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Evaluation of the Automated Distress Survey Equipment

FINAL REPORT
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16. Abstract

This research:

- Illustrated the abilities and limitations of the Automated Distress Survey Equipment and Software to collect, characterize, and analyze pavement cracking distresses under different lighting conditions.
- Assessed the NJDOT profiler crew's evaluation of these same sections.
- Used graphical comparisons and statistical analyses to make assessments of repeatability of multiple test runs under different lighting conditions and different degrees of data processing.

This research conclude that based on the analysis, the Automated Distress Survey Equipment can be used to collect cracking distress data with quality control checks to ensure that the cracking data collected, characterized, and analyzed is accurate.

This research recommends that the NJDOT needs to collaborate with the vendor to refine the data collection and analysis procedures to differentiate the location of cracking (within and outside of the wheel paths) and to provide quality control on the data collection and analysis.

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BACKGROUND

The Bureau of Pavement and Drainage Technology is upgrading their Pavement Management System (PMS) and assessing the current protocols for field pavement data collection. One important aspect of the field data collection that needs to be investigated is the potential use of Automated Distress Survey Equipment to supplement or replace the current manual visual distress data collection. The advances in this technology warrant the evaluation of these systems for use in New Jersey.

In NJDOT, the majority of the pavement distress ratings are based on cracking distresses. By surveying the severity and extent of these distresses and summarizing these conditions for each 0.10 miles, the Pavement Management System analyses tools can provide a relative condition index for a given section of pavement relative to another section; identify sections of pavement that are in unacceptable condition; suggest appropriate rehabilitation treatments; and provide a budget estimate necessary to maintain or improve the pavement network. The NJDOT's Pavement Management System uses the assessment of theses distress conditions along with an assessment of pavement ride quality and pavement rutting to identify pavements in need of repair and to develop the multi-year paving program. NJDOT also previously used the distress data collected by PMS Unit to identify the needs for routine maintenance, specifically the crack sealing program, and to select sections for the crack sealing program.

The current distress survey protocol describes the procedure used by the staff of the pavement management section to collect ride quality, rutting and distress survey data. The NJDOT uses an International Cybernetics Corporation (ICC) van, equipped with pavement profile lasers to collect pavement ride quality data, video equipment to collect right-of-way images, an INO rut system to collect wheel track rutting and a distress rater keyboards to collect pavement distress condition data on roughly 4,600 directional miles of state-maintained roadways. The pavement distress rater, sitting in the passenger seat, uses a rater keyboard to identify the severity of various visual distress types as the van travels at highway speeds (40-60 miles per hour). These subjective assessments of visible distresses are recorded in the on-board computer and transferred to Pavement Management System database for analyses. With any manual visual survey, the assessment of severity of each distress is subjective and can be influenced by rater fatigue, attention, distractions, as well as, variations in lighting condition and vehicle speed. At highway speeds of 55 mph (more than 80 foot per second), the rater has less than 1 second to rate a 0.01 mile (52.8 foot) longitudinal section of pavement across all lanes and shoulders.

The Automated Distress Survey Equipment that was evaluated in this research uses video or laser technology to record the pavement surface images as the van travels along the pavement (Figure 1). These images are later analyzed to identify the severity and lengths or area of cracks and other distresses.

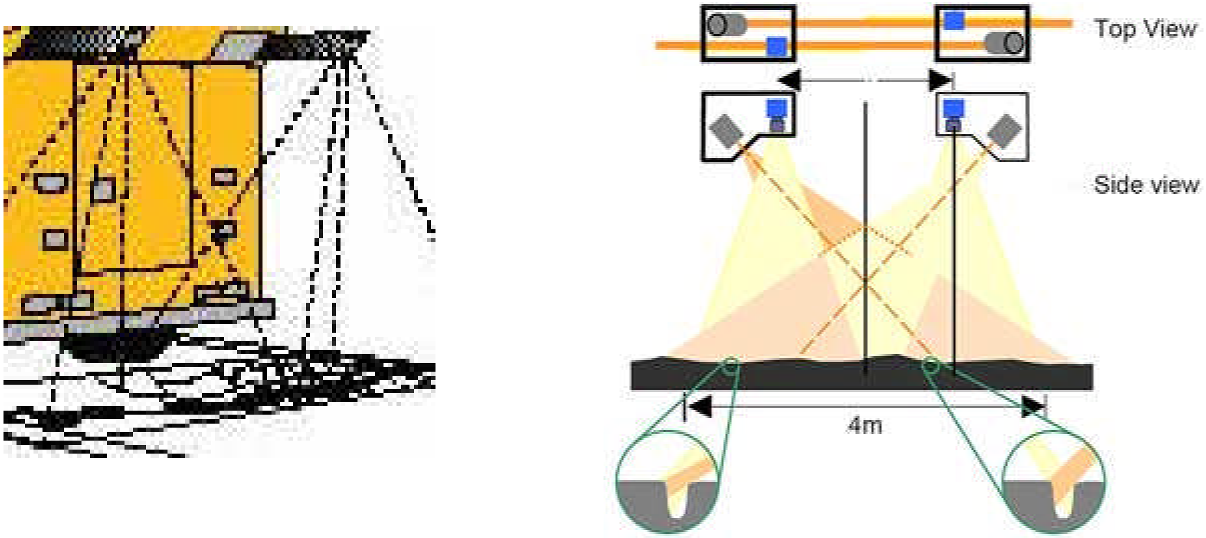

Figure 1. Examples of Distress Data Collection Technology

The research compared the data collected by the human raters of the NJDOT with those of the Automated Distress Survey Equipment. This assessment provided a comparison of the ability of the automated equipment and human rater in rating the various types of distresses and conditions. The assessment will allow the PMS staff to determine which forms of distress are better rated by human raters and which types of distress could be collected and analyzed by the automated distress survey technology.

RESEARCH OBJECTIVES

Since there are multiple vendors with this type of equipment and analysis capabilities, NJDOT wished to evaluate and compare these units in a side-by-side pilot for the next generation Pavement Management System data collection vehicle. The evaluation of the Automated Distress Survey Equipment to supplement or replace the current manual visual distress data collection could significantly improve the quality and repeatability of the PMS distress data and help NJDOT make better pavement rehabilitation decisions. This is especially important in this time of limited financial resources.

The objectives of this research study were:

- Evaluate the capabilities, limitations and repeatability of the various Automated Distress Survey Equipment technologies on various distress types on different pavement surface types at various distress severity levels, lighting conditions and highway speeds.

- Assess the capabilities, limitations and repeatability of NJDOT's PMS rater staff to evaluate various distress types on different pavement surface types at various distress severity levels, lighting conditions and highway speeds.
- Assess the level of effort and time required to process the images generated from the Automated Distress Survey Equipment.
- Determine which distress types are better collected with the Automated Distress Survey Equipment and which distress types should continue to be collected by PMS staff.
- Determine how the data collected by the Automated Distress Survey Equipment can be incorporated into the Pavement Management System.

INTRODUCTION

To address the research objectives, the research team conducted a comprehensive literature search to summarize the manufacture's description of the distress data collection technology. Other research was conducted to assess the current state-of-the-art in pavement imaging, distress identification and evaluation. The research team met with the PMS staff to identify fourteen individual one-mile test sections that have a variety of pavement types (Bituminous Concrete, BC, Composite, CO, and Reinforce Concrete, RC), distress types, severity levels and extents. The research team reviewed the Department's current distress survey protocol and developed distress definitions and evaluation criteria for use in the research study. Based on the content of the literature search and experience of the research team, a number of Automated Distress Survey Equipment vendors representing the various distress collection technologies were identified. These vendors were contracted to collect three runs on each test sites and conduct analyses of the image data for NJ DOT.

The PMS staff also collected distress data using the current NJDOT protocol. The testing order of the test sites was randomly assigned. The distress type, severity and extent levels of each site were documented for comparison between the Automated Distress Survey Equipment and the PMS raters.

SUMMARY OF THE LITERATURE REVIEW

In 2003, NCHRP contracted Ken McGhee to create a synthesis of current practices based on a survey of State DOTs and Canadian provinces. The synthesis, **NCHRP Synthesis 334 Automated Pavement Distress Collection Techniques [1],** provided a summary of the state practices and technical information to explain various data collection and analysis techniques. This National study concluded that twnty-three States Agencies and seven Canadian Provinces are collecting ride quality, rut depth and distress data in a single pass using an integrated pavement data collection vehicle. The ride quality data was automatically collected with wheel path laser sensors stored in onboard computers and transferred to office computers for further processing. Likewise, rut depth data was automatically collected with sensors (laser or acoustic) mounted on a specially equipped front bumper, stored in onboard computers and transferred to office computers for further processing. Pavement surface distress data was collected either semi-automatically with the use of rater-keyboards to record various forms, severity and extent, stored in onboard computers and transferred to office computers for further processing or through the use of image capture either through the windshield or with the use of vertically mounted cameras mounted on the rear of the vehicle. The images were later processed either semi-automatically or automatically with special software that could roughly identify digital pixels as cracks in the pavement surface. The image analysis could identify the approximate severity (crack width), length and direction of the crack. These could be characterized as either longitudinal, transverse, fatigue, or some combination of these types. Automated processing of pavement surface distresses from those images was employed by only fourteen of those agencies:

Alabama
Connecticut
Idaho
Illinois
Iowa
Louisiana
Maine
Maryland
Missouri
Nebraska
Pennsylvania
Vermont
Virginia
Washington

Since the focus of this research study was the evaluation of automated distress (pavement surface cracking) data collection and analyses, the remarks on the literature review will concentrate on this topic.

In the mid 1990s, Roadware Corporation introduced the WiseCrax subsystem as a means of automatically collecting pavement images and interpreting images for crack detection. The system used a combination two-camera two synchronized strobe illumination system to capture area-scan images at 2,048-pixel resolution. Image processing or interpretation was done off-line on a host PC in the office with operator assistance. [5]

The next introduction was technology developed by The Waylink Systems Company: a data collection vehicle using line-scan technology that can collect images at 4,096-pixel resolution at 60 miles per hour.

In 2005, INO of Quebec, Canada developed a laser illumination based technology called Laser Road Imaging System (LRIS) that can collect pavement image data without the influence of sun light or shadow.

Sampling Interval and Linear Referencing

Ride quality (roughness data) and rut data are collected continuously along the pavement lane at a frequency of several inches to 2 feet. Images usually provide continuous coverage at 3 to 5 m (10 to 15 ft) longitudinally per image in the lane that the test vehicle is traveling by stitching the images together.

Pavement data is referenced to the pavement surface using either a route, direction, milepost referencing system or through the use of Global Positioning System (GPS) X-Y coordinate system to facilitate linking data on Geographical Information System (GIS) maps.

In addition to the linear referencing of the data along the pavement, the images can be subdivided to address the location of the cracking distresses that are within and outside of the wheel paths as shown below in Figure 2.

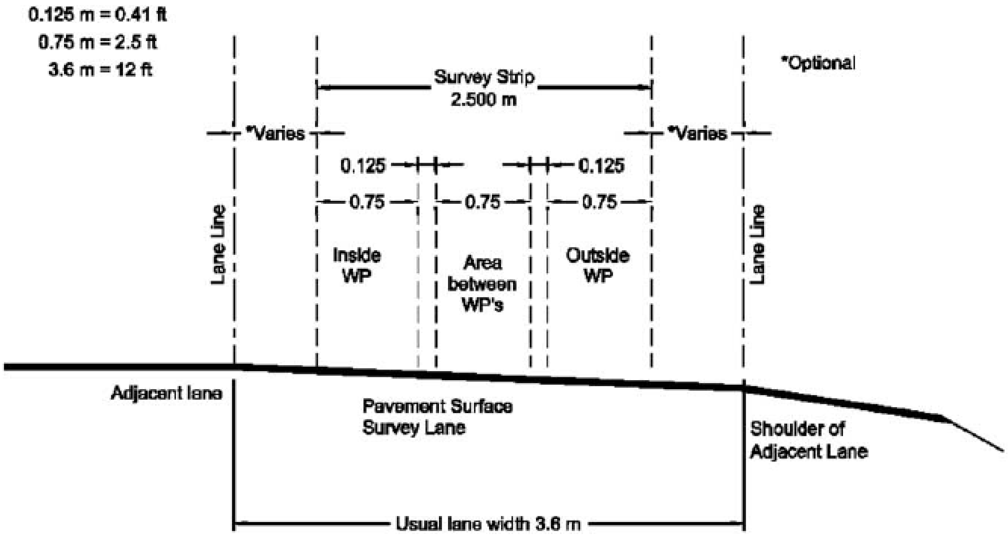

Figure 2. Cross section of lane showing wheel paths and defined survey area.

Method of Data Capture

Of the States and Canadian Provinces that capture pavement images, the predominant use of analog imaging of pavements was photograph (usually with 35-mm film) and videotaping. These Images can be of high quality, but they are not easily converted to digital format for computer storage and manipulation. Most agencies use film or videotape and utilize manual visual distress interpretation from the image data.

Some vendors now utilize digital camera technology and even line-scan and area-scan laser technology to capture the pavement image. These digital formats greatly enhance computer storage and interpretation. The area-scan images are usually one-half to one lane wide and 10-15 feet along the pavement. The line-scan images are captured as a single pixel width and merged together with adjacent line scans to form the image. This technology is capable of detecting cracks as small as 1 to 2 mm with 2,048 to 4,096-pixel resolution.

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Some road departments like Florida DOT have conducted research studies to evaluate pavement imaging systems. [2] As noted in their study, manual surveys and manual visual survey from a moving vehicle or photographic image are highly subjective, have a low productivity rate, and can expose the survey team to hazardous driving conditions. The research study evaluated the precision and accuracy of the automated imaging system under various speeds, lighting conditions (e.g., sunny or cloudy), pavement types, and with and without special illumination. For the imaging system used in the study, the special lighting system improved image quality and eliminated any shadows that could later be interpreted as cracks. The study found that under normal data collection speeds (25-45 miles per hour), there was no degradation of image quality. Lighting or illumination was found to be a critical element in capturing high quality image data. To properly characterize pavement cracks, illumination must be high and remain reasonably uniform over the entire field of view. [5]

Crack width characterization is directly proportional to the image resolution. A comparison of transverse resolution vs. crack width is shown below:

Table 1. Comparison of Transverse Resolution vs. Crack Width

Transverse Resolution	1300-pixels	2048-pixels	4096-pixels
Crack Width Determination	3 mm	2 mm	1 mm

Storage and Compression

Storage of image files would be difficult without appropriate compression software. Without compression, storage for a one kilometer 4-meters wide section of pavement image data would be 1.6 GB at 2048-pixel resolution and 6.6 GB at 4096-pixel resolution. Compression of these images is done through Joint Picture Expert Group (JPEG) software. The JPEG algorithm used for pavement images, is considered “lossy”, meaning that some information is lost during the compression process. The size of the compressed file for visually faithful JPEG images of the pavement surfaces is about one-fifth to one-eighth of the size of the original raw (uncompressed) image data file. The new JEPG2000 compression algorithm achieves a much higher compression ratio at similar image quality to traditional JPEG. The following table provides a comparison of the sizes of raw, JPEG and JEPG2000 image files for a mile section of road 4 meters wide. [5]

Table 2. Comparison of the sizes of Raw, JPEG and JEPG2000 Image Files

Raw TIFF Image	6.59 GB
JPEG	900 MB
JPEG2000	330 MB

Automated Distress Image Interpretation

Crack detection in the pavement image is based on an evaluation of pixel intensity that is appreciably darker than the surrounding (adjacent) pixels. The image analysis procedure divides the image in to 8x8 pixel cells. The software algorithm identifies potential cracks within the cell. In the initial level analysis, dark areas within the cell are identified as either non-crack or crack seeds. The crack cluster connection analysis helps to identify the existence, and orientation of the crack (longitudinal, transverse, or diagonal) and creates digital crack maps of the pavement surface. Analyses performed at the Center for Transportation Research in Texas found that data from three runs had a correlation in excess of 0.95 for on screen visual assessment vs. automated crack analyses. Slight differences from the multiple runs were associated with vehicle wander. [3, 4]

Numerous methods have been developed for crack data interpretation from digital images and the development of engineering indices. Of these crack classification protocols, the AASHTO Provisional Standard PP44-01, Standard Practice for Quantifying Cracks in Asphalt Pavement Surface, the World Bank’s Universal Cracking Indicator and the Texas Department of Transportation Method have been the most widely evaluated and used. [3, 4, 5]

The AASHTO protocol quantifies cracks in both the wheel path and non-wheel path areas. [6] The protocol defines cracks as discontinuities in the pavement surface with a minimum dimension of 3 mm (1/8 inch). The cracks are classified as either longitudinal, transverse, or interconnected (fatigue) cracks. Crack located within the wheel paths are considered load-associated cracks and those outside the wheel paths are considered environmental or reflective cracks. The AASHTO method identifies severity and intensity as:

- Severity Level 1 – cracks smaller than 3 mm (1/8 inch).
- Severity Level 2 – cracks with widths from 3-6 mm (1/8 inch to 1/4 inch).
- Severity Level 3 – cracks with widths greater than 6 mm (1/4 inch).

Each cracking level is quantified by the total length of cracking per unit area (m/m^2).

The World Bank's Universal Cracking Indicator uses a simpler index to assess cracking. The crack index multiplies the extent or area of the pavement cracked by the intensity or total length of crack in the pavement area by the mean crack width.

The Texas Department of Transportation Method characterizes cracks by type. Longitudinal cracks are determined as linear feet per station. Transverse cracks are measured in terms of the number of cracks per station. Cracks that are not full lane width are considered partial cracks. Alligator or fatigue cracks are measured as the percentage of the area of the wheel paths that contains this cracking. Block cracking is measured as the percentage of the total feet of full-lane width that contains block cracking.

NJDOT does distinguish between those cracks that are within and outside the wheel paths as load-associated cracks and those outside the wheel paths are considered environmental or reflective cracks, but the pavement distress index is calculated based on the presence and severity of cracking within each 0.01 mile (52.8 foot) pavement section.

SUMMARY OF THE WORK PERFORMED

The following section describes the summary of the work performed to achieve the objectives.

NJDOT Pavement Distress Identification Manual

In order to ensure consistency in the manual and automated distress evaluation, the first step in the research was to develop a Distress Identification Manual based on NJDOT's current cracking distress types and the description of the distresses collected by the automated distress survey collection equipment.

The Manual provided visual and text descriptions of the distresses currently collected by NJDOT as shown in Table 3. The distresses shown in bold are the cracking distresses evaluated in this research. The manual provided the procedure for rating the cracking distresses based on:

- Distress types.
- Definitions of severity levels.
- How extent is measured.

Other distresses can be evaluated based on windshield survey or from review of pavement images in the office.

Table 3. NJDOT Pavement Distress Types based on Pavement Type

BC and CO Pavements	RC Pavements
Multiple Cracks	Patching
Transverse Cracks	Shoulder Condition
Longitudinal Cracks	Shoulder Drop
Patching	**Cracks**
Shoulder Condition	Faulting
Shoulder Drop	Longitudinal Joint Condition
	Transverse Joint Condition

BC – Bituminous Concrete Pavements CO – Composite Pavements
RC –Reinforced Concrete Pavements

The research team used distress types, severity levels, and extent measurements based on the SHRP Distress Identification Manual (SHRP P-338, 1993).

Severity level is based on a visual assessment of crack width. The extent of the distress is based on a calculation of the proportion of the 0.1 mile section that exhibits a given distress type at a given severity level indicated by the rater (e.g., For a 0.1 mile section where 4 (0.01 foot sections) out of 10 have are identified to have a high severity level of longitudinal cracking, the extent is calculated to be 40%).

Automated Distress Survey Equipment and analyses has the ability to:

- Reports crack type, severity, extent and location
- Detects and analyzes cracks as small as 1 mm (0.03 in.)
- Prepares crack maps of the pavement surface automatically

The cracking distress types from the automated equipment can be characterized as:

Longitudinal	Alligator (Fatigue)
Transverse	Block

The strength of the automated systems analysis software was identifying Longitudinal and Transverse cracking. Alligator (Fatigue) and Block cracking required manual identification most of the time. The severity levels (slight, moderate and severe) are based on the average crack width identified in the distress identification manual.

Test Section Selection

The selection of test sites was based on a Design of Experiment (DOE) from sites identified by the Rutgers research team and the PMS staff. The DOE included the following parameters:

- Pavement type – BC, CO and RC.
- Multiple pavement distress types and severity condition levels.
- Pavement Load-related and Non-load related distress locations.

Each test site was visited by members of the research team and PMS staff to verify the data available in NJDOT PMS. Since no traffic control was used, the distress data was verified through a slow driving,shoulder survey. The overall site survey verified that no rehabilitation had been performed since the latest data collection cycle.

Based on the number of variables, fourteen one-mile test sections were identified to provide sufficient variability of distress types and severity levels. The selection and location of test sites allowed the fourteen sites to be tested over a two to three day period starting at 8:00 am, 12 noon, and 2:00 pm. Each site was tested at the posted highway speed. After the selection of test sites were finalized, route maps were developed. Table 4 is a list of the test site locations. Figure 3 provides the site map and test site locations. This allowed some variation in light conditions for the automated equipment and the PMS staff raters (e.g., east in morning or west in late afternoon or locations where shadows are a potential problem). As a part of this task, field testing plans and protocols were prepared for the use by vendors and NJDOT PMS staff.

Table 4. Test Site Locations

Sites	Rt	Direction	from	to	Pavement Type
1	**95M**	**N**	**5.00**	**6.00**	**BC**
2	295	S	52.10	54.00	RC
3	295	N	52.30	54.00	RC
4	**195**	**E**	**4.60**	**5.60**	**BC**
5	**195**	**E**	**7.90**	**8.90**	**BC**
6	**9**	**N**	**107.00**	**108.00**	**BC**
7	**9**	**N**	**108.80**	**109.80**	**BC**
8	**9**	**N**	**110.70**	**111.70**	**BC**
9	**33**	**W**	**13.00**	**14.30**	**BC**
10	**33**	**W**	**20.00**	**21.00**	**BC**
11	**130**	**S**	**63.10**	**64.10**	**BC**
12	**130**	**S**	**65.20**	**66.20**	**BC**
13	**1**	**N**	**14.5**	**16.5**	**CO**
14	**1**	**S**	**14.5**	**16.5**	**CO**

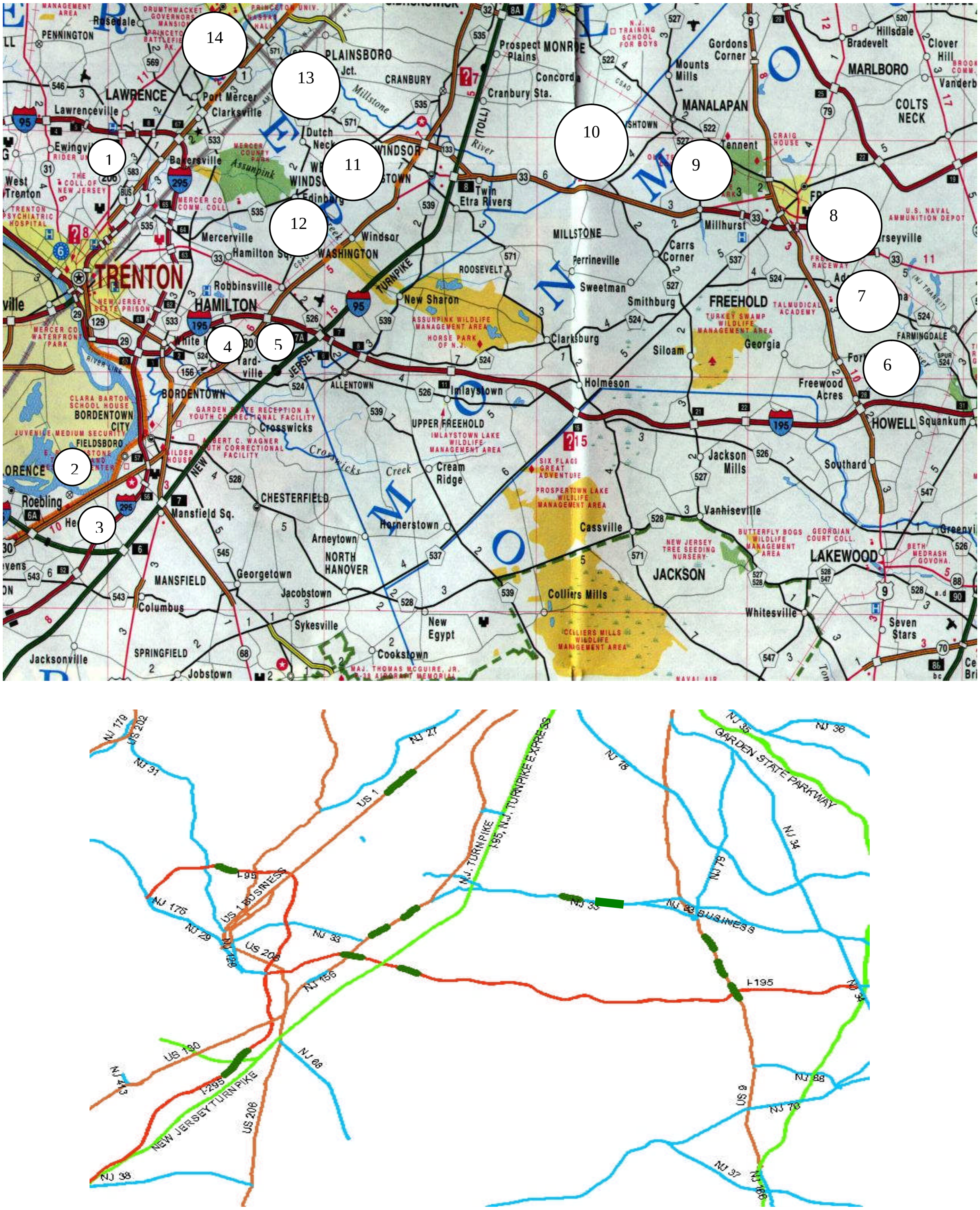


Figure 3. Test Site Map

VENDOR SELECTION

After review of the various vendor systems during the literature search and discussion with NJDOT, the CAIT research team chose two vendors to represent the automated distress technology. The vendors were selected to provide a variety of automated distress survey data collection and analysis techniques.

Vendors made presentations to the NJDOT PMS staff and research team on the capabilities, limitations, data collection and analysis procedures, and analysis time requirements. The presentations also addressed costs for purchase of the Automated Distress Survey Equipment, analysis software, and available and cost of service contracts.

The two vendors that were selected were Fugro-Roadware ARAN using an area scan imaging system and Wisecrax analysis software and Dynatest using the INO line scan imaging system and Waylink Automated Distress Analysis (ADA) software.

FIELD DATA COLLECTION AND DATA ANALYSES

Field Data Collection

NJDOT and the two selected vendors collected pavement condition data on the fourteen test sites. They collected the pavement condition data using the procedure provided. The NJDOT PMS staff was not told where the test sites were located. The NJDOT collected data in the morning and afternoon in one day.

The NJDOT staff collects pavement condition data through a windshield survey using a rater keyboard. The rater judges the severity level (slight, moderate, severe) of the longitudinal, transverse, and multiple cracks, patching condition, and shoulder condition outside of the wheel path as well as the condition of the other pavement lanes. The rater also examines the multiple longitudinal cracks within the wheel paths, while traveling at more than 50 mph.

The two vendors collected pavement images in the morning, midday and afternoon over two days. The starting point of the test sites were marked with a white paint stripe that could be identified in the images and assist the vendors with a reference point for the repeat runs of the test site.

Roadware ARAN

The ARAN unit's dual cameras (Figure 4) recorded continuous series of non-overlapping, area scan images that add to 4.9 ft (longitudinal) by 13 ft (transverse). The synchronized strobe lights eliminate shadows overhead objects. Images can be collected at variable highway speeds up to 50 mph.

Figure 4. ARAN Dual Camera System

Dynatest-Waylink

The Dynatest Road Surface Profilometer (RSP) with INO Laser road imaging system (LRIS) combines a line scan camera with laser illumination imaging system (Figure 5) records 1.15 mm wide (longitudinal) images across the 13 foot pavement lane width. The laser system eliminates shadows from overhead objects.

Both data acquisition and processing can be conducted real-time on-board at speeds up to 60 mph. For this project, the images were post processed in the office.

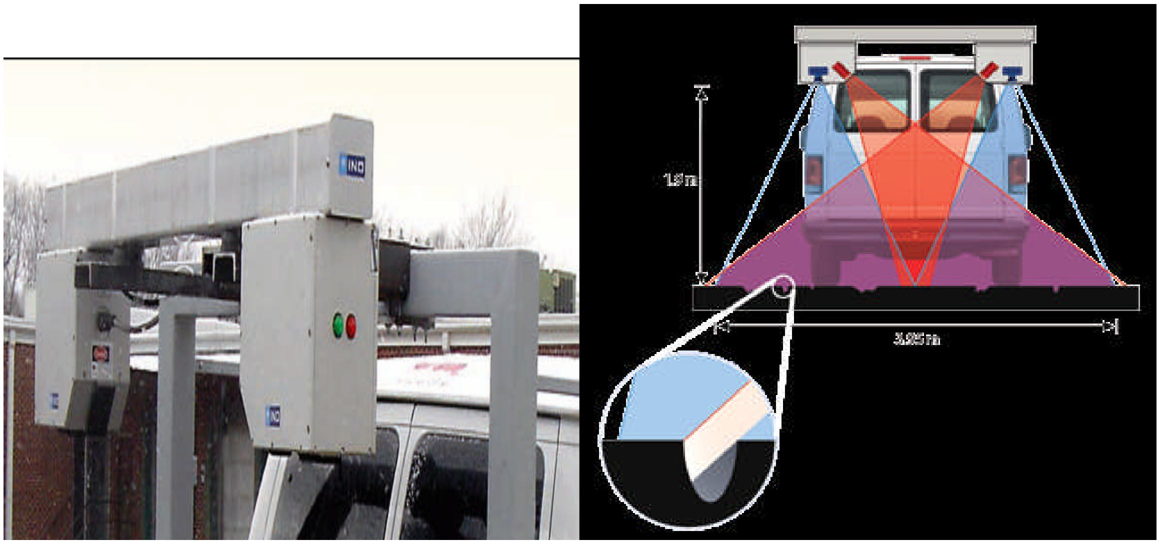


Figure 5. Dynatest-INO Imaging System

Data Analysis

Lighting and Pavement Image Quality

Variations in natural lighting can affect the quality of camera images or characterization of the cracking observations for manual windshield or video ratings. Figure 6 and 7 illustrate the variations in image quality due to variations in natural lighting that affect manual windshield ratings or ratings performed from right of way video images.

The strobe system used by the Roadware area-scan imaging system and the INO laser lighting used by the Dynatest line-scan imaging system provide consistent lighting of the pavement surface. This ensured enhanced quality of the image for use in the Wisecrax and Automated Distress Analysis software systems. Figure 8 and 9 provide illustrations of the pavement images taken at the same time as the row of way image in Figure 6 and 7.

Figure 6. Roadware-ROW images – AM, Midday, and PM

Figure 7. Dynatest-ROW images – AM, Midday, and PM

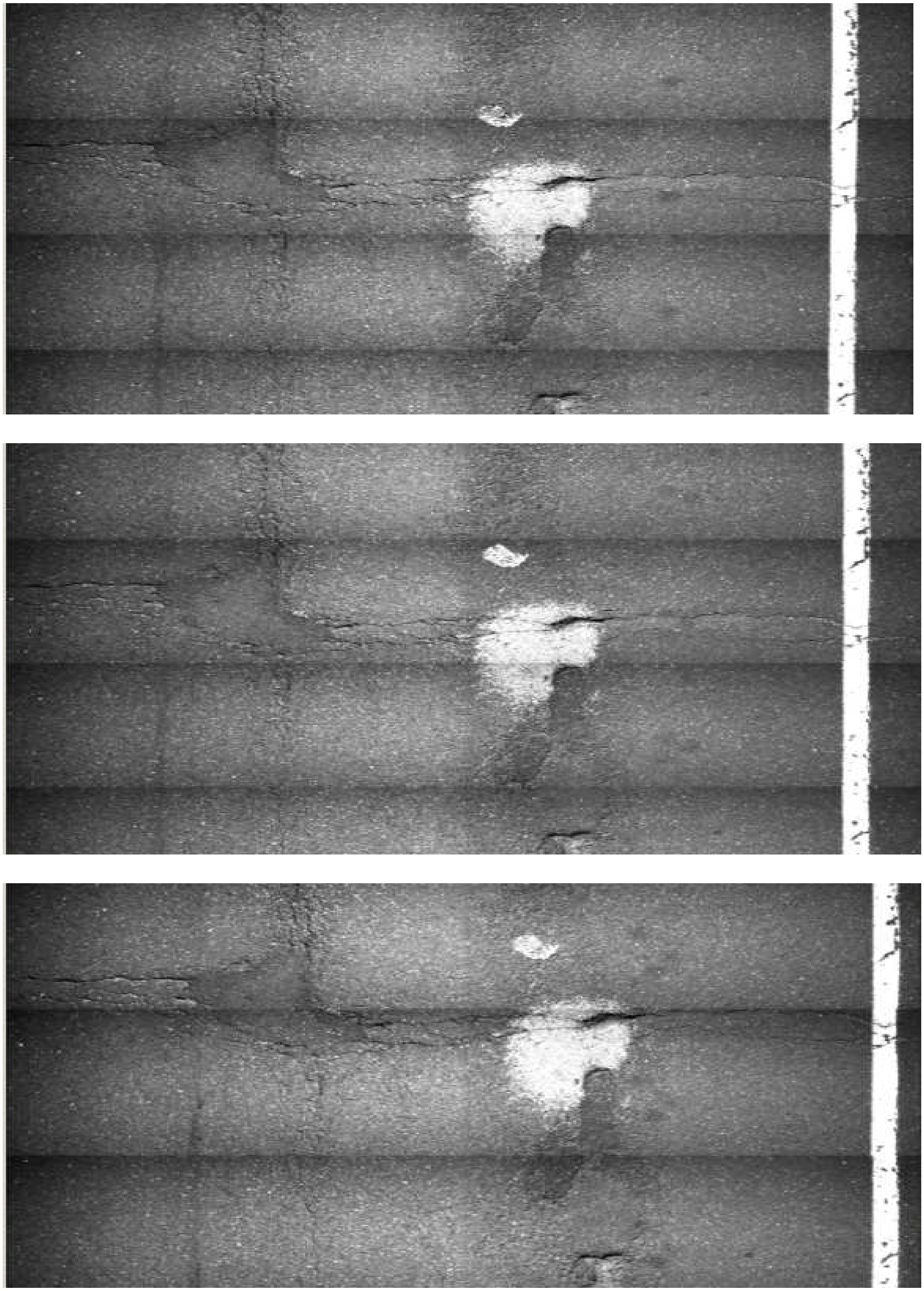


Figure 8. Roadway-Pavement images – AM, Midday, and PM

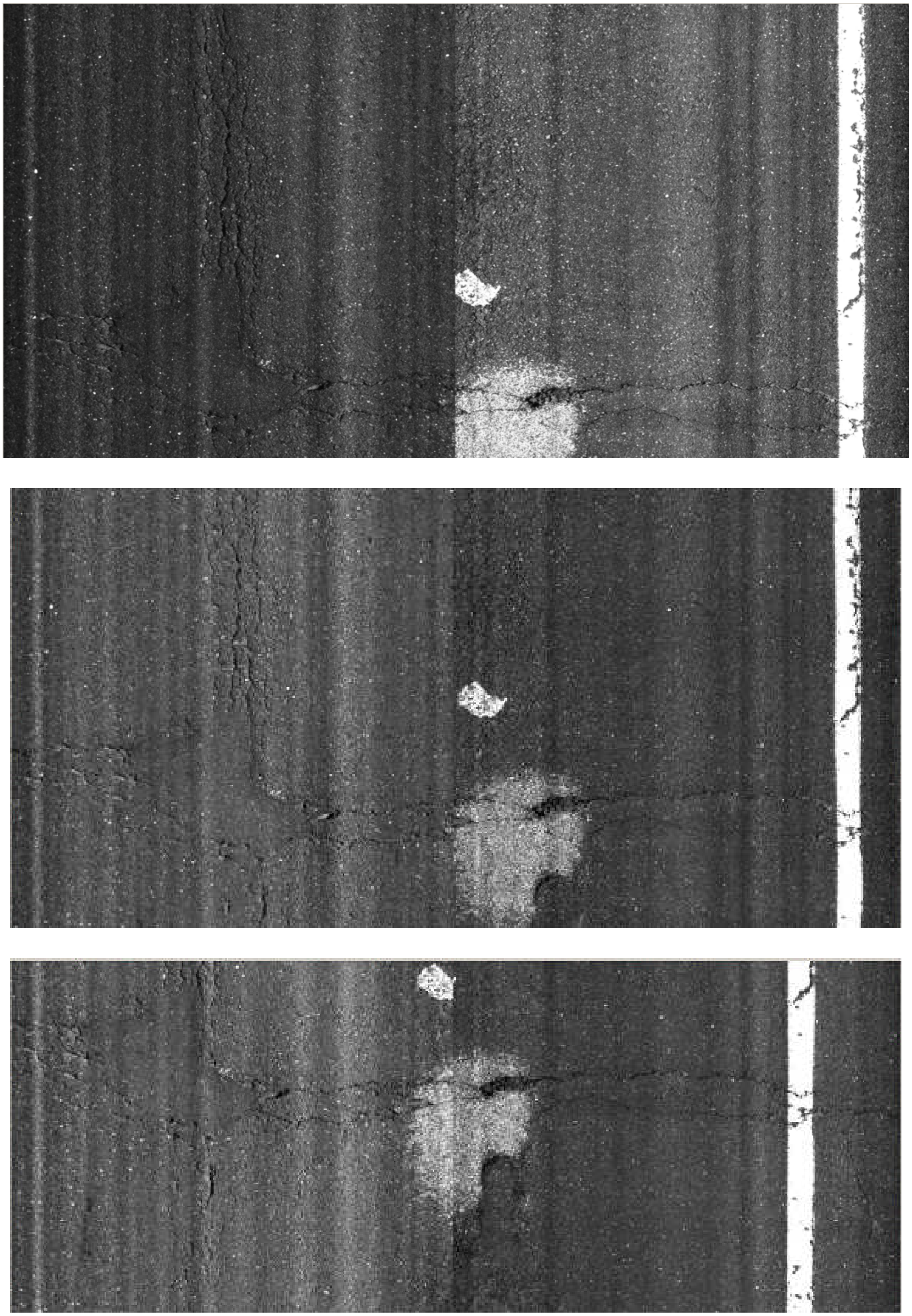


Figure 9. Dynatest-Waylink- Pavement images – AM, Midday, and PM

The downward-looking cameras provided a detailed crack maps that can be used by the PMS staff and pavement designer to refine the cracking distress rating and the treatment selection. The images in Figures 8 and 9 provide examples of the crack image maps.

Image Data Analyses - Crack Characterization

The ARAN area-scan images were brought to the office for crack characterization through image processing. The Wisecrax crack characterization software analyzed the images to identify cracking. The semi-automated crack characterization was reviewed by Roadware staff to identify any false crack characterization and adjustments were made to the crack summary.

The Wisecrax crack characterization software is not able to identify cracks on concrete pavements. Roadware chose to use their manual pavement condition software, DV-rate, to assess the pavement condition on the reinforced concrete pavement test sections. Since the NJDOT goal was to evaluate full automation for crack characterization, they chose to eliminate the two reinforced concrete pavement test section (site 2 and 3) from further consideration. The crack summary provided summations of crack lengths and crack counts for each subsection.

The Dynatest line scan images were brought back to the office for crack characterization. The Dynatest automated crack characterization software (Waylink ADA) can rate the pavement crack condition on HMA and Portland Cement concrete pavement surfaces while the van is collecting images data, but this feature was not used by the Dynatest crew. The crack analysis provided summations of crack lengths and crack counts for each 52.8 foot subsection of the raw data based on totally automated analyses from the Waylink ADA software. This summary was not adjusted by office review to better assess the capabilities of the ADA software.

At the request of the Rutgers-CAIT research team, a separate crack analysis was provided by Dynatest raters in the office based on a manual evaluation of the downward camera images. The ADA software was not used for this analysis. This analysis was conducted to provide NJDOT with information on conducting a manual survey from video images in the office.

Both vendors provided raw images, crack maps and tabular summaries of the analysis results to the research team and the NJDOT PMS staff for comparison with the previously conducted benchmark distress data collection and manual distress data collection. Each vendor made a presentation to the research team and NJDOT

PMS staff summarizing the data collection and analysis results.

Crack Data Summary Analyses

The research team conducted a graphical and statistical analyses of the repeatability of the severity and extent levels of the crack distress data capabilities and limitations of the automated distress data collection equipment, computerized analysis tools compared to those of the NJDOT current manual distress data collection and analysis protocols.

NJDOT uses a surface distress index which accounts for the presence and severity levels of each crack type for each 52.5 foot pavement section. The cracks are rated at the highest severity level. The extent is calculated based on the number of 52.8 foot sections in the 528 foot (0.1 mile) test section that exhibits a given level of severity for each distress type. To compare the crack data from the NJDOT with that of the vendors, all data was converted to a Surface Distress Index (SDI) using the current NJDOT procedure. Only the Non-load associated distress index (NDI) was used for the comparison.

Figures 10-21 provides a visual comparison of the multiple runs from the NJDOT and vendor equipment and analyses.

Site 1 was a new pavement. This site was included to determine if the vendor’s system and analysis would detect “cracks” in the new pavement.

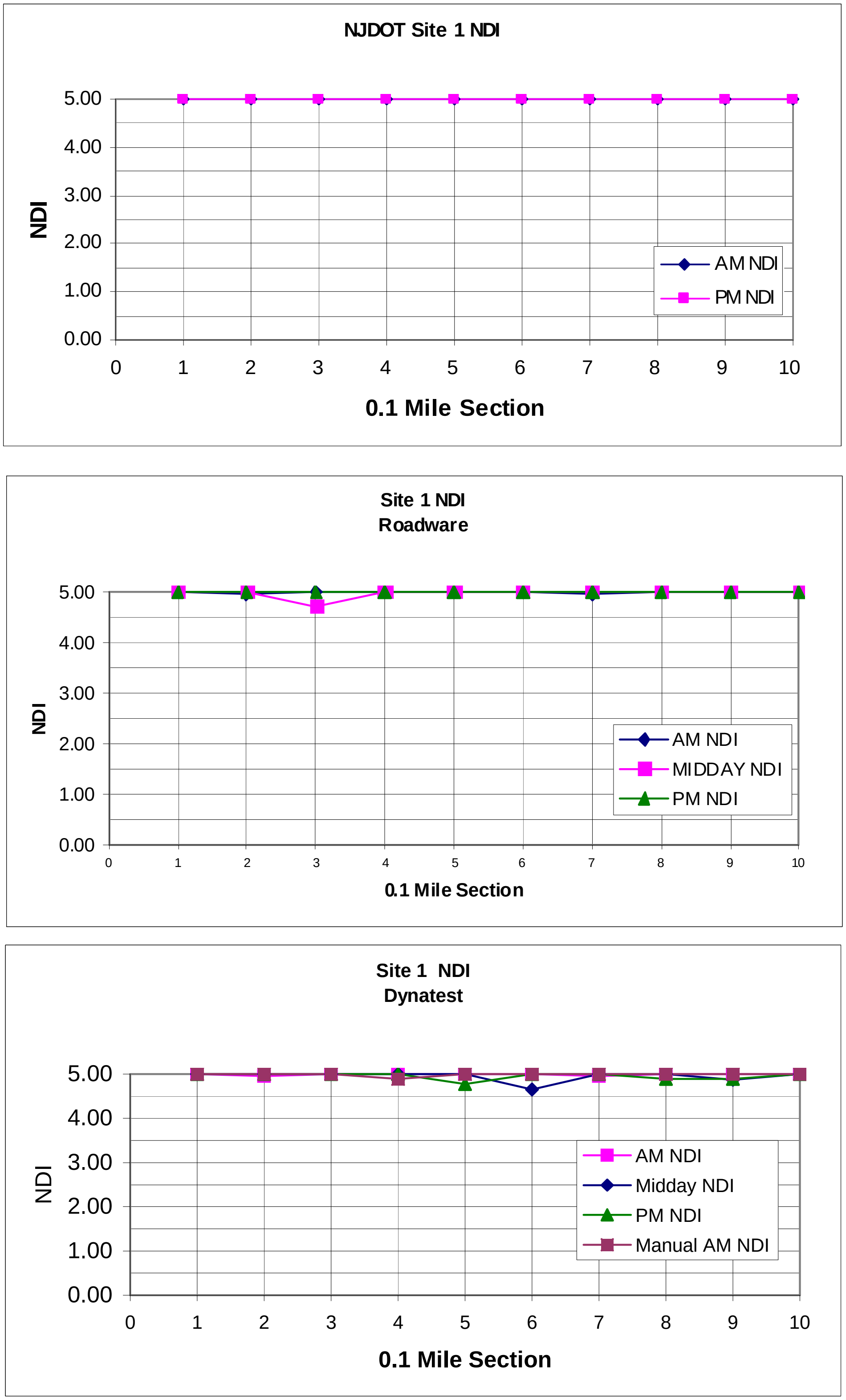


Figure 10. Site 1 Comparison of NDI

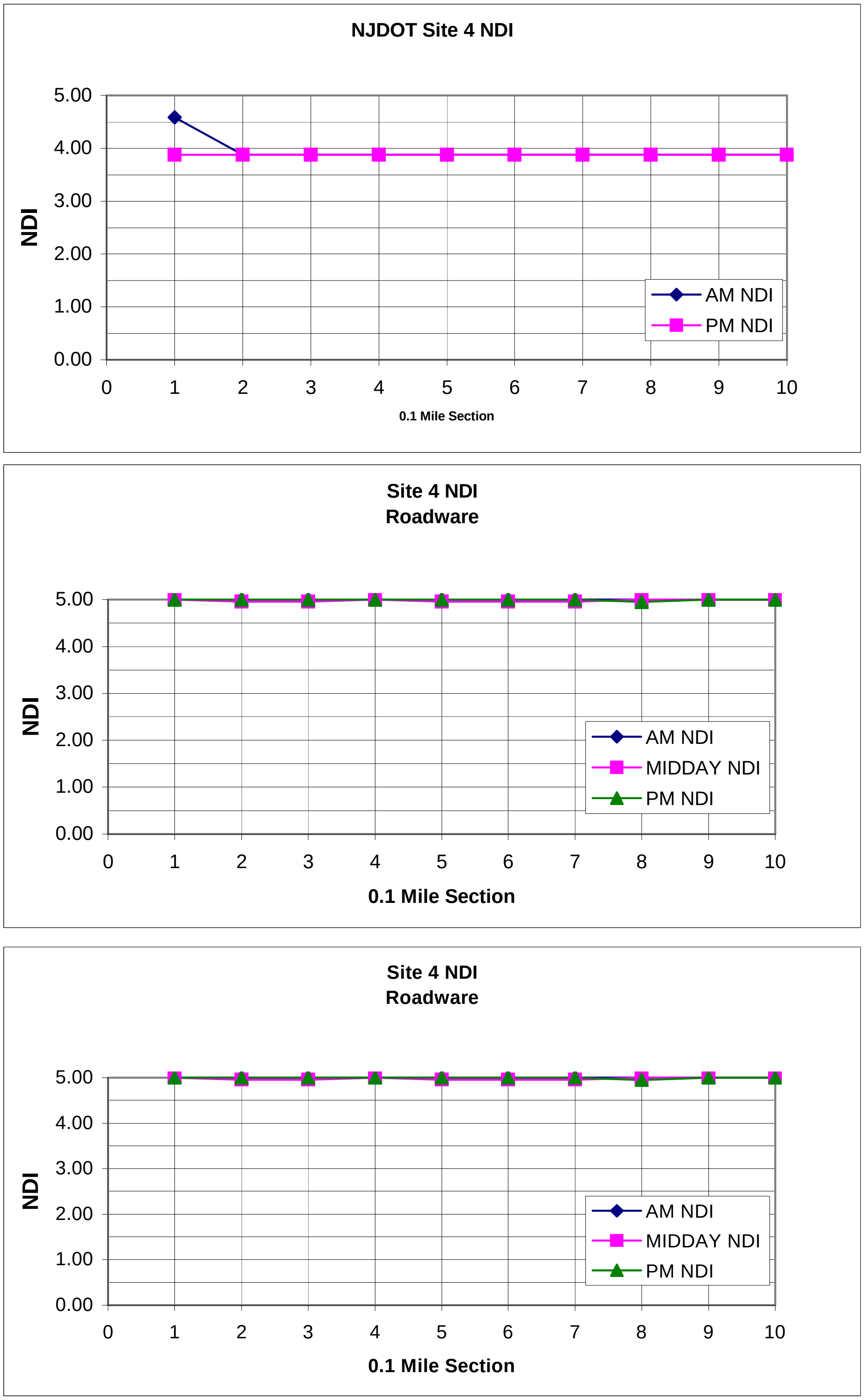


FIGURE 11. Site 4 Comparison of NDI

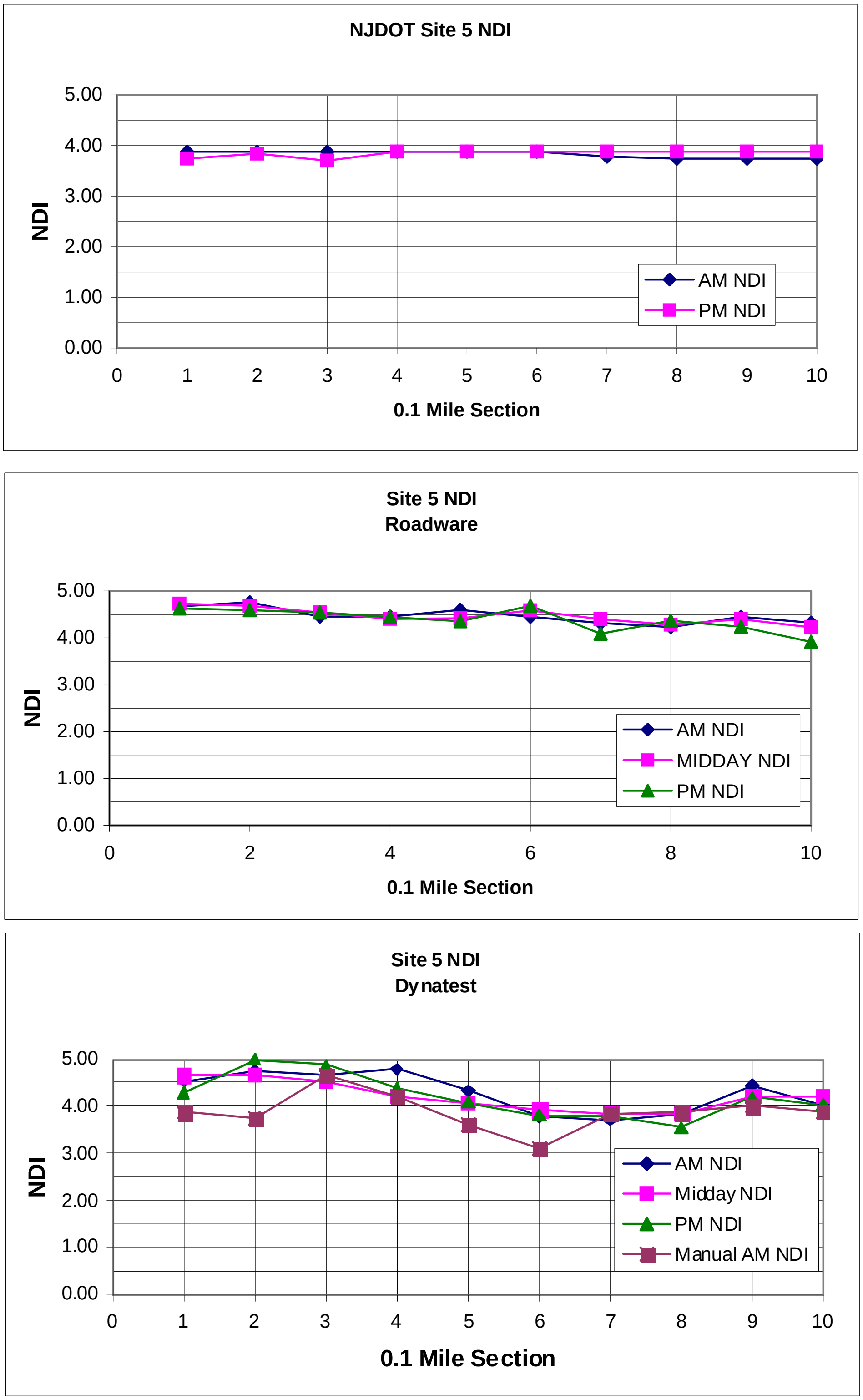


FIGURE 12. Site 5 Comparison of NDI

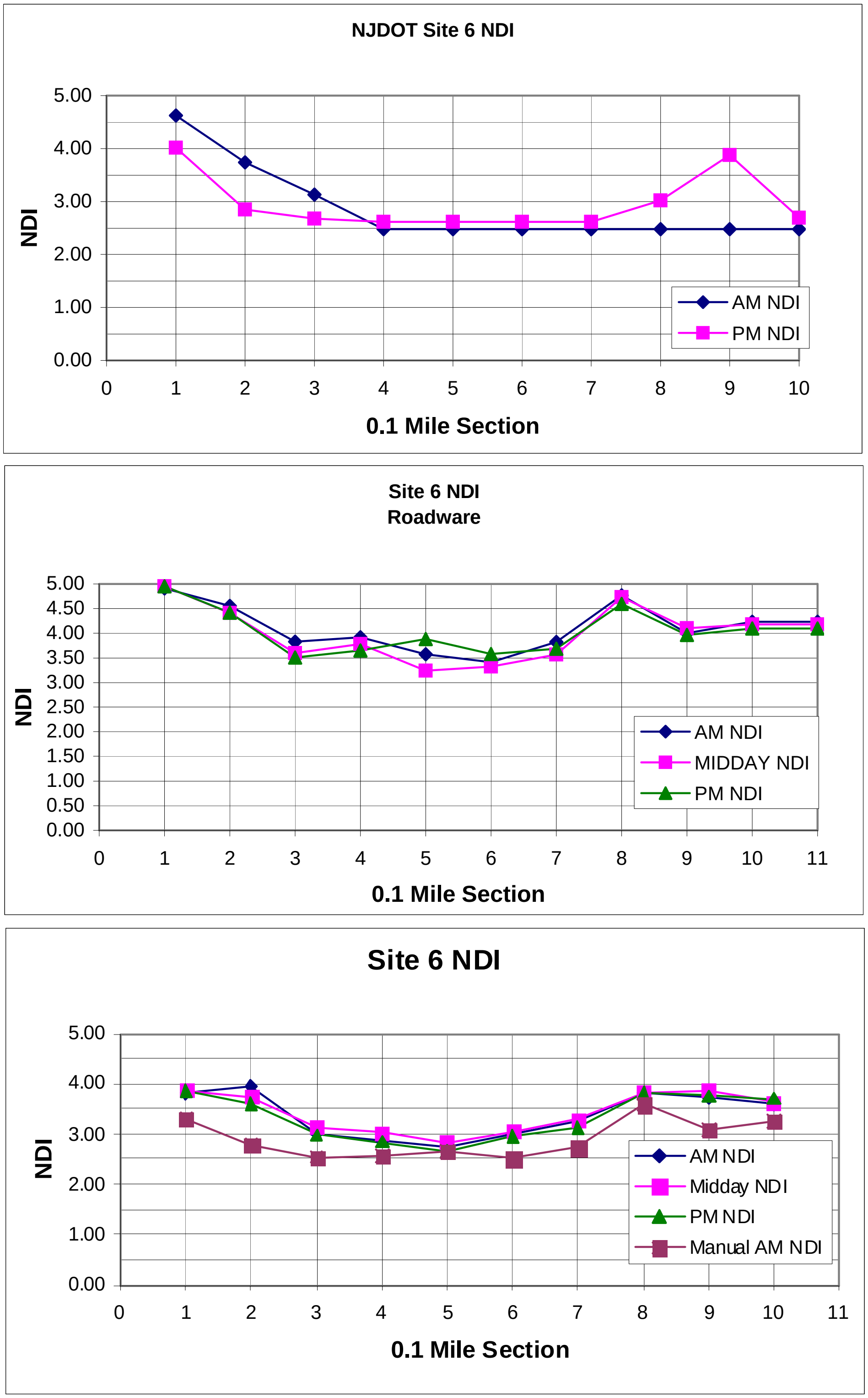


FIGURE 13. Site 6 Comparison of NDI

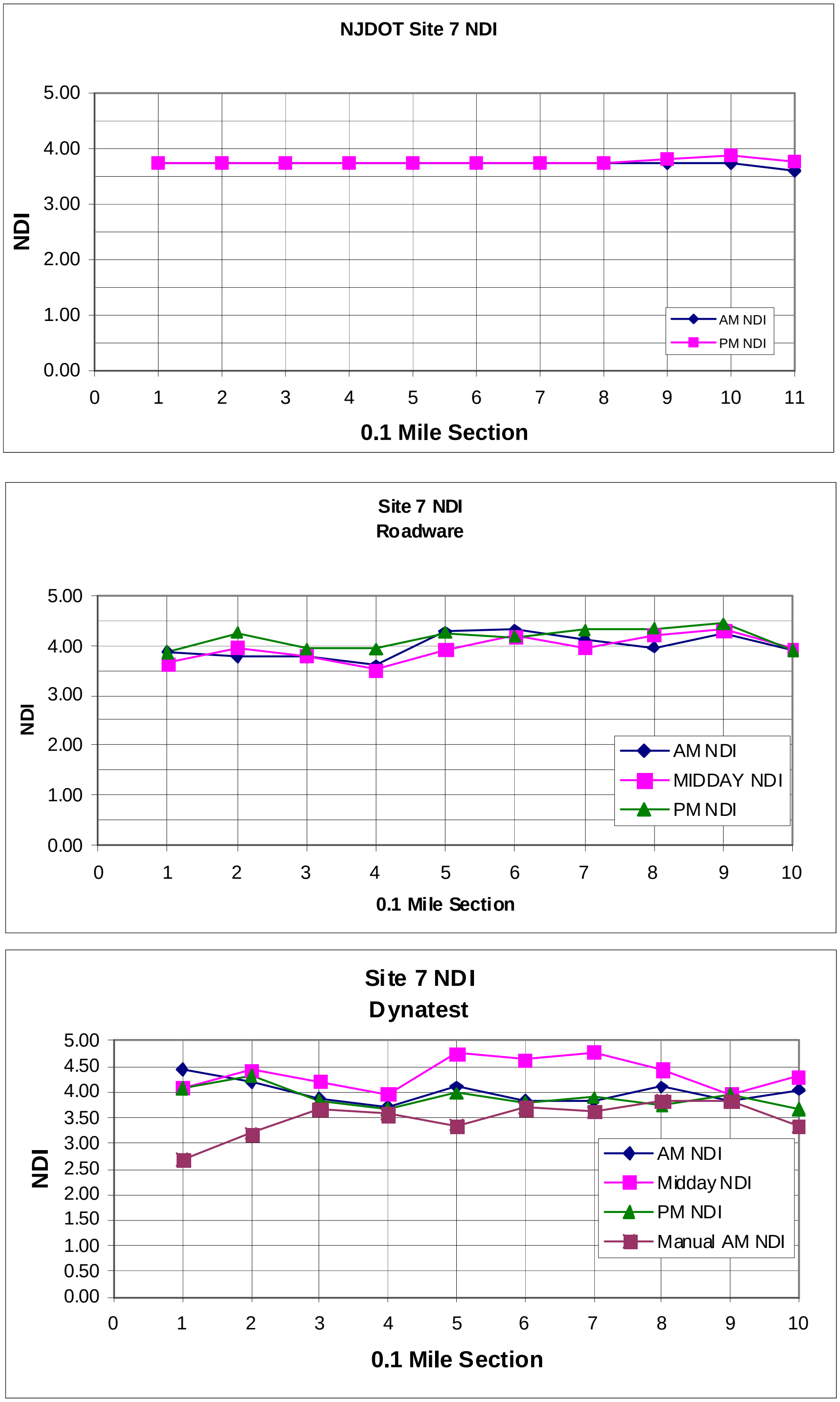


FIGURE 14. Site 7 Comparison of NDI

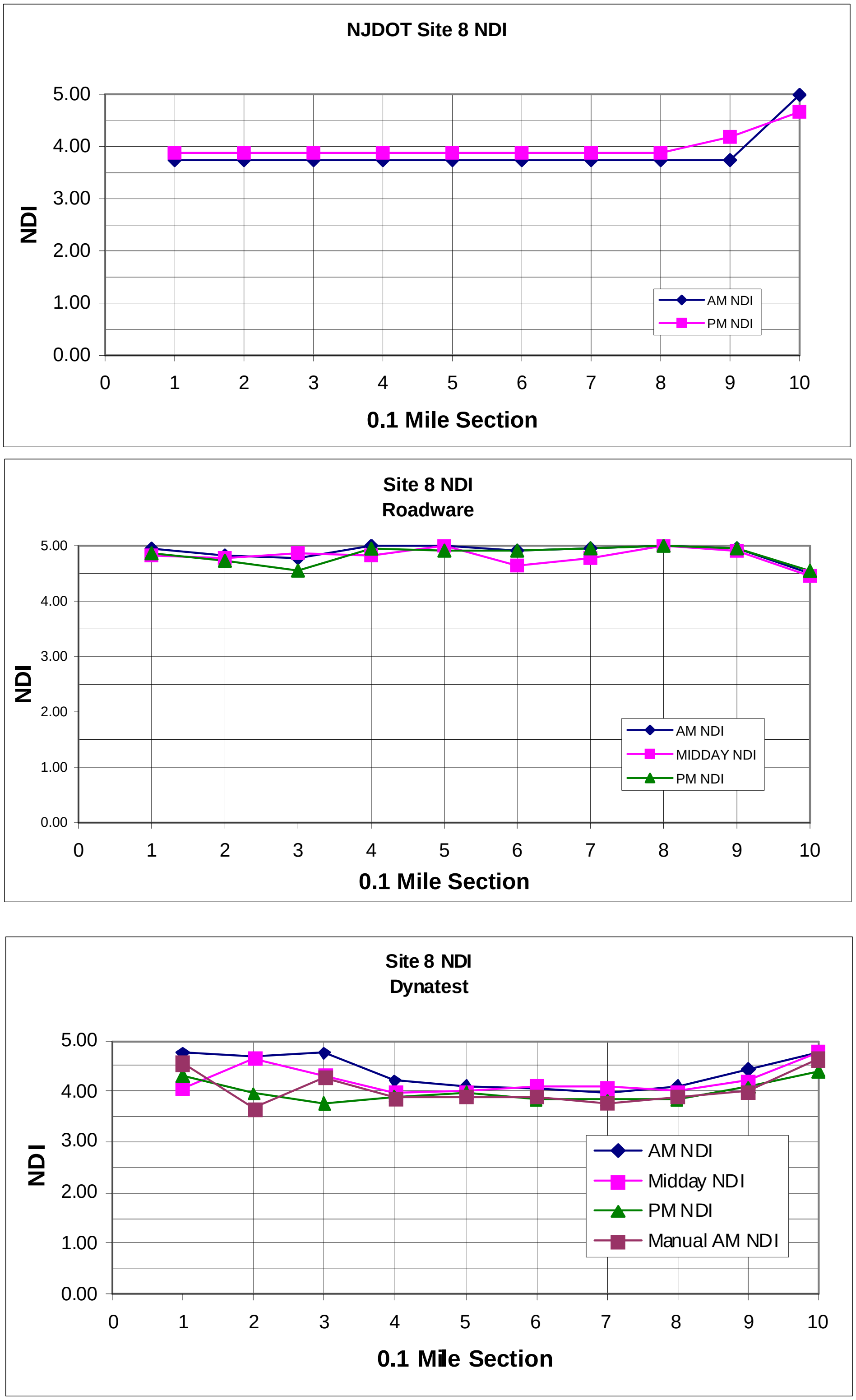
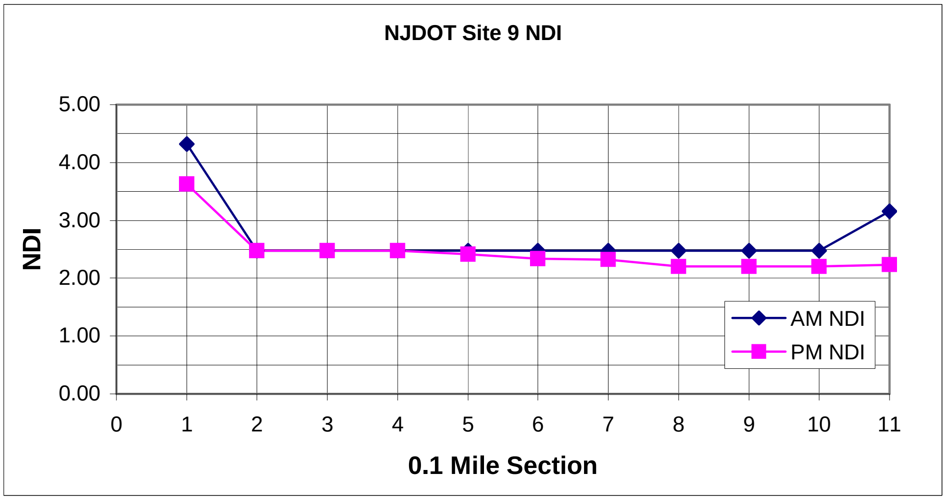
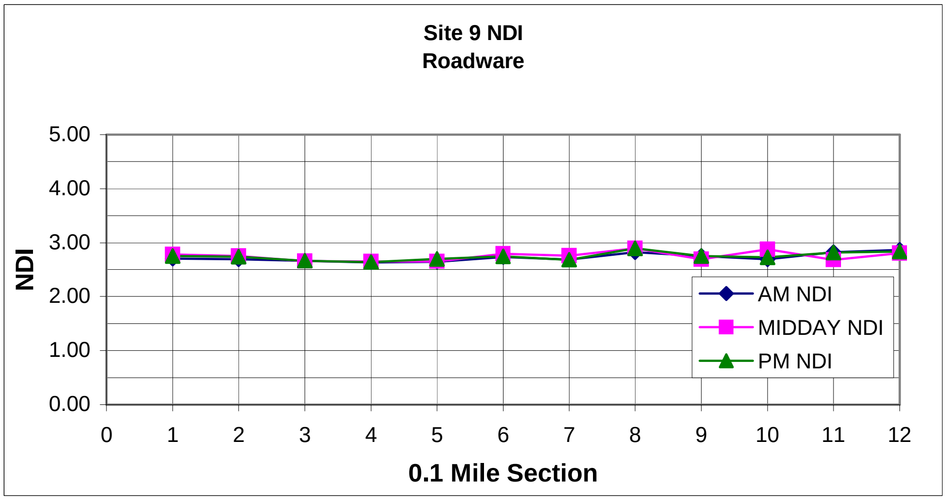


FIGURE 15. Site 8 Comparison of NDI





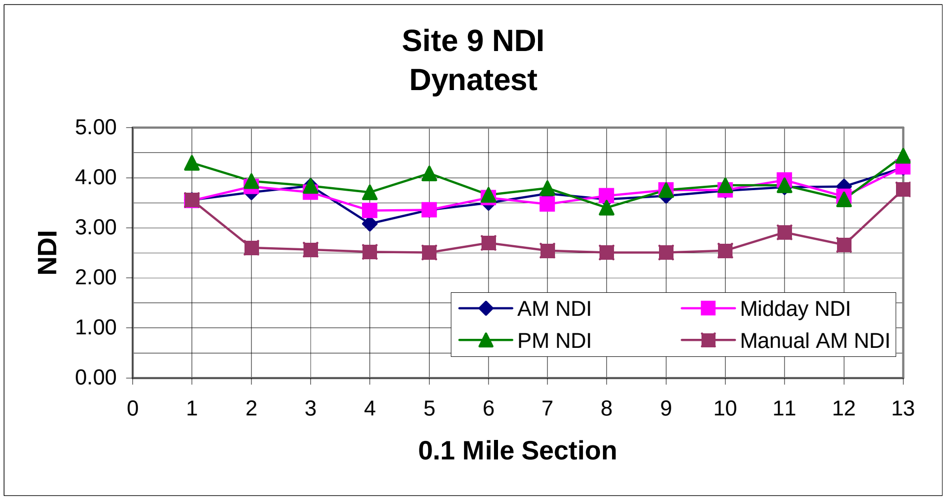


FIGURE 16. Site 9 Comparison of NDI

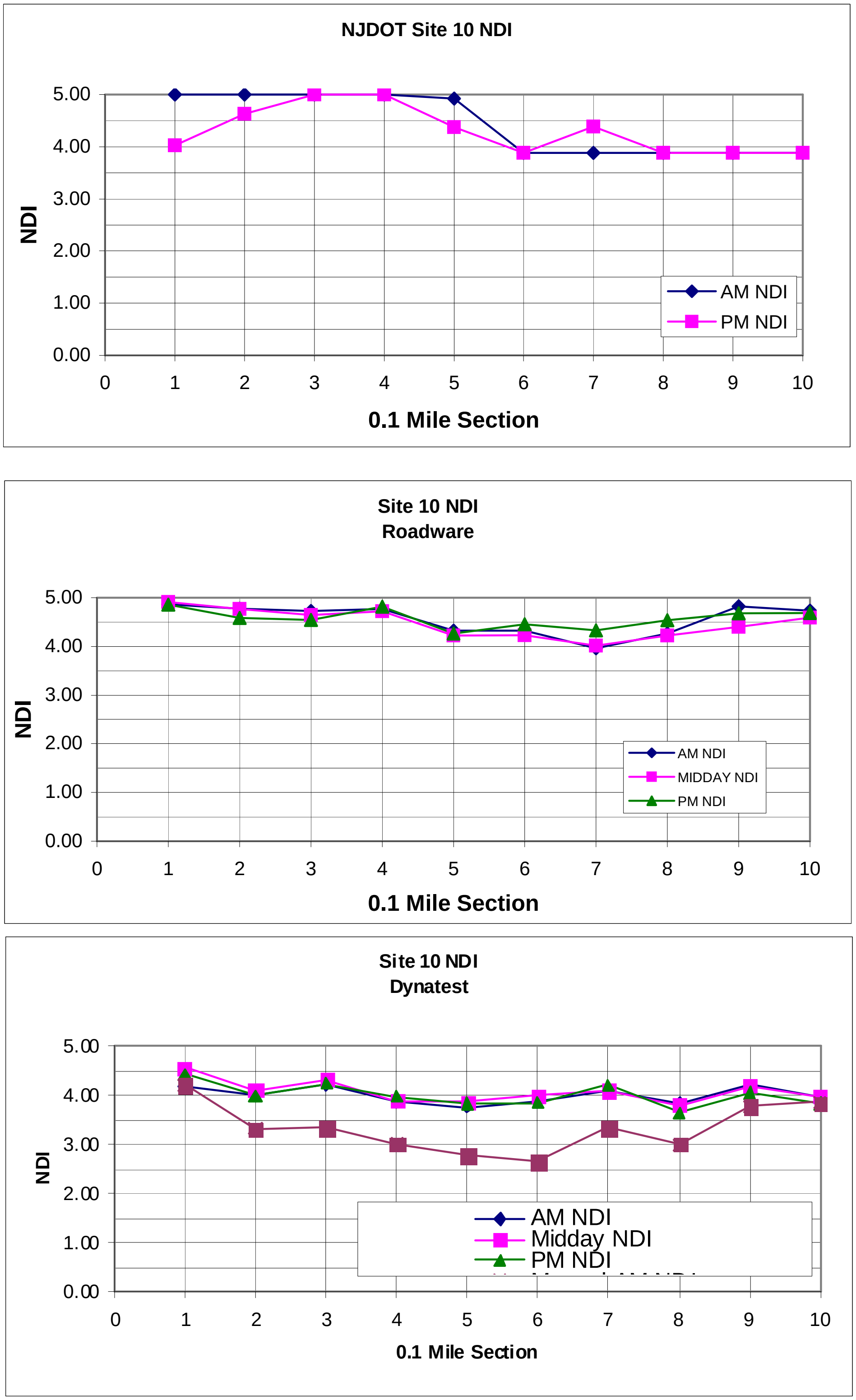


FIGURE 17. Site 10 Comparison of NDI

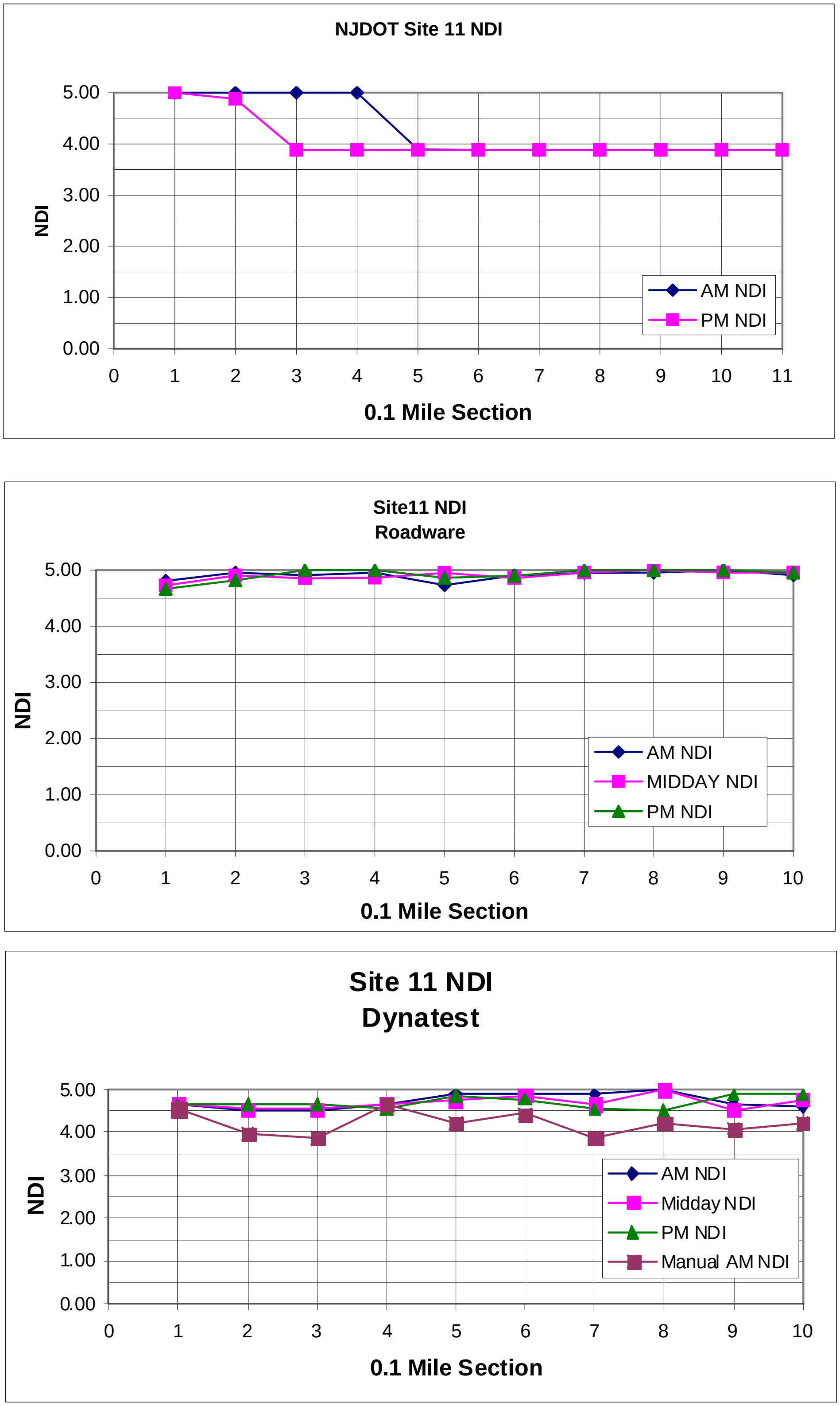


FIGURE 18. Site 11 Comparison of NDI

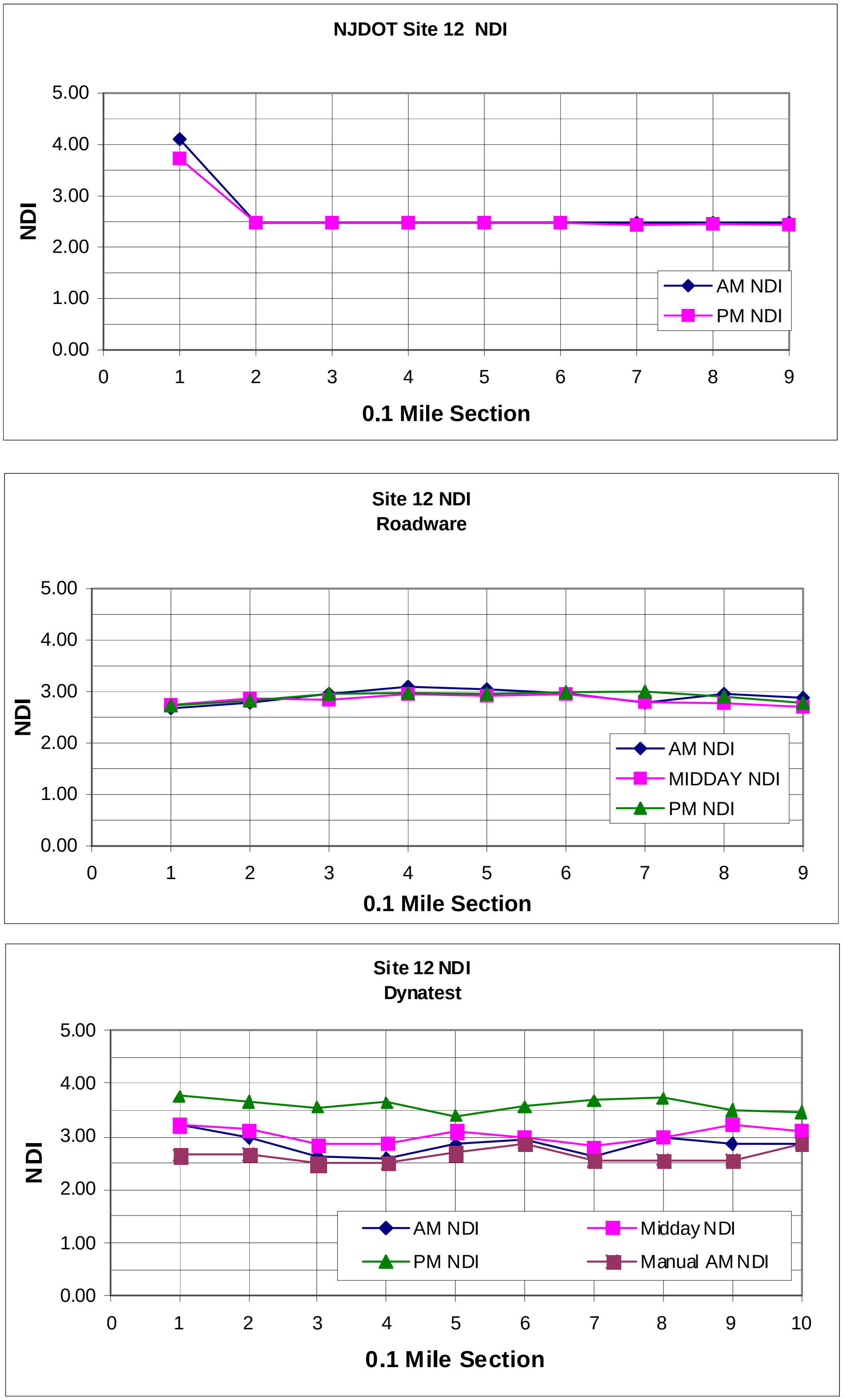


FIGURE 19. Site 12 Comparison of NDI

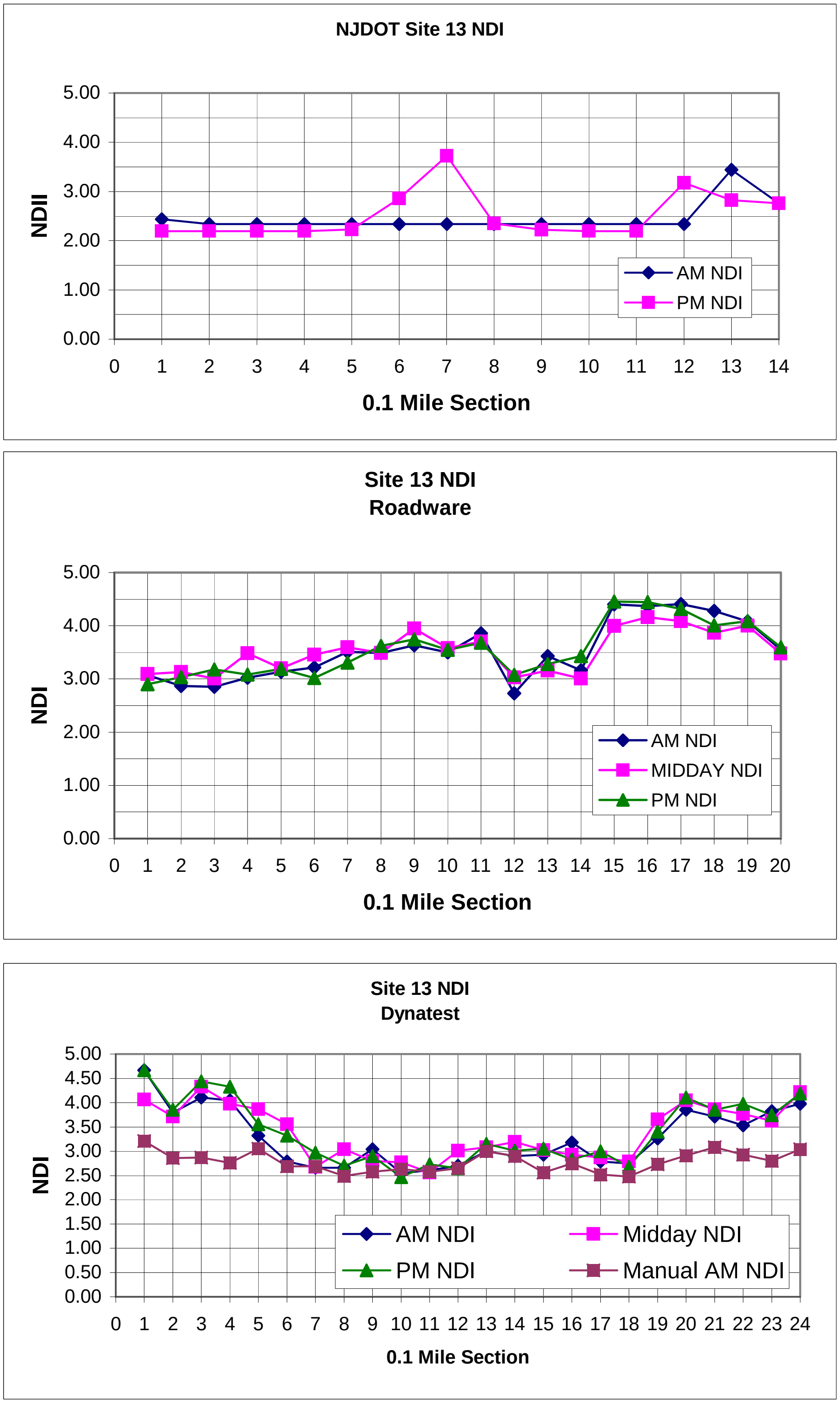


FIGURE 20. Site 13 Comparison of NDI

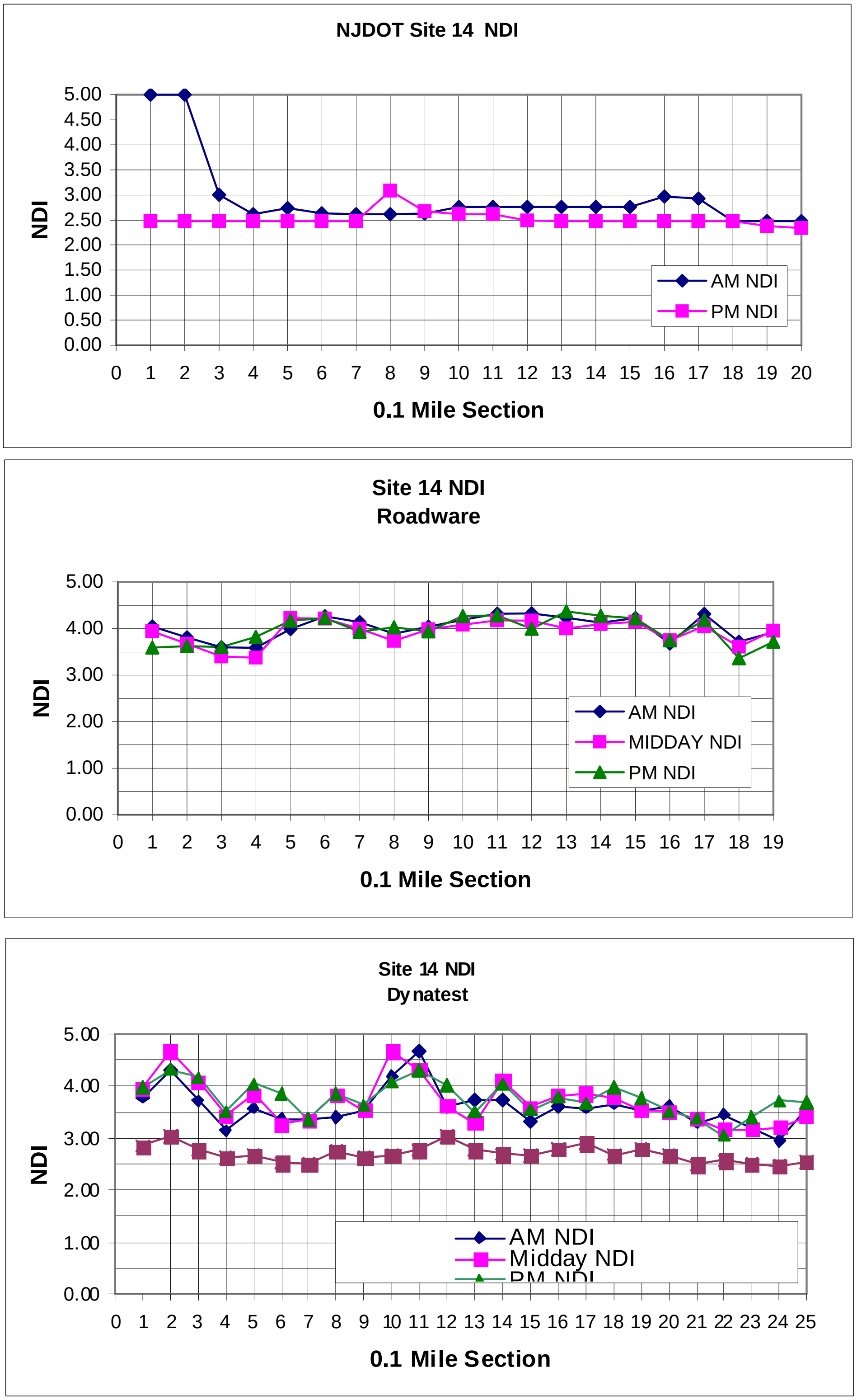


FIGURE 21. Site 14 Comparison of NDI

Statistical Analysis

These sections use a statistical tool to evaluate the repeatability of the equipment and software based on analysis of NDI and the effect of the repeatability of the data on the Service Life calculations. The tables and figures provide a summary of the statistical results.

Impact of Equipment and Time of Testing on NDI By Test Section

Pair-wise statistical analyses were performed to evaluate the significance of the difference between pairs of devices/time of testing by comparing the NDI of different pairs of devices/runs for all test sections. In this analysis, the difference of pairs of data points are evaluated to determine if the difference is statistically significance based on the following:

Hypothesis (H_o):	The difference between pair of NDI values for the same 0.1 mile section of the test site is not significant
Type of Measurements	NDI per 0.1 mile – Analyses are performed on the difference between the measurements of the pair of devices/tests
Statistical Test:	Two-Sided T-Tests with a 90% confidence level

The pairs of data evaluated for each test site included:

Table 5. Statistical Test Pairs

Statistical Test Number	Data Sets	
S1	Dynatest AM	Dynatest Midday
S2	Dynatest AM	Dynatest PM
S3	Dynatest Midday	Dynatest PM
S4	Roadware AM	Roadware Midday
S5	Roadware AM	Roadware PM
S6	Roadware Midday	Roadware PM
S7	Dynatest Manual	Dynatest AM
S8	NJDOT AM	NJDOT PM
S9	NJDOT AM	Dynatest Manual

The pairs evaluated were based on the type of data collection and analysis used to determine the NDI values. The Dynatest AM, Midday and PM data were raw data files directly from the Dynatest Profiler and processed from the ADA software with no quality control. The Dynatest Manual data was determined from manual rating of the videos without the use of ADA software. The Roadware AM, Midday, and PM data were data files collected with the ARAN Profiler, processed with the Wisecrax software, and followed by quality control checks and modification of the output.

Table 6 provides a summary of the statistical analysis results for NDI for each site. As can be seen from the table, the conclusions of the statistical analysis vary significantly among test sections. For example, Sites 1, 4, 5, 6, 11, and 13, the results of all combinations of devices/time of testing indicated that the differences among devices/time of testing are not significant (conclude Ho for all of the cases). However, for Sites 7, 8, 9, 10, 12, and 14, the majority of the combinations of devices/time of testing indicated that the differences among devices/time of testing are significant. Table 7 provides a summary for each vendor and NJDOT as well as a comparison for the manual rating with Dynatest Raw analysis and the manual rating with NJDOT rating.

Table 6. Statistical Summary for NDI for Each Site

	Test Site																							
Statistical Case	**1**		**4**		**5**		**6**		**7**		**8**		**9**		**10**		**11**		**12**		**13**		**14**	
	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1
Dynatest AM Dynatest Midday	1		1		1		1			1		1	1			1	1			1	1			1
Dynatest AM Dynatest PM	1			1	1		1			1		1		1	1		1			1		1		1
Dynatest Midday Dynatest PM	1			1	1			1		1		1		1		1	1			1	1		1	
Roadware AM Roadware Midday	1			1	1			1	1			1		1		1	1			1	1			1
Roadware AM Roadware PM	1		1		1		1			1		1		1	1		1		1		1		1	
Roadware Midday Roadware PM	1		1		1		1			1	1		1			1	1			1	1		1	
NJDOT AM NJDOT PM	1		1		1		1		1			1		1	1		1		1		1			1
Dynatest Manual Dynatest AM	1		1			1		1		1		1		1		1		1		1		1		1
NJDOT AM Dynatest Manual	1			1	1		1			1	1		1			1	1		1			1	1	
Total	9	0	5	4	8	1	6	3	2	7	2	7	3	6	3	6	8	1	3	6	6	3	4	5
Percentage	100	0	56	44	89	11	67	33	22	78	22	78	33	67	33	67	89	11	33	67	67	33	44	56

Table 7. Summary of the Statistical Analysis for NDI for All Sites

Dynatest		
Ho	17	47%
H1	19	53%
Roadware		
Ho	23	64%
H1	13	36%
NJDOT		
Ho	9	75%
H1	3	25%
Manual/Dyn AM		
Ho	2	17%
H1	10	83%
Manual/NJDOT AM		
Ho	8	67%
H1	4	33%
Overall		
Ho	**59**	**55%**
H1	**49**	**45%**

By comparing the Dynatest Raw percentages with that of Roadware and the manual Dynatest percentages, the need for quality control checks of the data is emphasized. The missing transverse cracks significantly affected the overall statistical analysis for the Dynatest-ADA.

The differences between the NJDOT AM and PM were not significantly different 75% of the time. While this is a very good percentage, most sites had very little variation in NDI readings over the mile long site.

Impact of Equipment and Time of Testing on Expected Remaining Service Life By Test Section

Since one of the important applications of NDI is used in is the estimation of the Remaining Service Lives (RSL) of different sections, and prioritizes them, selecting optimum timing and treatments…etc., it is very beneficial to evaluate the impact of type of equipment and time of testing on the expected remaining service lives of different sections. In other words, evaluation of the impact of type of equipment and time of testing will be performed at the outcomes level rather than the input level.

The NDI for each 0.1 mile section is used to estimating the remaining service life until it reaches a trigger of 3 for each pair (for Dynatest AM-Dynatest Midday). The difference in RSL is analyzed in the same statistical fashion to determine if the difference between the RSL of the pair is statistically significant.

A typical NDI service life model was used to convert the NDI values calculated from all equipment runs and test section to corresponding service life. An assumption is made that pavements will be triggered at NDI 3.0. Figure 22 shows the NDI – Remaining Service Life Model used in the analysis.

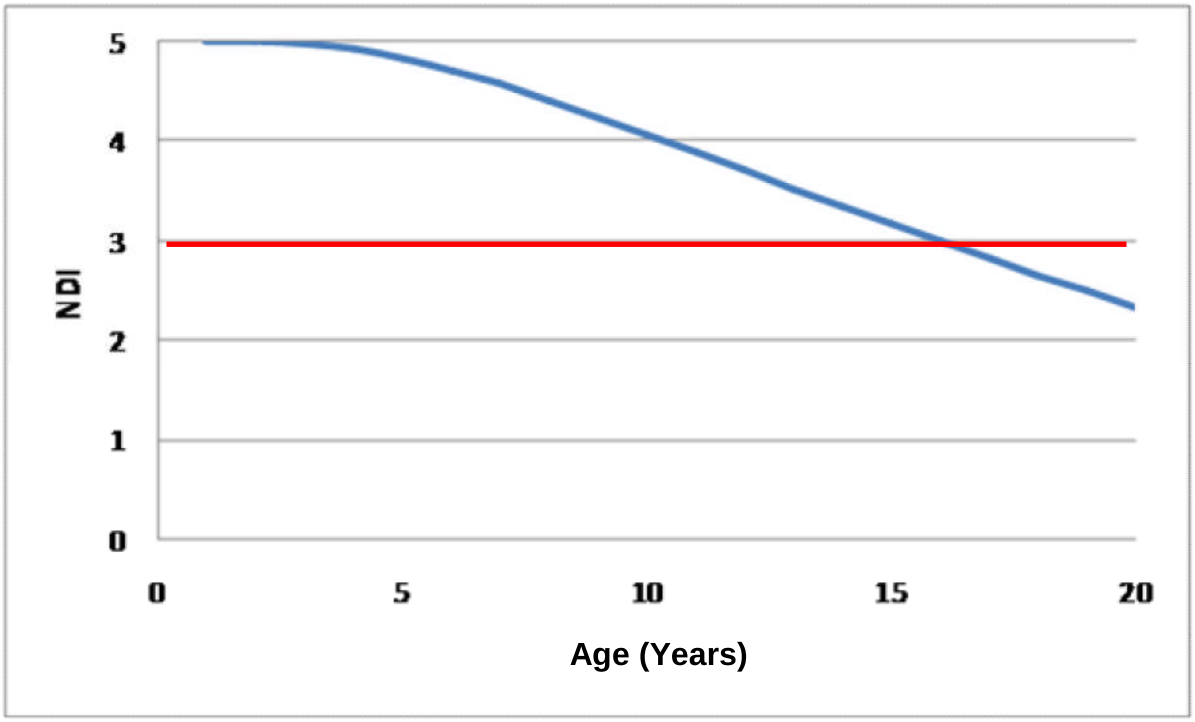


Figure 22 NDI – Service Life Model

Similar to the analysis performed on NDI, pair-wise statistical analyses were performed to evaluate the significance of the difference between pairs of devices/time of testing by comparing the expected service life of different pairs of devices/runs for all test sections. In this analysis, pairs of data points are evaluated based on the following:

Hypothesis: No significant difference between the service life estimated based on the measurements of the two devices/tests for all test sections.

Type of Measurements Service life per 0.1 mile – Analyses are performed on the difference between the measurements of the pair of devices/tests.

Statistical Test: Two-Sided T-Tests with a 90% confidence level.

Table 8 provides a summary of the statistical analysis results for RL for each site. As seen from the table, the conclusions of the statistical analysis vary significantly among test sections. For example, Sites 1, 4, 5, 6, 9, 10, 11, 12, 13, and 14, the results of all combinations of devices/time of testing indicated that the differences among devices/time of testing are not significant (conclude Ho for all of the cases). However, for Sites 7 and 8, the majority of the combinations of devices/time of testing indicated that the differences among devices/time of testing are significant. Table 9 provides a summary for each vendor and NJDOT as well as a comparison for the manual rating with Dynatest Raw analysis and the manual rating with NJDOT rating.

Table 8. Statistical Summary for RL for Each Site

	Test Site																							
Statistical Case	**1**		**4**		**5**		**6**		**7**		**8**		**9**		**10**		**11**		**12**		**13**		**14**	
	H_o	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**	**H_o**	**H_1**
Dynatest AM Dynatest Midday	1		1		1		1			1		1	1		1		1			1	1		1	
Dynatest AM Dynatest PM	1			1	1		1		1			1		1	1		1			1		1	1	
Dynatest Midday Dynatest PM	1			1	1			1		1		1		1		1	1			1	1		1	
Roadware AM Roadware Midday	1			1	1		1		1			1	1		1		1		1			1		1
Roadware AM Roadware PM	1		1		1		1			1		1	1		1		1		1		1		1	
Roadware Midday Roadware PM	1		1		1		1			1	1		1		1		1		1		1		1	
NJDOT AM NJDOT PM	1		1		1		1		1		1		1		1		1		1		1		1	
Dynatest Manual Dynatest AM	1		1			1		1		1		1		1		1		1	1		.	1		1
NJDOT AM Dynatest Manual	1			1	1		1			1	1		1			1	1		1		1		1	
Total	9	0	5	4	8	1	7	2	3	6	3	6	6	3	6	3	8	1	6	3	6	3	7	2
Percentage	100	0	56	44	89	11	78	22	33	67	33	67	67	33	67	33	89	11	67	33	67	33	78	22

Table 9. Summary of the Statistical Analysis for RSL for All Sites

Dynatest		
Ho	21	58 %
H1	15	42 %
Roadware		
Ho	29	81 %
H1	7	19 %
NJDOT		
Ho	12	100 %
H1	0	0 %
Manual/Dyn AM		
Ho	3	25 %
H1	9	75 %
Manual/NJDOT AM		
Ho	9	75 %
H1	3	25 %
Overall		
Ho	**74**	**69 %**
H1	**34**	**31 %**

CONCLUSIONS AND RECOMMENDATIONS

This research study illustrated the abilities and limitations of the Automated Distress Survey Equipment and software to collect, characterize and analyze pavement cracking distresses under different lighting conditions. The study also assessed the NJDOT's profiler crew in evaluating these same sections.

The analysis used graphical comparisons and statistical analyses to make assessments of repeatability of multiple test runs under different lighting conditions and different degrees of data processing.

Based on the analysis, the Automated Distress Survey Equipment can be used to collect cracking distress data <u>with quality control checks</u> to ensure that the cracking data collected, characterized, and analyzed is accurate. NJDOT needs to work with the vendor to refine the data collection and analysis procedures to differentiate the location of cracking (within and outside of the wheel paths).

The use of this technology can free up the pavement condition rater in the van to concentrate on other type of distresses such as shoulder condition, patch condition, and assessment of adjacent lanes.

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