls located around Research Triangle Park in North Carolina were selected for demonstration of a system for inventory and condition assessment of walls. Each of the four walls is a part of a bridge abutment structure. The wall locations are as follows:

At the interchange of NC 98, Wake Forest Bypass, from west of US 1 to west of US 1A (designated as US1/NC98 wall),

- At the interchange of I-85 from west of Canden Avenue to east of Midland Terrace and 0.8 miles south of Cheek road on US-70 (designated as US70/I85 wall),
- At the intersection of US 147 at Hillandale street in Durham city (designated as US147 Hillandale wall), and
- At the intersection of US 70 at Aviation Parkway and Westgate road in west of Raleigh city (designated as US47 Westagate wall).

Other than US70/I-85 wall, all walls are MSE (Mechanically Stabilized Earth) type. The US-70/I-85 wall is an anchored tie-back type wall. The dimensions and information about each wall are treated in Table 5.5.

Table 5.5. Static Data of the Walls Survey for Condition Assessment.

Items	US1/NC98	US147 Hillandale	US70/I85	US47 Westgate
Height, Hmax (ft)	25.75	22.00	25.75	25.10
Length, L (ft)	348	118	325	131
Wall Type	MSE Wall	MSE Wall	Tie-Back Wall	MSE Wall
Backfill Material	#57 stone	Aggregate Base Course	#57 stone for panel backfill	#57 stone
Reinforcement	9 Metal strips	Unknown	Lmin=34.4 ft	L=17 ft wire mesh of 8 layers
Year Built	2005	1987	2001	1992

5.6.1.1. US1/NC98 MSE retaining wall

The retaining wall was built in 2005. The height of wall varies from 23 to 26 feet for the main section, and the length of the wall is 348 feet, as shown in Figure 5.4 (a). The MSE wall has nine metal strips, each is 26 feet of length, and was backfilled with #57 washed stones.

5.6.1.2. US-147 Hillandale MSE wall

The wall is a typical retaining structure of a bridge abutment, as shown in Figure 5.4 (b). The wall was built in 1987 as MSE type-wall, but details of the reinforcement type are not found on files. Again, this points out to the importance of having a GAM system that includes the inventory of walls and assessment of their condition.

5.6.1.3. US70/I85 Anchored Tie-back wall

The wall consists of soldier piles constructed using HP360×132 sections, and wood lagging. Permanent tie back anchors are used, and segmental precast panels were placed as a facing with a coil thread rods. The wall was built in 2001, and has a geometric shape, as shown in Figure 5.5.

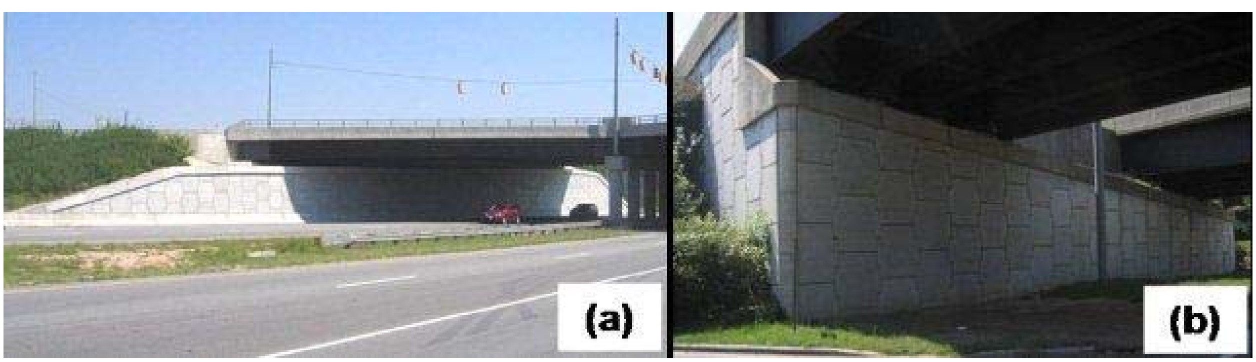


Figure 5.4. Retaining walls for study: (a) US1/NC98 and (b) US147 Hillandale wall.

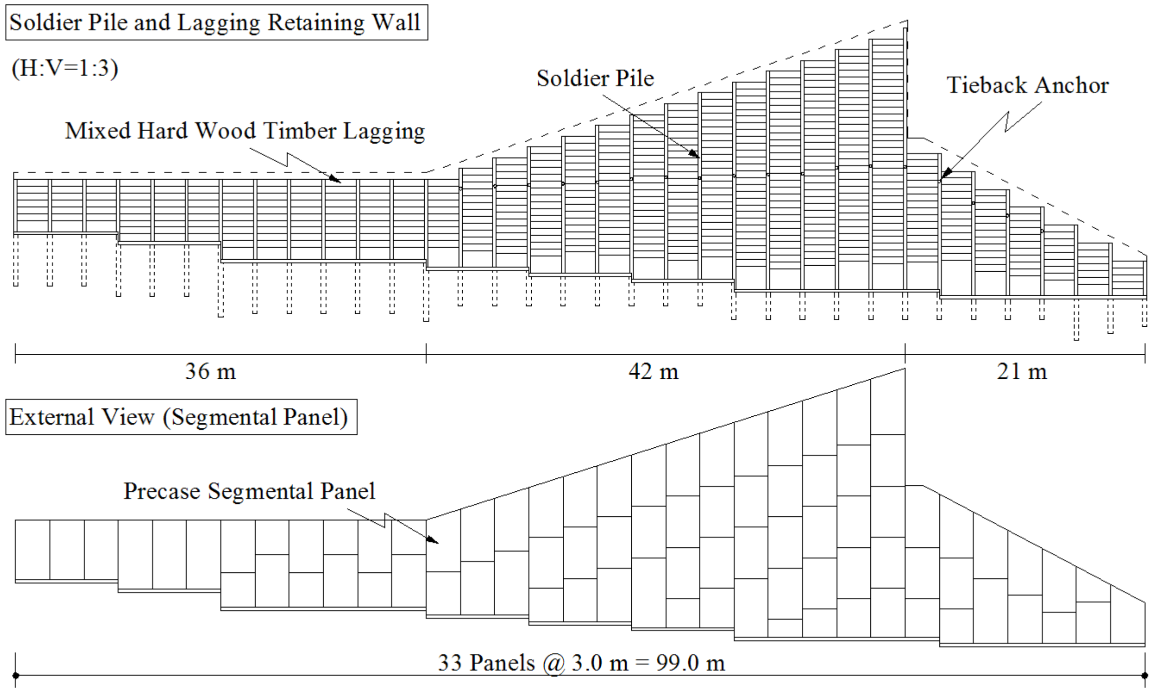


Figure 5.5. Geometry of US70/I85 retaining wall (front view with sloped Face at H:V=1:3).

5.6.1.4. US-70 Westgate MSE wall

The wall has been built in 1992, and 8 layers of wire meshes were used for reinforcing the wall. The details of geometry are shown in Table 5.5.

5.6.2. Asset Management of Walls

Figure 5.6 shows an example of LIDAR survey results of US-147 Hillandale MSE wall. Each pixel in the image represents a set of data points that is tied to x, y, and z coordinates. Linking the output of the LIDAR survey with the database of the walls coordinates can automate the process of condition assessment, and provides synoptic approach to asset management of walls.

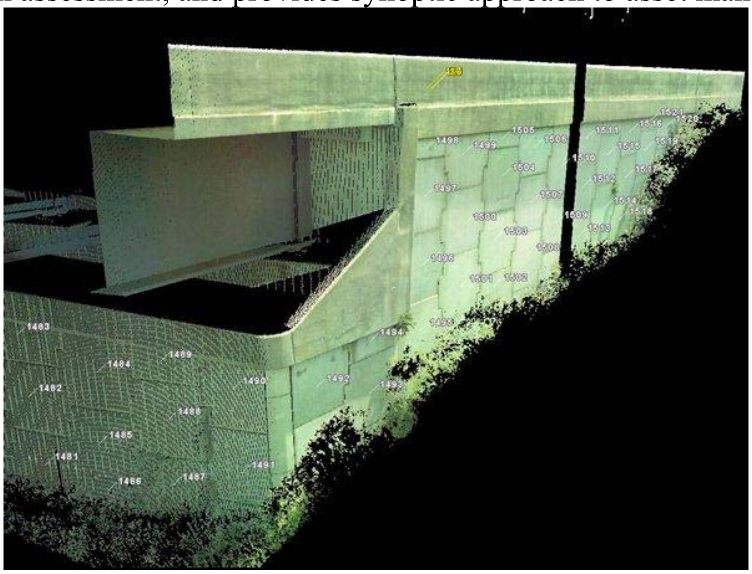


Figure 5.6. LIDAR mapping of US-147 Hillandale MSE wall.

The data collected for the workshop show that the LIDAR equipment is capable of collecting 3-D data on the wall facing in an efficient manner. Survey year and survey results can be linked to the cross-section views and locations of the wall. The survey of wall facing with time can provide important information regarding the condition of the wall since perceptive deformation can be detected by comparing the consecutive scans. A wall inventory database clearly needs to include static data such as wall latitude, longitude, and implement such data within state coordinate system. In addition, foundation type, depth of embedment, and drainage measures should be included.

5.7. Bridge Approach Slab

The individual components of a bridge approach (i.e., the bridge end bent, the approach slab, and the adjoining pavement section) may settle at different rates and magnitudes. A bridge approach slab is commonly constructed to improve rideability by bridging over grade differences that may be induced by differential movements of the adjoining pavement section in relation to the bridge foundation. If the differential settlement is severe, a "bump" in the road is felt by drivers on the road. This is not only a question of comfort, but also a concern related to safety and reliability of our highway system. Briaud et al. (1997) recommended an allowable angular distortion value not to exceed 1/200 for the approach slab length; this is equivalent to a 1.5–inch relative movement for a 25 foot slab.

Reason for the "bump" may include the impact of cyclic loading associated with vehicular traffic on fills supporting the bridge approach slab, which leads to permanent plastic deformation, and degradation in the strength of the foundation materials. In addition, internal piping and erosion of materials under the slab may lead to the creation of relatively large voids that contribute to excessive movements. This differential movement manifests itself in the form of lateral spreading and vertical deformation of the supporting layers.

In the early 1990's, engineers at the NCDOT developed a design approach and specifications for retaining fill behind bridge abutments by incorporating geosynthetic materials. The geosynthetic materials were mainly for the purpose of fill confinement but an additional benefit was a decrease in settlement of structures placed above this fill. Luna (2004) suggested nine measures to potentially minimize differential settlement within the bridge approach area and, therefore, the severity of the "bump". These included: i) construction staging such that the slab and pavement sections are constructed congruently and after the embankment has undergone initial settlement; ii) use of preloading in conjunction with lightweight fill ; iii) improvement of foundation soils prior to embankment construction using techniques such as radial consolidation, deep soil mixing, and/or stone columns; iv) use of a pre-cambered approach as recommended by Hoppe (1999); v) use of reinforced fill to attenuate traffic loading and reduce the lateral stress (and therefore the lateral movement) on the abutment wall; vi) use of shallow foundation over reinforced soil to support the end bents; vii) use adequate drainage and high quality fill material; viii) Implementation of mechanical or pneumatic sleeper slabs as suggested by Tadros and Benak (1989); and ix) use of temporary paving until differential settlement has occurred then permanent paving is applied.

However, before selecting and implementing a rehabilitation measure, the assessment of the extent of the differential settlement and its impact on rideability are needed. As a part of managing rideability, comfort, and safety levels, a quantifiable characterization of the differential approach slab movement is needed. Such characterization can be feasible from an asset management perspective if it is performed in an automated manner with measurements made on a frequent basis.

International Roughness Index (IRI) values, suggested by Sayers et al. (1986), and Riding Number (RN) values, by Janoff et al. (1985), can be used as parameters indicating the roughness of pavement as described in FHWA's Highway Performance Monitoring System (HPMS). Schleppi and Roberts (2008) presented a case study in which they expressed the change in rideability, due approach slab settlement, as a function of the International Roughness Index (IRI). The IRI value represents an accumulation of a vehicle suspension movement over distance. According to FHWA (2004), IRI value of 60 in/mile represents a "Good" threshold for road rideability, while IRI value exceeding 220 in/mile is "very poor" rideability. An issue with such characterization, however, is apparent when one considers the possibility of abrupt change in grade over a short driving distance (length of approach slabs in both directions). On the average, the IRI may be still under 60 in/mile, but the large "bump" at a one location is not reflected given the perspective of "average" characterization. As such, the quantified characterization of a displacement profile with distance along the wheel path is an important parameter for establishment of management of maintenance for safe rideability.

Two approaches emerge as providing potential tools for characterizing the displacement profile of the bridge approach slabs. Profilometry has shown to be an effective means for quantifying the relative deformation of road sections for the study of differential settlement (Seo 2003). In this case, deviation, frequency, slope, and abruptness can provide indications of road rideability. The second, which has not been used on a large scale for this specific application, is the use of LIDAR mapping to obtain spatial displacement for a given area (approach slab.) The advantage of LIDAR mapping is the areal coverage of the approach slab such that 3-D data (x,y, and settlement) are provided. Such coverage could be obtained from Profilometry, but would require several passes to achieve.

5.7.1. Profilometry versus LIDAR Mapping

The characterization of deformation profile for approach slabs was performed for two bridges along US 64. The first bridge is located on US 64 Bypass over Smithfield road (Smithfield bridge), and the second is at US 64 Bypass over Norfolk & Southern Railroad (Railroad bridge) in Wake County, North Carolina. Both bridges have approach slabs of 12 feet in length, and 69 feet in width on each end bent. The foundation type of each end bent is a cap on HP 310×70 steel piles with average pile length of 54 feet to 70.5 feet.

Deformation profiles were surveyed by both LIDAR (Light Detection and Ranging), and Profilemeter techniques. Figure 5.7 shows a comparison of longitudinal profiles from both approaches for the "US 64 over Railroad" bridge. The longitudinal profile data from the Profilemeter shows clearly an abrupt change between the bridge deck and the approach slabs. On the other hand, data from LIDAR were not conclusive. The LIDAR data were taken over the whole bridge area as shown in Figure 5.8, which did not provide a resolution high enough to clearly detect the abrupt deformation shown in the Profilemeter data.

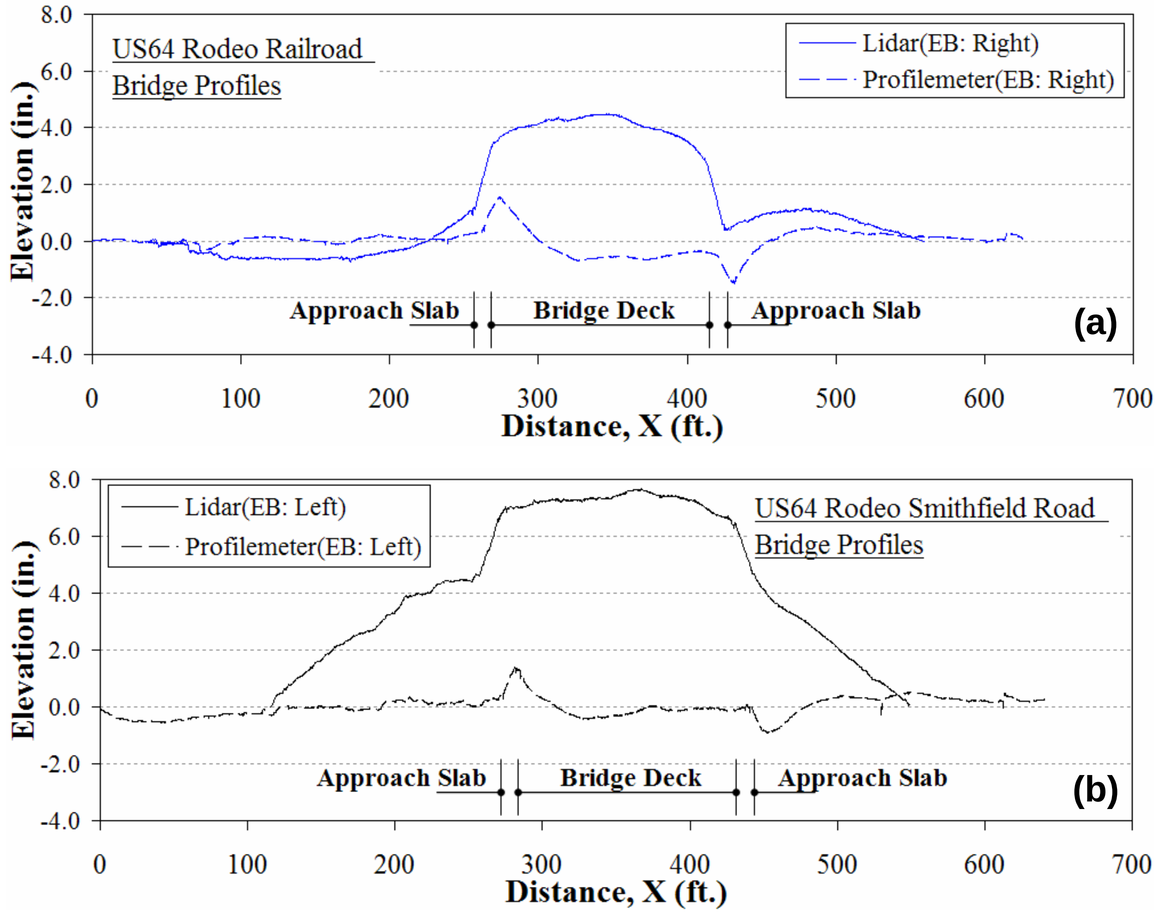


Figure 5.7. Longitudinal bridge profiles by LIDAR and Profilemeter: (a) US 64 over railroad and (b) US 64 over Smithfield road.

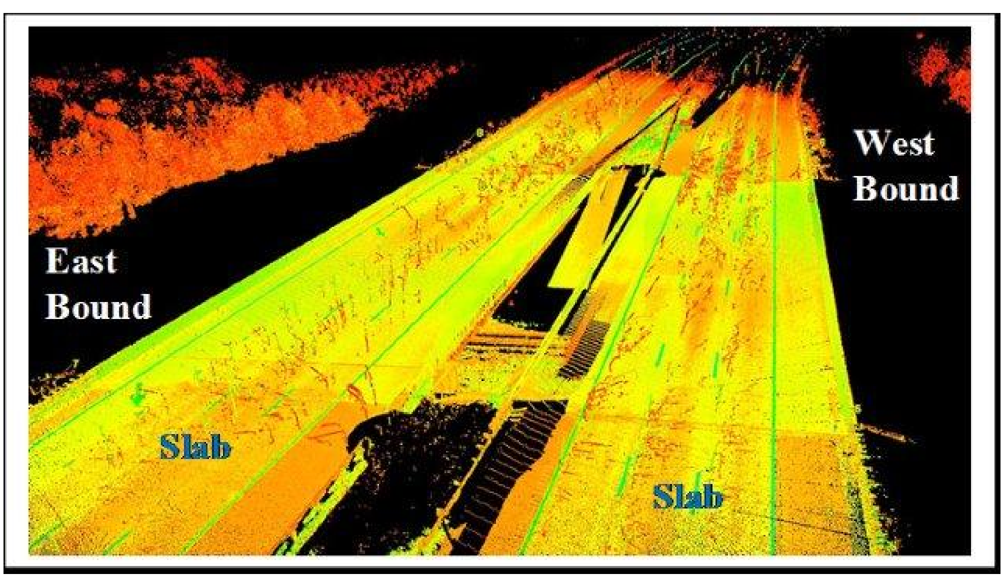


Figure 5.8. LIDAR image of US-64 bridge over railroad.

5.7.2. Comparative Assessment

The results from Profilometry and LIDAR Mapping were input into the computer program ProVAL (Profile Viewing and AnaLysis) by the Transtec Group. The IRI and RN (Riding Number) values were estimated, as presented in Table 5.6. It is recognized that this approach was not developed with the LIDAR data in mind, but is utilized herein for the sake of comparison. Since RN values are in inverse proportion to IRI, RN values close to '5' rating mean higher serviceability. IRI values from Profilemeter for left lane of east bound Smithfield bridge are the highest obtained in this case. The average IRI value for the Smithfield bridge location is 139 with a coefficient of variation of 9.6%, while the average IRI value for the Railroad bridge is 129 with a coefficient of variation of 6.7%. These values correspond to a "fair" to "poor" rideability.

Table 5.6. IRI and RN Estimated from Longitudinal Profiles.

Location \ Method		Railroad bridge				Smithfield bridge			
		LIDAR		Profilemeter		LIDAR		Profilemeter	
		IRI (in/mi)	RN	IRI (in/mi)	RN	IRI (in/mi)	RN	IRI (in/mi)	RN
East Bound	Left	115.6	3.31	127.4	2.99	154.5	3.04	165.3	2.64
	Center	131.7	3.20	116.3	3.19	154.1	2.93	145.9	2.62
	Right	144.3	2.97	133.5	3.00	126.8	3.00	135.1	2.79
West Bound	Left	132.9	3.18	130.6	2.98	111.7	3.12	132.7	2.79
	Center	141.0	3.18	144.1	2.80	110.5	3.08	125.8	2.90
	Right	135.8	3.02	122.3	2.91	93.9	3.02	129.2	2.70
Average		133.6	3.14	129.0	2.98	125.3	3.03	139.0	2.74

The IRI values from the Profilemeter are plotted and compared with the results of LIDAR data as presented in Figure 5.9. It is of interest to note that data from the LIDAR profile are yielding comparable values to those obtained from the Profilemeter. In this case, the data from the Profilemeter are considered more accurate representation of the approach slab condition. In addition, and based on the IRI values, PSR (Present Serviceability Rating; see AASHO 1962) values are estimated using Equation (5.1), and are plotted in Figure 5.10. PSR greater than 3.5 are needed to rate the site as "good." PSR values are estimated from the relationship with IRI, as presented in Figure 5.10. All values were below the threshold of PSR=3.5.

$$PSR = 5 \times e^{(-0.0041 \times IRI)} \tag{5.1}$$

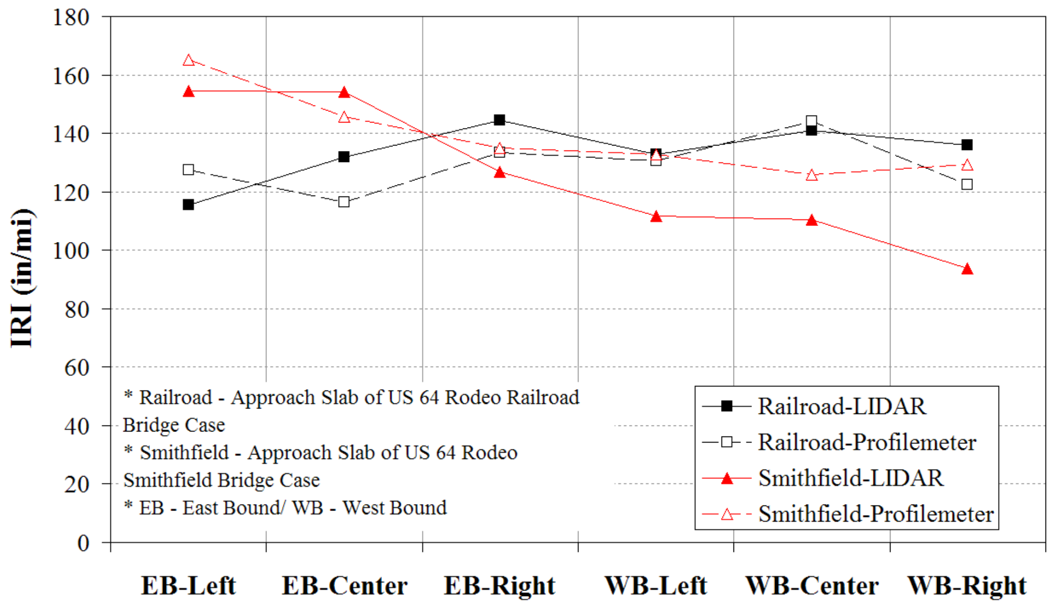


Figure 5.9. IRI variation for the selected cases.

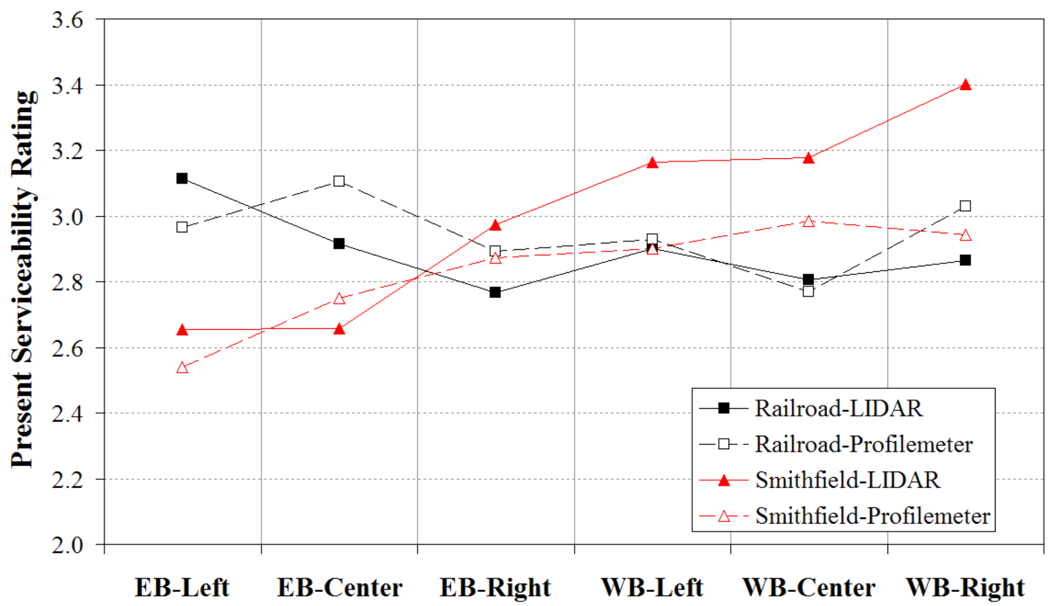


Figure 5.10. PSR variation for the selected cases.

5.8. Summary

In general, asset management of geotechnical structures has not been regarded as an explicit area within the realm of highway asset management systems. The implication of an absence of such a system for operation and maintenance of highway infrastructure is tremendous given the interaction and reliance of various highway components on aspects of geotechnical structures functionality. With the constraints of budget-limited projects, asset management within the realm of geotechnical engineering can lead to increased operational efficiency and increased cost benefits.

In recognition of the gaps in our knowledge regarding management of state highway assets, the North Carolina Department of Transportation spear headed the 2008 National Workshop on Highway Asset Management and Data Collection. The workshop effort was supported by the Federal Highway Administration, North Carolina State University, Transportation Research Board, United States Department of Transportation and American Association of State Highway Transportation Officials. This event was one of few in the past decade with an organized focus on geotechnical asset management (GAM). The geotechnical focus of the workshop included four areas; 1) unknown foundations, 2) corrosion of buried metals, 3) settlement of bridge approach slabs and 4) retaining walls inventory and profile measurements. These four areas were selected since they represent a myriad of challenges faced by departments of transportation across the nation and worldwide, and there have been innovative geotechnical work performed for management of these assets. Two of these areas, namely settlement of bridge approach slabs, and retaining walls inventory and profile measurements, provide the opportunity of data collection on a network level, while the other two areas, unknown foundations, and corrosion of buried metals, provide a demonstration of data collection on a project location level.

Two classes of assets can be considered within the geotechnical realm: i) data collected during subsurface site investigation including subsurface stratigraphy describing lithology, and parameters describing soil properties evaluated through in situ as well as laboratory testing, and, ii) performance data collected by measurement of the infrastructure response during operating conditions with time, or through a survey and inspection of the infrastructure condition. There are several systems for managing the former, but few for managing the latter.

One of the main reasons for the lack of development of GAM system can be related to the fact that the automation of the data collection process on a network level with regard to geotechnical structures is still in its infancy. For two of the areas considered herein, namely the evaluation of unknown foundation, and corrosion of metallic elements, network-level data collection is not possible with today's technology. For a network level data collection, one thought is the emphasis should be placed on outfitting the structure itself with sensors capable of sending the condition data to a GAM system. The structure itself then acts as a sensor that is capable of detecting loading functions as well as its response, and relaying this information on a regular basis within a network. This approach is similar to the "smart bridges" initiatives occurring at present, but perhaps more challenging due to the fact that the geotechnical components are often buried. Two obstacles to overcome in this case are the availability of reliable power supply, and wireless transmission signals.

On the other hand, the other two areas addressed during the conference of retaining walls and approach slabs condition assessment seem to be amenable to data collection on a network level. In the case of the conditions assessment of retaining walls, it seems that surveying technology such a LIDAR can be deployed efficiently for providing a 3-D data profile of the wall surface. While at present this approach can be effectively deployed on a project level, it is not far in the future when such data can be collected on a network level. Using the data collected over the years, an inventory can be developed for management of walls as a highway asset. In the case of the approach slab settlement, current technology is available for providing data on a network level. The use of Profilemeter for roughness measurement can be extended to measure the specific interface area between the slab and pavement where differential settlement is most severe. Normally, however, several passes are required for complete lane coverage. On the other hand, the use of the LIDAR approach seems to provide high areal coverage with the potential being more efficient and cost effective if it can be deployed for collection of data on a higher resolution basis.

CHAPTER 6 ROADSIDE APPURTENANCES

6.1. Introduction

Knowledge of roadside and roadway geometric elements is critical to the efficient operations of highway agencies. For example, maintenance units need to know the extent of features like curbs and guardrails, and the conditions of these features, to be able to budget for and plan activities. Safety units need to know the sharpness of horizontal curves, the steepness of vertical grades, and the widths of lanes to forecast collisions and generate countermeasure alternatives. Traffic engineering units need to know the number and quality of signs and extent and quality of pavement markings to budget for and plan replacements and to meet Federal standards.

The traditional methods highway agencies used to measure the extent and quality of roadside and roadway geometric features were manual measurements by personnel walking along the roadway. While these methods are usually simple to learn, required simple equipment, and provided data of sufficient quality for most decisions and applications, they were also slow. Manual data collection methods for these elements often do not allow speeds of more than a few miles per person per day. In addition, traditional methods often required data collectors to be in the roadway, and on a roadway with more than minimal traffic this means that expensive and disruptive traffic control must be provided.

About 20 years ago, companies and agencies began developing mobile data collection capabilities for roadside and roadway geometric elements. At the most basic level, the equipment needed is a camera mounted in a vehicle that is also equipped with an odometer for measuring the vehicle’s location. During the past few years many advances have been made to this basic level, of course, so that today’s data collection vehicles are often outfitted with a wide variety of sensors. Data collection from a vehicle moving with traffic means faster data collection and eliminates the need for traffic control.

However, many agencies still have questions about the quality of the data produced by mobile methods. The key question is, ‘Do the data on roadside and roadway geometric elements compare well to data produced by more traditional manual methods?’ Some comparisons between mobile and manual data have been performed in the past, but none of the prior comparisons has been on a wide range of data elements. In addition, newer technologies that are available today mean that those earlier comparisons may not be relevant. Also, prior comparisons tended to be with smaller samples and with only a few vehicles, so they were not generally considered helpful to highway agencies.

This report describes an exercise carried out as part of the effort for the National Workshop on Highway Asset Inventory and Data Collection. The objective was to compare, for typical and common data elements that pertain to the roadside and the roadway geometry, data collected by highway agency personnel on foot to data collected by vendors from vehicles traveling with traffic. The intent of this effort was to allow comparisons for a wide range of elements and using larger sample sizes. The intent was also to make the comparison for a number of different data collection vehicles (from a number of different vendors) so that more general conclusions about elements that could or could not be collected accurately by mobile means could be reached.

It is important to note that the effort reported here was in no way intended to identify the best or winning vendor from among those who agreed to participate. The study team made every effort to keep the ‘playing field level’ for all participating vendors, so that highway agencies interested in a certain set of elements could look at these results and make some distinctions among the vendors. However, the study team made no value judgments about which elements or which errors were more or less important. Instead, the role of the study team, and the intent of this report, was to describe as completely and accurately as possible what was done and what the results were so that others can apply their values, make their judgments, and find the best vendor or method for a particular situation.

6.2. Literature Review

There is a large set of literature on the topic of mobile data collection methods for roadside and roadway geometry elements. The intent in this section is to very briefly summarize this literature and provide readers with references to some of the best previous papers and reports. As mentioned above, the general conclusion reached by the study team after reviewing this literature is that no one previously had conducted a comparison of manual versus mobile data collection methods that was recent and comprehensive enough to be very helpful to interested highway agencies.

Readers should note that Project S-03 of the SHRP-II program, ‘Roadway Measurement System Evaluation,’ is underway as of September 2008 and is also making a comparison of manual and mobile data collection methods. However, Project S-03 has the objective of finding the best vendor to collect a specific set of variables. So, while the information from the S-03 project should also be useful to readers of this report, agencies should be cautious in using the information from S-03 in that their values and judgments may be different from those of the S-03 panel and contractor.

6.2.1. Mobile Measurement Evaluation

In the literature, evaluations of mobile measurement and data collection technologies have entailed comparing ground-truth asset condition surveys with asset inventory and condition data collected by various mobile units (Barcena and Speir 2006, Hummer et al. 2000, Karimi et al. 2000, Khattak et al. 2001, Kim and Lee 2006, Mullis and Shippen 2005, Selezneva 2004, Smith and Fletcher 2001). Researchers have generally used analysis of variance and similar statistical techniques to evaluate whether there were statistically significant differences between the ground-truth data and the mobile-collected data (Capuruco et al. 2006; Karimi et al. 2000). Generally, the mobile-collected data was found to be less accurate than the ground-truth data, but in some situations, they were equivalent.

6.2.2. Roadside Asset Inventory and Recognition

Work in roadside asset inventory and recognition has included using GPS and GIS to locate, inventory, and manage roadside assets; development of automated or mobile roadside asset inventorying technologies; and asset management and IT frameworks to better manage roadside assets (Blaine et al. 1999, Hawkins et al. 2007, Idaho DOT 2005, Jones 2004, Kingston and Laflamme 2007, Laflamme et al. 2006, Long 1997, Maerz and McKenna 1999, Mastandrea et al.

1995, Schiffer 2006, Schwarz 1993, Wang et al. 2007a). Lasers and digital imaging processing algorithms have been used to automate roadside asset recognition.

6.2.3. Digital Imaging

Digital image processing has been used in the literature to identify assets from images taken by satellites, aircraft, or mobile automated data collection vehicles traveling at highway speeds (Florida DOT 2004, Lovell 1999, Mraz et al. 2005, Wang et al. 2007b, Wu and Tsai 2005). Several researchers have developed algorithms that can process the many images collected and discern certain roadside features. Some algorithms focus on identifying certain roadside assets or features of these assets, while other algorithms are used to remove parts of the image.

6.2.4. Road Geometry

Road geometry data collection has been automated through the use of two techniques (Awuah-Baffour 1996, Easa et al. 2007, Harkey et al. 2004, Namala and Rys 2006, Soulevrette et al. 2003, Toth and Grejner-Brzezinska 2004, Wu and Tsai 2006). The first technique is using a GPS-enabled mobile unit at highway speeds to measure grades, superelevation, and crown measurements. The other technique involves analyzing existing road centerline and visual data in the office. Road centerline data can be combined with digital elevation model (DEM) data (collected using LIDAR or other techniques) to determine three-dimensional road geometry. High-resolution satellite imagery can also be used to establish digital road maps and find simple and reverse circular curves.

6.2.5. Retroreflectivity Measurement

Road sign and pavement marking retroreflectivity should have an effect on safety. Therefore, the presence of signs and pavement markings not only must be recognized but their retroreflectivity performance, but should also be recorded. A sizeable body of literature describes activity in this area (Austin 2004, Fletcher et al. 2007, Highway Innovation Technology Evaluation Center 2001, Immaneni et al. 2006, Lumia 1989, Maerz and Niu 2003a and 2003b, Mandli 2005, Pardillo-Mayora et al. 1996, Rasdorf et al. 2006, Harris et al. 2007, Rasdorf et al. 2007, Sitzabee 2008). Currently, there is some mobile measurement of sign visibility and/or retroreflectivity under development, but these technologies are still being proven. The alternative for sign retroreflectivity measurement is to use a handheld retroreflectometer or qualitative visual inspections. However, mobile measurement of pavement marking retroreflectivity has been evaluated and is currently in use by some agencies.

6.3. Data Collection

One big decision made by the study team was the list of elements to include in the study. The members of the organizing committee interested in roadside elements included representatives from the safety, signing, pavement marking, and maintenance units of the NCDOT, so each of these had a voice in the final list of elements. The criteria that the study team employed to arrive at the final list of elements included:

- Elements had to be important to (used in an application of) one or more units of a highway department (and particularly to safety, signing, pavement marking, and maintenance units);
- Elements that are already collected by units of a highway department;

- Elements that would be available in a decent sized sample on the course;
- Elements that were not obvious or trivial to collect; and
- Elements that had been or could be collected by vehicles moving at highway speeds.

Table 6.1 shows the final list of eighteen data elements chosen by the roadside appurtenances study team. The list is comprehensive and challenging. The study team believed that the elements on the list largely met the criteria shown above. The data element list was obviously of great importance to the participating vendors, so the list was a key part of the catalog given to the vendors, and also included in this report in Appendix A, to guide their data collection efforts.

As mentioned previously, the SHRP-2 project S-03 was running simultaneously with this project. The RFP for that project included a list of data elements of interest, which were consulted by the study team. However, since the SHRP-2 S-03 project had a different objective from this project the study team chose not to use the list exactly.

Table 6.1. Categories of Roadway Appurtenances.

Signs	• Sign location, MUTCD type, size, retroreflectivity
Pavement Markings	• Lateral location, color, width, type, retroreflectivity • Special marking location, description, material • Raised pavement marking location, number, type
Road Geometry	• Centerline bearing, grade • Vertical curve location, length • Horizontal curve location, length, radius, cross slope • Number of width of lanes • Intersection location, number of approaches, skew angle[a]
Roadside	• Shoulder type, width, condition • Rumble strip presence, location • Barrier location, offset, type, height, condition[b] • Attenuator location, type, condition[b] • Curb location, blockage, damage, type • Drop inlet location, blockage, damage • Driveway location • Median opening location • Median location, type, width

[a] Skew in terms of light, moderate, or heavy
[b] Functional or not

Not only did the test course include many different roadway types, but also included each of the eighteen data elements the Expo team intended to include in the comparison. Since manual data collection of some elements of interest is time consuming and expensive, the Expo team chose small segments along the entire course which could be used to collect baseline data for comparison for those elements.

Once the course was established and agreed upon by the Expo team, NCSU team members drove the course with two video cameras. Preliminary counts of roadside assets from these videotapes ensured that a sufficient quantity of the attributes were present along our chosen segments for the data collection efforts. Based on the team's observations from video, the large majority of roadway asset data elements were congregated along a 3.5-mile stretch of US-70/Glenwood Avenue, two small segments of NC-98, and two small segments of US-64, so this is where we concentrated manual data collection efforts. The Expo team did not inform any of the vendors where the manual data collection segments were located. The team believed it was important to not disclose this information so that no vendor could focus more attention on segments used for comparison.

Various members of the Expo team conducted manual data collection of the elements, with each unit collecting the data pertaining to its specialty area: the NCDOT Traffic Survey Unit collected roadway geometric elements, the NCDOT Maintenance Unit collected roadside elements, the NCDOT Signing Section collected sign data, and the NCDOT Work Zone Traffic Control Unit collected pavement marking data. The NCSU team members were available during collection of many of the elements to make sure that all data were collected satisfactorily for comparison purposes. The manual data collection methods were the standard methods used by trained NCDOT professionals operating on foot, including:

- Collection of survey point data using a Leica TCR 702 total station;
- Collection of sign retroreflectivity using a handheld RetroSign 4500; and
- Collection of pavement marking retroreflectivity using a handheld LTL-X.

All manual observations of location were made with handheld GPS units of various models, typically WAAS-enabled with accuracies of plus or minus 10 feet or less. Traffic control was necessary for roadway geometric and pavement marking data collection; the other manual data collection efforts were conducted from the shoulder or roadside. The catalog which was provided to the vendors contains more details on the manual data collection methods, including the distances between observations.

Overall, manual data collection sample sizes were good, with significant samples for many roadway elements. Table 6.2 shows the manual data segments and sample sizes for each roadside element. Table 6.3 shows the post-processing time that each vendor reported spending on roadside elements.

Table 6.2. Manual Data Collection Locations and Sample Sizes.

Location	Roadway Element	Data Collection Segments	Sample Size
Right Side	Shoulder	Glenwood/US 70 from I-440 Beltline to Hilburn Drive and a portion of US64 and a portion of NC98	115
	Rumble Strips	Entire Course	6
	Signs	Entire Course	370
	Barriers	Glenwood/US 70 from I-440 Beltline to Hilburn Drive and a portion of US64	30
	Attenuators	Glenwood/US 70 from I-440 Beltline to Hilburn Drive and a portion of US64	6
	Curb	Glenwood/US 70 from I-440 Beltline to Hilburn Drive	188
	Drop Inlets	Glenwood/US 70 from I-440 Beltline to Hilburn Drive and a portion of US64	57
	Driveways	Glenwood/US 70 from I-440 Beltline to Hilburn Drive	52
	Markings	NC98 and US64	29
Left Side of Travel Lane	Raised Pavement Markers	Glenwood/US 70 from I-440 Beltline to Hilburn Drive	293
Left Side of Roadway	Median	Entire Course	38
	Median Openings	Glenwood/US 70 from I-440 Beltline to Hilburn Drive.	6
Other	Intersections	Entire Course	140
	Number of Lanes	NC98 and US64	154
	Special Markings	Glenwood/US 70 from I-440 Beltline to Hilburn Drive	140
	Centerline	NC 98 US 64	348
	Vertical Curves	NC 98 and NC 39	12
	Horizontal Curves	NC 98 and NC 39	4

Table 6.3. Reported Post-Processing Hours by Vendor.

Vendor	Number of Hours
Geo-3D	100
Navteq	300
Pathway	72
Precision Scan	4
Roadware	228
Yotta	360

6.4. Results

Upon completion of the test course, vendors were given time to assemble the necessary data for as many of the potential data elements they felt comfortable. The study team summarized manual data from various entities within NCDOT, along with any vendor data provided the six Expo participants: Geo-3D, Pathway, Navteq, Precision Scan, Roadware, and Yotta. The goal of this effort was to compile the individual vendor data sets and provide summary statistics against data collected by various experts manually from the field. The responsibility of the study team was to provide the information in an unbiased manner, making no judgments or direct comparisons between any vendors.

Although six vendors participated, some provided more data than others for various reasons. In some instances, vendors provided data that was not possible to summarize because it was not in the correct format or they did not follow directions provided in the catalog which was provided, Appendix A. In some instances, the mobile equipment used was apparently not capable of collecting certain types of data. On other occasions, vendors were time constrained due to the need to provide services to paying customers. Table 6.4 summarizes the usable data elements provided by the vendors to the study team.

Table 6.4. Summary of data elements submitted by each vendor.

Vendor	Geo-3D	Navteq	Pathway	Precision Scan	Roadware	Yotta
Attenuators	X		X		X	X
Barriers	X	X	X		X	X
Centerline		X	X		X	
Curb	X	X	X		X	X
Driveway Openings	X	X	X		X	
Drop Inlets	X		X		X	X
Horizontal Curves		X	X		X	
Intersections	X	X	X		X	X
Lanes		X	X		X	X
Markings/Striping	X	X		X		X
Median	X	X	X		X	X
Median Openings	X	X	X		X	X
Raised Pavement Markers					X	X
Rumble Strips	X	X	X		X	X
Shoulders	X	X	X		X	X
Signs	X	X	X		X	X
Special Markings	X	X	X		X	X
Vertical Curves		X	X		X	

In the following sections, we will briefly discuss each of the eighteen data elements, the instructions for data collection given to the vendors, and the summary statistics compiled by the study team. For specifics on the course, manual data collection methods, or instructions provided to the vendors, refer to the catalog which was provided to the vendors, Appendix A.

When reading the results tables, please keep in mind several factors. First, remember the importance of relating the sample sizes for a given data element to the outcome. For instance, a vendor that only finds three of six possible data points (50% accuracy) does not necessarily mean that a larger sample from an entire city roadway system would also yield the same results. Second, remember that any difference between manual and mobile data could be due to errors in the manual data as well as the mobile data. While the manual data were collected and reported carefully, they are certainly not perfect.

A critical step in the data analysis was matching each manual observation to the corresponding observation in a vendor's data set. This was accomplished by means of an automated spreadsheet routine that computed the distance between each feature reported manually and each feature of that type in each vendor's data set, based on the latitude and longitude reported for each point. The criteria for declaring that there was a match between a manual observation and a vendor observation were:

- That the distance between the two points was 200 feet or less; and
- That the matched point was the closest of that type in the vendor data set.

Every match was confirmed by a manual check of the results file by a member of the project team. Most matched points were obvious and there were very few close calls. Where average difference and percent difference are calculated in the following sections, the equations are noted below. The average difference was determined by:

$$\sum_{i=1}^{n} \frac{\left|(m_i - v_i)\right|}{n} \tag{6.1}$$

The percent difference was determined by:

$$\frac{\sum_{i=1}^{n} \frac{\left|(m_i - v_i)\right|}{v_i}}{n} * 100 \tag{6.2}$$

where *m* and *v* are the manual and vendor collected data, respectively.

6.4.1. Attenuators

Attenuators are intended to redirect traffic and/or absorb a portion of the kinetic energy caused by an impacting vehicle. Vendors were asked to collect a point location (latitude and longitude) of every attenuator on the right side of the road in the driving direction only. The attenuator was defined as an end treatment or attenuator and given a classification of functioning or non-functioning.

Table 6.5 summarizes the data from manual and vendor data collection methods. As an example, statistics for Geo-3D were calculated in the following manner:

- Of the 6 **Total** manually collected attenuators, Geo-3D correctly identified 5 data points, for 83% accuracy.
- Of the <u>5 total attenuators located</u> by Geo-3D,

- the **Type** of attenuators was identified correctly 5 times, for an accuracy of 100%,
- the **Condition** of the attenuators was identified correctly 4 times, for an accuracy of 80%, and
- 2 **Extra Data Points** were collected by the vendor, for a percent error of 2 / 5 or 40%.

Table 6.5. Attenuator Summary.

			Vendor Observed/Classified							
Factor	Level	Manual	Geo-3D		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%
# of Attenuators	Total	6	5	83%	5	83%	6	100%	1	17%
Type[a]	End Treatment	5	5	100%	5	100%	5	83%	0	0%
	Attenuator	1								
Condition[a]	Functioning	4	4	80%	4	80%	4	67%	0	0%
	Non-Functioning	2								
Extra Data Points[a]	Total	----	2	40%	0	0%	4	67%	0	0%

[a] Percent of classified is based on the total number of attenuators identified by the vendor, and not the observed data.

6.4.2. Barrier

Barriers are safety devices designed to provide protection to motorists from hazards near the roadway such as insufficient sideslopes or structural elements such as columns. Vendors were asked to detect barriers on the right side of the road in the direction of travel only. Measurements were taken every 100 feet along a barrier and at any point where there was a change in barrier type, offset, condition, or height. The type of barrier was defined as w-beam, cable, concrete, or other. The offset was measured from the middle of the edge line to the face of the barrier. The condition was defined as functioning or non-functioning as described in the excerpt from the *2006 NCDOT Maintenance Condition Assessment Manual* supplied in the catalog given to the vendors. Once the data were submitted, the Expo team averaged measurements every 0.1 mile. The nearest vendor point was used for comparison to manual data points.

Table 6.6 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Yotta were calculated in the following manner:

- Of the 30 **Total** manually collected barriers, Yotta correctly identified 18 data points, for 60% accuracy.
- Of the 18 total barriers located by Yotta,
  - the **Type** of barriers was identified correctly 17 times, for an accuracy of 94%,
  - the **Condition** of the barriers was identified correctly 18 times, for an accuracy of 100%,
  - the **Average Height** was 8 inches or 28% different from the manual data, and
  - the **Average Offset** was 8 feet or 89% different from the manual data.

Table 6.6. Barrier Summary.

Factor	Level	Manual	Vendor Observed/Classified									
		Manual	Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of Barriers	Total	30	30	100%	28	93%	30	100%	15	50%	18	60%
Type[a]	Concrete	1	27	90%	28	100%	30	100%	12	80%	17	94%
	W-Beam	29										
Condition[a]	Functioning	30	29	97%	--[d]	n/a	30	100%	12	80%	18	100%
	Non-Functioning	0										
Average Height Difference[b]	Average	---	4	13%	--[d]	n/a	3	10%	--[d]	n/a	8	28%
Average Offset Difference[c]	Average	---	10	145%	4	72%	4	51%	6	83%	8	89%

[a] Percent of classified is based on the total number of attenuators identified by the vendor, and not the observed data.
[b] Average barrier height difference in inches and percent between manual observation and vendor data.
[c] Average barrier offset difference in feet and percent between manual observation and vendor data.
[d] No data provided.
n/a: Not applicable, defined by no barriers being denoted in this classification field.

6.4.3. Centerline

Centerline data define the direction (bearing or azimuth) and grades along a roadway. Vendors were asked to report the bearing and grade every 100 feet along the test course. All of the vendors reporting data provided azimuths instead of bearings.

Table 6.7 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Pathway were calculated in the following manner:

- Of the 347 **Total** manually collected centerline data points, Pathway correctly identified 347 data points, for 100% accuracy.
- Of the <u>347 total centerline locations located</u> by Pathway,
  - the **Average Azimuth** was 0.7˚ or 0.4% different from the manual data, and
  - the **Average Grade** was 0.5 percent (rise/run) or 60% (in statistical terms) different from the manual data.

Table 6.7. Centerline Summary.

Factor	Level	Manual # Obs.	Vendor Observed/Classified					
			Navteq		Pathway		Roadware	
			#	%	#	%	#	%
# of Centerline Data Points	Total	347	347	100%	347	100%	347	100%
Average Azimuth Difference[a]	Average	n/a	0.6	0.4%	0.7	0.4%	0.5	0.3%
Average Grade Difference[b]	Average	n/a	0.2	34%	0.5	60%	0.3	41%

[a] Average azimuth difference in decimal degrees and percent between manual observation and vendor data
[b] Average grade difference in percent grade and percent between manual observation and vendor data
n/a: Not applicable

6.4.4. Curb

Curbs are designed to enhance drainage and redirect errant vehicles, among other things. Vendors were asked to provide the location of a curb along the right side of the road in the direction of travel. Data points were taken every 100 feet where a curb existed and at any point where there is a change in gutter blockage, damage, or curb type. Gutter blockage and damage were defined in an excerpt from the *2006 NCDOT Maintenance Condition Assessment Manual* supplied in the catalog given to vendors. Curb types include vertical, sloping, or other as shown in Exhibit 4-6 of the 2004 AASHTO "Green Book" also supplied in the catalog which given to the vendors. Note that most vendors called Type B sloping curbs "vertical curbs" in their datasets.

Table 6.8 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Roadware were calculated in the following manner:

- Of the 188 **Total** manually collected curb data points, Roadware correctly identified 188 data points, for 100% accuracy.
- Of the 188 total curbs located by Roadware,
  - the **Type** of curbs was identified correctly 13 times, for an accuracy of 7%,
  - the **Blockage** of the curbs was identified correctly 171 times, for an accuracy of 91%, and
  - the **Damage** to the curb was identified correctly 185 times, for an accuracy of 98%.

Table 6.8. Curb Summary.

Factor	Level	Manual # Obs.	Geo-3D #	Geo-3D %	Navteq #	Navteq %	Pathway #	Pathway %	Roadware #	Roadware %	Yotta #	Yotta %
# of curbs	Total	188	188	100%	180	96%	188	100%	188	100%	188	100%
Type[a]	Vertical	15	15	8%	142	79%	15	8%	13	7%	15	8%
	Sloping	173										
Blockage[a,b]	Blocked	7	175	94%	--[c]	n/a	99	53%	171	91%	176	94%
	Not Blocked	180										
Damage[a]	Damaged	3	185	98%	--[c]	n/a	174	93%	185	98%	178	95%
	Not Damaged	185										

Note: the Geo-3D, Navteq, Pathway, Roadware and Yotta columns are grouped under "Vendor Observed/Classified".

[a] Percent of observed/classified is based on the total number of curbs matched for the vendor.
[b] Manual observation of curb blockage at the beginning and end of the vendor data collection resulted in a change in blockage of one curb. This data point was subsequently taken out of the blockage data set.
[c] No data provided.
n/a: Not applicable, defined by no curbs being denoted in this classification field.

6.4.5. Driveway Openings

Driveway openings are particularly useful for safety studies and access management groups. Vendors were asked to provide point locations of every driveway opening along the right side of the road in the direction of travel. The exact point should have been recorded where the radius for the driveway starts. Driveways were defined as a private point of access to a city or state road.

Table 6.9 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Navteq were calculated in the following manner:

- Of the 52 **Total** manually collected driveways, Navteq correctly identified 44 data points, for 83% accuracy.
- 2 **Extra Data Points** (driveways that were not in the manual data set) were collected by Navteq, for a percent error of 2 / 44 or 5%.

Table 6.9. Driveway Summary.

Factor	Manual # Obs.	Geo-3D #	Geo-3D %	Navteq #	Navteq %	Pathway #	Pathway %	Roadware #	Roadware %
# of Driveways	52	43	83%	44	85%	47	90%	40	77%
Extra Data Points[a]	----	0	0%	2	5%	3	6%	0	0%

Note: the Geo-3D, Navteq, Pathway and Roadware columns are grouped under "Vendor Observed/Classified".

[a] Percent of observed/classified is based on the total number of driveways matched for the vendor.

6.4.6. Drop Inlets

Drop inlets are designed to remove water from the streets and prevent excessive ponding of water in low lying areas along roadways. Vendors were asked to provide a point location of a drop inlet along the right side of the road in the direction of travel. For points that were located, blockage and damage were recorded as yes or no values as defined in the *2006 NCDOT Maintenance Condition Assessment Manual* supplied in the catalog which was provided to the vendors. The nearest vendor point was used for comparison to manual data points.

Table 6.10 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Geo-3D were calculated in the following manner:

- Of the 53 **Total** manually collected drop inlets, Geo-3D correctly identified 52 data points, for 98% accuracy.
  - Of the 52 total drop inlets located by Geo-3D,
    - **Damage** was identified correctly 51 times, for an accuracy of 98%.
    - Only 42 of the 53 total drop inlets were measurable for blockage due to changes in this characteristic noted by the project team throughout the vendor data collection period. Of the 42 measureable drop inlets matched by Geo-3D, **Blockage** was identified correctly 42 times, for an accuracy of 100%.
    - 15 **Extra Data Points** were collected by this vendor, for a percent error of 15 / 52 or 29%.

Table 6.10. Drop Inlet Summary.

Factor	Level	Manual	Vendor Observed/Classified							
			Geo-3D		Pathways		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%
# of Drop Inlets	Total	53	52	98%	36	68%	49	92%	50	94%
Damage[a]	Damage	0	51	98%	25	69%	47	96%	48	96%
	No Damage	53								
Blockage[a,b]	Blockage	2	42	100%	15	56%	33	85%	38	95%
	No Blockage	41								
Extra Data Points[a]	No Damage	53	15	29%	4	11%	3	6%	2	4%
	Total	----								

[a] Percent of observed/classified is based on the total number of drop inlets matched for the vendor.
[b] Manual observation of drop inlet blockage at the beginning and end of the vendor data collection resulted in a change in blockage of 10 drop inlets. These data points were subsequently taken out of the blockage data set.

6.4.7. Horizontal Curves

Horizontal curves are designed to provide safe traversal of roadways at posted speeds. Vendors were asked to calculate the curve length, the curve radius, and the maximum cross slope encountered on the curve.

Table 6.11 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Roadware were calculated in the following manner:

- Of the 4 **Total** manually collected horizontal curves, Roadware correctly identified 4 curves, for 100% accuracy.
- Of the 4 total horizontal curves located by Roadware,
  - The **Average Length** was 414 feet or 60% different from the manual data,
  - The **Average Radius** was 1145 feet or 49% different from the manual data, and
  - The **Average Cross Slope** was 1% (rise/run) or 23% (statistically) different from the manual data.

Table 6.11. Horizontal Curve Summary.

Factor	Level	Manual	Vendor Observed/Classified					
			Navteq		Pathway		Roadware	
		# Obs.	#	%	#	%	#	%
# of Horizontal Curves	Total	4	4	100%	4	100%	4	100%
Average Length Difference[a]	Average	---	652	97%	549	90%	414	60%
Average Radius Difference[b]	Average	---	571	26%	1987	99%	1145	49%
Average Cross Slope Difference[c]	Average	---	--[d]	n/a	2	28	1	23%

[a] Average of horizontal curve length difference in feet and percent between manual and vendor data.
[b] Average of horizontal curve radius length difference in feet and percent between manual and vendor data.
[c] Average of horizontal curve cross slope difference in slope and percent between manual and vendor data.
[d] Data not provided.
n/a: Not Applicable.

6.4.8. Intersections

Locations of intersections, and their associated characteristics, are important for safety studies and managers. Vendors were asked to provide point locations of every intersection along with the number of approaches in the travel direction and the skew angle of the intersection. Skew angles were categorized. Intersections were considered to be the intersection of two named roadways denoted with signs. Driveways and median openings were not considered as intersections.

Table 6.12 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Navteq were calculated in the following manner:

- Of the 133 **Total** manually collected intersection locations, Navteq correctly identified 78 data points, for 59% accuracy.
- Of the 78 total intersections located by Navteq,
  - the number of **Approaches** was identified correctly 69 times, for an accuracy of 88%, and
  - the **Skew** angle between intersecting roads was correctly classified 59 times, for an accuracy of 76%.

Table 6.12. Intersection Summary.

Factor	Level	Manual	Vendor Observed/Classified									
			Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of Intersections	Total	133	88	66%	78	59%	41	31%	92	69%	33	25%
Approaches[a]	2	22	75	85%	69	88%	32	78%	79	86%	0	0%
	3	74										
	4	37										
Skew[a, b]	Light	103	67	76%	59	76%	34	83%	70	76%	21	23%
	Medium	21										
	Heavy	9										

[a] Percent of observed/classified is based on the total number of intersections matched for the vendor.
[b] Skew is defined as light (< 90˚ ± 20˚), medium (90 ˚± 20˚ - 40˚), or heavy (> 90 ˚± 40˚).

6.4.9. Lanes

The number and width of lanes is important for safety and operations personnel. Vendors were asked to take measurements every 100 feet in the direction of travel. Widths were to be measured as the distance between the centers of the lane lines. Lanes that were not fully-developed were not to be included in the data set.

Table 6.13 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Yotta were calculated in the following manner:

- Of the 154 **Total** number of lane segments manually collected, Yotta correctly identified 138, for 90% accuracy.
- Of the 138 total lane segments located by Yotta,
  - the number of **Approach Lanes** was identified correctly 138 times for an accuracy of 100%, and
  - the **Average Width** was 3.2feet or 30% different from the manual data.

Table 6.13. Lanes Summary.

Factor	Level	Manual	Vendor Observed/Classified							
			Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%
# of Segments	Total	154	154	100%	154	100%	154	100%	138	90%
App. Lanes[a]	1	92	154	100%	154	100%	137	89%	138	100%
	2	62								
Average Width Difference[b]	Average	---	0.4	4%	1.3	13%	0.6	6%	3.2	30%

[a] Percent of observed/classified is based on the total number of lanes matched for the vendor.
[b] Average width difference in feet and percent between manual observation and vendor data.

6.4.10. Median Openings

An inventory of median openings is particularly useful for safety studies and access management groups. Vendors were asked to provide point locations of every median opening, including emergency crossovers on freeways that are not open to the public and crossovers serving private and unsignalized access points. Vendors should not have included openings that serve intersections with public streets.

Table 6.14 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Geo-3D were calculated in the following manner:

- Of the 6 **Median Openings** manually collected, Geo-3D correctly identified 4, for 67% accuracy.
- 2 **Extra Data Points** were collected by Geo-3D, for a percent error of 2 / 4 = 50%.

Table 6.14. Median Opening Summary.

Factor	Manual	Vendor Observed/Classified									
		Geo-3D		Navteq		Pathway		Roadware		Yotta	
	# Obs.	#	%	#	%	#	%	#	%	#	%
Median Openings	6	4	67%	1	17%	6	100%	3	50%	6	100%
Extra Data Points[a]	----	2	50%	0	0%	4	67%	0	0%	1	17%

[a] Percent of observed/classified is based on the total number of median openings matched for the vendor.

6.4.11. Medians

Medians provide various degrees of separation for conflicting traffic. Vendors were asked to provide the location of the beginning of a median and continue every 100 feet until the end. They were asked to avoid collecting data in transition areas such as tapers. Median widths were also recorded along with types which included grass, raised concrete, and jersey type barrier. The nearest vendor point was used for comparison to manual data points.

Table 6.15 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Yotta were calculated in the following manner:

- Of the 38 **Total** number of median segments manually collected, Yotta correctly identified 24, for 63% accuracy.
- Of the 24 total median segments located by Yotta,
    - the **Type** of median was identified correctly 21 times, for an accuracy of 88%, and
    - the **Average Width** was 24feet or 59% different from the manual data.

Table 6.15. Median Summary.

Factor	Level	Manual	Vendor Observed/Classified									
			Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of medians	Total	38	38	100%	38	100%	38	100%	2	5%	24	63%
Type[a]	Grass	33	34	89%	34	89%	35	92%	2	100%	21	88%
	Jersey Barrier	4										
	Raised Concrete	1										
Average Width Difference[b]	Average	n/a	27	62%	--[c]	n/a	15	37%	16	39%	24	59%

[a] Percent of correctly observed/classified is based on the total number of medians matched for the vendor
[b] Average width difference in feet between manual observation and vendor data
[c] No data provided
n/a: Not applicable

6.4.12. Pavement Markings

Pavement markings are particularly important for maintenance groups needing to replace old and worn striping along roadways. Vendors were asked to take retroreflectivity measurements every 20 feet and material and color data every 100 feet on the right side of the lane in the direction of travel. Pavement marking materials could include paint, thermoplastic, and polyurea. The team averaged retroreflectivity data measurements every 0.1 miles for manual and vendor data for comparison.

Table 6.16 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Precision Scan were calculated in the following manner:

- Of the 29 **Total** segments manually collected, Precision Scan correctly identified 29, for 100% accuracy.
- Of the 29 lane striped segments located by Precision Scan,
  - the striping **Color** was not noted,
  - the striping **Material** was not noted, and
  - the **Average Retroreflectivity** was 36 mcd/m^2/lux or 13% different from the manual data.

Table 6.16. Pavement Marking Summary.

<table>
<tr><th rowspan="3">Factor</th><th rowspan="3">Level</th><th>Manual</th><th colspan="8">Vendor Observed/Classified</th></tr>
<tr><th rowspan="1"></th><th colspan="2">Geo-3D</th><th colspan="2">Navteq</th><th colspan="2">Precision Scan</th><th colspan="2">Yotta</th></tr>
<tr><th># Obs.</th><th>#</th><th>%</th><th>#</th><th>%</th><th>#</th><th>%</th><th>#</th><th>%</th></tr>
<tr><td># of Marking Segments</td><td>Total</td><td>29</td><td>29</td><td>100%</td><td>29</td><td>100%</td><td>29</td><td>100%</td><td>8</td><td>28%</td></tr>
<tr><td>Color[a]</td><td>White</td><td>29</td><td>29</td><td>100%</td><td>29</td><td>100%</td><td>--[d]</td><td>n/a</td><td>8</td><td>100%</td></tr>
<tr><td rowspan="2">Material[a]</td><td>Paint</td><td>13</td><td rowspan="2">--[d]</td><td rowspan="2">n/a</td><td rowspan="2">--[d]</td><td rowspan="2">n/a</td><td rowspan="2">--[d]</td><td rowspan="2">n/a</td><td rowspan="2">4</td><td rowspan="2">50%</td></tr>
<tr><td>Thermo-plastic</td><td>16</td></tr>
<tr><td>Average Width Difference[b]</td><td>Average</td><td>---</td><td>--[d]</td><td>n/a</td><td>--[d]</td><td>n/a</td><td>--[d]</td><td>n/a</td><td>--[d]</td><td>n/a</td></tr>
<tr><td>Average Retro-reflectivity Difference[c]</td><td>Average</td><td>---</td><td>--[e]</td><td>n/a</td><td>--[d]</td><td>n/a</td><td>36</td><td>13%</td><td>--[d]</td><td>n/a</td></tr>
</table>

[a] Percent of observed/classified is based on the total number of pavement markings matched for the vendor.
[b] Average width difference in inches and percent between manual observation and vendor data.
[c] Average retroreflectivity difference (mcd/m^2/lux) and percent between manual observation and vendor data
[d] No data provided.
Qualitative descriptors provided by vendor (low, medium, high); however it was not possible to analyze against manual observations. See website for vendor data.
n/a: Not applicable, defined by no markings being denoted in this classification field.

6.4.13. Raised Pavement Markers

Raised pavement markers help define lanes along a given roadway and are important to maintenance groups needing to reinstall markers where they have been removed or are missing. Vendors were asked to record the number of markers between the starting and ending point on the lane line to the left of the travel lane every 400 feet. The type of markers was defined as stick-on or snowplowable. Note that Roadware provided data on the type of markers for this variable; however, the number of markers was not provided.

Table 6.17 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Yotta were calculated in the following manner:

- Of the 293 **Total** manually collected raised pavement markers, Yotta correctly identified 246, for 84% accuracy.

Table 6.17. Raised Pavement Marker Summary.

Factor	Level	Manual	Vendor Observed/Classified			
			Roadware		Yotta	
		# Obs.	#	%	#	%
# of Raised Pavement Markers	Total	293	--[b]	n/a	246	84
Type[a]	Snowplowable	4	--[c]	n/a	--[b]	n/a
	Stick-on	289	--[c]	n/a	--[b]	n/a

[a] Percent of correctly observed/classified is based on the total number of raised pavement markings matched for the vendor
[b] Data not provided
[c] Roadware correctly identified the type but did not provide the number of markers associated with the type
n/a: Not applicable

6.4.14. Rumble Strips

Rumble strips are a tactile roadway safety feature to alert drivers of potential danger. Vendors were asked to provide the locations where rumble strips started and ended in the direction of travel only.

Table 6.18 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Pathway were calculated in the following manner:

- Of the 6 **Total** manually collected rumble strip segments, Pathway correctly identified 6 segments, for 100% accuracy.

Table 6.18. Rumble Strip Summary.

Factor	Manual	Vendor Observed/Classified									
		Geo-3D		Navteq		Pathway		Roadware		Yotta	
	# Obs.	#	%	#	%	#	%	#	%	#	%
Rumble Strips	6	6	100%	6	100%	6	100%	6	100%	5	83%

6.4.15. Shoulders

Shoulders provide refuge for drivers and keep traffic flowing in the event of an emergency. Roadway safety and maintenance units find this type of data useful since the condition of the shoulder can affect the ability of drivers to recover safely in the event a vehicle leaves the roadway, drainage of water with high shoulders is problematic, and pavement edges can erode or degrade if poorly maintained. Vendors were asked to provide the location of shoulder every 100 feet in the direction of travel where a shoulder existed and at any point where there was a change in the shoulder type, width, or condition. Shoulder type could be paved or gravel; grass was not considered a shoulder for this effort. Condition was high, normal, or low as described in the *2006 NCDOT Maintenance Condition Assessment Manual* supplied in the catalog which was provided to the vendors.

Table 6.19 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Yotta were calculated in the following manner:

- Of the 115 **Total** number of shoulder segments manually collected, Yotta correctly identified 69, for 60% accuracy.
- Of the 69 <u>total shoulder segments located</u> by Yotta,
  - the **Type** of shoulder was identified correctly 69 times, for an accuracy of 100%,
  - the **Condition** of the shoulder was identified correctly 69 times, for an accuracy of 100%, and
  - the **Average Width** was 1.4 feet or 29% different from the manual data.

Table 6.19. Shoulder Summary.

			Vendor Observed/Classified									
Factor	Level	Manual	Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of Shoulders	Total	115	50	43%	39	34%	94	82%	6	5%	69	60%
Type[a]	Paved	91	50	100%	39	100%	87	93%	6	100%	69	100%
	Unpaved	24										
Condition[a]	Low	11	--[c]	n/a	--[c]	n/a	91	97%	6	100%	69	100%
	Normal	102										
	High	2										
Avg. Width Difference[b]	Average	---	0.8	15%	--[c]	n/a	0.9	22%	1.0	16%	1.4	29%

[a] Percent of observed/classified is based on the total number of shoulders matched for the vendor.
[b] Average of shoulder width difference in feet and percent between manual observation and vendor data
[c] No data provided
n/a: Not applicable, defined by no shoulders being denoted in this classification field.

6.4.16. Signs

Signs are posted along roadways to provide information to drivers. Maintenance units are interested in the number, type, and quality of signs, and safety units use the data for consideration of collision countermeasures. Vendors were asked to provide a point location for every sign on the right side of the road in the direction of travel. Overhead signs, or signs on the left side, were ignored for this effort. The MUTCD designation codes were provided as a reference in the catalog. Other information the team requested was sign width, height, and retroreflectivity. However, for this effort no vendors provided retroreflectivity data for signs.

Table 6.20 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Geo-3D were calculated in the following manner:

- Of the 370 **Total** manually collected signs, Geo-3D correctly identified 344, for 93% accuracy.
- Of the 149 **Regulatory and Warning** signs manually collected, Geo-3D correctly identified 123, for 83% accuracy.
- Of the 123 <u>regulatory and warning signs located</u> by Geo-3D,

- the **Average Width** was 9 inches or 26% different from the manual data, and
- the **Average Height** was 7 inches or 26% different from the manual data.

Table 6.20. Signs Summary.

			Vendor Observed/Classified									
Factor	Level	Manual	Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of Signs	Total	370	344	93%	242	65%	341	92%	314	85%	358	97%
MUTCD Code Designation[a]	Regulatory	67	123	83%	110	64%	134	73%	130	69%	140	77%
	Warning	82										
Average Width Difference[b]	Average	---	9	26%	--[d]	n/a	15	37%	34	92%	7	16%
Average Height Difference[c]	Average	---	7	26%	--[d]	n/a	18	91%	29	91%	9	27%

[a] Percent of correctly observed/classified is based on the total number of signs matched for the vendor.
[b] Average width difference in inches and percent between manual observation and vendor data.
[c] Average height difference in inches and percent between manual observation and vendor data.
[d] No data provided.
n/a: Not applicable.

6.4.17. Special Markings

Special markings for this effort were defined as pavement markings not associated with lane-line striping. These included such markings as left turn arrows, through arrows, right turn arrows, railroad crossings, school markings, and pedestrian crossings. Vendors were asked to provide a point location for each individual marking in the direction of travel and also the material type used (paint, thermoplastic, or polyurea). Only turning movement arrows were present on the portion of the test course used for manual data collection. No vendors collected the material type.

Table 6.21 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Navteq were calculated in the following manner:

- Of the 140 **Total** special pavement markings manually collected, Navteq correctly identified 140, for 100% accuracy.
- Of the 140 total markings located by Navteq,
  - the **Description** of the marking was identified correctly 135 times, for an accuracy of 96%.

Table 6.21. Special Markings Summary.

Factor	Level	Manual	Vendor Observed/Classified									
			Geo-3D		Navteq		Pathway		Roadware		Yotta	
		# Obs.	#	%	#	%	#	%	#	%	#	%
# of Special Markings	Total	140	140	100%	140	100%	0	100%	137	98%	137	98%
Special Marking Description[a]	Left Arrow	45	139	99%	135	96%	0	n/a	121	88%	112	82%
	Thru Arrow	54										
	Right Arrow	29										
	Thru + Right Arrow	6										
	Only Text	6										

[a] Percent of observed/classified is based on the total number of special markings matched for the vendor.
n/a: Not applicable, defined by no special markings being denoted in this classification field.

6.4.18. Vertical Curves

Vertical curves are designed to provide safe traversal of roadways at posted speeds. Vendors were asked to provide, for every vertical curve, the starting point, the ending point, and the length.

Table 6.22 summarizes the data from manual and vendor data collection methods. As an example, the statistics for Navteq were calculated in the following manner:

- Of the 12 **Vertical Curve** segments manually collected, Navteq correctly identified 12, for 100% accuracy.
- Of the 12 total curve segments matched by Navteq,
  - the **Average Length** was 147 feet or 19% different from the manual data.

Table 6.22. Vertical Curve Summary.

Factor	Level	Manual	Vendor Observed/Classified					
			Navteq		Pathway		Roadware	
		# Obs.	#	%	#	%	#	%
# of Vertical Curves	Total	12	12	100%	7	58%	12	100%
Average Length Difference[a]	Average	12	147	19%	1381	177%	285	40%

[a] Average of vertical curve length difference in feet and percent between manual observation and vendor data

6.5. SUMMARY OF FINDINGS

Collection of asset data is critical to highway agencies for making key decisions and utilizing available manpower efficiently. Mobile collection of asset data is particularly attractive because manual data collection is cumbersome and inefficient; the staff time it consumes is needed for other projects. Mobile methods for data collection are also of interest to agencies because they can be done in a relatively short time frame and can be quickly updated. However, there has been little work determining the accuracy with which mobile data are collected.

The objective of this effort was to compare roadside data collected by typical manual methods—on foot and often requiring traffic control--to data collected by vehicles moving with traffic. The "roadside" data items of interest included elements like curbs and guardrails as well as signs, pavement markings, and roadway geometry. The comparison was made using data from a 90-mile course in central North Carolina over a variety of highways. The manual data were collected by NCDOT professionals using typical manual methods and equipment.

Six mobile data collection vendors submitted data. No vendors supplied sign retroreflectivity data, indicating that that technology may not yet be mature. One vendor submitted pavement marking retroreflectivity data, three vendors submitted roadway geometry data, and five vendors submitted data on the various roadside elements.

The results showed that mobile data compared reasonably well to manual data for most of the desired variables. Some general observations based on the results include:

- Mobile data on elements in or close to the road, such as numbers of special markings, generally matched manual data better than elements further from the road.
- Item counts generally provided a good fit between mobile and manual data.
- Variables like numbers of driveways and drop inlets have good potential for mobile data collection.
- Offset measurements (such as median width) were generally difficult for mobile data collection.
- Mobile data that needed qualitative judgments tended to be less well matched to manual data. Curb type was an extreme example of a variable requiring a judgment where the match between manual and mobile data was poor.
- Mobile data matched manual better on vertical data elements like vertical curves and grades better than horizontal alignment data elements.

Agencies now have a benchmark against which to judge the best data collection method for a particular variable or set of variables of interest.

CHAPTER 7 CONCLUSIONS AND FUTURE STUDY

7.1. Pavements

The key conclusion that was drawn from the pavement group's study was that an agency must have very clear definitions of distresses before beginning an automated distress survey. Simply providing a manual of practice to the vendors does not adequately capture some of the subtle nuances of an agencies' standard practice for network level surveys. During this process, an agency must honestly review their existing survey practices to identify potential errors and factors that will likely not be matched well by the vendors, but which vendors may actually measure with a far higher degree of accuracy than the agency's existing protocols. If the agency intends to use this automated distress survey data in their existing pavement management system, then the clear definition of distresses should help reduce data compatibility issues.

To ensure proper calibration of the automated distress surveys, communication between the two parties is the single most important factor that will lead to success. The other important aspect is for the agency to have a clear understanding of how they intend to include the automated distress survey results into their existing pavement management system. This study was not able to fully reconcile the vendor and reference surveys but the approach taken in this study did move the two results closer to one another. Future study should focus on the most effective communication methods to reconcile these two results. Other agencies considering the use of automated distress surveys should carefully consider the use of an initial test loop from which they may calibrate the automated distress results.

7.2. Bridges

Based on the presentations, data collection demonstrations and results comparison for bridge applications at the National Workshop on Highway Asset Inventory and Data Collection, several conclusions were drawn. It was found that significant activity is underway to better understand bridge performance and the Federal Highway Administration expects this to continue and expand. Through these efforts, additional tools, such as LIDAR and bridge instrumentation, have become available for the assessment of critical bridge structural details and for monitoring bridge health.

These tools are aiding in the continuing development of bridge management systems as the ability to collect, store and retrieve greater volumes of data have become available in recent years. States are benefiting from the implementation of these advanced assessment and management tools. Even with these advances, visual inspection of bridge components within arms length and inspector knowledge of problematic details remains critical for condition assessment.

Automated surveys are currently most active in the area of sign and bridge clearances at grade separations. However, the continued development of these approaches is important to improve their capabilities. To continue this development and enhancement of advanced technologies for bridge inventory and condition assessment, it is necessary for transportation agencies to support demonstration projects and active use of the technologies to maintain the technology development pipeline.

7.3. Geotechnical Features

There are clearly advances in the area of testing and instrumentation that can be utilized in a GAM system. In general, adequate technology currently exists for condition assessment of geotechnical structures on a project level. Even with data collected on a project level, there is seldom a systematic program that links such an assessment to GAM system. On the other hand, the collection of data on a network level requires in some cases (such as, for example, condition assessment of foundation, and corrosion of metallic structures) a paradigm shift whereby the structure itself becomes capable of acting as the sensor providing the data. The development of a GAM system that can be integrated with a comprehensive Infrastructure Management System (IMS) will represent a milestone in managing and maintenance of the nation's highway assets.

7.4. Roadside Appurtenances

The main lesson learned during this project was the need for developing crystal clear specifications before embarking on a mobile data collection program. Simply asking a vendor to collect data on certain variables with minimal instruction on how the agency typically collects those data and defines the characteristics of interest would be problematic. By providing the data tables in a format such as in the catalog which was given to vendors, agencies will alleviate many of the potential pitfalls that could lead to errors during data collection. Also, in many cases the data tables and supplementary information the study team provided sparked questions from the vendors which opened a mutually beneficial dialog. However, even the provided catalog proved to have problems and could use improvement. The curb type variable was a spectacular failure during this effort, for example. We are confident that the vendors could have correctly identified the type of curb in more than a handful of cases if only we would have provided clearer guidance than the diagrams from the AASHTO "Green Book".

The study team recommends that agencies beginning to work with data collection vendors on these types of data elements ask for a submittal for a small sample of roads before the bulk of the data collection takes place. A few good miles with a variety of characteristics, like the test course used here, should be enough to highlight major discrepancies in the data vendors are supplying. Common sense suggests, and this effort verified, that minor differences between reference and vendor surveys are inevitable in mobile measurements, but a pretest should be able to highlight correctable and major errors.

Future research along the lines of this effort should center on extending the range of variables tested and the sample sizes of some of the more important variables. This effort did not conduct any testing in urban areas, for example, where utilities, sidewalks, and similar features would be of interest. In addition, the sample sizes of important variables like horizontal curve radius were limited in this effort and could be larger.

The most disappointing aspect of mobile data submitted for this effort was the lack of sign retroreflectivity data. This is a critical variable—particularly in light of the new Federal standards for this variable—and would seem to lend itself to mobile data collection given the large numbers of signs along the highways. Maybe soon vendors will have this capability.

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APPENDIX A VENDOR CATALOG

To Expo Participants,

Welcome to the 2008 Highway Asset Inventory and Data Collection test track. We thank you for your participation in this exciting Expo. We hope you are excited to take this opportunity to showcase the services your company has to offer. As you are already aware, NCDOT has identified a challenging 92-mile course in central North Carolina. This course covers various roadway types and terrain and should prove to be a quality test track for comparing your data to manually-collected data.

This catalog provides information related to roadside appurtenance and pavement data collection, as well as general information regarding the upcoming Expo in September. Specifically, you will find points of contact, general information, driving directions, data collection sheets, and supplemental information on how to collect certain types of data. If at any time you have questions about some part of this process, please feel free to call the appropriate contact person. Good luck, and we look forward to seeing you at the Expo.

TABLE OF CONTENTS

GENERAL INFORMATION

The purpose of this document is to make sure that you, Expo data collection participants in the pavement and roadside areas, have all the information you need to provide Expo attendees with the best possible look at the capabilities of your equipment. Expo staff members are striving to insure that this exercise is as fair and productive as possible. If there is anything that you need from the Expo staff during data collection, during post-processing, or leading up to the Expo itself that would help us all achieve our objectives, please ask.

Lane-by-lane driving directions are a few pages later in this catalog. The course will begin near the Century Center and end on US-64 back near the Century Center. For data consistency purposes, please follow these directions as precisely as possible. Please note that the Expo team will not be publishing data collected in transition areas and lane changes, so make your transitions and lane changes as safely as possible without worrying about data collection at those spots. In addition, you should not collect data in any roadway work zones you may encounter. Please drive the course just once.

After driving the course, we ask that you call your designated Expo staff person for a quick debrief. We would like to know that you finished the course successfully and whether you encountered problems. Also call this staff person in the event that weather or some other circumstance interrupts your drive of the course.

This catalog contains a list of Expo staff contacts. The contacts include NCDOT and NCSU professionals. Generally, questions about the Expo event should be directed to NCDOT. Questions regarding data post-processing and analysis should be directed to an NCSU team member in the respective focus area.

This catalog contains instructions on submitting data. Submitted data should be accompanied by two forms. First, we are asking for a timesheet showing how much time your staff spent during post-processing of Expo data. This information will be helpful to Expo attendees in judging what your costs would have been. Second, we are asking for acknowledgement that the NCDOT will become the owner of the data that you submit to the Expo. Blank forms for these purposes are included in this catalog. This catalog also includes details on data formats for the roadside and pavement areas.

The catalog includes the Agenda and Flyer for the Expo event in September. We look forward to seeing you at the National Workshop on Highway Asset Inventory and Data Collection from September 24-26, 2008 here in North Carolina.

Thank you for participating in the Expo!

Points of Contact

<u>Vendor Contact</u>

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Driving Directions

Figure A.1 shows the course.

Figure A.1. Course Map

Directions begin at the NCDOT facility, Century Center B, located at 1020 Birch Ridge Drive, Raleigh NC 27610.

Exit parking area turning left onto Birch Ridge Drive, going uphill to traffic signal. Turn right onto Poole Rd, staying in right hand lane. Turn right onto **I-440**. *Begin data collection at the end of the ramp, represented as the paint striped gore. This is course milepost 0.00.*

Change lane into third lane from median. After I-40 East interchange, again change lanes into third lane from median. I-440 runs concurrent with I-40 for 10.4 miles. At sign for “exit 293-1 mile”, move to second lane from median. Stay on I-40 toward RDU Airport past the I-440 turn-off for about 4.2 miles.

Take **exit 289 Wade Avenue** (SR 1728) for about 2.75 miles, staying in the right-most through lane, to the exit for I-440/US 1, North toward Rocky Mount, Wilson.

Take **I-440 north** for 2.65 miles, staying in the outside through-lane, to **Exit 7 (Glenwood Avenue, US 70)**. Ramp has 2 left turn lanes. Get in the right-hand left turn lane.

At bottom of ramp, turn left onto **US 70 West**. Move to right-most through lane. Move to 2nd lane from median after Millbrook Rd. as the right hand lane will become ‘turn only’. Drive US-70 for a total of 6.99 miles.

Take **I-540 east** toward Wake Forest. Get in the third lane from the median and continue about 12.1 miles to **Exit 16, US 1/Capital Blvd.**

Go North on Exit 16, US 1. Move to 2nd lane from median, as right lane will become turn only. Continue about 6.5 miles, toward Wake Forest to **NC 98**.

Turn right onto **NC 98 east**, going 17.25 miles toward Bunn. Stay in right-most lane. After Jones Dairy Road, move left one lane as the road narrows to 2-way/2-lanes.

In Bunn, turn right onto **NC 39 south** toward Pilot. Be alert and take the fork to the right and travel 6.5 miles to US 64.

Take **US 64 west bound** toward Raleigh, for 20.38 miles. Remain in outside through-lane. *End data collection at the 'exit 419' overhead sign.*

Merge left onto I-440 toward Durham/Benson and stay in right-hand lane. Stay in the "ramp lane" and exit at Poole Road, Exit 15. Total distance is about 0.5 miles.

If you would like to return to the Century Center, you can do so by turning right on Poole Road and immediately into left turn lanes into Birch Ridge Drive. Continue down hill to Century Center B on the right hand side.

Instructions for Submitting Data

To allow us to fully analyze the data prior to the Expo and provide a complete summary to the attendees, we ask that you submit your data to us in a timely fashion. We would like you to submit your data to us within one month after driving the course. The deadline for turning in data is August 1, 2008. Data submitted after this date may not be fully analyzed for the Expo attendees.

Submit pavement data to Professor Richard Kim. Submit roadside data to Professor Joe Hummer.

Data submitted for analysis should be formatted in flat files in Microsoft Access or Excel. All tables and definitions provided in this document are also provided on the Expo website (http://www.itre.ncsu.edu/NCassetMgmtConf/) for your convenience. Generally, English units of measure will be requested unless the current custom for that particular variable is to use metric units. We have tried to convey to you the desired data and format in a clear way and we will be available to answer any questions you may have about data or formatting at any point during post-processing. Our aim is to provide all teams participating with the fairest possible exercise; this should benefit you and all of your potential customers.

When submitting data, please also submit a signed time sheet and a signed data ownership agreement. Blank forms for those documents are included in this catalog. Submission of scans of signed forms is fine. In addition, any notes or narratives about your drive along the course are welcome.

Timesheet

Please provide your estimates of the time your staff spent post-processing the data from the Expo course (i.e., from the end of the drive of the course to data submittal, not including travel) in each of the two focus areas. Please note that time estimates are total person-hours.

Roadside Appurtenances: ___________ hrs

Pavement: _________ hrs

I, ____________________________ **(Print Name)**, acknowledge that the stated estimates of time for Expo data post-processing are accurate to the best of my knowledge.

Signature: _________________________

Title: _________________________

Company: _____________________

Date: _________________________

Transfer of Data Ownership Form

I, ____________________________ **(Print Name)**, acknowledge that the data submitted to the NCDOT and NCSU as part of the 2008 Highway Asset Inventory and Data Collection effort are henceforth the property of the NCDOT.

Signature: _________________________

Title: _________________________

Company: _____________________

Date: _________________________

Expo Agenda and Flyer

Wednesday, September 24

10:00 AM	Registration Opens
1:00 PM	Welcome and Opening - Imperial Ballroom
1:45 PM	General Session - Keynote Speakers
3:30 PM	Break
4:00 PM	General Session - Experimental Design and Ground Truthing
5:00 PM	Adjourn
6:00 PM	Reception - Vendor Area

Thursday, September 25

7:00 AM	Breakfast
8:00 AM	Pavement and Bridge Concurrent Technical Sessions*
9:30 AM	Break
10:00 AM	Pavement and Bridge Concurrent Technical Sessions - continued*
12:00 PM	Lunch
1:30 PM	Roadside Elements and Geotechnical Concurrent technical Sessions*
3:00 PM	Break
3:30 PM	Roadside Elements and Geotechnical Concurrent technical Sessions - continued*
5:30 PM	Adjourn
6:00 PM	Dinner

Friday, September 26

7:00 AM	Breakfast
8:00 AM	Report Outs from the technical sessions
9:30 AM	Break
10:00 AM	Key Issues and Challenges - State Perspective
10:30 AM	Key Issues and Challenges - Vendor Perspective
11:00 AM	Closing Session - The Future of Asset Management
12:00 PM	Adjourn

with Equipment Showcase

National Workshop on Highway Asset Inventory & Data Collection

An efficient and accurate inventory of an agency's assets, along with the means to assess their condition and model their performance, is critical to enabling an agency to make informed investment decisions in a Transportation Asset Management (TAM) environment. Today, new technologies provide fast and improved ways to gather, process, and analyze data. The key is to identify the important information elements and assess how much of it is needed to make informed decisions.

The workshop and equipment showcase is the forum to find the latest in technology for managing highway assets. Four focus areas (Pavements, Bridges, Roadside Appurtenances, and Geotechnical and Drainage) have been identified as the leading areas for inventory and analysis. Below is a description of each area for the workshop:

Save the Date!

Pavements

The Pavements group will focus on surface distresses, roughness, rutting, and texture or friction. A 130-mile test course located near Raleigh, NC provides a location with varied roadway classifications, road geometry, pavement and shoulder type, conditions, and types of data elements, terrain, and vegetation. Both urban and rural roadways are included in this test course.

Bridges

The Bridges group will focus on devices for field data collection and entry, and assessment technologies for deck, superstructure, and substructure including underwater inspection. These technologies may be used for assessing maintenance needs, probable bridge component life fracture critical bridge details, component strength, material characteristics and deterioration, remote sensing, and health monitoring. Varied conventional and innovative technologies will be showcased, demonstrated and evaluated at this workshop.

Dates:
September 24-26, 2008

Location:
Sheraton Imperial
Hotel & Convention Center
Durham, NC
www.sheratonrtp.com

Geotechnical and Drainage

The Geotechnical group will showcase and evaluate technologies available for assessment of existing Infrastructure components. On a network level, the area of interest includes slope stability through remote sensing technologies. On a project level, areas of interest include smart foundation and health monitoring, settlement of bridge approach slabs, unknown foundation evaluation, buried metals, MSE walls deformation monitoring, and drainage issues.

Roadside Appurtenances

Gathering inventory and condition data on a network basis for multiple roadside assets can be extremely time consuming. The Roadside Appurtenances group will highlight vendor technologies that collect roadway data such as pavement markings, signs, guardrail and shoulder conditions. Vendors will be invited to inventory and assess the condition of targeted sections of a test track, and then showcase their results as compared to actual ground conditions.

Co-Sponsored By:

TRB AASHTO
USDOT FHWA

Co-Hosted By:

NCDOT NCSU

For general information, contact Terry Canales, PE NCDOT at 919-733-2210 or tcanales@dot.state.nc.us

ROADSIDE APPURTENANCES

The roadside area includes 18 different data elements. To prevent any confusion during data collection, we would like to stress the importance of familiarization with NCDOT's data collection methods. As noted in the cover letter, our objective is to be as informative as possible. Therefore, if there is any confusion during post-processing please call someone from the roadside area at NCSU.

This part of the catalog begins with the table formats in which we would like you to submit the roadside data. ***We require <u>one table per data element</u>.*** In each table, one row of data will pertain to one particular item being measured (e.g., each sign). Data items should be listed in each table sequentially, as encountered in your drive along the course. This document provides detailed definitions, desired levels of precision, and desired units of measure for each variable and data element.

To familiarize your team with data collection methods used during NCDOT's manual data collection, we have assembled a short supplemental guide based on relevant pages from NCDOT's 2006 Maintenance Condition Assessment Manual, the 2003 MUTCD, and the 2004 AASHTO Greenbook.

It is very important to note the location of the roadway elements we are asking vendors to collect. A summary of the eighteen roadway elements and their locations appears below.

Table A.1. Location of Roadway Elements.

Location	**Roadway Element**
Right Side	Shoulder, Rumble Strips, Signs, Barriers, Attenuators, Curb, Drop Inlets, Driveways
Right Edge of Pavement	Markings
Left Side of Travel Lane	Raised Pavement Markers
Left Side of Your Direction of Roadway	Median, Median Openings
Other	Intersections, Number of Lanes, Special Markings, Centerline, Vertical Curves, Horizontal Curves

Note that some of the longitudinal elements will be averaged over 1/10th –mile segments by the Expo team.

Roadside Data Tables

Roadside					
Shoulder					
NCDOT Data Collection Method: Measurements should be taken every 100' where a shoulder exists and at any point where there is a change in shoulder type, width, or condition. Shoulder type can be paved or gravel. Grass is not considered as part of the shoulder for this effort. Measure width from the center of the edgeline to the edge of pavement or gravel. Condition is high, nornal, or low as described in the 2006 NCDOT Maintenance Condition Assessment Manual. At a later time, the expo team will average the measurements every 0.1 mile.					
Collector:			Weather:		
Date:			Temperature:		
Course Milepost	Latitude	Longitude	Type	Width (feet)	Condition
17.26 (Example)	35.76812	78.65949	Paved	6	Normal

Roadside						
Rumble Strip						
NCDOT Data Collection Method: N/A						
Collector:				Weather:		
Date:				Temperature:		
Starting Point			Ending Point			Presence
Course Milepost	Latitude	Longitude	Course Milepost	Latitude	Longitude	
17.26 (Example)	35.76812	78.65949	17.27	35.76822	78.65957	Yes

Roadside						
Barrier						
NCDOT Data Collection Method: Measurements should be taken every 100' where a barrier exists and at any point where there is a change in barrier type, offset, condition, or height. Measure offset from middle of edgeline to the face of the barrier. Type of barrier is w-beam, cable, concrete, or other. Condition of barrier is functioning or non-functioning as described in the 2006 NCDOT Maintenance Condition Assessment Manual. At a later time, the expo team will average the measurements every 0.1 mile.						
Collector:			Weather:			
Date:			Temperature:			
Course Milepost	Latitude	Longitude	Offset (feet)	Type	Condition	Height (inches)
17.26 (Example)	35.76812	78.65949	6	W-Beam	Functioning	32

Roadside				
Attenuator				
NCDOT Data Collection Method: Type is either end treatment or attenuator. Condition of attenuator is functioning or non-functioning.				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Type	Condition
17.26 (Example)	35.76812	78.65949	Attenuator	Functioning

Roadside					
Curb					
NCDOT Data Collection Method: Measurements should be taken every 100' where a curb exists and at any point where there is a change in gutter blockage, gutter damage, or curb type. Gutter damage and gutter blockage are yes or no items as shown in the 2006 NCDOT Maintenance Condition Assessment Manual. Curb types include vertical and sloping, as shown in Exhibit 4-6 of the 2004 AASHTO Green Book, as well as other or none.					
Collector:			Weather:		
Date:			Temperature:		
Course Milepost	Latitude	Longitude	Gutter Blockage	Gutter Damage	Curb Type
17.26 (Example)	35.76812	78.65949	No	No	None

Roadside				
Drop Inlet				
NCDOT Data Collection Method: Blockage is a yes or no item as shown in the 2006 NCDOT Maintenance Condition Assessment Manual.				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Blockage	Damage
17.26 (Example)	35.76812	78.65949	No	No

Roadside		
Driveway		
NCDOT Data Collection Method: Latitude and longitude coordinates should be recorded at the point where the radius for the driveway starts, in the direction of travel. For this study, a driveway is classified as a private point of access.		
Collector:		
Date:		
Weather:		
Temperature:		
Course Milepost	Latitude	Longitude
17.26 (Example)	35.76812	78.65949

Roadside				
Median				
NCDOT Data Collection Method: Measure width every 100 feet; avoid transition areas such as tapers.				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Type	Width (feet)
17.26 (Example)	35.76812	78.65949	Grass	30'

Roadside		
Median Opening		
NCDOT Data Collection Method: Latitude and longitude coordinates should be recorded on the right side of the road, even with the centerline of the opening. Do not include median openings that serve intersections with public streets. Include emergency crossovers on freeways that are not open to the public and private, unsignalized access points.		
Collector:		
Date:		
Weather:		
Temperature:		
Course Milepost	Latitude	Longitude
17.26 (Example)	35.76812	78.65949

Road Geometry				
Intersection				
NCDOT Data Collection Method: Configuration describes the skew in terms of light (90° ± 20: 70° to 110°), moderate (90° ± 40: 50° to 70° or 110° to 130°), or heavy (<50° or >130°).				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Number of Approaches	Configuration
17.26 (Example)	35.76812	78.65949	4	Light

Road Geometry				
Lanes				
NCDOT Data Collection Method: Width is measured from the center of the lane-line to center of the edge line for a multi-lane facility and center of the roadway to the center of the edgeline for a two-lane roadway. Record data every 100'. Number of lanes is in your direction of travel (your side of the centerline) only and includes fully-developed auxiliary and turning lanes.				
Collector:			Weather:	
Date:			Temperature:	
Course Milepost	Latitude	Longitude	Number	Width (feet)
17.26 (Example)	35.76809	78.65954	1	12

Pavement Markings				
Special Marking				
NCDOT Data Collection Method: Include markings in all lanes in your direction of travel. Latitude and longitude coordinates are measured on the roadside. Materials include paint, thermoplastic, and polyurea.				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Description	Material
17.26 (Example)	35.76803	78.65948	Right Turn Arrow	Thermoplastic

Road Geometry				
Centerline				
NCDOT Data Collection Method: Collect data every 100 feet.				
Collector:		Weather:		
Date:		Temperature:		
Course Milepost	Latitude	Longitude	Bearing (decimal degrees)	Grade (%)
17.26 (Example)	35.76812	78.65949	105.35925	4.32%

Road Geometry			
Vertical Curve			
*NCDOT Data Collection Method: I*nformation should be recorded at the beginning of each vertical curve. Length of curve should include the distance that the grade is changing. If consecutive curves are closely located, the vertical curve ends at the point where a sag turns into a crest or vice versa.			
Collector:		Weather:	
Date:		Temperature:	
Course Milepost	Latitude	Longitude	Length (feet)
17.26 (Example)	35.76812	78.65949	800'

Road Geometry					
Horizontal Curve					
*NCDOT Data Collection Method: I*nformation should be recorded at the beginning of every horizontal curve. Cross slope should be recorded as the maximum cross slope encountered on the curve.					
Collector:			Weather:		
Date:			Temperature:		
Course Milepost	Latitude	Longitude	Length (feet)	Radius (feet)	Cross Slope (%)
17.26 (Example)	35.76812	78.65949	1200'	3800'	5.20%

Signs										
NCDOT Data Collection Method: Calibrate equipment. Take five measurements on each sign so an average sign retroreflectivity can be calculated. Latitude and longitude should be recorded at the middle of the sign. Each sign should be measured; for example, a sign assembly might have multiple signs and each individual sign should be measured. See additional pages for regulatory and warning sign codes from the MUTCD. No code tables are available from the MUTCD for guide signs.										
Collector:				Weather:						
Date:				Temperature:						
Course Milepost	Latitude (decimal degrees)	Longitude (decimal degrees)	MUTCD Code	Size		Retroreflectivity (mcd/m^2/lux)				
				Width (in)	Height (in)	# 1	# 2	# 3	# 4	# 5
17.26 (Example)	35.76803	78.65948	R1-1	30	30	10	11	10	9	10

Pavement Markings										
Marking										
NCDOT Data Collection Method: Collect data on edgeline only. Measure retroreflectivity every 20'. All other data recorded every 100'. Marking materials include paint, thermoplastic, and polyurea. At a later time, the expo team will average the retroreflectivity measurements every 0.1 mile.										
Collector:					Weather:					
Date:					Temperature:					
Course Milepost	Latitude	Longitude	Color	Width (inches)	Material	Retroreflectivity (mcd/m2/lux)				
						0 feet	20 feet	40 feet	60 feet	80 feet
17.26 (Example)	35.76803	78.65948	White	6	Thermoplastic	100	112	105	96	103

Pavement Markings							
Raised Pavement Marker							
NCDOT Data Collection Method: Record the number of markers between the starting and ending point, on the lane line to the left of the travel lane. The ending point should be 400' from the starting point. Types of raised markings include stick-on and snowplowable.							
Collector:				Weather:			
Date:				Temperature:			
Starting Point			Ending Point			Number of Markers	Type
Course Milepost	Latitude	Longitude	Course Milepost	Latitude	Longitude		
17.26 (Example)	35.76809	78.65954	17.34	35.76803	78.65948	5	Stick-on

Roadside Supplement

Shoulders

Low Shoulders

Feature Description: Low shoulders occur when the elevation of the unpaved shoulder is lower than the roadway edge of pavement. A low shoulder can result in an unsafe recovery in the event a vehicle leaves the roadway. A low shoulder can also hold water that may eventually penetrate the base and subgrade and weaken the roadway.

Threshold Condition: A low shoulder should be noted where the elevation difference is **2 inches** below the roadway edge of pavement, or lower.

Figure A.2. Low shoulders.

High Shoulders

Feature Description: High shoulders occur when the elevation of the unpaved shoulder is higher than that of the roadway edge of pavement. A high shoulder can restrict water drainage and result in ponding at the edge of roadway. The standing water can cause vehicle hydroplaning, and may also infiltrate the base and subgrade and weaken the roadway. The relief of ponding caused by a high shoulder may also scour the shoulder and front slope.

Threshold Condition: A high shoulder should be noted where the elevation difference is **1 inch** above the road surface, or higher.

Figure A.3. High shoulders.

Curb

<u>Gutters Blocked</u>
Feature Description: Gutters are open drainage channels that direct the flow of water from the road surface and roadside area to a catch basin or other outlet. Examples of open-channel gutters are curb and gutter, valley gutter, and the drainage at the base of a concrete barrier. A blockage in the gutter may divert water flow onto the travelway and cause vehicle hydroplaning.

Threshold Condition: Gutters that are not functioning as designed due to an obstruction **2 inches or greater for at least 2 feet** of gutter length should be noted.

Special Instructions: Blockage will not be noted if it will not obstruct water flow (grass growing in a construction joint, trash that will be flushed clean in the next storm, etc.). At intersections, measure the gutter longitudinally through the intersection; do not measure around the corner radius. Short sections of monolithic barrier (e.g., 4-foot wide by 50-foot long concrete median island) will not be included in this inventory.

Figure A.4. Gutters blocked.

<u>Gutters Damaged</u>
Feature Description: See feature description for Gutters Blocked. If the gutter is damaged, water can infiltrate the road base and weaken the roadway.

Threshold Condition: Any **damaged** gutter should be noted, such as cracking, settlement, misalignment, or deterioration.

Figure A.5. Gutters damaged.

Drop Inlet

<u>Inlets Blocked</u>
Feature Description: Inlets are the openings through which water enters an underground drainage network. They can be found in curbs, ditches, valley gutter, and at other locations that are designed to collect water runoff. Examples of inlets are catch basins, drop inlets, shoulder drains, and slope flumes. If the inlet is blocked, water ponding may occur at the obstructed opening. This can result in scour and erosion at an off-road structure, or vehicle hydroplaning if adjacent to the travelway.

Threshold Condition: Inlets that are **50% blocked** or more should be noted.

Figure A.6. Inlets blocked.

Barrier

<u>Barriers</u>
Feature Description: Barriers are a safety device designed to protect errant motorists from hazards near the roadway. They shield roadside obstacles, protect drivers from steep dropoffs, and can even be used to separate opposing traffic. Examples of barriers are W-beam guardrail, cable rail, and concrete barrier. Barrier that is not functioning properly can be as dangerous as the hazard it is meant to protect. While severely damaged barrier needs to be repaired as soon as possible, barrier that is only moderately damaged and still functions may be scheduled for repair later with other work. Minor damage that is only aesthetic may not need repair at all.

Threshold Condition: Barrier should be noted when it is **not functioning as designed** or has been **damaged**. Damaged barrier is defined as follows:

- W-beam guardrail – the rail beam is crushed more than 18 inches out of line, if the rail has been severed, or if three or more posts have been broken,
- Cable rail – if any cable is broken, if the cable is sagging to the point that it would not function properly, or if four or more posts have been knocked down, and
- Concrete barrier – if it has been damaged such that it would not function properly.

Figure A.7. Damaged barriers.

Excerpts from 2003 MUTCD

Table 2B-1. Regulatory Sign Sizes (Sheet 1 of 5)

Sign	MUTCD Code	Section	Conventional Road	Expressway	Freeway	Minimum	Oversized
Stop	R1-1	2B.04	750 x 750 (30 x 30)	900 x 900 (36 x 36)	—	600 x 600 (24 x 24)	1200 x 1200 (48 x 48)
Yield	R1-2	2B.08	900 x 900 x 900 (36 x 36 x 36)	1200 x 1200 x 1200 (48 x 48 x 48)	1500 x 1500 x 1500 (60 x 60 x 60)	750 x 750 x 750 (30 x 30 x 30)	—
To Oncoming Traffic	R1-2a	—	600 x 300 (24 x 12)	—	—	—	—
4-Way	R1-3	2B.04	300 x 150 (12 x 6)	—	—	—	—
All Way	R1-4	2B.04	450 x 150 (18 x 6)	—	—	—	—
Yield Here to Peds	R1-5	2B.11	450 x 450 (18 x 18)	—	—	—	—
Yield Here to Pedestrians	R1-5a	2B.11	450 x 600 (18 x 24)	—	—	—	—
In-Street Ped Crossing	R1-6,6a	2B.12	300 x 900 (12 x 36)	—	—	—	—
Speed Limit (English)	R2-1	2B.13	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Speed Limit (Metric)	R2-1	2B.13	600 x 900 (24 x 36)	900 x 1350 (36 x 54)	1200 x 1650 (48 x 66)	—	—
Truck Speed Limit (English)	R2-2	2B.14	600 x 600 (24 x 24)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	—	—
Truck Speed Limit (Metric)	R2-2	2B.14	600 x 750 (24 x 30)	900 x 1050 (36 x 42)	1200 x 1350 (48 x 54)	—	—
Night Speed Limit (English)	R2-3	2B.15	600 x 600 (24 x 24)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	—	—
Night Speed Limit (Metric)	R2-3	2B.15	600 x 750 (24 x 30)	900 x 1050 (36 x 42)	1200 x 1350 (48 x 54)	—	—
Minimum Speed Limit (English)	R2-4	2B.16	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Minimum Speed Limit (Metric)	R2-4	2B.16	600 x 900 (24 x 36)	900 x 1350 (36 x 54)	1200 x 1650 (48 x 66)	—	—
Combined Speed Limit (English)	R2-4a	2B.16	600 x 1200 (24 x 48)	900 x 1800 (36 x 72)	1200 x 2400 (48 x 96)	—	—
Combined Speed Limit (Metric)	R2-4a	2B.16	600 x 1350 (24 x 54)	900 x 1950 (36 x 78)	1200 x 2550 (48 x 102)	—	—
Fines Higher	R2-6	2B.17	600 x 600 (24 x 24)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	—	—
Turn Prohibition	R3-1,2,3,4, 18	2B.19	600 x 600 (24 x 24)	900 x 900 (36 x 36)	—	—	1200 x 1200 (48 x 48)
Mandatory Movement Lane Control	R3-5 series	2B.21	750 x 900 (30 x 36)	—	—	—	—
Optional Movement Lane Control	R3-6	2B.22	750 x 900 (30 x 36)	—	—	—	—
Mandatory Movement Lane Control	R3-7	2B.21	750 x 750 (30 x 30)	—	—	—	—
Advance Intersection Lane Control	R3-8,8a,8b	2B.23	variable x 750 (variable x 30)	—	—	—	—
Two-Way Left Turn Only (overhead mounted)	R3-9a	2B.24	750 x 900 (30 x 36)	—	—	—	—
Two-Way Left Turn Only (ground mounted)	R3-9b	2B.24	600 x 900 (24 x 36)	—	—	—	900 x 1200 (36 x 48)
Reversible Lane Control (symbol)	R3-9d	2B.25	2700 x 1200 (108 x 48)	—	—	—	—
Reversible Lane Control (ground mounted)	R3-9f	2B.25	750 x 1050 (30 x 42)	—	—	—	—
Advance Reversible Lane Control Transition Signing	R3-9g,9h	2B.25	2700 x 900 (108 x 36)	—	—	—	—
End Reverse Lane	R3-9i	2B.25	2700 x 1200 (108 x 48)	—	—	—	—
Preferential Only Lane Ahead (ground mounted)	R3-10 series	2B.26	750 x 1050 (30 x 42)	900 x 1500 (36 x 60)	1950 x 2400 (78 x 96)	—	—
Preferential Only Lane Operation (ground mounted)	R3-11 series	2B.26	750 x 1050 (30 x 42)	—	1950 x 2400 (78 x 96)	—	—

Table 2B-1. Regulatory Sign Sizes (Sheet 2 of 5)

Sign	MUTCD Code	Section	Conventional Road	Expressway	Freeway	Minimum	Oversized
Preferential Only Lane Ends (ground mounted)	R3-12 series	2B.26	750 x 1050 (30 x 42)	900 x 1500 (36 x 60)	1200 x 2100 (48 x 84) 1200 x 2400 (48 x 96)	—	—
Preferential Only Lane Ahead (overhead mounted)	R3-13 series	2B.26	1650 x 900 (66 x 36)	2100 x 1200 (84 x 48)	3600 x 1950 (144 x 78) 3600 x 2400 (144 x 96)	—	—
Preferential Only Lane Operation (overhead mounted)	R3-14 series	2B.26	1800 x 1500 (72 x 60)	2400 x 1800 (96 x 72)	3600 x 2650 (144 x 106) 3600 x 3100 (144 x 124) 3600 x 2250 (144 x 90)	—	—
HOV 2+ Lane Ends (overhead mounted)	R3-15 series	2B.26	1650 x 900 (66 x 36)	2100 x 1200 (84 x 48)	2550 x 1500 (102 x 60)	—	—
Do Not Pass	R4-1	2B.29	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	450 x 600 (18 x 24)	—
Pass With Care	R4-2	2B.30	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	450 x 600 (18 x 24)	—
Slower Traffic Keep Right	R4-3	2B.31	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Trucks Use Right Lane	R4-5	2B.32	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Truck Lane XX Meters (XX Feet)	R4-6	2B.32	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Keep Right	R4-7,7a,7b	2B.33	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	450 x 600 (18 x 24)	—
Keep Left	R4-8	2B.33	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	450 x 600 (18 x 24)	—
Do Not Enter	R5-1	2B.34	750 x 750 (30 x 30)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	—	—
Wrong Way	R5-1a	2B.35	900 x 600 (36 x 24)	900 x 600 (36 x 24)	1050 x 750 (42 x 30)	—	—
No Trucks	R5-2,2a	2B.36	600 x 600 (24 x 24)	750 x 750 (30 x 30)	900 x 900 (36 x 36)	—	1200 x 1200 (48 x 48)
No Motor Vehicles	R5-3	2B.36	600 x 600 (24 x 24)	—	—	—	—
Commercial Vehicles Excluded	R5-4	2B.36	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Vehicles with Lugs Prohibited	R5-5	2B.36	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
No Bicycles	R5-6	2B.36	600 x 600 (24 x 24)	750 x 750 (30 x 30)	900 x 900 (36 x 36)	—	1200 x 1200 (48 x 48)
Non-Motorized Traffic Prohibited	R5-7	2B.36	750 x 600 (30 x 24)	1050 x 600 (42 x 24)	1200 x 750 (48 x 30)	—	—
Motor-Driven Cycles Prohibited	R5-8	2B.36	750 x 600 (30 x 24)	1050 x 600 (42 x 24)	1200 x 750 (48 x 30)	—	—
Pedestrians, Bicycles, Motor-Driven Cycles Prohibited	R5-10a	2B.36	750 x 900 (30 x 36)	—	—	—	—
Pedestrians and Bicycles Prohibited	R5-10b	2B.36	750 x 450 (30 x 18)	—	—	—	—
Pedestrians Prohibited	R5-10c	2B.36	600 x 300 (24 x 12)	—	—	—	—
One Way	R6-1	2B.37	900 x 300 (36 x 12)	1350 x 450 (54 x 18)	1350 x 450 (54 x 18)	—	—
One Way	R6-2	2B.37	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	900 x 1200 (36 x 48)	450 x 600 (18 x 24)	—
Divided Highway Crossing	R6-3,3a	2B.38	750 x 600 (30 x 24)	900 x 750 (36 x 30)	—	600 x 450 (24 x 18)	—

Table 2B-1. Regulatory Sign Sizes (Sheet 3 of 5)

Sign	MUTCD Code	Section	Conventional Road	Expressway	Freeway	Minimum	Oversized
No Parking	R7-1,2,2a,3, 4,5,6,7,8, 107,108	2B.39	300 x 450 (12 x 18)	—	—	—	—
Van Accessible	R7-8a,8b	2B.40	450 x 225 (18 x 9)	—	—	300 x 150 (12 x 6)	—
No Parking, Bike Lane	R7-9,9a	9B.09	300 x 450 (12 x 18)	—	—	—	—
No Parking (with transit logo)	R7-107a	2B.39	300 x 750 (12 x 30)	—	—	—	—
No Parking / Restricted Parking (combined sign)	R7-200	2B.40	600 x 450 (24 x 18) 300 x 750 (12 x 30)	—	—	—	—
Tow Away Zone	R7-201,201a	2B.40	300 x 150 (12 x 6)	—	—	—	—
This Side of Sign	R7-202	2B.39	300 x 150 (12 x 6)	—	—	—	—
No Parking on Pavement	R8-1	2B.39	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
No Parking Except on Shoulder	R8-2	2B.39	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
No Parking	R8-3	2B.39	600 x 750 (24 x 30)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	450 x 600 (18 x 24)	—
No Parking (symbol)	R8-3a	2B.39	600 x 600 (24 x 24)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	300 x 300 (12 x 12)	—
Emergency Parking Only	R8-4	2B.42	750 x 600 (30 x 24)	750 x 600 (30 x 24)	1200 x 900 (48 x 36)	—	—
No Stopping on Pavement	R8-5	2B.39	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
No Stopping Except on Shoulder	R8-6	2B.39	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Emergency Stopping Only	R8-7	2B.42	750 x 600 (30 x 24)	1200 x 900 (48 x 36)	—	—	—
Do Not Stop on Tracks	R8-8	2B.42	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	—	—	—
Tracks Out of Service	R8-9	8B.09	600 x 600 (24 x 24)	900 x 900 (36 x 36)	—	450 x 450 (18 x 18)	—
Stop Here When Flashing	R8-10	8B.10	600 x 900 (24 x 36)	—	—	600 x 750 (24 x 30)	—
Walk on Left Facing Traffic	R9-1	2B.43	450 x 600 (18 x 24)	—	—	—	—
Cross Only at Crosswalks	R9-2	2B.44	300 x 450 (12 x 18)	—	—	—	—
No Pedestrian Crossing	R9-3	2B.44	300 x 450 (12 x 18)	—	—	—	—
No Pedestrian Crossing (symbol)	R9-3a	2B.44	450 x 450 (18 x 18)	600 x 600 (24 x 24)	750 x 750 (30 x 30)	—	—
Use Crosswalk	R9-3b	2B.44	450 x 300 (18 x 12)	—	—	—	—
No Hitch Hiking	R9-4	2B.43	450 x 600 (18 x 24)	—	—	450 x 450 (18 x 18)	—
Hitch Hiking Prohibition (symbol)	R9-4a	2B.43	450 x 450 (18 x 18)	—	—	—	—
Bicyclists (symbol) Use Ped Signal	R9-5	9B.10	300 x 450 (12 x 18)	—	—	—	—
Bicyclists (symbol) Yield to Peds	R9-6	9B.10	300 x 450 (12 x 18)	—	—	—	—
Keep Left/Right to Pedestrians & Bicyclists (symbols) – Travel-path Restriction	R9-7	9B.11	300 x 450 (12 x 18)	—	—	—	—
Pedestrian Crosswalk	R9-8	6F.12	900 x 450 (36 x 18)	—	—	—	—
Sidewalk Closed	R9-9	6F.13	750 x 450 (30 x 18)	—	—	—	—

Table 2B-1. Regulatory Sign Sizes (Sheet 4 of 5)

Sign	MUTCD Code	Section	Conventional Road	Expressway	Freeway	Minimum	Oversized
Sidewalk Closed, Use Other Side	R9-10	6F.13	1200 x 600 (48 x 24)	—	—	—	—
Sidewalk Closed Ahead, Cross Here	R9-11	6F.13	1200 x 900 (48 x 36)	—	—	—	—
Sidewalk Closed, Cross Here	R9-11a	6F.13	1200 x 600 (48 x 24)	—	—	—	—
Cross On Green Light Only	R10-1	2B.45	300 x 450 (12 x 18)	—	—	—	—
Pedestrian Traffic Signal Signs	R10-2, 2a,3,3a,3b, 3c,3d,4,4a,4b	2B.45	225 x 300 (9 x 12)	—	—	—	—
Countdown Pedestrian Sign	R10-3e	2B.45	225 x 375 (9 x 15)	—	—	—	—
Left on Green Arrow Only	R10-5	2B.45	600 x 750 (24 x 30)	—	—	—	1200 x 1500 (48 x 60)
Stop Here on Red	R10-6	2B.45	600 x 900 (24 x 36)	—	—	—	—
Stop Here on Red	R10-6a	2B.45	600 x 750 (24 x 30)	—	—	—	—
Do Not Block Intersection	R10-7	2B.45	600 x 750 (24 x 30)	—	—	—	—
Use Lane with Green Arrow	R10-8	2B.45	600 x 750 (24 x 30)	900 x 1050 (36 x 42)	—	—	1500 x 1800 (60 x 72)
Left (Right) Turn Signal	R10-10	2B.45	600 x 750 (24 x 30)	—	—	—	—
No Turn on Red	R10-11,11a	2B.45	600 x 750 (24 x 30)	—	—	—	1200 x 1200 (48 x 48)
No Turn on Red	R10-11b	2B.45	600 x 600 (24 x 24)	—	—	—	750 x 750 (30 x 30)
Left Turn Yield on Green	R10-12	2B.45	600 x 750 (24 x 30)	—	—	—	—
Emergency Signal	R10-13	2B.45	900 x 600 (36 x 24)	—	—	—	—
Turning Traffic Must Yield To Pedestrians	R10-15	2B.45	750 x 900 (30 x 36)	—	—	—	—
U-Turn Yield to Right Turn	R10-16	2B.45	750 x 900 (30 x 36)	—	—	—	—
Right on Red Arrow After Stop	R10-17a	2B.45	750 x 900 (30 x 36)	—	—	—	—
Traffic Laws Photo Enforced	R10-18	2B.46	900 x 450 (36 x 18)	1200 x 750 (48 x 30)	1800 x 900 (72 x 36)	—	—
Photo Enforced	R10-19	2B.46	600 x 450 (24 x 18)	900 x 750 (36 x 30)	1200 x 900 (48 x 36)	—	—
MON—FRI (and times) (3 lines)	R10-20a	2B.45	600 x 600 (24 x 24)	—	—	—	—
SUNDAY (and times) (2 lines)	R10-20a	2B.45	600 x 450 (24 x 18)	—	—	—	—
Left Turn Signal— Yield on Green	R10-21	2B.45	750 x 900 (30 x 36)	—	—	—	—
Bike Actuation	R10-22	9B.12	300 x 450 (12 x 18)	—	—	—	—

Table 2B-1. Regulatory Sign Sizes (Sheet 5 of 5)

Sign	MUTCD Code	Section	Conventional Road	Expressway	Freeway	Minimum	Oversized
Keep Off Median	R11-1	2B.47	600 x 750 (24 x 30)	—	—	—	—
Road Closed	R11-2	2B.48	1200 x 750 (48 x 30)	—	—	—	—
Road Closed - Local Traffic Only	R11-3,3a, 3b,4	2B.48	1500 x 750 (60 x 30)	—	—	—	—
Weight Limit	R12-1,2	2B.49	600 x 750 (24 x 30)	900 x 1200 (36 x 48)	—	—	900 x 1200 (36 x 48)
Weight Limit	R12-3	2B.49	600 x 900 (24 x 36)	—	—	—	—
Weight Limit	R12-4	2B.49	900 x 600 (36 x 24)	—	—	—	—
Weight Limit	R12-5	2B.49	600 x 900 (24 x 36)	900 x 1200 (36 x 48)	1200 x 1500 (48 x 60)	—	—
Metric Plaque	R12-6	2B.49	600 x 225 (24 x 9)	—	—	—	—
Weigh Station	R13-1	2B.50	1800 x 1200 (72 x 48)	2400 x 1650 (96 x 66)	3000 x 1100 (120 x 84)	—	—
Truck Route	R14-1	2B.51	600 x 450 (24 x 18)	—	—	—	—
Hazardous Material	R14-2,3	2B.52	600 x 600 (24 x 24)	750 x 750 (30 x 30)	900 x 900 (36 x 36)	—	1050 x 1050 (42 x 42)
National Network	R14-4,5	2B.53	600 x 600 (24 x 24)	750 x 750 (30 x 30)	900 x 900 (36 x 36)	—	1050 x 1050 (42 x 42)
Railroad Crossbuck	R15-1	8B.03	1200 x 225 (48 x 9)	—	—	—	—
Look	R15-8	8B.16	900 x 450 (36 x 18)	—	—	—	—

Notes:
1. Larger signs may be used when appropriate.
2. Dimensions are shown in millimeters followed by inches in parentheses and are shown as width x height.

Table 2C-1. Categories of Warning Signs

Category	Group	Section	Signs	MUTCD Codes
Roadway Related	Changes in Horizontal Alignment	2C.06	Turn, Curve, Reverse Turn, Reverse Curve, Winding Road, Hairpin Curve, 270-Degree Curve	W1-1 through W1-5, W1-11, W1-15
		2C.07	Combination Horizontal Alignment/Advisory Speed	W1-1a, W1-2a
		2C.08	Combination Horizontal Alignment/Intersection	W1-10
		2C.09	Large Arrow (one direction)	W1-6
		2C.10	Chevron Alignment	W1-8
		2C.11	Truck Rollover	W1-13
	Vertical Alignment	2C.12	Hill	W7-1, W7-1a, W7-1b
		2C.13	Truck Escape Ramp	W7-4, W7-4a
		2C.14	Hill Blocks View	W7-6
	Cross Section	2C.15	Road Narrows	W5-1
		2C.16-17	Narrow Bridge, One Lane Bridge	W5-2, W5-3
		2C.18-20	Divided Road, Divided Road Ends, Double Arrow	W6-1, W6-2, W12-1
		2C.21	Dead End, No Outlet	W14-1, W14-1a, W14-2, W14-2a
		2C.22	Low Clearance	W12-2, W12-2p
	Roadway Surface Condition	2C.23-24	Bump, Dip, Speed Hump	W8-1, W8-2, W17-1
		2C.25	Pavement Ends	W8-3
		2C.26	Shoulder	W8-4, W8-9, W8-9a
		2C.27	Slippery When Wet	W8-5
		2C.28	Bridge Ices Before Road	W8-13
Traffic Related	Advance Traffic Control	2C.29-30	Stop Ahead, Yield Ahead, Signal Ahead, Be Prepared To Stop, Speed Reduction	W3-1, W3-2, W3-3, W3-4, W3-5, W3-5a
	Traffic Flow	2C.31-35	Merge, Lane Ends, Added Lane, Two-Way Traffic, Right Lane Ends, Lane Ends Merge Left, No Passing Zone	W4-1, W4-2, W4-3, W4-5, W4-6, W6-3, W9-1, W9-2, W14-3
	Change in Speed	2C.36	Advisory Speed	W13-2, W13-3, W13-5
	Intersections	2C.37	Cross Road, Side Road, T, Y, and Circular Intersection	W2-1 through W2-6
		2C.38	Large Arrow (two directions)	W1-7
		2C.39	Oncoming Extended Green	W25-1, W25-2
	Vehicular Traffic	2C.40	Truck Crossing, Truck (symbol), Emergency Vehicle, Tractor, Bicycle, Golf Cart, Horse-Drawn Vehicle	W8-6, W11-1, W11-5, W11-5a, W11-8, W11-10, W11-11, W11-12p, W11-14
	Nonvehicular	2C.41-42	Pedestrian, Deer, Cattle, Snowmobile, Horse, Wheelchair, Playground	W11-2, W11-3, W11-4, W11-6, W11-7, W11-9, W15-1
Supplemental Plaques	Distance	2C.45	XX Feet, XX Miles, Next XX Feet, Next XX MI	W16-2, W16-3, W16-4, W7-3a
	Speed	2C.46	Advisory Speed	W13-1
	Arrow	2C.47	Advance Arrow, Directional Arrow, Diagonal Arrow	W16-5p, W16-6p, W16-7p
	Hill-Related	2C.48	Trucks Use Low Gear, X% Grade	W7-2, W7-3
	Street Name Plaque	2C.49	Advance Street Name	W16-8
	Intersection	2C.50	Cross Traffic Does Not Stop	W4-4p
	Share The Road	2C.51	Share The Road	W16-1
	HOV	2C.52	High-Occupancy Vehicle	W16-11
	Photo Enforced	2C.53	Photo Enforced	W16-10
	Traffic Circle	2C.37	Traffic Circle	W16-12p

Table 2C-2. Warning Sign Sizes

Description: Shape	Description: Sign Series	Conventional Road	Express-way	Freeway	Minimum	Oversized
Diamond	W1, W2, W7, W8, W9, W11, W14, W15-1, W17-1	750 x 750 (30 x 30)	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	600 x 600 (24 x 24)	———
	W1 Combination, W3, W4, W5, W6, W8-3, W10, W12	900 x 900 (36 x 36)	1200 x 1200 (48 x 48)	1200 x 1200 (48 x 48)	750 x 750 (30 x 30)	———
Rectangular	W1 - Arrows	1200 x 600 (48 x 24)	———	———	900 x 450 (36 x 18)	1500 x750 (60 x 30)
	W1 - Chevron	450 x 600 (18 x 24)	750 x 900 (30 x 36)	900 x1200 (36 x 48)	300 x 450 (12 x 18)	———
	W7-4	1950 x 1200 (78 x 48)	1950 x 1200 (78 x 48)	1950 x1200 (78 x 48)	———	———
	W7-4b, 4c	1950 x 1500 (78 x 60)	1950 x 1500 (78 x 60)	1950 x 1500 (78 x 60)	———	———
	W10-9, 10	600 x 450 (24 x 18)	———	———	———	———
	W12-2p	2100 x 600 (84 x 24)	2100 x 600 (84 x 24)	2100 x 600 (84 x 24)	———	———
	W13-2, 3, 5, W25	600 x 750 (24 x 30)	900 x1200 (36 x 48)	1200 x 1500 (48 x 60)	600 x 750 (24 x 30)	1200 x 1500 (48 x 60)
Pennant	W14-3	900 x 1200 x 1200 (36 x 48 x 48)	———	———	750 x 1000 x 1000 (30 x 40 x 40)	1200 x1600 x 1600 (48 x 64 x 64)
Circular	W10-1	900 (36) Dia.	1200 (48) Dia.	———	750 (30) Dia.	1200 (48) Dia.

Notes: 1. Larger signs may be used when appropriate
2. Dimensions are shown in millimeters followed by inches in parentheses and are shown as width x height

***Table 2E-4. Minimum Letter and Numeral Sizes for Freeway Guide Signs According to Sign Type** (Sheet 1 of 2)*

Type of Sign	Minimum Size (mm)	Minimum Size (inches)
A. Pull-Through Signs		
Destination — Upper-Case Letters	400	16
Destination — Lower-Case Letters	300	12
Route Sign as Message		
Cardinal Direction	300	12
1- or 2-Digit Shield	900 x 900	36 x 36
3-Digit Shield	1125 x 900	45 x 36
B. Supplemental Guide Signs		
Exit Number Word	250	10
Exit Number Numeral and Letter	375	15
Place Name — Upper-Case Letters	330	13.3
Place Name — Lower-Case Letters	250	10
Action Message	250	10
C. Changeable Message Signs		
Characters	265*	10.6*
D. Interchange Sequence Signs		
Word — Upper-Case Letters	330	13.3
Word — Lower-Case Letters	250	10
Numeral	330	13.3
Fraction	250	10
E. Next X Exits Sign		
Place Name — Upper-Case Letters	330	13.3
Place Name — Lower-Case Letters	250	10
NEXT X EXITS	250	10
F. Distance Signs		
Word — Upper-Case Letters	200	8
Word — Lower-Case Letters	150	6
Numeral	200	8
G. General Service Signs		
Exit Number Word	250	10
Exit Number Numeral and Letter	375	15
Services	250	10
H. Rest Area and Scenic Area Signs		
Word	300	12
Distance Numeral	375	15
Distance Fraction	250	10
Distance Word	300	12
Action Message Word	300	12

Table 2E-4. Minimum Letter and Numeral Sizes for Freeway Guide Signs According to Sign Type *(Sheet 2 of 2)*

Type of Sign	Minimum Size (mm)	Minimum Size (inches)
I. Reference Location Signs		
Word	100	4
Numeral	250	10
J. Boundary and Orientation Signs		
Word — Upper-Case Letters	200	8
Word — Lower-Case Letters	150	6
K. Next Exit and Next Services Signs		
Word and Numeral	200	8
L. Exit Only Signs		
Word	300	12
M. Diagrammatic Signs		
Lane Widths	125	5
Lane Line Segments	25 x 150	1 x 6
Gap Between Lane Lines	150	6
Stem Height (up to upper point of departure)	750	30
Arrowhead (standard "up" arrow)	200	8
Space Between Arrowhead and Route Shield	300	12

*Changeable Message Signs may often require larger sizes than the minimum. A size of 450 mm (18 in) should be used where traffic speeds are greater than 90 km/h (55 mph), in areas of persistent inclement weather, or where complex driving tasks are involved.

Excerpts from 2004 AASHTO Greenbook – Curb Types

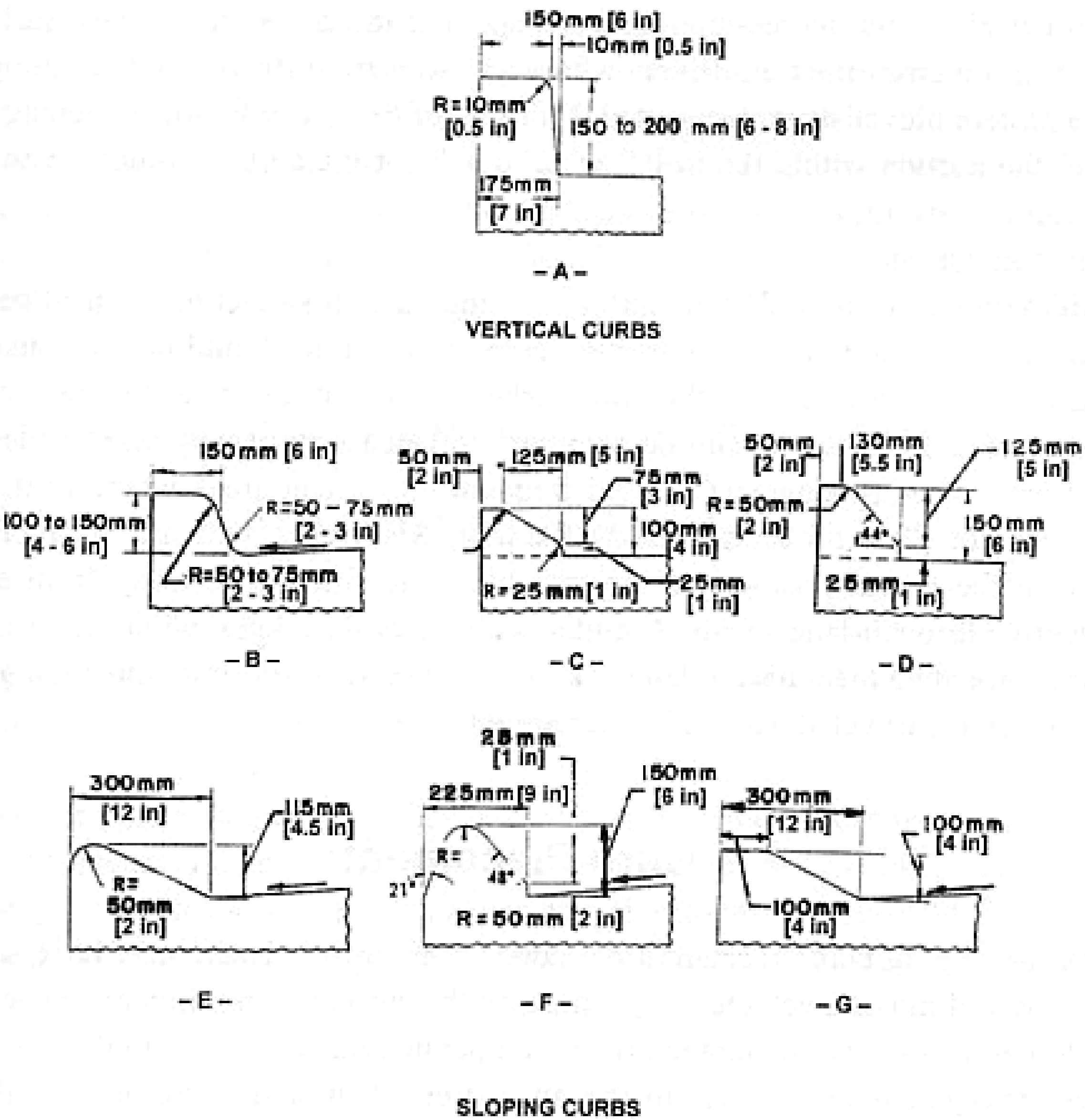

Exhibit 4-6. Typical Highway Curbs

During data collection, the curb type should only be described as "vertical" and "sloping", as shown in Exhibit 4-6 of the 2004 AASHTO Green Book, as well as "other" or "none".

PAVEMENT

The pavement condition survey will be divided into two formats: the current NCDOT pavement condition survey and the LTPP pavement condition survey. Manuals for these surveys can be found at the Expo website (http://www.itre.ncsu.edu/NCassetMgmtConf/index.html). Data element types, detailed definitions of each data element type and severity, and desired units of measure are provided in these manuals.
We request your team to report the survey data using the data tables shown in the NCDOT pavement condition survey manual and the LTPP pavement condition survey manual. For the LTPP survey data tables, please add the beginning mile post and the section length. If GPS coordinates can be determined from your system, please stamp the beginning of each section with the GPS coordinates.

A summary of the data elements to be measured for different pavement types is shown on the following pages.

Summary Tables of Data Elements

Table A.2. NCDOT Pavement Condition Survey (Asphalt Pavement).

Data Elements
Alligator Cracking (Fatigue
Transverse cracking
Raveling
Oxidation
Bleeding
Patching
Ride Quality (Roughness)
Rutting
Texture
Friction

Table A.3. NCDOT Pavement Condition Survey (Concrete Pavement).

Pavement Type	Data Elements
General	Shoulder Condition
	Surface Wear
	Pumping
	Ride Quality
	Texture
	Friction
JCP	Patches
	Longitudinal Cracking
	Transverse Cracking
	Corner Break
	Spalling
	Joint Seal Damage
	Faulting of Transverse
CRCP	Patches
	Longitudinal Cracking
	Transverse Cracking
	Punchouts
	Narrow Cracks
	‘Y’ Cracks

Table A.4. LTPP Pavement Condition Survey (Asphalt Pavement).

Data Elements
Alligator Cracking (Fatigue Cracking)
Transverse Cracking
Raveling
Bleeding
Patching
Block Cracking
Edge Cracking
Longitudinal Cracking
Reflection Cracking at Joint
Potholes
Shoving
Polished Aggregate
Lane-to-Shoulder Drop-off
Water Bleeding and Pumping
Roughness
Rutting

Table A.5. LTPP Pavement Condition Survey (Concrete Pavement)

Pavement Type	Data Elements
General	Roughness
JCP	Drop-off
	Patches
	Longitudinal Cracking
	Transverse Cracking
	Corner Cracking (Corner Break)
	Spalling
	Lane-Joint Seal Damage
	Joint Seal Damage
	Faulting of Transverse Joints
	Durability Cracking (D-Cracking)
	Map Cracking
	Scaling
	Polished Aggregate
	Blow up
	Lane-to-Shoulder Separation
	Transverse Construction Joint
	Surface Wear (Water Bleeding)
	Pumping
CRCP	Drop-off
	Lane-Joint Seal Damage (Longitudinal)
	Patches
	Longitudinal Cracking
	Transverse Cracking
	Punchouts
	Durability Cracking (D-Cracking)
	Map Cracking
	Scaling
	Polished Aggregate
	Blow up
	Lane-to-Shoulder Separation
	Lane-to-Shoulder Drop Off
	Transverse Construction Joint
	Spalling of Longitudinal Joint
	Surface Wear (Water Bleeding)
	Pumping

APPENDIX B VENDORS PARTICIPATING IN TESTING

- **Fugro Roadware, Inc.**
  Phone: 800.828.2726 / 519.442.2264
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  Website: www.fugro-roadware.com

- **GEO-3D**
  Phone: 1.888.90.GEO3D
  Address: 9655 Ignace Street, Suite L
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  Website: http://www.geo-3d.com/home.html

- **NAVTEQ**
  Phone: 312.894.7205
  Address: 425 W. Randolph St,
  Chicago, IL 60606 USA
  Website: www.navteq.com

- **Mandli Communications, Inc.**
  Phone: 608.835.3500
  Address: 4801 Tradewinds Parkway, Suite 100
  Madison, WI 53718 USA
  Website: www.mandli.com

- **Pathway Services, Inc.**
  Phone: 918.259.9883
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  Tulsa, OK 74147 USA
  Website: http://www.pathwayservices.com

- **Precision Scan**
  Phone: 336.475.7550
  Address: 115 Todd Ct
  Thomasville, NC 27360 USA
  Website: www.precisionscan.com

- **Terrametrix**
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APPENDIX D INSTRUCTIONS FOR PAVEMENT DATA RESUBMISSION

INSTRUCTIONS TO VENDORS

Each vendor has provided NCSU and NCDOT with copies of their respective software and data files for the North Carolina test loop. NCDOT personnel have reviewed portions of these data and developed comments regarding the ratings. These comments are being provided to each vendor in the attached packet. Using this information, the vendors are expected to perform the following actions.

1. View the NCDOT notes/comments on their respective data;
2. Use these notes to calibrate the survey techniques to the NCDOT methodology;
3. Redo the data analysis on the sections that NCDOT performed LTPP survey using; 1) the NCDOT survey protocols and 2) the LTPP survey protocol. (GPS coordinates are given below);
4. Report the findings from the NCDOT survey protocol with the ***NCDOT Survey*** worksheet in the Microsoft Excel file ***Survey Resubmit Data Templates.xls*** (the NCDOT survey manual provided to you at the beginning of this project is also included in the packet of information and a sample table is shown in the ***NCDOT Survey Example worksheet***);
5. Report the findings from the LTPP survey protocol with the ***LTPP Survey*** worksheet in the Microsoft Excel file ***Survey Resubmit Data Templates.xls***, (you may either duplicate the data from the first data submission or actually redo the analysis but please note whether the resubmitted data is a copy of the original or is an actual reanalysis)

The goal of the analysis is to compare vendor calibrated and NCDOT survey results. For efficiency purposes the vendors are not asked to redo the entire test loop. Instead comparisons will be made at three specific locations along the test loop. These locations consist of ten segments (approximately 1 mile) of the vendor data. For the LTPP survey protocol only 2 of these segments need to be analyzed. The beginning and ending GPS coordinates for the ten segments and the beginning and ending GPS coordinates for the two LTPP segments are given below. Justification for any blank cells in the attached Microsoft Excel sheets should be given. If none is given, it will be assumed that the data gathered by the vendor could not be used to compute the required value.

Table D.1. NCDOT Survey Protocol GPS Coordinates.

Section	Begin or End	Latitude (North)	Longitude (West)
1	Begin	35.9763078164	78.3536852275
	End	35.9701070217	78.3383462077
2	Begin	35.9617442085	78.2878542962
	End	35.9587520203	78.2706177551
3	Begin	35.834995774	78.344769286
	End	35.8282977984	78.3605848516

Table D.2. LTPP Survey Protocol GPS Coordinates

Section	Begin or End	Latitude (North)	Longitude (West)
1-a	Begin	35.9717078456	78.3413244976
	End	35.9708718381	78.3398643625
1-b	Begin	35.9708718381	78.3398643625
	End	35.9701070217	78.3383462077
2-a	Begin	35.9586676757	78.2741926358
	End	35.9587078431	78.2724033751
2-b	Begin	35.9587078431	78.2724033751
	End	35.9587520203	78.2706177551
3-a	Begin	35.8338143618	78.3480234657
	End	35.8331171666	78.3495898315
3-b	Begin	35.8331171666	78.3495898315
	End	35.8324176491	78.3511542609