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16. Abstract This project provides the basis and direction for developing equipment to evaluate potential automated pavement distress data collection equipment for use in TxDOT's Pavement Management Information System (PMIS). Researchers discuss a variety of options for evaluating automated equipment and present the development of a prototype device, including results from some initial testing.					
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**DEVELOPMENT OF CERTIFICATION EQUIPMENT FOR TXDOT
AUTOMATED PAVEMENT DISTRESS EQUIPMENT**

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CHAPTER 1. INTRODUCTION AND NEEDS

INTRODUCTION

There are numerous methods that can be used to collect surface distress information. Distress surveys can be conducted and analyzed manually, or equipment can be used to automate some of the steps. In general, methods that are more costly are also more accurate, more precise, and have the greatest resolution (Smith et al. 1996). Since the terms accuracy, precision, and resolution will be used throughout this report, they will be defined so the terms will have the proper meaning. Accuracy is the degree to which the method provides a value that matches an accepted reference value (ASTM 1992). Precision is the closeness of agreement, or repeatability, among multiple measurements obtained under defined conditions (ASTM 1992). Resolution is the smallest increment that can be measured.

The accuracy, precision, and resolution needed depend on the goals of the pavement management system and the funds available to pay for the inspection services. Some methods are more subjective than others. References by Hicks and Mahoney (1981), Epps and Monismith (1986), Cable and Marks (1990), and TxDOT (undated) describe in detail many of the data collection methods.

Some agencies find it easier to contract for distress data collection rather than to devote agency personnel to that effort. Some agencies want to contract for distress data collection because they believe that the distress collection from more automated methods reduces subjectivity and errors inherent in the manual methods. Others want to use a more automated distress data collection process in order to improve the safety of the process. When contracting for distress collection services, some of the agencies have specified that the data will be collected with a certain type of equipment. However, some of these agencies express concerns that the data collected by automated equipment has not provided the accuracy, precision, and resolution that they think is needed in their data.

Whether the distress surveys are conducted manually or using some type of automated equipment, the surface of the pavement is viewed, or imaged, and an evaluation is made to determine the type, severity, and quantity of distresses present on the pavement surface (FHWA 1995 and Haas

et al. 1994). The distress type defines the kind of damage that is present. The distress severity, although not currently used in the TxDOT Pavement Management Information System (PMIS) survey, describes the seriousness of the damage. The distress quantity defines how much of the pavement has been damaged with that distress type and severity. All three of these are required to fully describe the damage on the pavement surface. They are used to help determine the type and timing of maintenance, rehabilitation, and reconstruction needs.

MANUAL DISTRESS DATA COLLECTION

Manual distress collection can vary from a detailed walking survey to a riding survey at 50 miles per hour (80 km/hr). In general, the methods in use include the following (FHWA 1995):

1. a detailed walking survey of 100 percent of the pavement surface in which all distress types, severities, and quantities are measured, recorded, and mapped;
2. a detailed walking survey of 100 percent of the pavement surface in which all distress types, severities, and quantities are measured and recorded but not mapped;
3. a walking survey of a sample of the pavement surface in which all distress types, severities, and quantities within the sample areas are measured and recorded;
4. a walking survey of a sample of the pavement surface in which all distress types, severities, and quantities within the sample areas are estimated and recorded;
5. a riding survey in which distress types, severities, and quantities are estimated while riding on the shoulder at a slow speed with periodic stops where selected distress types, severities, and quantities within the selected area are estimated and recorded while walking;
6. a riding survey in which some distress types, severities, and quantities are estimated while riding at normal traffic speeds with periodic stops where distress types, severities, and quantities within the selected area are estimated and recorded while walking or standing along the edge of the pavement surface;
7. a riding survey in which distress types, severities, and quantities are estimated and recorded while riding on the shoulder at a slow speed (current TxDOT method);
8. a riding survey in which distress types, severities, and quantities are estimated and recorded while riding on the pavement at normal traffic speed; and
9. a riding survey in which the rater gives the pavement a general category or sufficiency rating without identifying individual distress types while riding on the pavement at normal traffic speed.

The cost, need for traffic control, accuracy, precision, and resolution normally decrease from methods 1 through 9 described above while the subjectivity increases. However, as long as people are making the surveys, it will be impossible to eliminate subjectivity from the process; the subjectivity of manual inspections is affected by the time of day, training, experience, fatigue, weather, and supervision of the raters. The same definitions of distress types and severities apply to each method; however, the ability to identify lower severity levels decreases from methods 1 through 9. In addition, fewer distress types are able to be identified and recorded as the speed of travel increases. In many riding surveys, only the higher severities are included, and relatively few distress types are collected. The same methods of defining quantities can also be used; however, the accuracy of quantity estimates decreases from methods 1 through 9. In general, when riding surveys are used, the raters are often required only to identify ranges of quantities, such as 1 to 5 percent, 6 to 15 percent, etc., rather than closely estimating quantities. In the method used by TxDOT (method 7 above), it is a combination of estimating quantities for each lane stripe (40 foot interval (12m)) and accumulating these estimates for the entire section, usually 0.5 miles (0.8 km).

Although manual systems have been used for several years, there is a certain amount of error involved, and most agencies do not know the amount of error in the procedure they currently use.

AUTOMATED DISTRESS DATA COLLECTION

Imaging and distance measuring techniques are being developed to measure distress ([Epps and Monismith 1986](#), [Cable and Marks 1990](#), and [FHWA 1990](#)). There are several classes of automated data collection and interpretation ([FHWA 1995](#)):

1. Digital distress images are collected on film or high resolution video, and image analysis techniques are used to identify type, severity, and quantity of individual distress types in real-time while the vehicle collects the data;
2. Digital distress images are collected on film or high resolution video, and image analysis techniques are used to identify type, severity, and quantity of individual distress types in the office at some time after the vehicle collects the data;
3. Analog distress images are collected on film or high resolution video, and a trained observer identifies type, severity, and quantity of individual distress types in the office while viewing the images at some time after the vehicle collects the data; and

4. Data from laser-based equipment are used to determine changes in surface texture and distance, which are interpreted by computer algorithms to determine some distress types.

In general, as the method changes from 1 through 4 above, the subjectivity increases. The resolution is a function of the equipment used to make the image and the equipment used to interpret or display the images. The resolution of 35 mm photography is a function of the film and vehicle speed, coverage area, and lighting. Historically, 35 mm photography has had higher resolution than video, although these differences are disappearing with the continued development of digital imaging. Although it can be used directly for manual interpretation, most often the 35 mm photography must be digitized prior to automated image analysis.

Digital images or video are in a digitized format when the image is made, and resolution is a function of the number of pixels per area, vehicle speed, coverage area, and lighting. The resolution of the laser equipment is a function of the size of the laser footprint and the analysis algorithm used to convert changes in texture to distress.

Principle of Line Scan Cameras

The proposed TxDOT method will utilize a line scan camera. Since this is relatively new equipment, a brief explanation is provided.

The line scan camera system can be used to identify distresses more quickly, and with higher resolution, than human vision. This type of camera is installed in many industrial processing machines such as those used in the film, glass, food, and medical industries as well as the electronic industry. Further, line scan cameras are installed in many of the manufacturing lines and utilized as dimension-measuring, position-inspecting devices.

A typical line scan camera consists of a charge coupled device (CCD) element, lens, and driver control circuit. The image of the object is created on the CCD element via the lens, and the quantity of light is converted into a video pulse signal and then output. [Figure 1](#) illustrates this process.

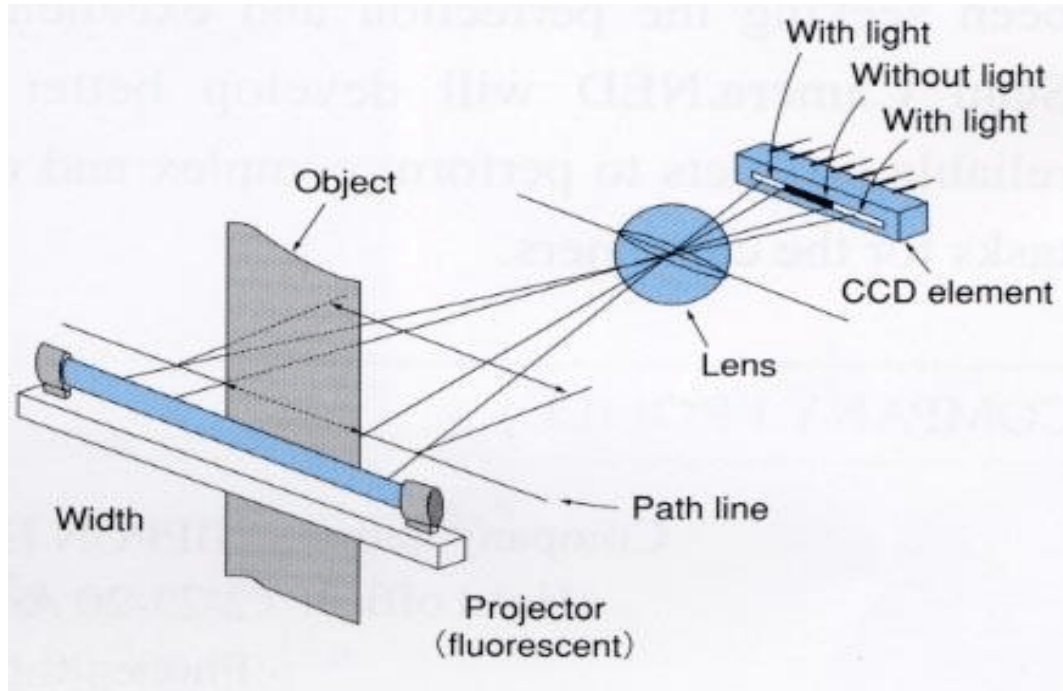


Figure 1. Principle of Line Scan Camera (From w.mmjp.or.jp/ned/english/prod_lsc_first.html).

The following features are provided as a comparison between a line scan camera and an area camera:

- *Higher Resolution*
 A comparison of the resolution between an area camera with 512 pixels and a line scan camera with 5000 pixels in 100 mm field of view is:
 Area camera $100/512 = .195$ mm/pixel, line scan camera $100/5000 = .020$ mm/pixel.
 The resolution of a line scan camera is approximately 10 times (10^2 times in two dimensional) higher than an area camera.
- *Higher Speed*
 A line scan camera can scan at 20 MHz per scan (50 nsec/pixel). The image capture speed by a line scan camera is considerably faster compared to 10 MHz (33.3 msec/frame) for an area camera.
- *Continuous Processing*
 In the inspection of an object which moves continuously, like pavement, it is more difficult to get synchronization with an area camera. However, continuous processing is easily done with a line scan camera because of the video output for each scan.

Precision and accuracy are functions of the interpretation, lighting, and placement of the image during repeat runs. Laser-based systems have more precision problems because they view

small areas that are combined to give estimated distress information. If a repeat run is a few inches (millimeters) off from the location of the first run, the information can be quite different.

For the imaging systems, the images can be affected by shadows from trees, poles, and other overhead or nearby objects. The image can change from one time of day to another as the angle and direction of the sunlight striking the pavement surface change. Any of the methods using vision technology can control the lighting conditions. The pavement and camera can be encapsulated in an enclosure with controlled lighting, or the surveys can be completed at night using fixed lighting. When controlled lighting is used, the lights can be set at a fixed angle to create consistent shadowing to help identify crack widths, elevation differences, etc. There are still many questions about whether these lighting systems can provide enough light to effectively minimize the effects of the sun.

One of the selling points for using more automated distress survey procedures is that they are less subjective than manual surveys, especially with respect to eliminating the rater-to-rater variability. However, subjectivity is a function of the type of interpretation. In many systems, the images are manually interpreted, or at least manually verified. The inspector identifies, quantifies, and records or adjusts distress data from the image rather than from the pavement surface directly. This takes the inspector off the road and reduces traffic interruption, both of which are extremely important for safety on high volume highways. However, subjectivity is still present because a trained observer is still identifying the distress types, severities, and quantities. The resolution is decreased because the trained observer is viewing a two-dimensional photograph or video image rather than the three-dimensional pavement.

The least subjective system is the fully automated analysis of the images. However, image analysis by automated means has been found to be quite complex. The distresses can take many patterns, and complex pattern recognition algorithms must be developed that can distinguish between types of cracks, between a patch and pavement markings, etc. Some distresses, such as weathering and raveling, patching, and potholes, do not appear on images very well and must be interpreted based on surface texture, stereoscopic vision, or other approaches. The pavement surface texture varies considerably between pavement surface types that must be considered in the interpretation. It is also important to consider the fact that colors of pavement surfaces vary considerably.

There are many variations in the interpretation methods described above. Some vendors use a trained observer traveling in the vehicle to press computer keys during the collection that tell the distress interpretation programs to use certain pattern recognition algorithms, e.g., the trained observer presses the key for fatigue or alligator cracking so that the interpretation calls the fatigue-cracking algorithm for that section of the film or video. Some vendors collect the data and run the video through the automated interpretation, but then the film and the results of that analysis are manually edited by a trained observer who makes changes where it is apparent that the automated system is in error. Other combinations could, and probably are, being used. One advantage of all of these systems is that the film or video from which the distress information is extracted can be reviewed later if questions arise. The other key advantage is that the automated systems remove the raters from walking or driving slowly on the road surface, which is a safety concern in most agencies.

Any distress information collected and reduced using automated procedures needs to be carefully analyzed to determine if the accuracy, precision, and resolution meet the requirements of the contracting agency.

INTERPRETING DISTRESS INFORMATION

Distress information can be converted into a condition score, or information on each distress type and severity can be used individually. The condition score combines information from all or some of the distress types, severities, and quantities into a single number. This number can be used at the network level to define the condition state, to identify when treatments are needed, as a part of ranking/prioritization, and in condition projection. Individual distress type, severity, and quantity information at the network level is normally restricted to use in a decision tree procedure to identify feasible treatments. At project level analysis, individual distress information is routinely used in determining the cause of deterioration, identifying feasible treatments, and estimating repair quantities.

Most previous evaluations of distress data collection have considered collecting selected distress types based on standard definitions. Few of them have been used to determine how well the condition indexes from the distress data collection compared to those collected using manual methods. From experience with manual systems, it is apparent that even though there is some

deviation in distress types, severities, and quantities among raters during network level surveys, the condition indexes may agree reasonably well. Since the condition indexes are used as key management indicators at the network level, they can be used if they are reasonably accurate and precise, even if the collection of individual distress types may not give the accuracy, precision, and resolution desired for individual distresses at the project level.

Different surface types have different distress types that must be addressed in condition indexes. Pavements with asphalt concrete (AC) surfaces are the predominant surface type in Texas, and the most important distress types on AC surfaces must be included. Asphalt concrete overlays on portland cement concrete (APC) have reflective cracks and crack deterioration that would not typically be found on other surface types. Pavements with a slurry seal applied to asphalt concrete (slurry) have fine, relatively uniform surface texture. The bituminous surface treatment (BST) pavements have a coarse surface texture that tends to mask some of the distress types, and they tend to have more distresses caused by pavement layer instability. The portland cement concrete (PCC) pavements have a completely different set of distress types, but the amount of PCC pavement in Texas is somewhat limited. Although other pavement surface types are present, they can generally be included in one of these groups. For ease of discussion, when the generic term asphalt is used, it includes all of the asphaltic and bituminous surface types (AC, APC, slurry, and BST). PCC will be used to identify pavements with Portland cement concrete surfaces, and the individual names will be used to address the specific surface types.

PURPOSE OF DISTRESS DATA COLLECTION

Distress surveys are performed to collect data on the entire network (network level), to determine the type and cost of treatment for a specific project (project level), and to collect data for research purposes (research level). These different purposes require different data collection methods and accuracy. The objectives of each are summarized below ([FHWA 1995](#)):

Network level:

- a. Expediency in field condition survey;

- b. Reproducibility of survey results should be provided within a reasonable degree of accuracy; and
- c. Useful information should be provided for identifying potential rehabilitation projects, identifying potential budget needs, and establishing priorities.

Project level:

- a. Reproducibility of survey results within a high degree of accuracy;
- b. Useful information should be provided for identifying causes of failures and determining effective maintenance and repair techniques;
- c. Useful information should be provided for estimating costs of maintenance, repair, and restoration; and
- d. Expediency in field condition survey (e.g., less than one quarter man day per project).

Research level:

- a. Accuracy of survey results with a high degree of reproducibility;
- b. Useful information should be provided for identifying causes of distresses;
- c. Location information should be provided for locating distresses so that they can be tracked over time; and
- d. Expediency in field condition survey (e.g., less than one half man day per project).

Network level inspections are usually conducted by a driving type survey. Project level evaluations can be conducted from a slowly moving vehicle but are also conducted through a walking survey, while research level inspections are usually a detailed walking survey. All three levels could be supported by automated equipment. For the network level, summary statistics would probably be the only output, while for the project and research level detailed distress data would be needed. For the research level, a plot of the distresses would be useful.

CURRENT METHOD OF DISTRESS DATA COLLECTION IN TEXAS

Currently, the method used to conduct network level distress data collection for pavements in Texas involves having crews drive at approximately 15 miles per hour (mph) (24 km/hr) along the shoulder or in the lane and estimate the quantity of each distress type for a given length. For all asphalt surfaces and continuously reinforced concrete pavement (CRCP), the length used to estimate distress is 40 feet (12m), which in the field is the distance from the start of one lane stripe to the start of the next lane stripe. For jointed reinforced concrete pavement (JRCP), most of the distresses are estimated for each slab or joint. Except for the under construction or otherwise identified miles, nearly 100 percent of the system is inspected. For roads that have undivided roadbeds, only one lane (the lane in the worst condition) is inspected. For divided roads, one lane in each direction is inspected. TxDOT hires contractors to perform this service and has TxDOT and personnel from the Texas Transportation Institute (TTI) check the results by performing an audit survey of a small percentage of the pavements.

Prior to the start of the inspection season, contractor, TxDOT, and TTI personnel attend training classes to become certified inspectors for the calendar year. Changes to the manual, including clarifications and interpretations, and inspections of selected sections are used in order to reduce the rater-to-rater variability between inspection teams.

PROBLEMS WITH CURRENT METHOD

In spite of the best efforts of TxDOT and all parties involved, there are significant problems with the current inspection method:

- One problem is certainly the cost. The annual cost of these inspections is approximately \$2,000,000. When the current contract expires and is renegotiated, costs typically increase.
- Vehicles driving very slowly along the shoulder or within the lane are a potential safety hazard for both the inspectors and the traveling public.
- There is considerable variability in the inspections. [Figure 2](#) illustrates the variability of inspection on the sites surveyed during two training classes. Normally, these inspections during class would be expected to be the most consistent and have a smaller standard deviation than there would be during production inspection because:
 - all parties know they are being observed;
 - there would be no “burn out” since only a few pavements are inspected during class;

- there is no incentive, time limit, or rush to finish the inspection;
 - definitions of distresses to be used are fresh in the minds of the inspectors; and
 - there are three or four inspectors in each vehicle so no distresses should be missed.
- Inspectors in different regions may be rating differently. Since there is no overlap of inspections on the same pavements, this hypothesis is never tested.

NEED FOR AUTOMATED SURVEYS

The highest degree of accuracy would be obtained from having a few, well-trained inspectors conducting inspections and drawing crack maps while walking on the pavement that has been closed to traffic. However, the cost, length of time, and level of danger would be prohibitively high. All other methods are a tradeoff from this method, but automated data collection and analysis provides the most benefit, least problems and cost, and potential for the most accuracy.

With a fully automated system, distresses are measured instead of estimated, at a reduced cost, with extremely standardized distress identification and with a reduction of the bias (systematic difference from the norm). With an automated system, the bias will be removed from the rater (including weather, lighting, fatigue, speed of travel, traffic volume, boredom, misidentification, input errors, etc.) and transferred to the hardware and software used to analyze the data. This bias can be measured and improved through better hardware, algorithms, analysis software, and with the development and implementation of rules for dealing with unique situations as they are encountered.

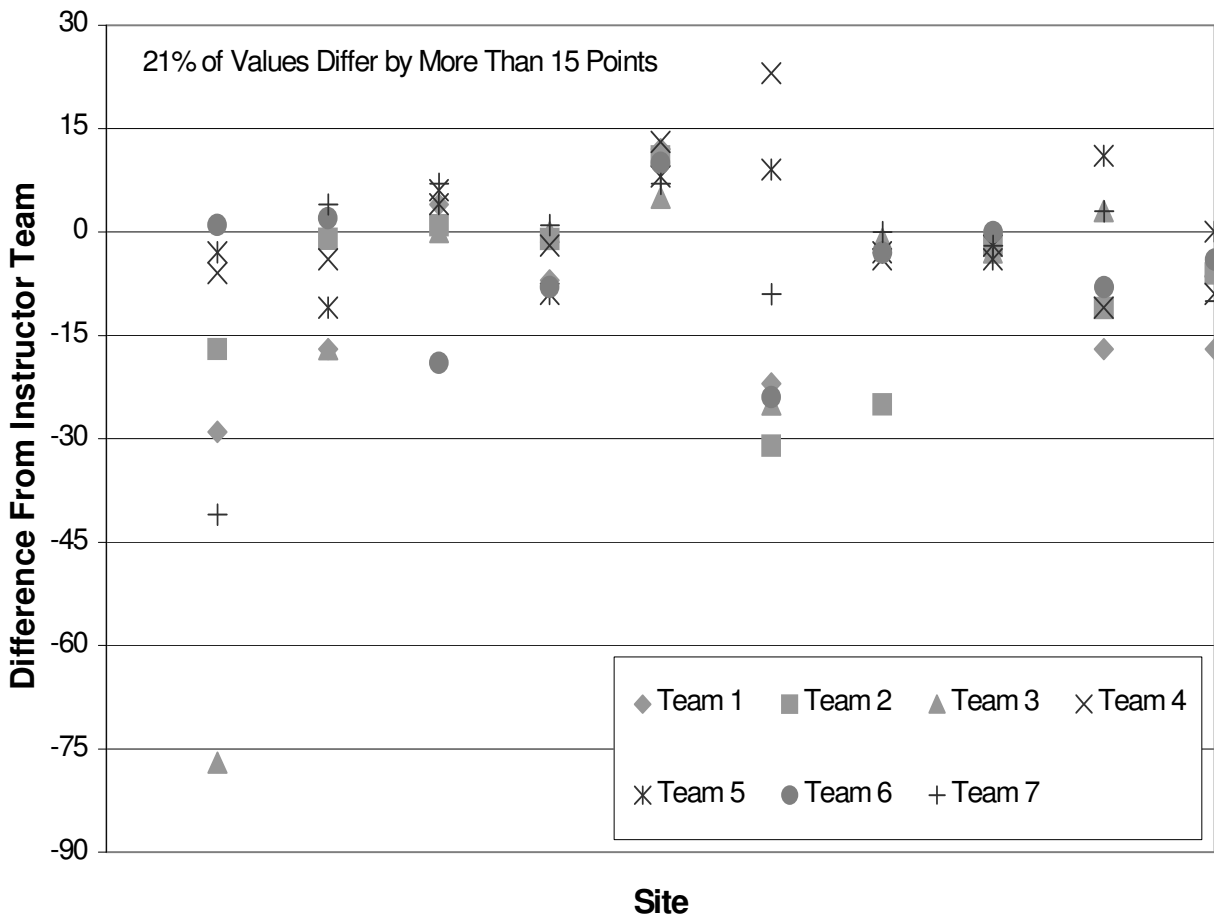


Figure 2. Variance of Inspection during Training Class for 10 Asphalt Pavements Inspected at a Single Training Class.

CHAPTER 2. AUTOMATED DATA TO BE COLLECTED

If an automated system is to be effective in reducing biases present in manual inspections and improving the distress data collection effort, a method to verify the performance of the automated system must be implemented. Prior to describing methods of calibration and standardization, researchers identified the data that needed to be collected.

There will be some trade-offs between a manual method and an automated one. The human eye can accurately recognize differences in color and shading that would be difficult to implement in an automated system. During the training classes, differences in shading often cause problems in identifying patches, raveling, and flushing. Because of these differences, the distresses that would be difficult to identify and quantify using an automated system will probably not be collected through automated means, or will require human interaction.

PMIS DISTRESS TYPES FOR FLEXIBLE PAVEMENTS

[Table 1](#) lists the current distresses used in the TxDOT Pavement Management Information System ([TxDOT 2002](#)). Currently, there are no severity levels associated with the PMIS distress survey. If, with the introduction of this new distress measurement methodology, severities could be defined, they could be implemented. The addition of severities would complicate the process of defining distress but would provide added utility to the PMIS process as wider cracks could be separated and accounted for separately from hairline cracks.

Any automated survey method must accurately, and at least as importantly consistently, quantify and identify the appropriate distress type. Although it is sometimes difficult to obtain consensus, even among qualified inspectors, as to whether a particular distress is still longitudinal cracking or whether it has progressed to the point where it should be considered alligator cracking, once a decision is made, the automated equipment must reliably and consistently identify and measure the distress accurately. The following is a brief discussion on each of the distresses and the difficulties likely to be encountered in identifying the distresses with automated equipment. All quotations and references are from the TxDOT PMIS manual ([TxDOT 2002](#)).

Table 1. FY2003 PMIS Distress Types for Flexible Pavements.

Distress	Measurement
Failures	Number per Section
Block Cracking	Percent Lane Area
Alligator Cracking	Percent Wheel Path Length
Longitudinal Cracking	Length per 100 feet
Transverse Cracking	Number per 100 feet
Rutting-Shallow	Collected with Profiler
Rutting-Deep	Collected with Profiler
Patching	Percent Lane Area
Flushing (Optional)	Category
Raveling (Optional)	Category

Failures

“A failure is a localized section of pavement where the surface has been severely eroded, badly cracked, depressed, or severely shoved. Failures are important to rate because they identify specific structural deficiencies that may pose safety hazards.” This distress is subjective in nature and will require that a few more guidelines be developed that describe the size requirements that constitute a failure. Some of this has already been done and is included in the extended description in the PMIS manual. Because this distress type is often misidentified during training classes and during audit surveys, considerable latitude should be given to the accuracy of defining this distress by an automated survey as long as the identification is consistent.

Block Cracking

“Block cracking consists of interconnecting cracks that divide the pavement surface into approximately rectangular pieces, varying in size from 1 foot by 1 foot (0.3 meter by 0.3 meter) up to 10 feet by 10 feet (3 meters by 3 meters). Although similar in appearance to alligator cracking, block cracks are much larger. Block cracking is not load-associated. Instead, it is commonly caused by shrinkage of the asphalt concrete or by shrinkage of cement or lime-stabilized base courses.” The

difficulty with this distress will be in the identification of the distress. If the automated method views a small picture, the scale will not allow for the recognition of the pattern associated with block cracking. However, block cracking is merely a lot of longitudinal and transverse cracking. Normally, this is called block cracking because it would be difficult to keep track of so much distress when performing a manual survey. The automated method should not have this problem, but converting block cracks into longitudinal and transverse cracks may change the score on previous ratings.

Alligator Cracking

“Alligator cracking consists of interconnecting cracks which form small, irregularly shaped blocks that resemble the patterns found on an alligator's skin. Blocks formed by alligator cracks are less than 1 foot by 1 foot (0.3 meter by 0.3 meter). Larger blocks are rated as block cracking. Alligator cracks are formed whenever the pavement surface is repeatedly flexed under traffic loads. As a result, alligator cracking may indicate improper design or weak structural layers. Heavily loaded vehicles may also cause alligator cracking.” It will be very important to accurately assess this distress, since it has a major impact on the distress score, maintenance level of service, and maintenance needs. Fortunately, because the PMIS survey does not have severity levels, it should be possible to obtain a high level of accuracy and repeatability. With severity levels, the distress has to be assigned to the different categories based on distress definitions that are not easily quantifiable. For example, the Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) distress definitions for fatigue cracking ([SHRP 1993](#)) include the following:

- **LOW**
An area of cracks with no or only a few connecting cracks; cracks are not spalled or sealed; and pumping is not evident.
- **MODERATE**
An area of interconnected cracks forming a complex pattern; cracks may be slightly spalled; cracks may be sealed; and pumping is not evident.
- **HIGH**
An area of moderately or severely spalled interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; and pumping may be evident.

Definitions that include “few,” “slightly,” and “complex pattern” are not as easy to quantify in a computer program as definitions that include a width of cracks. In addition, an area of alligator cracking will contain areas at different severities, which greatly complicates the severity assignment procedure.

Longitudinal Cracking

“Longitudinal cracking consists of cracks or breaks which run approximately parallel to the pavement centerline. Edge cracks, joint or slab cracks, and reflective cracking on composite pavement (i.e., overlaid concrete pavement) may all be rated as longitudinal cracking. Differential movement beneath the surface is the primary cause of longitudinal cracking.” The functional definition of a longitudinal crack is that if it is at least 1/8 inch (3 mm) wide (generally, can be seen while seated in the rating vehicle), it should be recorded as a longitudinal crack. As with alligator cracking, the measurement of longitudinal cracking is both important and relatively straightforward to implement.

Transverse Cracking

“Transverse cracking consists of cracks or breaks which travel at right angles to the pavement centerline. Joint cracks and reflective cracks may also be rated as transverse cracking. Differential movement beneath the pavement surface usually causes transverse cracks. They may also be caused by surface shrinkage due to extreme temperature variations.” Transverse cracks may be the easiest distress to catalog, though narrow cracks (1/8 inch [3 mm] wide) will be more difficult as the speed of travel increases. However, for flexible pavements, they have little impact unless there are many (5 cracks per 100 feet [30.5 m] result in a score of 91-94).

Rutting

Rutting will continue to be collected by automated equipment, but patching, raveling, and flushing will probably be discontinued.

Patching

Patching is considered a distress because it induces roughness and is a measure of the maintenance that has been required on a pavement. However, roughness is already being measured

with the profiler, and the maintenance cost per mile is recorded in another database. Distresses within patches have always been recorded separately. Therefore, except for the loss of continuity between the years where patches were recorded as defects and future years when they are not, there will be little impact. In addition, problems with recording patches have been a continuing problem in PMIS because the definition of what is to be counted as a defect (patch) is continually being debated. For example, a patch that is 495 feet long is a patch, but if it were to be 500 feet long, it would be counted as an overlay and have no impact on the pavement score. One section would be rated as having a score of 74, while the overlay would receive a score of 100. Functionally, these pavements are equivalent. A measure of the complicated nature of patches is that the current PMIS manual contains 11 separate explanations and modifications, called “Special Cases” in the manual.

Flushing and Raveling.

Flushing (sometimes called bleeding) and raveling are optional distresses that do not affect the distress score. While these optional distresses may be useful in identifying pavements needing routine or preventive maintenance, comprehensive skid testing rather than the network level approach of one skid test per half-mile[0.8 km]) provides a more quantifiable measure of pavements that need attention.

PMIS DISTRESS TYPES FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS (CRCP)

Table 2 lists the current distresses used in the TxDOT Pavement Management Information System (TxDOT 2002) for CRCP pavements. All quotations and references are from the TxDOT PMIS manual (TxDOT 2002).

Table 2. FY2003 PMIS Distress Types for Continuously Reinforced Concrete Pavements.

Distress	Measurement
Spalled Cracks	Number per Section
Punchouts	Number per Section
Asphalt Patches	Number per Section
Concrete Patches	Number per Section
Average (Transverse) Crack Spacing	Distance

Spalled Cracks

“A spalled crack is a crack that shows signs of chipping on either side, along some or all of its width.” The distress definition also includes a width definition (spall is greater than 3 inches [76 mm]), so the automated system should improve the accuracy of identifying this distress since the 3 inch [76 mm] width is difficult to estimate while in a moving vehicle. The spalled crack distress is often a source of substantial variation in the rater class ratings.

Punchouts

“A typical punchout is a full depth block of pavement formed when one longitudinal crack crosses two transverse cracks. Although usually rectangular in shape, some punchouts may appear in other shapes.” This distress can be difficult to accurately and consistently recognize during a field survey and will be difficult to completely describe and identify for the automated survey.

Asphalt Patches

“An asphalt patch is a localized area of asphalt concrete which has been placed to the full depth of the surrounding concrete slab, as a temporary method of correcting surface or structural defects.” This distress may need to be abandoned, but the defects that were patched usually reflect through the patch in time.

Concrete Patches

“A concrete patch (a ‘longer lasting’ repair) is a localized area of newer concrete which has been placed to the full depth of the existing slab as a method of correcting surface or structural defects.” Concrete patches may not be identified during an automated survey.

Average Crack Spacing

“Average crack spacing is not, in itself, a pavement distress type. It is rated as a method of obtaining the percentage of transverse cracks that are spalled. However, average crack spacing is valuable as a measure of whether or not the CRCP slab is behaving as designed. A CRCP section with a small average crack spacing may deteriorate rapidly into a series of small punchouts if the proper corrective procedures are not applied.” This distress should be easy to measure using the automated method; however, at high speeds the narrow cracks may be a problem. Fortunately, it does not have a big impact.

PMIS DISTRESS TYPES FOR JOINTED CONCRETE PAVEMENTS (JCP)

Table 3 lists the current distresses used in the TxDOT Pavement Management Information System (TxDOT 2002) for JCP pavements. All quotations and references are from the TxDOT PMIS manual (TxDOT 2002).

Table 3. FY2003 PMIS Distress Types for Jointed Concrete Pavements.

Distress	Measurement
Failed Joints and Cracks	Number per Section
Failures	Number per Section
Shattered (Failed) Slabs	Number per Section
Slabs with Longitudinal Cracks	Number of Slabs per Section
Concrete Patches	Number per Section
Average Joint Spacing	Distance

Failed Joints and Cracks

“The distress type ‘failed joints and cracks’ covers two major items: spalled joints and transverse cracks, and asphalt patches of spalled joints and transverse cracks.” Although the definitions for this distress are straightforward and well defined, considerable variability in results was typical for the raters classes.

Failures

“Failures are localized areas in which traffic loads do not appear to be transferred across the reinforcing bars. Failures are typically areas of surface distortion or disintegration.” Failures on JCP were usually identified fairly consistently in the classes but will be difficult to implement in an automated system.

Shattered Slabs

“A shattered slab is a slab that is so badly cracked that it warrants complete replacement.” This distress was also identified fairly consistently and accurately with the manual method. Many examples will need to be verified to ensure the automated system is rating properly.

Slabs with Longitudinal Cracks

“A longitudinal crack is a crack that roughly parallels the roadbed centerline.” Although this distress was sometimes misidentified, most of the time inspectors were accurate. Since the measurements are fairly well defined, the automated system should be able to identify this distress consistently.

Concrete Patches

“A concrete patch (a ‘longer lasting’ repair) is a localized area of newer concrete which has been placed to the full depth of the existing slab as a method of correcting surface or structural defects.” This distress will be very difficult to implement in an automated system, but as with asphalt patches on asphalt pavements, the impact of ignoring this distress should be small. However, an automated system may identify the patches as longitudinal and transverse cracks.

Apparent Joint Spacing

“Some transverse cracks may become so wide (long) that they look and act like joints. The crack must be greater than ½ inch (13 mm) wide (long) across the complete width of the lane. These ‘apparent’ joints are important because they serve to divide the original slab into smaller units.”

AASHTO DISTRESS PROTOCOL

Currently, the American Association of State Highway and Transportation Officials (AASHTO) is in the process of developing and adopting a standard that will assist agencies and vendors in establishing a common set of definitions and data collection requirements for distress data collection. If an acceptable standard can be developed, agencies will be able to compare data more effectively, and data collection equipment and algorithms can be standardized. To date, a provisional standard, PP 44, “Quantifying Cracks in Asphalt Surface Pavements,” has been developed. Some of the interesting features of this standard are that cracks are assigned to either in the wheelpath or between wheelpaths. [Figure 3](#) illustrates these designations.

[Table 4](#) lists some of the interesting features of the provisional standard. If TxDOT were to adopt this method, it would require several modifications to the PMIS program. For example, there would be no alligator cracking. Instead, the length of cracks in an alligator-cracked area, which

would be considerable, would be recorded. In addition, the width of cracks would be used to develop severity levels, which are not currently used by TxDOT.

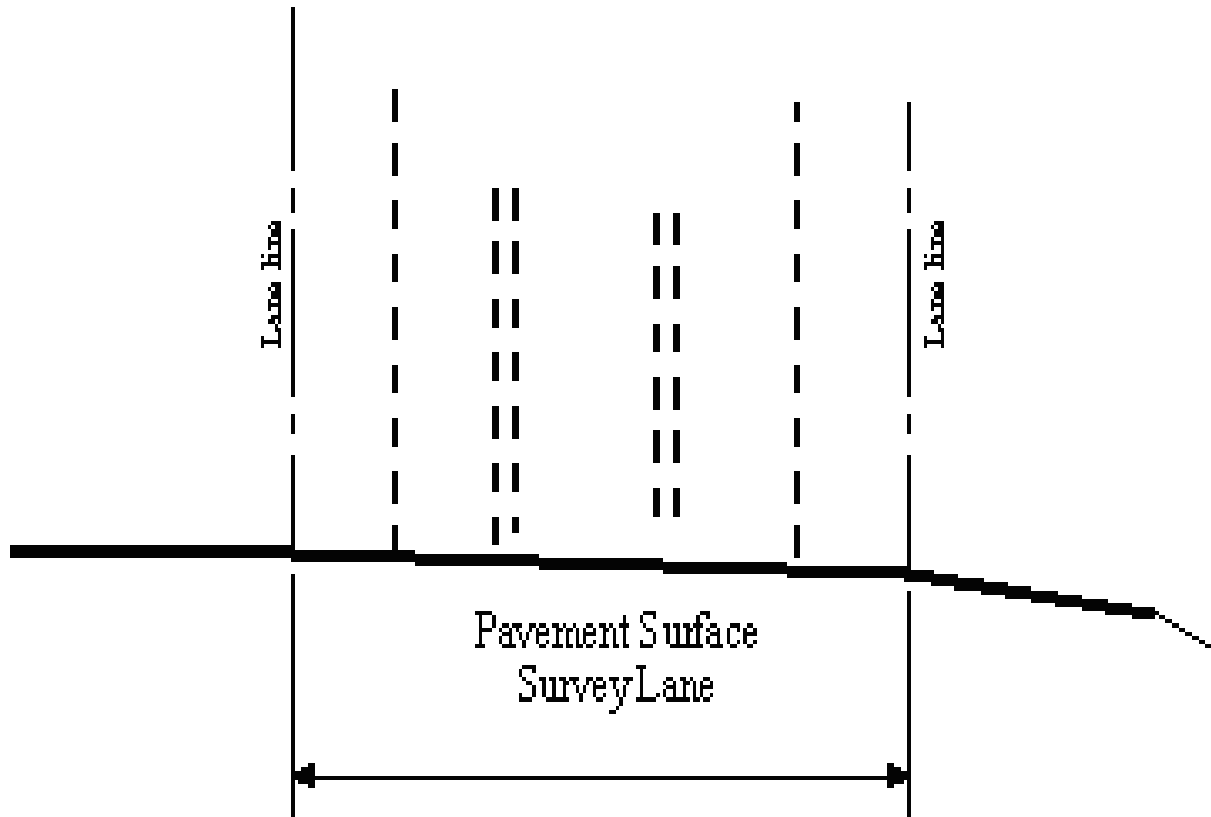


Figure 3. Crack Locations for AASHTO Provisional Standard.

Table 4. Selected Items from the AASHTO Provisional Standard (Maryland 2002).

Item	Study Factor
Scope	Automated Survey – Use a vehicle traveling at near highway speeds and collect data on the entire length of roadway.
	Manual Surveys – Observe distresses and record data at a minimum percent sample of the lane surveyed. Rating continuous film or tape in an office setting is considered a manual survey.
Cracking Definition	Survey an 8 ft (2.500 m) strip in the outside lane. As another option, survey the 12 ft (3.6m) full lane width.
	For undivided highways, survey one direction.
	For divided highways, survey the outside lane in both directions.
	Sealed cracks will not be quantified by manual surveys. Automated survey equipment will not quantify any discontinuity greater than 25 mm.
	Wheel path cracking is determined in both inside and outside wheel path as shown in Figure 2 (Figure 3 in this report).
	Non-wheel path cracking is determined in the area between the wheel path as shown in Figure 2 (Figure 3 in this report).
	Additional non-wheel path cracking will be defined by the agency.
	Severity level 1 crack classified as $> .04$ and $\leq .12$ inch (> 1 mm and ≤ 3 mm).
	Severity level 2 crack is $> .12$ and $\leq .24$ inch (> 3 mm and ≤ 6 mm).
	Severity level 3 crack is $> .24$ inch (> 6 mm).
	Quantify intensity of each cracking level as the total length of cracking per unit area (ft/ft^2 or m/m^2) for each defined survey strip.
Recording of Data	The length of the data collection section is determined by the agency and shall be between 0.06 mile and 0.6 mile (0.10 km and 1.0 km).
	The entire length of the data collection section shall be surveyed (100 percent sample).
	The data summary interval shall be 0.06 mile (0.1 km).
	Minimum data recorded requirements.
Quality Assurance	Qualification and training
	Equipment
	Validation sections
	Additional checks

CHAPTER 3. METHODS OF ESTABLISHING PERFORMANCE

NEED FOR CALIBRATION AND STANDARDIZATION

If an automated system is to be effective in reducing the biases detailed previously, and improve the distress data collection effort, it must provide accurate and repeatable results. As was discussed earlier, accuracy is the degree to which the method provides a value that matches an accepted reference value (ASTM 1992). Precision is the closeness of agreement, or repeatability, among multiple measurements obtained under defined conditions (ASTM 1992). Resolution is the smallest increment that can be measured. All are necessary for an effective measurement, and all must be determined. Although the goal would be to have perfect accuracy, precision, and resolution, the standard should be whether the proposed method provides better (more accurate, precise, and higher resolution) or cheaper results than the current method. The accuracy of the current manual method is described in the final report of project 0-1861 - Statistical Analysis of PMIS Data Elements, which has not yet been published. This chapter will consider proposed methods of measuring the performance of the automated system.

METHODS INVESTIGATED

The project team developed, investigated, and discussed several methods of establishing the accuracy, precision, and resolution, and after much discussion, the list was narrowed to the following four proposed methods:

Pavement Test Sections

The first, and most obvious, method that could be used to verify the performance of the automated system is to establish physical test sections on in-service pavement sections. An experiment design of different distresses and pavement types, and the resulting test section location, would be developed. Some sections would have wide cracks, while others would have narrow and very narrow cracks. Ideally, many of these sections would have been at the TTI Riverside Annex, where the maintenance could be controlled.

This method was rejected because it would require constant re-inspection to ensure that conditions would not change or that the current condition was accurately documented. These

inspections would be subject to all of the problems discussed earlier regarding bias, and without accurate, consistent results, it would be difficult to establish calibration or certification limits.

Video Projection

Researchers discussed an “outside the box” proposal where high quality videos of test sections in different conditions would be obtained and the images projected onto a screen where the automated equipment would analyze the images.

This idea was rejected because the images would not be realistic, and sufficient resolution to provide appropriate images could not be guaranteed.

Mylar Clamped to Road Surface

One promising method investigated was to fabricate long sheets of mylar or canvas that could be clamped to the road surface and have the automated equipment drive over the sheets. With this method, the sheets would be very consistent, different types of cracks would be drawn as realistically as possible, different backgrounds could be tested, and different widths of cracks could be represented, which would allow researchers to accurately measure the resolution.

However, the cost of developing 500 foot long (152.4 m) sheets, clamping them tightly enough to the road that the moving vehicle would not rip them, and the potential damage to these expensive sheets, made this method undesirable.

Mylar or Canvas on a Rolling Platform

Finally, the proposed method was to fabricate a device that would have mylar sheets on a roll that would pass under the automated equipment. Sheets that have different distresses, crack widths, backgrounds, and representing different surface types can be developed and used. A speed control is used to determine the highest speed that resolution is maintained was made a part of the design.

The proposed method does have some drawbacks. Instead of being a 12 feet (3.7 m) wide, or lane width, the image will be smaller due to fabric and printing constraints. The next chapter discusses this design in more detail.

DIGITAL PRINTERS AND SOFTWARE

The researchers found printers that were designed specifically for printing on cloth or fabric that would suffice for printing road distresses. To purchase and operate the unit would not be cost effective due to the low number of prints needed. At the time of the report the printer cost \$14,000 for a model 850 that prints 60 inches wide. Printer controlling software costs \$3500. The production software for importing the highway distress images costs between \$6000 and \$12,000. Other overhead costs, such as maintenance, ink, nylon, and other consumables, would increase the cost. To solve these problems, researchers found companies in Austin, San Diego, and New York that were able to produce the prints of the quality required on the material specified. These companies could make a print on nylon, for example, for approximately \$5500. This is the most cost-effective option.

CHAPTER 4. PROTOTYPE RESULTS AND LESSONS LEARNED

PROTOTYPE DEVELOPMENT

The design of the prototype was discussed in several project meetings. It was agreed that the prototype crack simulator would be as simple as possible while still fulfilling the requirements. The unit was designed so that readily available, existing materials could be used for crack simulation. The design was based on standard mylar film that could be easily printed on production-type roll printers. With this design, a 3 foot (0.9 m) wide footprint was the maximum width that could be used without expensive, specialized equipment. Since the TxDOT camera uses a line scan camera, the length of the mylar film was not a critical dimension in the initial prototype. The optimal speed of the simulator was to be designed to be 60 mph (96.6 km/hr). This criterion was given to the design engineer at the Texas Engineering Extension Service (TEES) machine shop. Although there were numerous delays and problems to be solved, the final version of the prototype crack simulator with a mylar film of longitudinal cracking is shown in [Figure 4](#).

The crack designs were printed on mylar sheets, as shown in [Figure 5](#), and were taped and heat treated to seal the joint in order to make a circular unit that could be placed on the prototype crack simulator. After consultation with TxDOT, it was decided that the printed simulated cracks would be made in .04, .08, .12, and .15 inch (1 mm, 2 mm, 3 mm, and 4 mm) printed widths. [Figure 6](#) shows the stack of finished printouts. The prototype was tested with the printed cracks. One of the major concerns was whether there would be adequate strength in the heated tape bond at the two ends of the mylar. Testing showed this taped bond between the ends of the mylar to be acceptable and relatively durable.

There were several difficulties with the prototype. The unit had excessive vibration at speeds over 30 mph (48.3 km/hr). The vibration caused the breakage of the arbor of the drive motor, which caused a slight setback in further testing. A static electricity buildup between the white plastic background plate and the mylar caused problems during operation. The residual static electricity remains on the system and causes an attraction between the mylar and the plastic background. This attraction was enough to cause a drag on the speed of the motor. Some of the workable solutions to avoid this problem included inserting a small solid tube of teflon between the background plate

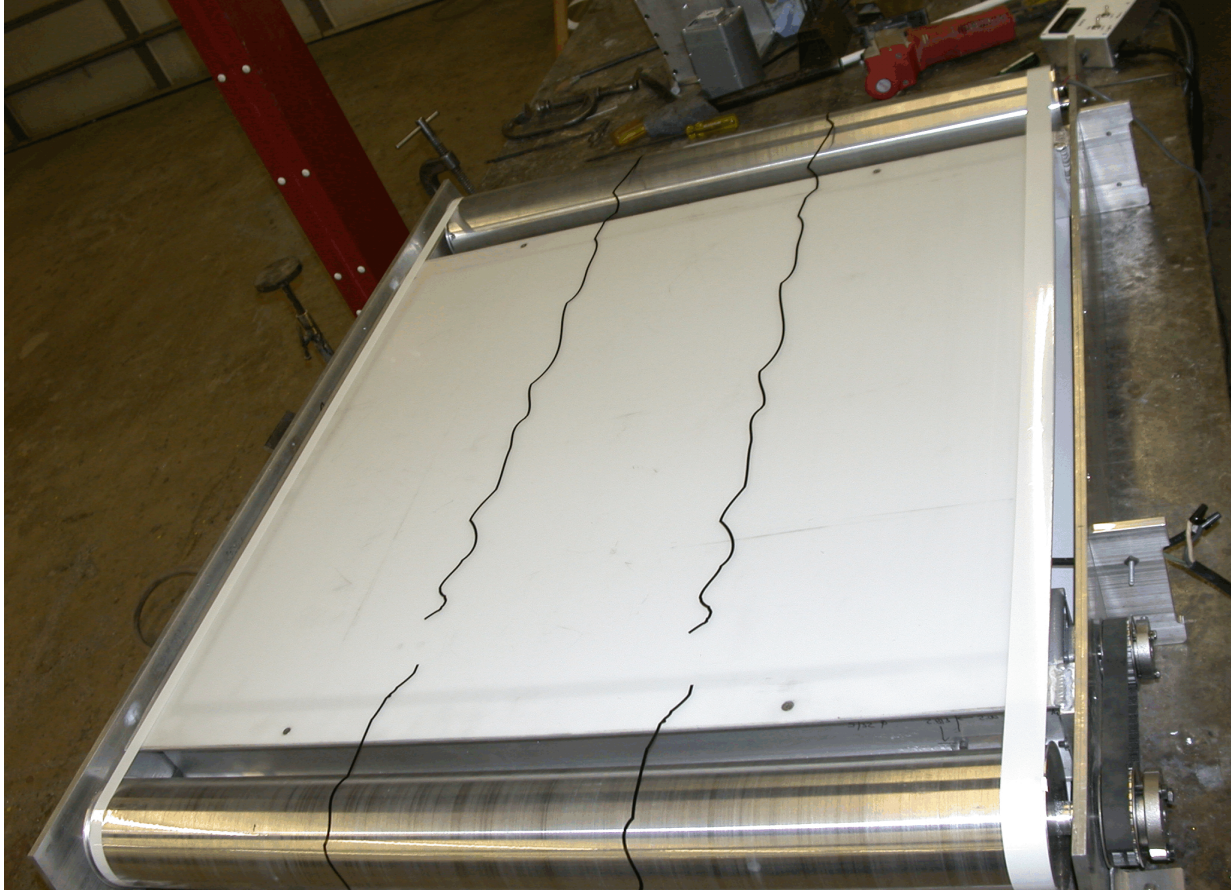


Figure 4. Prototype Crack Simulator.



Figure 5. Printing Simulated Crack.



Figure 6. Stack of Test Plots.

and the mylar or using a container of antistatic solution used for computer monitors. The antistatic solution worked the best. The static did not build up, so there was no static drag between the mylar and the plastic backing plate.

The Center for Transportation Research (CTR) brought over the line scan camera and real-time analysis system to test the crack simulator prototype. After some camera-mounting adapters were fabricated, the camera system was set up. CTR adjusted the analysis system before coming to TTI to account for the white-colored background with black lines simulating cracks. Even though there was optimum contrast, CTR's system was set for gray and black colors that resemble asphalt pavement. The testing was conducted indoors. There was a problem with glare from the fluorescent overhead light on the mylar film. Alternative flood lights were used, and the overhead lights were turned off (Figure 7).

Different types of pavement distress were tested. These included single longitudinal cracking, double longitudinal cracking, transverse cracking, alligator cracking, and block cracking patterns. At first, the prototype crack simulator was bolted to the floor, but it was decided that the camera system worked well throughout the range of available speeds the prototype could produce. The researchers decided to operate at a relatively slow speed, mostly for the convenience of the researchers trying to count the revolutions and observe the performance. The continuous loops were changed to test and demonstrate the different cracking patterns. The researchers first tried the 0.16 inch (4 mm) line width for the cracks. CTR's camera system was able to identify and quantify the crack pattern. Researchers then mounted the .04 inch (1 mm) crack width pattern, and again the camera system was able to identify and quantify the pattern; however, for the .04 inch (1 mm) crack width pattern, the camera system was not always able to capture a small portion of the fringes. [Figure 8](#) shows the monitor illustrating the recognition and capture of a block crack pattern.

The pattern shown on the monitor is the same pattern that was drawn on the mylar. The crack width that was used was .08 inch (2 mm) wide.

The prototype crack simulator functioned acceptably well for its intended purpose. The use of a continuous loop mylar system proved to be a viable solution. The difficulties with the current prototype include controlling the velocity of the mylar, knowing the number of revolutions, manufacturing the continuous loop, and changing from one crack type or loop to another crack type.



Figure 7. Testing of Prototype Crack Simulator.

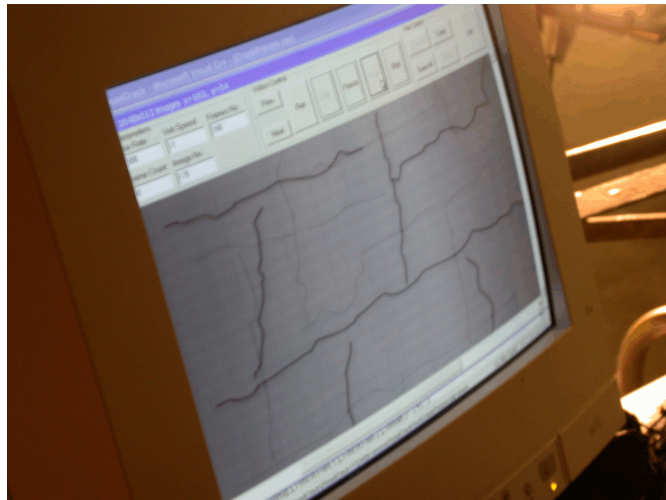


Figure 8. Recognized Block Cracking.

In order to move to the production machine, researchers have determined that the images will need to be printed on nylon or vinyl material. The next chapter discusses the costs and options that were investigated.

CHAPTER 5. SPECIFICATION FOR PRODUCTION EQUIPMENT

The prototype crack simulator worked effectively well. After discussions with the project director and CTR researchers, two conceptual designs were preferred. Design 1 would be a unit with a 5 foot (1.5 m) wide simulated road bed (5 feet being close to a half lane width). This should be a viable device for automated pavement analysis devices. The distresses would be printed on a continuous 5 foot wide material to make a scroll-type system. The scrolling system will need to have lead-in and lead-out sections so the system can reach a steady state velocity. Design 1 would also have a controller to automatically start, stop, forward, and reverse, and maintain the predetermined velocity of the scrolling simulated pavement distresses. The simulated pavement distresses are to be on one sheet with a transition between each of the distress types. The lower velocity worked acceptably well during the acceptance testing. The simulated pavement distress can be printed on a 360 dots per inch (dpi) printer or a 1200 dpi printer with the trade-off being durability of the printed medium. If the 360 dpi system is used, the full 5 feet can be printed and a more durable medium can be used. If the 1200 dpi system is used, only 59.5 inches (1.5 m) wide can be printed and a slightly less durable medium will be used. The cost of a 70 foot (21.3 m) long by 5 foot wide printout for the described processes, when this report was written, ranged from \$2300 to \$3000 for vinyl. Using the fabric printing system, a pavement distress could be printed on nylon for \$4500 to \$5500. The electro-mechanical system will have two reels for the scrolling subsystem operated by a DC motor. The camera viewing platform will be 5 feet long by 5 feet wide. The control panel should include speed control, distance, and a pulsar output. The pulsar output will allow for synchronization of crack analysis systems to the speed of Design 1. The cost estimate for Design 1 is \$ 16,000 for the frame with the controlling system. After adding the \$3000 for the simulated 70 foot long by 5 foot wide pavement cracking, Design 1 should cost \$19,000 to \$23,000.

Design 2 is a scaled down version of Design 1. Design 2 would only have a camera viewing bed of 3 feet wide by 1 foot long. Design 2 is more specifically designed for the CTR unit and could be taken to the field as a calibration or functional check unit. The cost of this unit would be less than Design 1.

Figure 9 is a schematic diagram of the production unit.

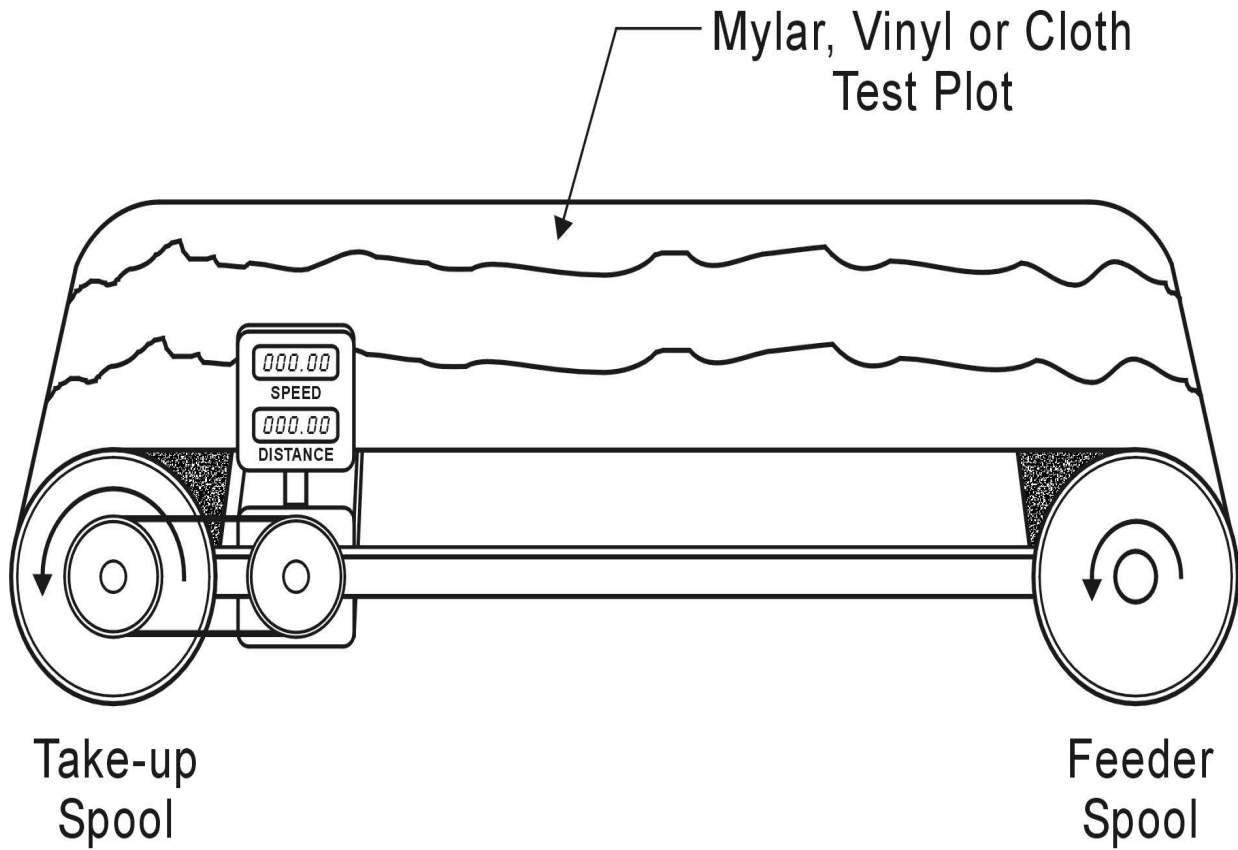


Figure 9. Schematic of Prototype Crack Simulator.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

The development of the prototype crack simulator has proven the viability of the selected approach. The continuous loop machine will allow for calibration of hardware and software without the problems associated with field test sections, video projection, or mylar clamped to the road. Different crack patterns and crack widths can be simulated and substituted with ease or moderate effort. Variable speed controls will allow units to be calibrated and certified at different speeds with known results.

Researchers recommend that TxDOT build and implement both of the designs described in the previous chapter. The sooner the manual methods currently in use can be replaced with calibrated, certified, automated equipment, the better the information on the actual condition of pavements in Texas will be available to administration, maintenance, pavement design, and researchers.

The researchers investigated methods of producing the prints of the distress images and found several companies that are able to produce the prints of the quality required on either nylon or vinyl. This is the most cost-effective option.

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