# Table of Contents

Acknowledgement .................................................................................. i
Equipment Vendors ................................................................................ ii
Introduction ............................................................................................. 1
Purpose .................................................................................................... 1
Scope ........................................................................................................ 2
Test Dates, Sites, and Weather Conditions ............................................. 3
Project Sections Description .................................................................. 4
Manual Rating Procedures ..................................................................... 5
Equipment Descriptions ......................................................................... 5
Data Reduction Speed ............................................................................ 9
Results of Data Comparison ................................................................. 9
Results ..................................................................................................... 10
Data Collection and Processing ............................................................. 10
Simulated Cracking ................................................................................ 11
Concluding Remark ............................................................................... 11
Future Testing ........................................................................................ 11

TABLES and CHARTS ............................................................................. 12

APPENDIX A - LTPP and PMIS Comparison ........................................ 13
APPENDIX B - Image Analysis Process ................................................ 14
APPENDIX C - Equipment Description .................................................. 15
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The following are the TWG members for Test and Evaluation Project No. 21:

- Robert Harris - Texas DOT (Project Coordinator)
- Freddie Baker - Maryland DOT
- Doug Bish - Oregon DOT
- G. Norman Clark - Kansas DOT
- Gaylord Cumberledge - Pennsylvania DOT
- Phil Elliot - Virginia DOT
- Mike Farrar - Wyoming DOT
- Wouter Gulden - Georgia DOT
- Dave Huft - South Dakota DOT
- Luis Rodriguez - FHWA (Project Coordinator)
- Bill Bellinger - FHWA
- Frank Botelho - FHWA
- Gary Henderson - FHWA
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- Sonya Hill - FHWA
- Evan Wisniewski - FHWA

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EQUIPMENT VENDORS

The following are the equipment companies that participated in the field test and evaluation:

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Norcross, Georgia 30071
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PASCO USA, Inc.
4913 Gettysburg Road
Mechanicsburg, Pennsylvania 17055
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INTRODUCTION

Pavement Management Systems (PMS) provide information to the pavement engineer to assist not only with funding needs and allocation but also with correct types and timing for pavement related work. One goal of a PMS is to help decision makers utilize their resources as effectively and efficiently as possible. Various PMS's use information differently to meet their users needs. However, the underlying data behind the information is often the same and includes: pavement inventory, pavement structure, pavement age, work history, traffic and pavement condition. Pavement condition includes a pavement's smoothness, structural capacity, skid demand capacity and surface defects. Automated equipment is available to measure roughness, profile, skid resistance and deflection. The equipment most difficult to develop and master is that which can safely, efficiently and objectively collect pavement surface defects known as surface distress.

Surface distress includes cracking, patching, and other surface manifestations detrimental to the pavement's performance or life. These distresses have been difficult to measure using automated equipment. Appendix B provides a short description of some of the problems associated with attempting to fully automate distress rating procedures.

During June 1990, Iowa State University was host to the "Automated Pavement Distress Seminar." This seminar included static equipment demonstrations, equipment data collection and reporting, papers and presentations concerning equipment hardware and software testing. One result of the meeting was a consensus that, while there have been significant improvements, fully automated systems were not yet realized. Since 1990 several vendors have made improvements to the equipment displayed in Iowa. The Iowa demonstration project provided an opportunity for the vendors to display and test their equipment.

PURPOSE

In the last few years, computer and video technology has progressed so that fully automated pavement distress collection and reduction equipment were developed and implemented. This demonstration project tests the equipment to provide information to PMS end users on its ability to collect and categorize data.

The work plan written by the project coordinators and approved by the TWG described the project purpose. The PRIMARY purpose was: "To field test and evaluate pavement distress survey equipment that can measure pavement distresses at highway speeds using 100 percent automated equipment, computers, and analysis packages without human intervention." A SECONDARY purpose was "To field test and evaluate manually assisted equipment." The equipment evaluation was limited to identifying and measuring different pavement "crack" types and their severity levels as defined by the project level, Strategic Highway Research Program (SHRP) - Long Term Pavement Performance (LTPP) "Distress Identification Manual."

Additionally, there is a network level simulation using the Texas Department of Transportation's (TxDOT), "Pavement Management Information System Rater's Manual." This evaluation limited data analysis to crack extent. No severity levels were analyzed.
The report and appendices presents:

1) The scope of the demonstration project.

2) A description of the test sections.

3) The manual data collection and conversion from the TxDOT Pavement Management Information System (PMIS) to LTPP procedures.

4) A description of the data collection equipment and data analysis and reporting equipment.

5) An estimate of the time required to reduce the collected data.

6) Tables and charts comparing results between the manual surveys and the equipment.

SCOPE

The demonstration project limited visual distress measurements to pavement cracking; no other distress types were considered. Besides the time of day, an attempt at estimating influences of different light angles, the demonstration project sections included other variables that might influence data analysis such as changes in pavement color and texture, shadows on the pavement, and marks on the pavement.

The principal cracking distresses measured in this project were:

Flexible Pavements
- Fatigue Cracking - Area & Severity
- Transverse Cracking - Length & Severity
- Longitudinal Cracking - Wheelpath, Non-Wheelpath, Length & Severity
- Edge Cracking, Length & Severity

Rigid Pavements
- Transverse Cracking - Number, Length & Severity
- Longitudinal Cracking - Length & Severity

"Simulated cracks" were painted at the end of a pavement section and measured with all equipment at the test speed to estimate the equipment's camera(s) resolution. The section on page 11 describes the simulated cracking in more detail.

The test included seven sections two kilometers to fifteen kilometers long simulating network level data collection. The manual, network level cracking survey simulation used the Texas Pavement Management Information System's (PMIS), "Visual Distress Rater's Manual." TxDOT conducted the PMIS Visual Evaluation with a TxDOT visual evaluation trainer. The project team modified the PMIS procedure to make it more compatible with data collected by the data collection equipment and reported in LTPP format. The network level comparison is given the reader an understanding of how well the equipment performs for pavement management system use while the LTPP procedure is more detailed and describes the equipment's use for project level or research project use.

Within the seven network simulation sections ten 150-meter segments were chosen for the LTPP distress rating procedure and randomly located throughout the network level simulations. A four member rater team supplied by the Federal Highway Administration (FHWA), including an LTPP instructor, rated the sections on a two day trip to Austin and Waco. Test site locations remained unpublished until the first day of the test.

The TWG members rotated through the vehicles during data collection. The TWG members were to note any discrepancies between reported data collection procedures and actual data collection. Data collection speed for the test was set at 80 km/h (50 mph) with the observers ensuring that the speed did not vary more than ± 8 km/h (5 mph) during the test. Observers also watched
the approximate wheelpath.

Vendors with fully automated equipment processed their data during their stay in Texas. TxDOT and the TWG observed the data reduction procedures to ensure that the ratings were truly automated. The observers commented on the functional steps for data reduction and estimated the data reduction speed. Problems observed during data reduction such as locating sections on video, computer lock up, incorrect crack identification, number of passes to successfully rate a section, etc. were noted.

Arrangements with TxDOT and the fully automated vendors provided for data submission to TxDOT after the test was completed. Both IMS and Roadware submitted some data after the test. The IMS data was originally processed in Austin and intentionally withheld. They were concerned about the data from two sections. After reviewing the data, they determined that it was acceptable to them and asked that it be included. This data was added a week later at their request. IMS met their obligation of two passes for each test time as requested in the original work plan, see the section on page 11 for more information. The additional data was from passes made in Waco demonstrating data collection to the TWG.

Roadware had problems processing the asphalt pavement surfaces and submitted three passes of section D by the December 19 deadline as offered to the manually rated systems below.

Vendors with manually assisted equipment were provided a list of sections to rate while in Austin. They were then provided the option to rate all sections in their home offices. One condition of this was that all data was to be in Austin one month after completion of the test.

TEST DATES, SITES, AND WEATHER CONDITIONS

The field tests and data reduction were conducted in Austin and Waco, Texas between November 15-19, 1993.

One goal of this test was to have a balance of test sections that would have asphalt, jointed concrete, and continuously reinforced concrete. Another goal to have a balance of the type, extent, and severity of transverse, longitudinal, block, and fatigue cracking.

During the test site selection stage of this project, it was not possible to find all the pavements and crack types to fully satisfy the goals of this test. Traffic disruption and safety also limited the scope of the field test. Consequently, the test sections lacked moderate and severe cracking levels in the flexible sections. The lack of moderate and severe cracking is partially a function of the LTPP distress rating procedure. Moderate cracks are typically between six millimeters and 19 millimeters wide with severe cracks greater than 19 millimeters wide. Few pavements in the part of the state where the test was held are allowed to stay in this wide a cracked condition for long. No jointed concrete pavement sections were evaluated in the test.

Seven test sections totaled approximately 30.45 km (18.9 miles) of flexible and rigid pavements. The TxDOT marked each 150 meter segment with a letter - number combination. Thus each section was uniquely identified for more detailed analysis. The site description and locations are listed below.
## PROJECT SECTION DESCRIPTION

<table>
<thead>
<tr>
<th>Network Section</th>
<th>LTPP Section(s)</th>
<th>Highway</th>
<th>Length</th>
<th>Width</th>
<th>Surface Type</th>
<th>Shoulder</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A3 &amp; A22 - dense graded hot mix</td>
<td>FM 1466</td>
<td>7.5 km</td>
<td>~ 3 m</td>
<td>alternating surface treatment and ACP</td>
<td>none</td>
<td>low</td>
</tr>
<tr>
<td>B</td>
<td>B69 - mix of approximately 30% surface treatment and 70% dense graded hot mix</td>
<td>FM 619</td>
<td>15 km</td>
<td>~ 3m</td>
<td>alternating surface treatment and dense graded hot mix</td>
<td>none</td>
<td>low</td>
</tr>
<tr>
<td>D</td>
<td>D8 &amp; D22 - light colored surface treatment</td>
<td>SH 95</td>
<td>4.5 km</td>
<td>~ 3.35m</td>
<td>light colored surface treatment</td>
<td>none</td>
<td>low</td>
</tr>
<tr>
<td>E</td>
<td>E3 - IH 35 frontage road</td>
<td>1.05 km</td>
<td>~ 3.66m</td>
<td>continuously reinforced concrete pavement</td>
<td>curb and gutter</td>
<td>mod.</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>F7 - IH 35 frontage road</td>
<td>1.05 km</td>
<td>~ 3.66m</td>
<td>continuously reinforced concrete pavement</td>
<td>curb and gutter</td>
<td>mod.</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>H4 - IH 35 frontage road</td>
<td>0.9km</td>
<td>~ 3.66m</td>
<td>continuously reinforced concrete pavement</td>
<td>curb and gutter</td>
<td>mod.</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>T2 - Decker Lake Road</td>
<td>0.45 km</td>
<td>~ 3 m</td>
<td>surface treatment</td>
<td>none</td>
<td>very low</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Project Site Description**

There was a problem with the section lengths that was not immediately obvious before data collection began. The 150 meter segments were marked off with a vehicle that had recently been repaired. This vehicle had two distance measuring instruments (DMI's) in it; one combined with vehicle instrumentation and one stand alone. The sections were laid out with the...
stand alone DMI. The stand alone DMI had not been recalibrated after the vehicle repairs resulting in inaccurate measurements.

Unfortunately, all the sections were approximately eight percent short. For two vendors, PASCO and Pave Tech, this did not affect them as their distress identification procedures use a manual procedure to locate the beginning and ending of each 150 meter segment. However, the two other vendors, IMS and Roadware, rely heavily on their DMI’s to accurately position data. The sections being too short would cause data reporting errors if they had used their correctly calibrated DMI’s. This problem was solved by recalibrating the two vehicle DMI’s to the measured section length and tricking the systems into reporting data in the correct test segment.

Field testing was originally scheduled for Monday, Tuesday and Wednesday, November 15 through 17 for all vendors except PASCO. They collected film data the week before. Data reduction was to start Tuesday and proceed through the end of the week. Data collected on Monday was not useful to either IMS or Roadware due to the section length problem described above. The TWG agreed to let IMS and Roadware recollect data Tuesday morning and then move to Waco for noon and afternoon data collection on the CRCP. Rain delayed data collection Tuesday morning. Checks with the Waco district and the weather service indicated that the rain would end during the morning. The TWG decided to move the tests to Waco for the afternoon run.

There was concern that the wet cracks in the afternoon run would be more obvious to the systems and influence the results. A review of the data does not seem to support this concern. On Wednesday the CRCP morning and noon runs were completed. The vehicles returned to the flexible sections and collected afternoon data on Wednesday and the remaining data Thursday.

Pasco began their data reduction efforts on Monday morning. Pave Tech began their data reduction on Tuesday morning. IMS and Roadware both had to wait until the data was collected using the proper DMI settings. Both vendors sent data to Austin on Wednesday morning from Waco to begin data reduction.

**Manual Rating Procedures**

Appendix A describes some differences between the LTPP crack rating procedure and the standard PMIS crack rating procedure. The appendix also describes the method used to convert the LTPP data into PMIS “equivalent” data. For more thorough descriptions of the two rating procedures, please see the appropriate references.

One additional difference should be noted concerning the section lengths rated. The LTPP procedure rates all 150 meters. The PMIS procedure typically rates a representative 61 meter (200 foot) section in a one-half mile PMIS section. For the purposes of this study 100 percent of each section were rated using with the PMIS procedure.

**Equipment Description**

The following section describes the data collection and reduction equipment as it was configured in Austin for the test. The description includes only those subsystems mounted in the vehicles for collecting surface distress data. Workstations used for the data reduction follow the vehicle descriptions. The reader is encouraged to review other literature or contact the manufacturers for other data subsystems available for the equipment.
IMS calls their pavement distress subsystem "PAVUE I." The system in Austin consisted of a van equipped with:

- Four overhead electronically shuttered video cameras on the back of the van.
- Strobe lights at the back of the van to provide even illumination of the pavement and eliminate shadows.
- One overhead electronically shuttered camera mounted on the front of the van for "right of way" view.
- Four crack detection lasers mounted on the front bumper.
- High resolution, optical shaft, distance encoder.
- Five PAL S-VHS VCRs.
- Other equipment for collecting video and laser measurements of the pavement surface at speeds up to 90 km/h (55 mph).

The VCRs use a video data encoder to record DMI location and synchronize all four pavement view video cameras and tape recorders.

When the PAVUE system is transported long distances, such as the trip from Atlanta to Austin, the cameras are removed. IMS aligns the cameras to provide the best possible video. They also periodically calibrate with a known grey scale source placed under the camera / lighting system. This allows them to supply video system performance to the office workstation system.

PAVUE records cracking information with the front mounted lasers stored in user defined summary intervals. This is done instead of storing all laser data to reduce the amount of disk storage space required on the van. For the test in Austin, IMS picked a summary interval of 25 meters. This means that for each 150-meter segment, there were six laser summaries recorded. The summarized laser data is why the DMI offset was such a critical problem for IMS. If the section lengths were off too much, they would be recording laser video for one section that was actually in another section.

The office workstation consisted of two racks of equipment. One rack held the VCRs and monitors. The second rack held the PAVUE system computer which consisted of approximately sixty, special purpose, proprietary, video processing VME Buss cards. These sixty cards are configured as two image processing systems, one for each half lane. The image processing system performs the edge detection and feature extraction process. The data is sent through a separate program to classify the cracking and merging it together with the laser data to estimate crack severity.

After the data has been collected in the field, a packet of five video tapes and a data diskette are returned to the workstation. The PAVUE system uses a pavement surface specific initialization file to load the correct processing parameters. The section beginning points were identified and then the PAVUE system started the image analysis. Image analysis was performed at realtime video tape recording speed. In the case of the PAVUE system this is 50 fields per second, the European PAL standard.

A program called "HYBRID" combines the analyzed the video data with the laser data to generated the final pavement cracking report indicating crack type, severity and extent for each 150 meter test segment. There were a number of intermediate steps in the process demonstrated in Austin. These intermediate steps reduced the overall data reduction speed. IMS informed the TWG that these steps will be incorporated into a batch process to speed up data reduction.
PASCO

The "Roadrecon" system consisted of a recreation vehicle (RV) size custom built vehicle equipped with an overhead 35 mm strip film camera and halogen lights located on the front bumper. The pavement surface filming was done the night of November 7 to allow time for the film to be developed. PASCO collects at night to control the lighting conditions and the effects of shadows. The film was recorded at vehicle speeds of 80 km/h. The film was sent to Pennsylvania for developing and returned to Austin on November 15 for data reduction.

The PASCO office workstation consists of an overhead strip film projector, digitizing table and personal computer. The section header and other pertinent information are keyed into the computer and the distress ratings begin.

A section of pavement is projected onto the digitizing table. A technician digitized the cracks outlining the area or length of the cracks and not the actual cracks. With the boundaries of the pavement film image keyed into the system, and the cracks identified with the digitizer, the program calculates the length or area of cracks. This procedure was repeated for each section until all 150 meters was completed. For the test in Austin, another workstation produced crack maps and distress survey summary sheets for each test segment.

Pave Tech

The Pave Tech system consisted of a van equipped with:

- Four electronically shuttered pavement cameras; two in front and two in back that are switched by the operator depending upon lighting conditions.
- Two front cameras one that provides right of way view and one that can be aimed towards signs or other items of interest.
- An operator keyboard.
- Distance Measuring Instrument

The system can collect video and other information at speeds up to 104 km/h (65 mph).

For this test the operator entered the road description, location, survey limits and road stations in the on-board computer. This information can also be downloaded from a pavement management system. Other information collected by the computer included DMI data and time code from the S-VHS VCRs. Time code and section header / DMI data is recorded and used to control the VCRs with the computer both for recording and playback.

The recorded videos were played back at variable speeds on video monitors at the Image Processing Workstation (IPW). A trained technician viewed the videos and identified and keyed-in the type, severity, starting and ending point of the cracks using a preset pavement distress input menu in the IPW's computer. The computer automatically calculated the length or area of the cracks and generated the distress data file and pavement cracking report. Distress information can be collected for the entire section or for specific sample locations as requested in this project. When a sample is taken, the computer system keeps track of the sample location so future distress surveys can be done at the same sample location. This provides the ability to conduct historical pavement evaluations and do performance monitoring.

Roadware

The Automatic Road Analyzer (ARAN) consisted of a modified van equipped with:

- Two electronically shuttered pavement view video cameras mounted at the rear of the vehicle on self extending booms, strobes lights on the rear of the vehicle to eliminate shadows from the pavement image.
• A video multiplexer for collecting two video images on one S-VHS recorder — the cameras collect video images simultaneously and then delay one image by a sixtieth of a second and record it on the second video field.

• One front mounted, electronically shuttered, right of way video camera.

• A computer rater keyboard for collecting event and other information.

• An optical shaft encoded DMI.

The ARAN can collect pavement images at speeds up to 80 km/h (50 mph).

As stated in the purpose section, this test was to evaluate automated equipment that did not have human intervention during data collection and reduction. A Roadware technician was observed using the rater keyboard during testing. When asked about using the keyboard, he explained that the image processing algorithm had difficulty distinguishing between block cracking and fatigue cracking. He was instructed to estimate when crack patterns changed between block and fatigue cracking and key this information into the rater keyboard. Discussions with other Roadware representatives support this explanation.

The office workstation consists of a 486 based personal computer, with two RISC image processors mounted on PC expansion cards and WISECRAX image processing software. The system uses an initialization file that provides information to the software about section length, pavement type, etc. The WISECRAX system demonstrated in Austin digitized 75 meters of pavement video at a time. The system then performed edge detection, feature extraction and classification based upon the requested rating procedures.

The office data reduction is fully automated, i.e., the operator set up section header information and inserts the video tape and the system runs until complete. The system uses the initialization file and relies on location from the DMI to calculate section lengths, beginnings, and endings. This section identification and length is why the section length problem was critical for data reporting. The ARAN DMI was corrected as described earlier.

Roadway chose to use off-the-shelf components to build the WISECRAX system. If data reduction speed increases are needed, it is available by increasing the number of RISC processor in the PC. Each additional set of cards can add a significant cost to the system and the reader should evaluate the benefit / cost to determine whether or not it is cost effective to increase the system speed.

Additional information about each equipment, hardware, and software is included Appendix C or the vendors can be contacted from the list at the beginning of the report.
DATA REDUCTION SPEED

The following table shows the estimated speed for completing two selected sections; Section D and Section H for those systems using computers to process video data. Roadware experienced problems processing the concrete video during the speed estimating trial and thus the results are for Section D only. The data reduction rate for the manually assisted systems is based on the time needed to rate one 150-meter pavement segment. The rates for some vendors is dependent upon the number and complexity of pavement distresses present on the sections. The reader is reminded that these data reduction rates include set up times and other file manipulations. There may be some different data reduction speeds for the automated systems at the network level as full video tapes, say two hour tapes, would be processed with little operator intervention. These estimates provide the reader with an indication of the relative speed available from the different vendors participating in the project. The times shown below indicate the processing speed of the systems in the configuration as demonstrated in Austin for this test.

<table>
<thead>
<tr>
<th>EQUIPMENT COMPANY</th>
<th>DATA REDUCTION RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMS</td>
<td>14 to 28 Km/h</td>
</tr>
<tr>
<td>PASCO</td>
<td>0.1 Km/h</td>
</tr>
<tr>
<td>Roadware</td>
<td>4.5 to 5 Km/h</td>
</tr>
<tr>
<td>Pave Tech</td>
<td>3 to 5 Km/h</td>
</tr>
</tbody>
</table>

Table 2: Data Reduction Rate

RESULTS OF DATA COMPARISON

ACCURACY AND PRECISION DEFINED

There are two concerns about how well the equipment performed at the test. The first is how accurately the equipment collected the data and the second is how precisely that data was collected.

Accuracy is defined as how close or near the measurements made were to the real or actual quantity being measured. The sources of accuracy errors are typically systematic errors and are reduced by calibrating a system. For the project, accuracy is how closely the equipment measured data compared to the manual LTPP and PMIS ratings. The project does not attempt to report the validity or accuracy of the LTPP manual rating procedure or the PMIS rating procedure. For information concerning the accuracy and precision of LTPP surveys, the reader is encouraged to review the "Evaluation of SHRP LTPP Distress Data Collection Procedures" by Brent Rahut Engineers, the LTPP Southern regional Contractor. The TxDOT has conducted audits of its manual Pavement Evaluation System ratings, the predecessor to PMIS, and these results may be available from the TxDOT.

Precision or repeatability is defined as the closeness with which the measurements agree with each other. Precision errors are random or accidental errors and can be an indicator of poor instrumentation or data processing. For the project, the closer each piece of equipment agrees with itself on any given section the more precise it is. Standard deviation of the repeat runs is reported to estimate repeatability. If the
standard deviation is low then the equipments agrees well with itself on any given section.

When reviewing the results, the reader should keep in mind that standard deviations for very small sample sizes, say two passes on the same section, statistically have little or no meaning. Additionally, the standard deviations include differences between passes made at different times of the day and may influence the results.

Results

Results for the LTPP segments are presented first. The results are shown in various ways to allow the reader to reach conclusions concerning the equipment’s performance. The results are presented:

- In tabular form for each cracking type and are the averages of all runs by severity and total.
- In X-Y scatter plots by equipment showing the average, standard deviation, and high and low for all passes.
- Bar charts of total average distress showing all participants.
- Bar charts for each vendor that show total distress for repeat passes with time of day identified.
- Two sets of 3-D bar charts by severity level for the LTPP sections; the first set of charts show the average of each severity level between equipment and the LTPP rating and the second set shows individual passes for each piece of equipment by severity level compared to the LTPP survey.

The PMIS network level simulations provide similar information although the results are presented for all the 150 meters segments. To simulate network level data collection, data is summarized into 750 meter “pavement management data collection sections.” The section length is very similar to the PMIS section length in Texas. The PMIS results for all sections are reported:

- In tabular form for each cracking type and are the averages of all runs by total only.
- In X-Y scatter plots by equipment showing the average, standard deviation, and high and low for all passes.
- Bar charts of total average distress showing all participants.

The charts have been displayed to focus as much attention as possible on the information about the equipment. To facilitate this, some bar charts also include text boxes with numbers in them. These numbers represent the manual ratings for those sections. The X-Y scatter charts have three symbols on them. Once again, in the interest of space, no legends are displayed. On the X-Y scatter diagrams, the black squares (■) represent the average of all passes over a particular section, the plus (+) signs show the high and low averages for the pass and the hollow triangles (△) represent the standard deviation for the passes.

Data Collection and Processing

Each vendor collected at least six passes on all the sections. The exception to this was PASCO who collected only two passes on each section. Either all the data was to be reduced or twenty of the 150-meter segments were to be reported depending upon whether or not the data reduction equipment was considered "fully automated." The IMS and Roadware systems were considered fully automated and results were requested by November 19. The Pave Tech and PASCO systems were considered manually assisted and they were asked to provide their results from the twenty 150-meter segments by November 19. The manually assisted vendors were provided the opportunity to complete the remaining sections and submit them to TxDOT by December 19.
IMS - provided data for all 150-meter segments, six passes of the flexible pavement sections and nine passes of the continuously reinforced concrete pavement sections for a total of approximately twelve hundred test sections. As indicated above two of the concrete sections were submitted after the end of the test although it was processed during the week of the test.

PASCO - provided data for two passes each of the twenty 150-meter sections. They supplied the remaining data to TxDOT by December 19.

Pave Tech - provided almost all the data for six passes of the twenty sections. They were unable to complete eight of the 150-meter segment repeat passes. These eight segments were scattered throughout the twenty sections. Pave Tech did provide at least four sets of data for each of the twenty sections. The remaining data for all sections was submitted to TxDOT by December 19.

ROADWARE - provided data for 19 passes of the CRCP sections and three passes of Section D. No other data was submitted for the flexible pavement sections. Roadware explained a problem they had with Wisecrax in its ability to estimate cracking on rough textured, surface treated, pavement surfaces. They declined to submit data for the remaining passes from Section D and all of Sections A and B.

SIMULATED CRACKING

An aluminum template with a cut in it the shape of a crack was borrowed from the Texas Transportation Institute. This template had been used in TxDOT sponsored projects to estimate the resolution of an automated crack identification system under development at TTI.

Cracks were painted with black paint at the end of Section B to simulate both transverse and longitudinal cracks. The purpose of painting these cracks was not to evaluate the adequacy of algorithms or raters. Instead it was done to estimate the resolution of the camera / recording system. The cracks varied in width from approximately two to ten millimeters. The tapes and film were then manually reviewed to see what the minimum resolution was for each system. All video and film systems showed visible results at the two millimeter crack width. It should not be assumed that the minimum crack resolution available from the equipment is two millimeters as there are many processing steps between the video or film and final product. Rather, this provides the reader with an indication of how small a crack was visible on the recording media. Additionally, paint marks smaller than two millimeters could not be painted on the pavement as the project team did attempt thinner lines.

CONCLUDING REMARK

The purpose of this report is to present quantitative data and objective information so each individual reader can form their own opinions. This report does not contain subjective conclusions, opinions, or ratings, because pavement condition data needs are different for individual highway agencies.

FUTURE TESTING

This test is intended as a starting point to help pavement management engineers better understand this new and evolving technology. Because of the project's complexity, it is not practical or feasible to make this test all inclusive or conclusive.

The FHWA will continue to monitor the equipment's technological advancements and conduct tests as new improvements are announced.

Pavement management engineers are encouraged to contact the equipment companies for additional information and to consider a personal demonstration on your particular pavement types and surfaces.
TABLES AND CHARTS
LIPP TABLES
LTPP X - Y Plots
Wheelpath Longitudinal Cracking LTPP vs. IMS

Wheelpath Longitudinal Cracking LTPP vs. PASCO

Wheelpath Longitudinal Cracking LTPP vs. Pave Tech

Wheelpath Longitudinal Cracking LTPP vs. Roadware
Combined Longitudinal Cracking LTPP vs. IMS

Combined Longitudinal Cracking LTPP vs. PASCO

Combined Longitudinal Cracking LTPP vs. Pave Tech

Combined Longitudinal Cracking LTPP vs. Roadware
IMS CRCP Longitudinal Cracking vs. LTPP

PASCO CRCP Longitudinal Cracking vs. LTPP

Pave Tech CRCP Longitudinal Cracking vs. LTPP

Roadware CRCP Longitudinal Cracking vs. LTPP
LTPP Bar Charts
PASCO Wheelpath Longitudinal Cracking Repeatability - LTPP Sections

PASCO Non-Wheelpath Longitudinal Cracking - LTPP Sections

PASCO Combined Longitudinal Cracking - LTPP Sections
LTTP 3-D BAR CHARTS
LTPP Sections Transverse Cracking - Average of Repeat Runs

![Graph showing transverse cracking meters for different vendors and section IDs. The x-axis represents Section ID & Vendors, the y-axis represents Transverse Cracking meters, and the graph uses different colors to indicate high, moderate, and low cracking levels.]
LTPP Sections Longitudinal Wheelpath Cracking - Average of Repeat Runs

Section ID & Vendors

- High
- Moderate
- Low
LTPP Sections Longitudinal Non-Wheelpath Cracking - Average of Repeat Runs

[Bar chart showing longitudinal cracking for different sections, with bars indicating high, moderate, and low levels of cracking.]
LTPP Sections Combined Longitudinal Cracking - Average of Repeat Runs
LTPP Sections Combined Longitudinal Cracking - Average of Repeat Runs

![Graph showing Longitudinal Cracking in meters across different sections and vendors.](image)
LTPP Sections CRCP Transverse Cracking (length) - Average of Repeat Runs

Section ID & Vendors

- High
- Moderate
- Low
LTPP Sections CRCP Longitudinal Cracking - Average of Repeat Runs

Section ID & Vendors

High
Moderate
Low
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<td>1198</td>
<td>1017</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1644</td>
<td>1365</td>
</tr>
<tr>
<td>Std Dev.</td>
<td></td>
<td>506</td>
<td>412</td>
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<table>
<thead>
<tr>
<th>Section ID</th>
<th>Run / Pass</th>
<th>Transverse Cracking</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Length</td>
</tr>
<tr>
<td>F1 - F6</td>
<td>PM / 1</td>
<td>695</td>
<td>576</td>
</tr>
<tr>
<td>PM / 2</td>
<td></td>
<td>676</td>
<td>552</td>
</tr>
<tr>
<td>PM / 3</td>
<td></td>
<td>687</td>
<td>567</td>
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<tr>
<td>8</td>
<td></td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>F1 - F4</td>
<td>AM /1</td>
<td>597</td>
<td>531</td>
</tr>
</tbody>
</table>

### Roadware Section H

<table>
<thead>
<tr>
<th>Section ID</th>
<th>Run / Pass</th>
<th>Transverse Cracking</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Length</td>
</tr>
<tr>
<td>H1 - H6</td>
<td>AM /1</td>
<td>3994</td>
<td>3438</td>
</tr>
<tr>
<td>AM /2</td>
<td></td>
<td>3706</td>
<td>3195</td>
</tr>
<tr>
<td>PM /1</td>
<td></td>
<td>642</td>
<td>501</td>
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<tr>
<td>Average</td>
<td></td>
<td>2781</td>
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<tr>
<td>Std Deviation</td>
<td></td>
<td>1517</td>
<td>1331</td>
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PMIS X-Y Plots
Edge Cracking PMIS vs. IMS

Edge Cracking PMIS vs. PASCO

Edge Cracking PMIS vs. Pave Tech
CRCP Longitudinal Cracking PMIS vs. IMS

CRCP Longitudinal Cracking PMIS vs. PASCO

CRCP Longitudinal Cracking PMIS vs. Pave Tech

CRCP Longitudinal Cracking PMIS vs. Roadware
Spalled CRCP Transverse Cracks PMIS vs. IMS

Spalled CRCP Transverse Cracks PMIS vs. PASCO

Spalled CRCP Transverse Cracks PMIS vs. Pave Tech

Spalled CRCP Transverse Cracks PMIS vs. Roadware
PMIS Bar Charts
Longitudinal Cracking Section A

Longitudinal Cracking Section B

Longitudinal Cracking Section D
IMS Edge Cracking All Runs - PMIS Sections

Section ID


Edge Cracking - meters

84  66  42  75  52  127  127

Section ID

B1-B5  B16-B20  B31-B35  B46-B50  B61-B65  B76-B80  B91-B95

Edge Cracking - meters

64  0  0  43  7  0  24  123  256  256

Section ID

D1-D5  D6-D10  D11-D15  D16-D20  D21-D25  D26-D30  T1-T3

Edge Cracking - meters

49  124  24  102  188  67  0
Roadware Fatigue Cracking Repeatability - PMIS Section D

Roadware Longitudinal Cracking Repeatability - PMIS Section D

Longitudinal Cracking PMIS Rating for Section D is 0
Roadware CRCP Spalled Transverse Cracks - PMIS Section

Roadware CRCP Transverse Cracking (number) - PMIS Sections

Roadware CRCP Longitudinal Cracking - PMIS Sections
<table>
<thead>
<tr>
<th></th>
<th><strong>LTPP</strong></th>
<th><strong>PMIS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fatigue Cracking</strong></td>
<td>Location: Predominantly Wheelpath, full lane width also rated</td>
<td>Location: Wheelpath</td>
</tr>
<tr>
<td></td>
<td>Description: Many-sided sharp angled pieces. Chicken wire / alligator skin appearance. Pieces are less than 1' x 1'</td>
<td>Description: Irregularly shaped blocks. Resemble patterns found on alligator skin. Pieces are less than 1' x 1'</td>
</tr>
<tr>
<td></td>
<td>Severity: Yes</td>
<td>Severity: No - However, you see it you rate it.</td>
</tr>
<tr>
<td></td>
<td>Rating: Square Meters</td>
<td>Rating: Percent Area of wheelpaths</td>
</tr>
<tr>
<td><strong>Block Cracking</strong></td>
<td>Location: Full Lane Width</td>
<td>Location: Full Lane Width</td>
</tr>
<tr>
<td></td>
<td>Description: Cracking pattern dividing the pavement into rectangular pieces ranging in size from 0.1 sq. m. to 10 sq. m.</td>
<td>Description: Interconnecting cracks dividing the pavement into approximately rectangular pieces ranging in size from 1' x 1' to 10' x 10'</td>
</tr>
<tr>
<td></td>
<td>Severity: Yes</td>
<td>Severity: No</td>
</tr>
<tr>
<td></td>
<td>Rating: Square Meters</td>
<td>Rating: Percent Area</td>
</tr>
<tr>
<td></td>
<td>Sealed: Yes</td>
<td>Sealed: Yes - not specified fully in manual</td>
</tr>
<tr>
<td><strong>Transverse Cracking</strong></td>
<td>Location: Full lane width</td>
<td>Location: Full lane width</td>
</tr>
<tr>
<td></td>
<td>Description: Predominantly perpendicular to pavement centerline. Length of individual cracks are recorded.</td>
<td>Description: Cracks which travel at right angles to the pavement centerline. Estimated crack length assigned a partial lane width</td>
</tr>
<tr>
<td></td>
<td>Severity: Yes</td>
<td>Severity: No - must be at least ½ inch wide</td>
</tr>
<tr>
<td></td>
<td>Rating: Number and length of cracking</td>
<td>Rating: Number of full width cracks per station (100')</td>
</tr>
<tr>
<td></td>
<td>Sealed: Yes</td>
<td>Sealed: Yes</td>
</tr>
<tr>
<td>Asphalt Concrete Pavement Crack Rating</td>
<td>LTPP</td>
<td>PMIS</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td><strong>Longitudinal Cracking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location:</td>
<td>Full Lane Width - distinction made between wheelpath and non-wheelpath cracking</td>
<td>Location: Full Lane Width - no distinction made between wheelpath and non-wheelpath. Longitudinal cracks at edge are rated!</td>
</tr>
<tr>
<td>Description:</td>
<td>Cracks predominantly parallel to pavement centerline. Record length in meters.</td>
<td>Description: Cracks approximately parallel to pavement centerline. Record length in feet.</td>
</tr>
<tr>
<td>Severity:</td>
<td>Yes</td>
<td>Severity: No - must be at least 1/8 inch wide</td>
</tr>
<tr>
<td>Rating:</td>
<td>Length in meters</td>
<td>Rating: Feet per station (100')</td>
</tr>
<tr>
<td>Sealed:</td>
<td>Yes</td>
<td>Sealed: Yes</td>
</tr>
<tr>
<td><strong>Edge Cracking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location:</td>
<td>Within 0.6m of pavement edge - no shoulders</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Crescent-shaped cracks or fairly continuous cracks which intersect the pavement edge. Includes longitudinal cracks within 0.6m of the pavement edge.</td>
<td>No Similar PMIS Rating</td>
</tr>
<tr>
<td>Severity:</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rating:</td>
<td>Length of pavement edge affected at each severity level.</td>
<td></td>
</tr>
<tr>
<td>Sealed:</td>
<td>No</td>
<td></td>
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</tbody>
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### CONTINUOUSLY REINFORCED CONCRETE PAVEMENT CRACK RATINGS

<table>
<thead>
<tr>
<th></th>
<th>LTPP</th>
<th>PMIS</th>
</tr>
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<tbody>
<tr>
<td><strong>Longitudinal Cracking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location:</td>
<td>Full lane width</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Crack predominately parallel to the</td>
<td>No similar PMIS rating!</td>
</tr>
<tr>
<td></td>
<td>pavement centerline</td>
<td></td>
</tr>
<tr>
<td>Severity:</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rating:</td>
<td>Length of sealed and unsealed cracks in meters.</td>
<td></td>
</tr>
<tr>
<td><strong>Transverse Cracking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location:</td>
<td>Full Lane Width</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Cracks that are predominantly perpendicular to</td>
<td>Rated as spalled cracks. Must have</td>
</tr>
<tr>
<td></td>
<td>the pavement centerline</td>
<td>spalling!</td>
</tr>
<tr>
<td>Severity:</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rating:</td>
<td>Number and length for each severity level as</td>
<td>Number of spalled transverse cracks. PMIS</td>
</tr>
<tr>
<td></td>
<td>well as total number in the section</td>
<td>also collects average crack spacing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>which is similar to total number of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>transverse cracks in the section.</td>
</tr>
</tbody>
</table>
CONVERSION FROM LTPP TO PMIS

PMIS Survey

The PMIS visual distress rating procedure for this project consisted of rating each 150 meter segment. A modified PMIS rating was conducted, estimating the extent of each cracking distress. No severity levels were recorded. The conversion from LTPP to PMIS for the network simulation follows for each cracking type.

Flexible Pavement Surfaces

Fatigue to Alligator Cracking:

LTPP reports the area in square meters of fatigue cracking for the entire lane width. The PMIS rating restricts alligator cracking to the wheelpaths. The modified PMIS survey will note fatigue cracking outside the wheelpaths. For this project the wheelpath for all flexible pavements is defined as starting 0.6 meters from the pavement edge (outside) and the centerline (inside). Each wheelpath is 0.8 meters wide and is 150 meters long. The PMIS rating was calculated as: percentage of wheelpath alligator cracking * 150 * 0.8meters * 2 + area of non-wheelpath alligator cracking = fatigue cracking in square meters.

Block Cracking:

Conditions in the part of Texas where the test was conducted typically does not produce block cracking and this was the case for the demonstration project. Thus block cracking is not reported.

Transverse Cracking:

The LTPP procedure records both the number and length of individual cracks along with their severity rating. Individually sealed cracks are included in the rating procedure. The PMIS procedure counts the number of full width cracks. As part of this procedure partial cracks are recorded, i.e. a 1.83 meter crack on a 3.66 meter lane is rated as one-half a crack. PMIS includes sealed transverse cracks in the rating procedure. The PMIS transverse cracking distress is recorded as the number of full length cracks per 30.48m (100') station. Since the PMIS rater will provide a rating in number per station, the number of transverse cracks recorded by the equipment is defined as: the number of transverse cracks in a 150 meter segment divided by 4.92; there are 4.92 stations in a 150 meter segment.

Conditions in the part of the state where the test was conducted typically does not produce transverse cracking and this was largely the case for the demonstration project. While there was some small cases of transverse cracking, only two or three 150 meter segments had enough to rate as one or more per station. Thus, there are no PMIS ratings vs. equipment vendors shown for transverse cracking.
LONGITUDINAL CRACKING:

LTPP distinguishes between wheelpath and non-wheelpath longitudinal cracking. The LTPP procedure also includes sealed cracks in the survey procedure. For the purposes of this project the longitudinal cracking reported by the equipment will be the length of the combined wheelpath and non-wheelpath longitudinal cracking. The PMIS procedure measures the length of cracking in feet per station. This rating procedure includes cracking close to the edge. For this project, edge cracking will be handled separately. Longitudinal cracking within 0.6 meters will not be included in the PMIS longitudinal edge cracking rating. For this project PMIS longitudinal cracking was converted to length in meters by the following formula: 

\[ \text{the feet per station of longitudinal cracking} \times 4.92 \text{ stations per segment} \times 0.3048 \text{ meters/foot} \]

EDGE CRACKING:

LTPP includes longitudinal cracking that intersect with the pavement edge and are within 0.6 meters of the pavement edge. Edge cracking applies only to those pavements without shoulders. Crescent-shaped cracks within 0.6 meter of the pavement edge are also rated. LTPP rates the severity of edge cracking. For this distress type, PMIS collected the feet of edge cracking per station. The PMIS edge cracking rating is converted to meters by the following formula:

\[ \text{the feet per station of edge cracking} \times 4.92 \text{ stations per segment} \times 0.3048 \text{ meters/foot} \]

RIGID PAVEMENT SURFACES

LONGITUDINAL CRACKING:

LTPP measures longitudinal cracking by severity levels and records the length in meters. The PMIS procedure does not measure longitudinal cracking on CRCP pavements. For this study, the length of longitudinal cracking in meters was recorded; no severity levels were used.

TRANSVERSE CRACKING:

LTPP records the number and length of all transverse cracks regardless of whether or not they are distressed. The PMIS survey only records those transverse cracks which are distressed, i.e. spalled. PMIS also collects the average crack spacing which provides an estimate of the number of transverse cracks in a section. For this study: 150 meters was divided by the PMIS average crack spacing to estimate the total number of transverse cracks. This number is then compared to the number of transverse cracks recorded by the equipment.

To estimate the number of spalled transverse cracks, the number of cracks reported by the vendors in the moderate and severe categories were separated and compared to the number of spalled transverse cracks in the PMIS procedure. Length of transverse cracks was not recorded.
APPENDIX B
The following describes some of the challenges with image analysis for pavement surface distress ratings. This short dialog is not intent as a complete description of all the steps required to perform automated distress rating. Instead, it is intended to provide the reader understanding about this procedure that the vendors are accomplishing.

• **RECORDING THE PAVEMENT IMAGE** An inexpensive, reliable, and easy to use recording device with adequate resolution has not been available until recently. Photographic film has the resolution needed to record fine pavement cracks however, light is a problem as well as exposure and shutter speed. Additionally, there is no means available to check the image quality until the film has been developed.

Video cameras and video tape were considered the most appropriate means available for capturing images. It has been only very recently with the development of electronically shuttered video cameras and higher resolution cassette based video taping systems that video has become a viable alternative for capturing pavement images.

• **CREATING A MACHINE READABLE VERSION OF THE IMAGE** Even if photographic film was used in the past, the images still had to be turned into something a computer program could read and process. While this is possible, it is expensive and there is a corresponding loss of resolution dependent upon the resolution of the scanning device available. Digitizing boards are now available that can directly read video, digitize the image and create a bit mapped image that a computer program can readily read and manipulate.

• **DIGITAL IMAGE SIZE** Digital image file sizes are big compared to other data types. For example, a simple 256 gray scale image 512 x 512 pixels wide is approximately 2 megabytes (Mbyte). Suppose one image can cover a full lane width, assuming of course that the resolution necessary for crack width is available, and that the image covers ten feet of lane length. One mile of continuous digital data from that one camera is approximately 1056 Mbyte. Obviously, even with the larger storage capacity media available at this time, storing digital images is cost prohibitive and difficult to do!

• **MANIPULATING THE DIGITAL IMAGE** Once an image is available it must be manipulated to extract the features of interest from all other extraneous information; background noise, skid marks, oil stains, shadows, etc. Typically for pavements a histogram of each image is computed to establish the background intensity or average grey scale. Since most pavement cracks are darker than the average grey scale, keep in mind that some pavements pump fines from the cracks and appear lighter and since they tend to look like edges, edge detection algorithms are used extract the cracks. After the edge detection phase is complete, feature extraction is used to "connect the dots and make a crack." Next comes the crack classification phase where type and extent of cracking and, if interested, severity of cracking are estimated.

• **THE PAVEMENT SURFACE** Pavement surfaces present an especially difficult challenge to machine vision systems. Pavement surfaces come in many different varieties of colors and textures from the smooth dark black of new surfaces asphalt concrete surfaces to gap graded surface treatments made with limestone aggregates. The constantly changing color and surface texture is extremely difficult to program and is time intensive because of all the calculations that are necessary. Additionally, patching, strip seals, skid marks, shadows and paint stripes create processing problems from differing background greyscale to false edges.
APPENDIX C
EQUIPMENT DESCRIPTION

IMS - PAVUE System

Vehicle

Basic vehicle is a Ford Econoline, standard except for heavy-duty towing package and an RV-type electrical generator full PAVUE and laser system installed in the van. The measurement survey speed range for collection of data is from 8 to 90 km/h (5 to 55 mph). The vehicle can collect data regarding pavement roughness, surface texture, condition survey, faulting, IRI, and right-of-way videologging. The pavement cameras horizontal Field of View (FOV) or imaged width is adjustable from 3.2 m to 4 m (10.5 ft to 13.1 ft), depending on the lane width surveyed. The PAVUE maximum vertical FOV is 0.75 m (2.5 ft).

Data Collection Equipment

4 Lasers mounted on the front bumper (32 Khz Selcom).
7 Strobe Lights (50 flashes/sec.)
4 Pavement Cameras.
2 Accelerometers (mounted in each wheel path)
1 Forward Camera.
5 S-VHS, PAL-video format, Video Tape Recorders (VTR’s).
1 Personal Computer (486 processor)
1 Distance Measurement Instrument (DMI)
1 Photocell (for optical start/stop)

IMS plans to incorporate this technology onto the laser RST technology and collect roughness/longitudinal profile, rut data, transverse profile, road geometry, GPS, etc. The laser RST includes the following equipment:

8 Lasers (32 Khz Selcom)
1 GPS receiver
Road Geometry Pack (inclinometers, rate gyros)

Data Collection

The data equipment is calibrated and the equipment operation is verified. The data measuring program is downloaded to the computer system. The five VCR’s are synchronize prior to start data acquisition.

General description of the pavement section is input to the data measuring program. The data acquisition is started either by manual key press or by a photocell start. The data collection is fully vehicle speed independent. Pavement videos are recorded using the five VCR’s corresponding to the four pavement cameras and one forward camera. The laser data is collected in the data measuring program and checked for abnormal readings prior to be stored in a floppy disk. The video and laser data are synchronized with the DMI for proper data post-processing.
Data Processing

The data post-processing is conducted in the PAVUE Processing Workstation. This workstation consist of:

1 PC Computer
1 PAVUE Image Processor
4 S-VHS VTR’s for playing pavement data
1 S-VHS VTR for playing forward video
3 Video Monitors

The data is then processed in the following steps:

The videotapes are loaded in the VCR’s and the laser data is transferred to the PAVUE database.

The main program in the PAVUE Image Processor is run to access the database, synchronize the VCR’s, and begin analysis of the video stream from the videotapes without any intervention from an operator. All measurements are computed and processed in real-time. Thus, the PAVUE analyzes the pavement data at the same speed at which it was collected, up to well above 90 km/h (55 mph)

The output of the PAVUE analysis is a set of two distress data files, one for each PAVUE image processor channel(two videotapes/channel). The files from each channel are combine automatically into a single presentation of the entire road width.

A distress classifier program is run to preliminary identify the type, severity and extend of the distresses.

The output of the distress classifier program and laser data are analyzed by a HYBRID program that generate the final pavement cracking report.

Data Output

Binary crack maps, available in computer disks or color printouts.
Distress data files use to generate pavement cracking reports.
Data file reports are also available and are generated from any of the specified measurement parameters.
Video tape archives
PASCO USA

Vehicle

The PASCO ROADRECON survey vehicle is equipped with two camera systems.

The vehicle operates at highway speeds, and all surveys are done at night, under controlled artificial lighting, so that the photographs are not affected by shadows and variable lighting (The lights for the survey systems are sufficiently bright that incidental light from street lights and/or passing vehicles does not significantly affect the quality of the photographs).

Data Collection Equipment

- 1 Distress camera system (35-mm slit camera).
- 1 Cross-profile camera system (35-mm pulse camera).*
- 1 Hairline projector.*
- A series of lights mounted on the front bumper.
- 1 Personal Computer.
- 1 Distance Measurement Instrument (DMI)

* Not used in this project

The distress camera is mounted on a boom which extends out over the pavement. The cross-profile camera is mounted on the rear of the vehicle. The hairline projector is located on the rear bumper. Both camera systems are controlled by computer from the front passenger seat of the survey vehicle.

Data Collection

The vehicle operates at highway speeds, and all surveys are done at night, under controlled artificial lighting, so that the photographs are not affected by shadows and variable lighting (The lights for the survey systems are sufficiently bright that incidental light from street lights and/or passing vehicles does not significantly affect the quality of the photographs).

The distress photographs obtained with the PASCO survey vehicle are continuous 35-mm film which provide 100 percent coverage of the full lane width, and a portion of the shoulder, about 4.9 m wide (16 ft.).

Cross-profile photographs are taken at 50-foot intervals on the SHRP sections, and, like the distress photos, cover slightly more than the full lane width.

Data Processing

The 35-mm film is developed and positive copies made using the developed negative copies. PASCO'S PADIAS System is used to reduce the distress data from the film. This system consists of projection equipment with a digitizing screen linked to a personal computer, and software for the identification and quantifying of the various distresses.

To reduce the distress data, a technician first loads the film into the projector, so that the image is displayed on the digitizing screen. A digitizing cursor is used to outline the distresses, and the computer determines the corresponding length of area, based on predetermined scale factors. The technician selects
the distress type and severity from menus displayed on the computer monitor. The SHRP's Distress Identification Manual provides guidance to the technician on the identification of distress type and severity level.

A number of quality assurance measures are used in the collection of distress photographs on the SHRP test sections. Quality assurance measures include checks of cameras resolution, linear distortion, lateral placement in the lane, location of cross-profile photographs with respect to the target location, and film processing quality.

Data Output

SHRP's Pavement Distress Survey Data Summary Sheets. (Distresses are quantified and tabulated in terms of type and severity level)

Crack Maps showing location and extent of different types of distresses in each 150 m pavement segment.
Pave Tech, Inc.

Vehicle

Basic vehicle is a Ford Econoline Van modified to carry overhead and panoramic cameras, video units, and computer hardware. The vehicle operates at speeds up to 104 km/h (65 mph).

Data Collection Equipment

1 486/50 Mhz Compaq personal computer
1 Eight inch color VGA monitor
5 High resolution CCD color video cameras
1 Remote controlled pan/tilt color video camera (up to 12 cameras optional)
4 S-VHS commercial grade video tape recorders (VTR's)
4 High resolution, high pitch video monitors
4 Frame Id generators
1 Distance Measurement Instrument (DMI)
1 Laser printer
1 Five sensor type South Dakota Profilometer including one optical infrared sensor
2 Two sensor faulting/raveling devices, one for each wheelpath
1 Pavement grade/cross slope gyroscope
1 Heading gyroscope
1 GPS receiver

Data Collection

General description of the pavement section including road name, project number, survey limits, station at the beginning of pavement section, etc. are loaded in the inboard computer database.

Two video images of the pavement are recorded using two overhead cameras. Each of these cameras cover half of the lane surveyed up to 2.1 m (7 ft) wide. Two video images of a perspective view of the road and shoulder/curb view are recorded using two additional cameras.

Data Processing

The Image Processing Workstation (IPW) is used to perform the pavement condition data processing. The IPW consists of the following equipment:

1 486/50 Mhz Compaq personal computer
1 SVGA monitor
4 S-VHS commercial grade video tape recorders (VTR's)
4 High resolution, super fine pitch video monitors
1 256 MB external optical disk drive
1 Video printer for image hard copy
1 Laser printer
1 Video character generator
A computer pavement distress video manager program is used to perform the pavement distress survey analysis. This program features a pavement distress input menu. This menu helps the technician to control the video playback, document pavement distresses and observe the status of a distress data file. Pave Tech's distress survey analysis is performed in the following steps:

A technician proceeds to load the recorded video in the VTR's and synchronize them to the same starting point.

The video images are playback at variable speeds ranging from the equivalent of one mile per hour to ten miles per hour allowing the technician to observe the pavement condition.

When the technician observes a distress starting in the video images he/she presses the corresponding menu option in the program that commands the computer to start measuring the corresponding distress.

When the technician observes the end of the distress the video image, he/she presses corresponding options for severity, width, location in the lane, and sealed or not sealed condition. The computer automatically measures the corresponding length or area of the distress and saves it in the distress data file.

This data file is then used to summarize the distresses in a format compatible with a pavement management system.

All distresses can be extracted in a single pass because the computer can follow several distresses simultaneously.

The videos can be reversed one frame at a time and replayed to review and/or revise the quality of the distress data. Edit/changes can be made in the distress files.

Data Output

Pavement Distress Condition Reports
Distress Database Summary for Quality Control
Roughness Data by User Defined Interval and Severity
Rutting Data by User Defined Interval and Severity
Faulting/Raveling Data by User Defined Interval and Severity
Road/Sign Inventory Reports
Video Tapes of Distress, Perspective and Shoulder views
Pavement Grade and Cross Slope
Heading, curvature and GPS reports
Hard copies of distress and road video images
Roadware - ARAN/WISECRAK

Vehicle:

The Roadware's ARAN (Automatic Road Analyzer) is the vehicle used to capture the pavement view video data. The ARAN captures continuous pavement video at 80 km/h (50 mph).

The ARAN vehicle can collect data regarding pavement roughness, cross sectional profile, rutting, texture, Right-of-Way video, geometries, condition survey, and measured distances.

Data Collection Equipment:

- 2 Pavement Cameras
- 1 Right of Way View Camera
- 2 S-VHS Video Tape Recorders (VTR's)
- 2 Strobe Lights (15 flashes per second)
- 3 Video Monitors
- 1 Personal Computer
- 1 Distance Measuring Instrument (DMI)
- 2 Lasers and accelerometers
- 1 GPS receiver
- 1 37 ultra sonic rut bar
- 1 gyroscope geometry package
- 2 keyboards for entering inventory, event and other data.

Data Collection:

Continuous pavement video is collected from two overhead cameras that supply 1.5 meter images of the pavement surface. Video frames are linked to the ARAN DMI and the ARAN Rater Keyboard. The Rater Keyboard manually records events, such as different pavement types, pavement joints, sealed cracks, crack categories, or other circumstances (such as bridge locations or railroad crossings) during data collection.

Data Processing:

Data from the ARAN is included on the floppy diskette and one S-VHS video tape. This information is processed on the following computer workstation:

- Computer: 486 PC with image processing boards.
- Monitor: 1 TV Monitor
- Playback: 1 Video Tape Player.
The data is then processed in the following steps:

- Analog to Digital Conversion
- Grey Scale processed to Black & White Crack Map.
- Generate Statistics from Black & White.
- Optional hard copy Crack Map.
- Summarize Data into Output Format from Statistics.

The Wisecrax crack image processing is a fully automated process that is performed offline. Once the image file has been created, several image processing routines are employed to correct false positive (pixels mistakenly identified as cracks during segmentation) and generation more descriptive crack statistics.

Two approaches are used to analyze the image, particle and width analysis. Particle analysis examines the image on an individual particle (blob) basis. Width analysis separates the image according to the width of the particles.

Width analysis provides details of the widths of cracking, which is analogous to the severity, and is with area statistics to determine the length of cracking. The pavement edge pavement is removed from the image using width analysis without removing edge cracking.

Wisecrax provides quantitative descriptions of the roadway cracking, including a crack map. The crack map is summarized statistically by severity (width), extent (length and area of coverage), location (edge, center, or wheel path), and by orientation (transverse or longitudinal).