Comparison of Methods and Equipment To Conduct Pavement Distress Surveys

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Selected distress survey methods and equipment, representing a range in automation, were tested and evaluated. The following methods and devices were included in the testing: manual mapping; detailed visual surveys using manual recording and automatic data logging; and the PASCO ROADRECON, Groupe Examen Routier Photographic (GERPHO), Automatic Road Analyzer (ARAN), and Laser Road Surface Tester (RST) high-speed survey vehicles. Field tests were conducted on flexible, rigid, and composite pavements exhibiting a range of pavement distresses. The distress survey methods and equipment were evaluated based on their performance and capabilities in the field. The study concludes that, at present, the GERPHO and PASCO ROADRECON can be used for both network level and project level distress surveys and are well suited for pavement research studies. The ARAN and Laser RST are recommended for consideration in network-level surveys. It is also recommended that automatic data loggers be used when manual distress surveys are conducted.

The Strategic Highway Research Program (SHRP) will produce results in the areas of pavement design, construction, and rehabilitation. One phase of this program is entitled "Long-Term Pavement Performance" (LTPP) and will involve the collection of uniform evaluation and performance data on numerous pavement sections throughout the United States. The Federal Highway Administration initiated the study Pavement Condition Monitoring Methods and Equipment to assist in this effort by providing a better understanding of the procedures and devices that are used to evaluate pavements. Although the study was initiated to aid in the SHRP-LTPP program, the results that were produced are of great value to state highway agencies and other agencies in their project- and network-level pavement management. This paper documents information pertaining to the study in which selected distress survey methods and devices were tested and evaluated (*1*).

INTRODUCTION

Pavement distress surveys, or condition surveys, are an important part of any pavement performance study or management system. They are used to quantify the condition of a pavement by classifying the amount and extent of distress present at a given time. The information collected from distress surveys can be used to document the performance of a pavement and can help determine appropriate rehabilitation alternatives.

Distress surveys have been traditionally performed by raters who walk or drive along the road and classify the distresses based on their visual observations. The distresses are recorded on data forms and the information is later reduced in the office. This type of manual procedure is slow, labor-intensive, and subject to transcription errors. Consistency between classification and quantification of the distresses can also be a problem.

Methods have been devised by various agencies to standardize distress classifications and to speed up the process by automating the recording, reduction, processing, and storage of the data. Condition survey manuals which define distress classifications using pictures and detailed descriptions have been developed to minimize interpretation differences among raters. Some procedures employ detailed measurements of the distress to minimize quantification errors. Small, hand-held computers and data loggers have been used to improve efficiency in recording and transferring the data from field to office. Vehicles which take photographs or other visual images of the pavement to be later interpreted in the office were developed to speed the field data collection time and provide a permanent visual record of the actual pavement condition. Other survey vehicles carry on-board microcomputers for manual entry, recording, and storage of the data directly in the field. In addition, a new class of condition survey vehicles is emerging which uses objective measures of the pavement surface to classify and quantify different types of distress.

The type and extent of condition survey performed depend upon its intended use. Condition surveys for network-level screening of sections may need only a windshield survey of the pavement in which only a few distresses are rated. At the other end of the spectrum are the detailed condition surveys needed for research studies such as SHRP-LTPP. This type of survey attempts to classify and quantify precisely all distresses and other features of a pavement which may influence its performance. The required level of effort and cost to conduct these different types of condition surveys varies with the intensity of the data collection effort.

EQUIPMENT SELECTED FOR FIELD TESTING

To study improved methods of conducting distress surveys, a variety of distress survey procedures employing different levels of automation were selected for field testing. The base level of distress survey methods was manual mapping of the

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distress on the pavement section. The next level was using a detailed visual survey in which the distresses were recorded on data sheets. A detailed visual survey was also conducted using an automated data logger. The next level of automation was using photographic survey vehicles in which the film was interpreted in the office. Two other survey vehicles, which combined the use of on-board computers to record data and objective measures to detect and quantify certain types of distresses, were also investigated in this study. The distress survey methods and devices selected for the field testing were as follows:

- Manual mapping
- Detailed visual survey, manual recording
- Detailed visual survey, automated data logging
- PASCO ROADRECON survey vehicle, featuring photographic equipment and laser height sensors
- GERPHO survey vehicle, featuring photographic equipment
- Automatic Road Analyzer (ARAN) survey vehicle, featuring video equipment, ultrasonic height sensors, and on-board computer
- Laser Road Surface Tester (RST) survey vehicle, featuring laser height sensors and on-board computer

DESCRIPTION OF SELECTED METHODS AND EQUIPMENT

A description of each of the distress survey procedures and devices selected for field testing is presented below.

Manual Mapping

The manual mapping method used for field testing consisted of a rater walking the pavement section and manually drawing a map showing the type and exact location of all distresses present on the section. This procedure is similar to the one used at the AASHO road test (*2*). The severity level of each distress was identified and recorded on the map. The mapping form shown in figure 1 was used to record the distresses. All distresses were identified and measured according to the standards found in the Highway Pavement Distress Identification Manual (*3*).

Detailed Visual Survey

The PAVER and Concrete Pavement Evaluation System (COPES) methods of conducting condition surveys were

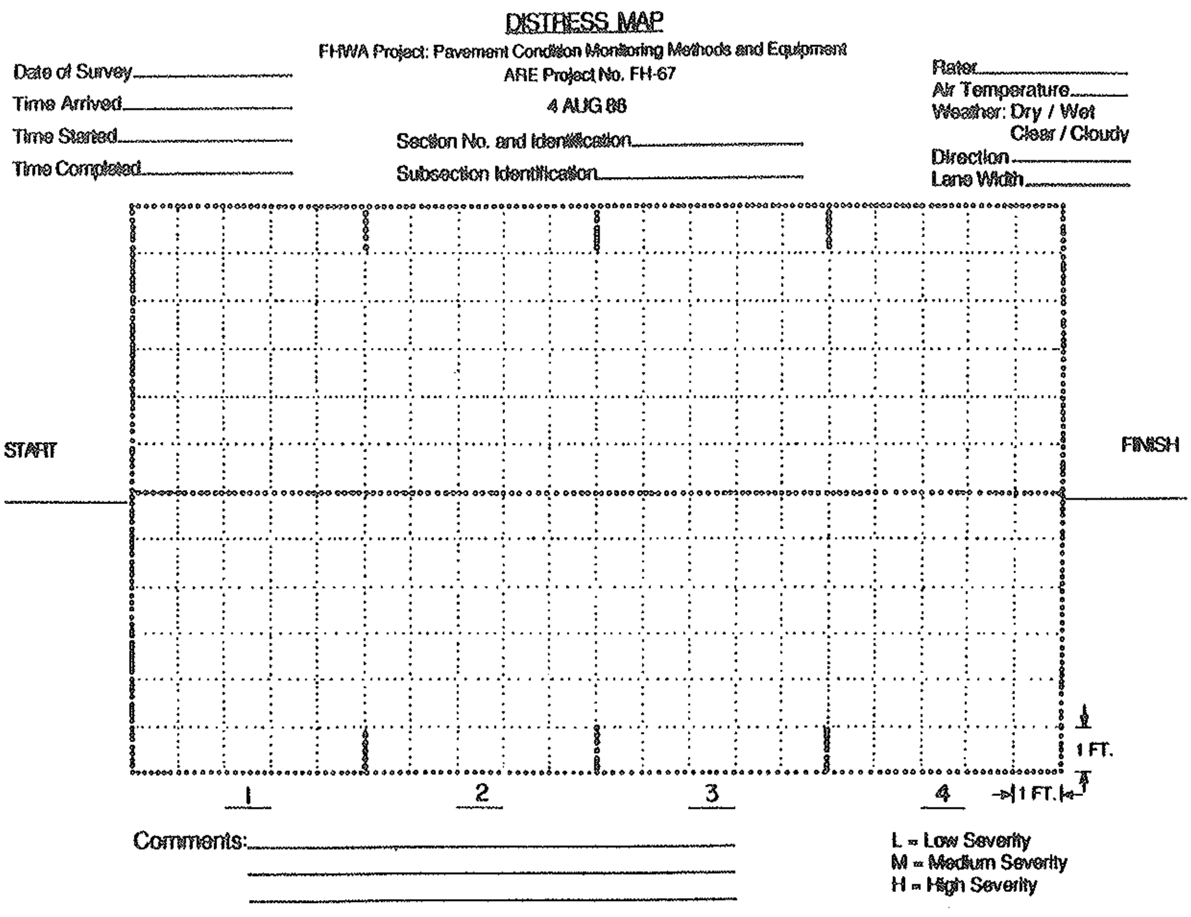

FIGURE 1 Manual mapping form used in the field.

selected as representative detailed visual distress survey methods. PAVER is a pavement evaluation system developed by the U.S. Army Construction Engineering Research Laboratory (*4*). The detailed condition survey procedure employed by the PAVER system was used for the flexible, composite, and jointed reinforced concrete pavement sections in the field study. The COPES distress survey method was used to rate the continuously reinforced concrete pavement (CRCP) sections, since PAVER was not developed for CRCP. COPES was developed in an NCHRP study (*5*) for evaluation of plain jointed, jointed reinforced, and continuously reinforced concrete pavement.

Automated Data Logger

The detailed distress survey using a field data logger was performed using a battery-operated Epson HX-20 portable computer programmed by ARE Inc. to record distress and section information. The interactive program prompts the rater for input of the severity and extent of each previously defined distress category. The information is stored on a computer-encoded microcassette. This allows the information to be downloaded in the office, using hardwired connections between computers and a communications program. Paper tapes that are produced in the field as the information is recorded serve as a backup. The automatic data logging keyboard is shown in figure 2.

Flexible pavement sections were rated using a procedure developed for the Rhode Island Department of Transportation by ARE Inc. (*6*), since the Epson was already programmed for this procedure. The distress categories were similar to those used in the PAVER system. The distress categories from the COPES method were used for the rigid pavement sections.

PASCO ROADRECON Systems

PASCO Corporation of Japan developed the continuous pavement surface photographing device (ROADRECON-70) in the late 1960s (*7*). The first operational survey vehicle was produced in 1970. Cracking, patching, and other distresses are recorded using the ROADRECON-70. The vehicle travels at speeds between 3 and 53 mph (5 and 85 kmph). A continuous photographic record of the pavement surface is made using a 35-mm slit camera. The system synchronizes film feed speed and camera aperture with the speed of the vehicle in order to equalize image density and photographic reduction. Road width of up to 16 feet (5 m) can be filmed.

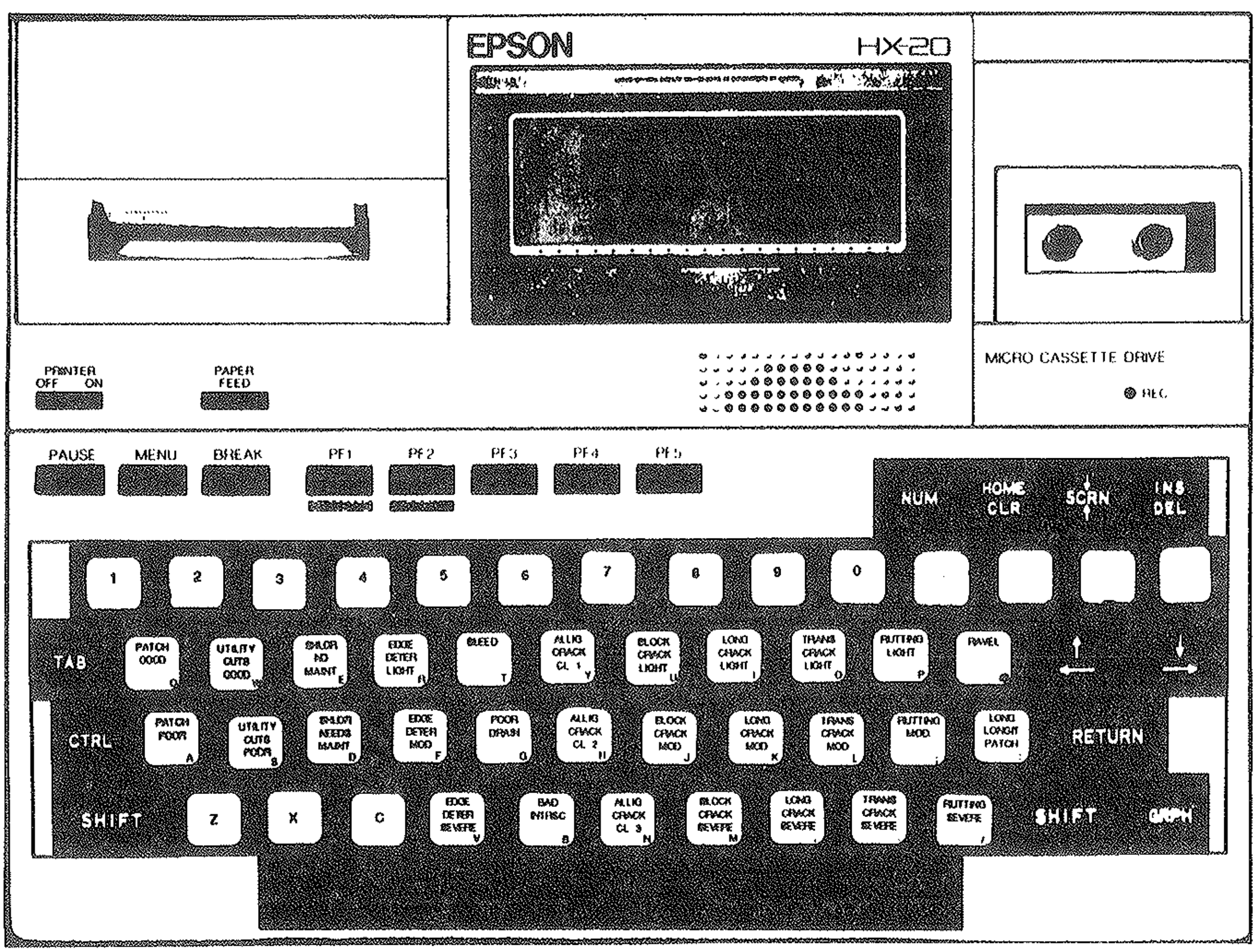

FIGURE 2 Epson HX-20 keyboard used for automatic distress data logging.

Photographing is performed at night using on-board lights. The lights are set at an angle to the road surface so that shadows are produced at cracks and other defects in the surface, making interpretation easier. Interpretations of the distresses are made by a technician viewing the developed 35-mm film enlarged ten times on the ROADRECON film digitizer. A grid pattern is overlaid on the film to aid in quantification of the distress for input into a computer database. The ROADRECON-70 survey vehicle and other systems used for the field testing are illustrated in figure 3.

Rut depth surveys can be carried out at speeds up to 50 mph (80 kmph) using the ROADRECON-75 system (*7*). A pulse camera mounted on the vehicle photographs hairline optical bars projected onto the road. The camera shutter and hairline projector are synchronized according to the distance covered by the projection vehicle, so the system is able to create a photographic record of rutting at variable distance intervals. The film is projected onto a digitizing table and traced with a computer "mouse," enabling the wave patterns to be processed into a transverse profile of the pavement surface.

Longitudinal roughness can be measured with the ROADRECON-77 by means of a tracking wheel, differential transformer, and an accelerometer. Longitudinal profile measurements can be made with this device at speeds up to 38 mph (60 kmph) (*7*). The data are stored on magnetic cassette tapes and plotted on a strip chart. Roughness is expressed as the standard deviation of the pavement profile measurements.

A high-speed automatic longitudinal profile and rutting survey device (ROADRECON-85B) was developed to measure longitudinal profile and estimate rutting at speeds up to 50 mph (80 kmph) (*7*). Three laser sensors, mounted on the rear bumper, are used to measure the longitudinal profile in the center of the vehicle and in both wheel paths. The data are recorded on magnetic tape and/or a paper chart.

GERPHO System

The Groupe Examen Routier Photographic (GERPHO) system, developed in France by the Ministere des Transports, employs a survey vehicle to take continuous 35-mm photographs of the pavement surface (*8*). The GERPHO has been used extensively in France since 1972. It has also been used to a limited extent in several other countries, including Spain, Portugal, and Tunisia (*9*). This system is similar to the PASCO ROADRECON-70.

The GERPHO system consists of a 35-mm continuously running (strip film) camera, mounted on a van, with a light source that illuminates the pavement, as illustrated in figure 4. The pavement surveys are conducted at night to allow for uniform lighting conditions. The camera is fitted with a 14.5-mm lens with an aperture of F-3.5. The picture covers a width of pavement of 15 feet (4.6 m). The film and light source are controlled as a function of vehicle speed. The

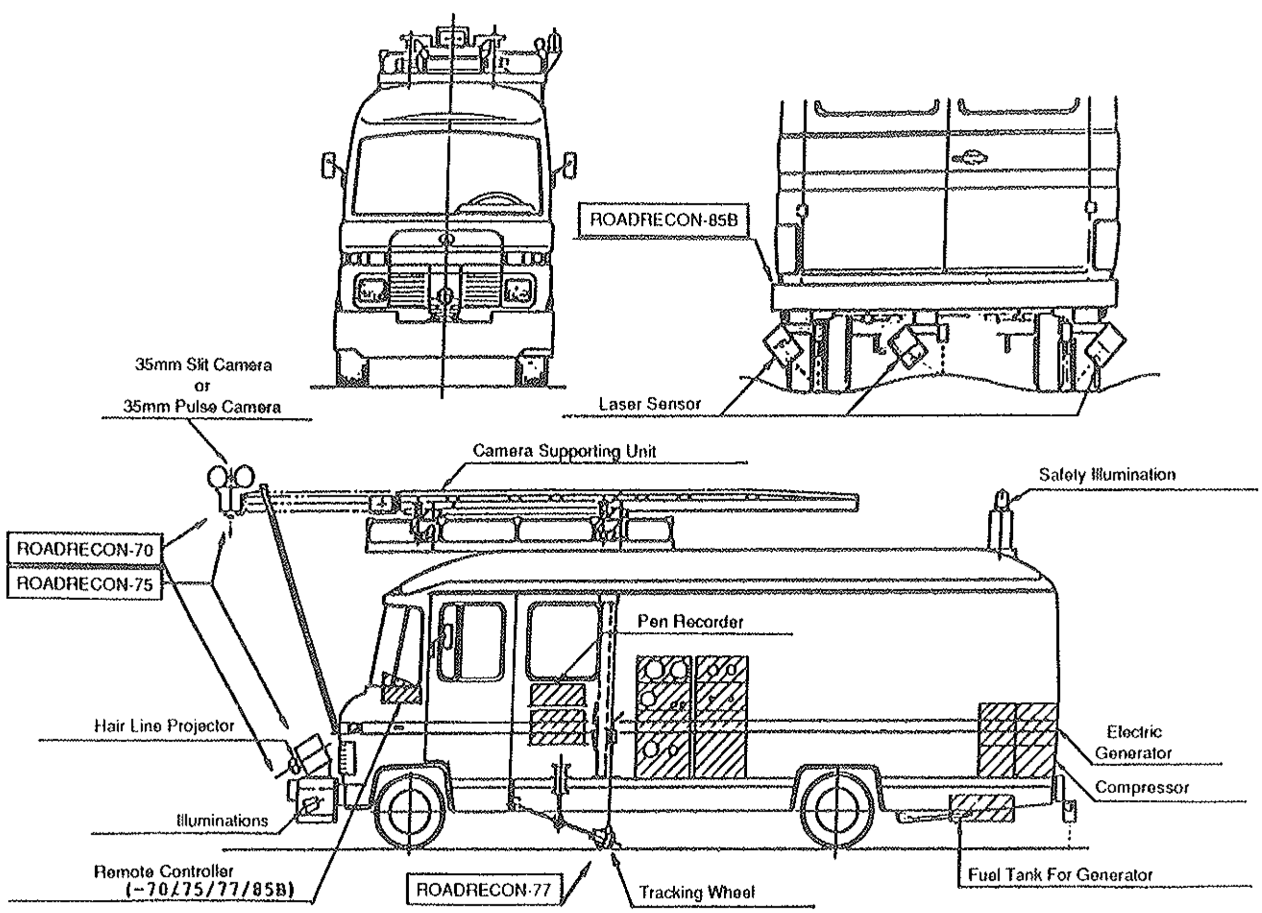

FIGURE 3 Schematic illustrating components of PASCO ROADRECON systems (*7*).

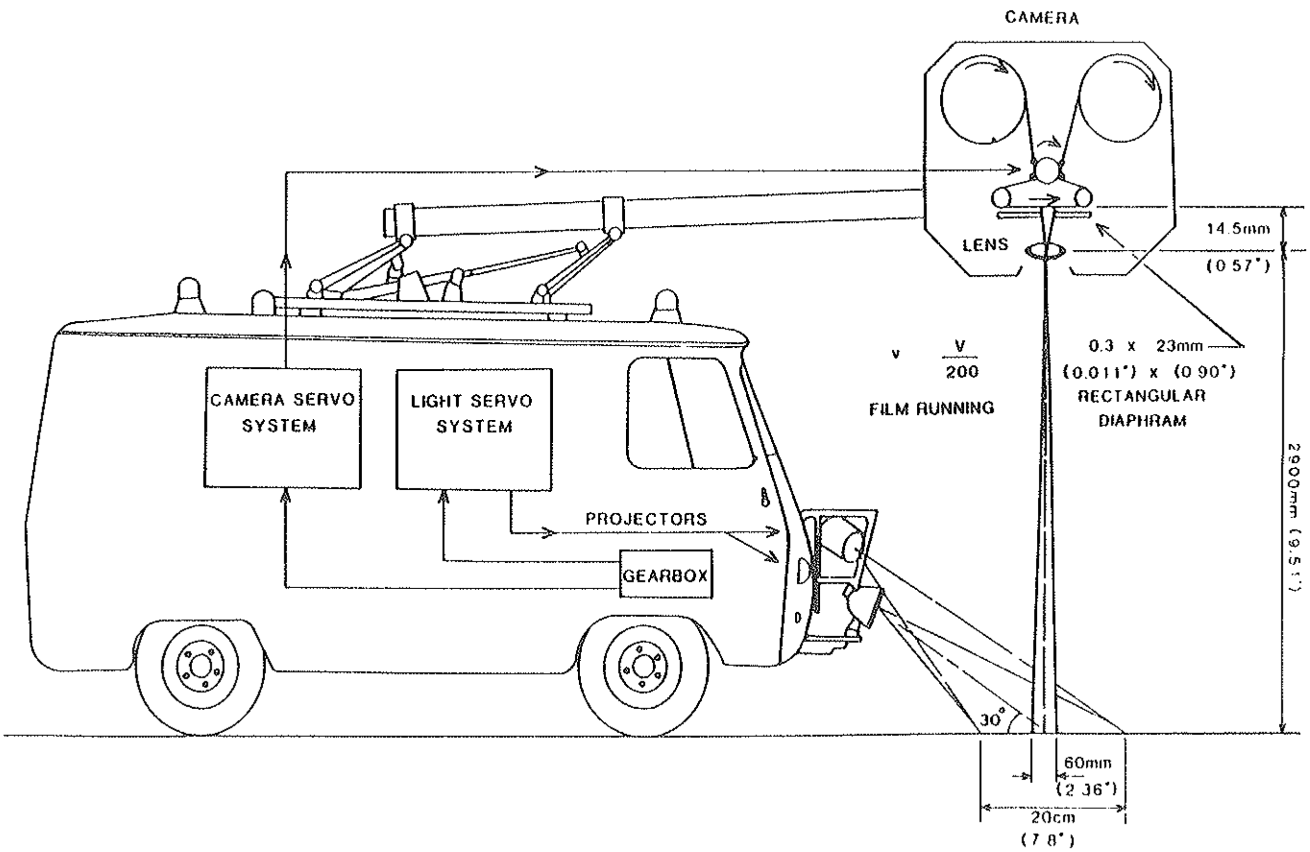

FIGURE 4 Schematic illustrating principles of GERPHO's automated photographic system (*8*).

GERPHO system takes a continuous image of the pavement surface at speeds up to 40 mph (60 kmph).

The interpretation of distresses from the negative films is done using a viewing table and data storage operating station. The distress data is directly entered into a microcomputer, using a keyboard equipped with a special template of distress codes. The microcomputer, special keyboard, CRT, and printer form the operating station.

Automatic Road Analyzer

The Automatic Road Analyzer (ARAN) vehicle is produced by Highway Products International, Inc. of Paris, Ontario, Canada. An ARAN Model III unit was used in the field testing (figure 5). The ARAN measures rut depth and transverse profile with ultrasonic sensors and ride/roughness quality with an accelerometer on the rear axle. The ARAN also takes a video picture of the road right-of-way through the windshield and the pavement surface with a shuttered video camera (in which the shutter takes thirty stills per second) behind the vehicle, and uses an on-board microprocessor to record distress data (*10*). Seven ultrasonic sensors on 12-inch (305-mm) centers, mounted in a front bumper rut bar, are reported by the manufacturer to measure the distance to the pavement surface with one millimeter precision at operating speeds up to 55 mph (90 kmph). Additional sensors and bar extensions can be used to extend the rut bar to a width of 10, 11, or 12 feet (3.1, 3.4, or 3.7 m). A calibration sensor is used to compensate for changes in air density due to temperature variation. Microprocessor-controlled, plug-in keyboards, with built-in liquid crystal displays, automate the collection and recording process. Dual keyboards have the capacity to handle up to twenty distresses with three severity categories.

Laser Road Surface Tester

The Laser Road Surface Tester (RST) was developed by the Swedish road and traffic research institute and has been used in Sweden for about three years (*11*). The Laser RST can reportedly measure crack depths and widths, rut depths, longitudinal profile from which roughness is computed, macrotexture, cross profile, and distance. A "windshield" condition survey can also be performed by one of the operators to identify types of cracking and other distresses. The device used in the field tests has eleven bumper-mounted laser range finders and an accelerometer to measure the transverse road profile and detect cracks while traveling at speeds of 18 to 55 mph (30 to 80 kmph) (personal communication, W. Uddin, Sept. 1986). A pulse transducer, mounted on the wheel hub, measures the distance traveled by the unit. Seven of the lasers pulse at 16 kHz and are used for the rut depth measurements. Four of the lasers pulse at 32 kHz and are used for measurement of rut depth and cracking. Two of these lasers are used for macrotexture and longitudinal profile measurements. These lasers have a reported accuracy of 0.01 inches (0.26 mm). An on-board microcomputer integrates the sensor signals with the accelerometer and distance transducer, averages the data into manageable sections, and provides the processed data in

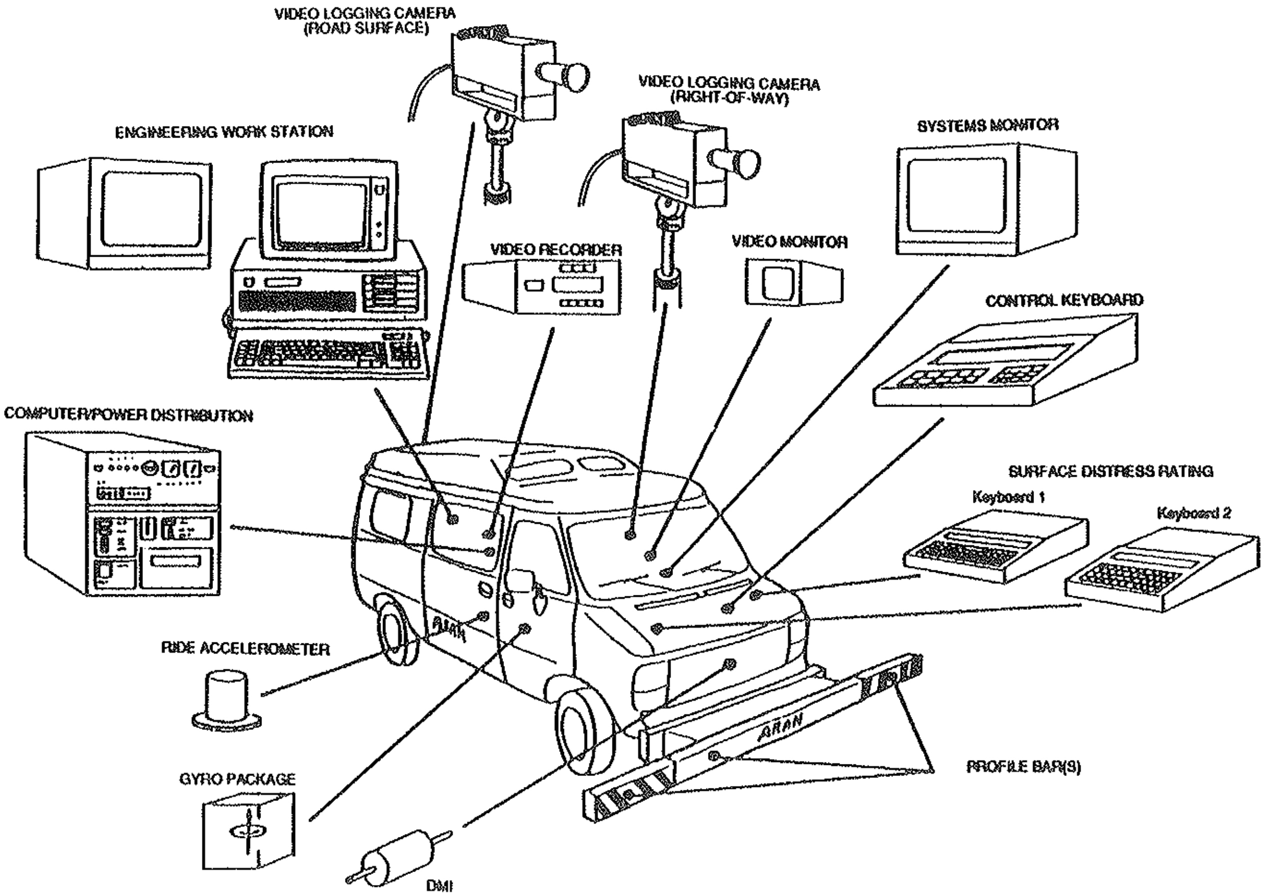

FIGURE 5 Schematic illustrating components of the ARAN (*10*).

real time. Eight three-position toggle switches are used to rate types of cracking and other distresses. An illustration of the Laser RST is provided in figure 6.

DESCRIPTION OF FIELD TEST SECTIONS

Test sections were selected to represent rigid, flexible, and composite (flexible overlay on a portland cement concrete pavement) types of pavement structure exhibiting good, moderate, and poor levels of distress. Potential locations were surveyed by members of the study staff and classified, based on subjective opinion, into the three distress-level categories. Twenty-five pavement sections, located in the central Texas area to minimize travel time, were selected.

Each test section was 1,000 feet (305 m) long. The sections were divided and marked at 100-foot (30.5-m) intervals. All of the sections were located on in-service trafficked roads. Two of the sections were located on the inside lane; the rest of the test sections on multilane highways were located in the outside lane.

In order to obtain meaningful results from the surveys, experienced raters and trained equipment operators were used for each procedure. The manual mapping, detailed condition surveys (PAVER and COPES), and detailed condition surveys using the data logger were performed by ARE Inc. personnel who had experience in performing the type of survey conducted. The surveys performed with the instrumented survey vehicles used the operating configuration, standard test procedure, and equipment operators which the manufacturer or technical representative considered to be most appropriate.

"Repeat" and "replicate" measurements were performed on a subset of the test sections. Repeat measurements were taken immediately after the initial survey was completed. Replicate measurements were taken three to four days after the initial survey, and the section numbers were changed in an effort to reduce bias from the previous measurements made on the sections.

It was initially planned to conduct side-by-side tests of all the devices. Due to scheduling difficulties and time constraints, the field surveys were instead performed at different times over a three-month period. The test sections were monitored on a regular basis by the study staff to detect any significant changes in the distresses present on the sections or any maintenance to the section which would change its characteristics. No significant changes were observed during the testing period.

EVALUATION OF THE SELECTED DEVICES

Comparative evaluation of the manual methods and the instrumented survey vehicles was made from several perspectives: (1) availability of a permanent record of the pavement surface, (2) evaluation and comparison based on the analysis of the surface distress and rutting data collected dur-

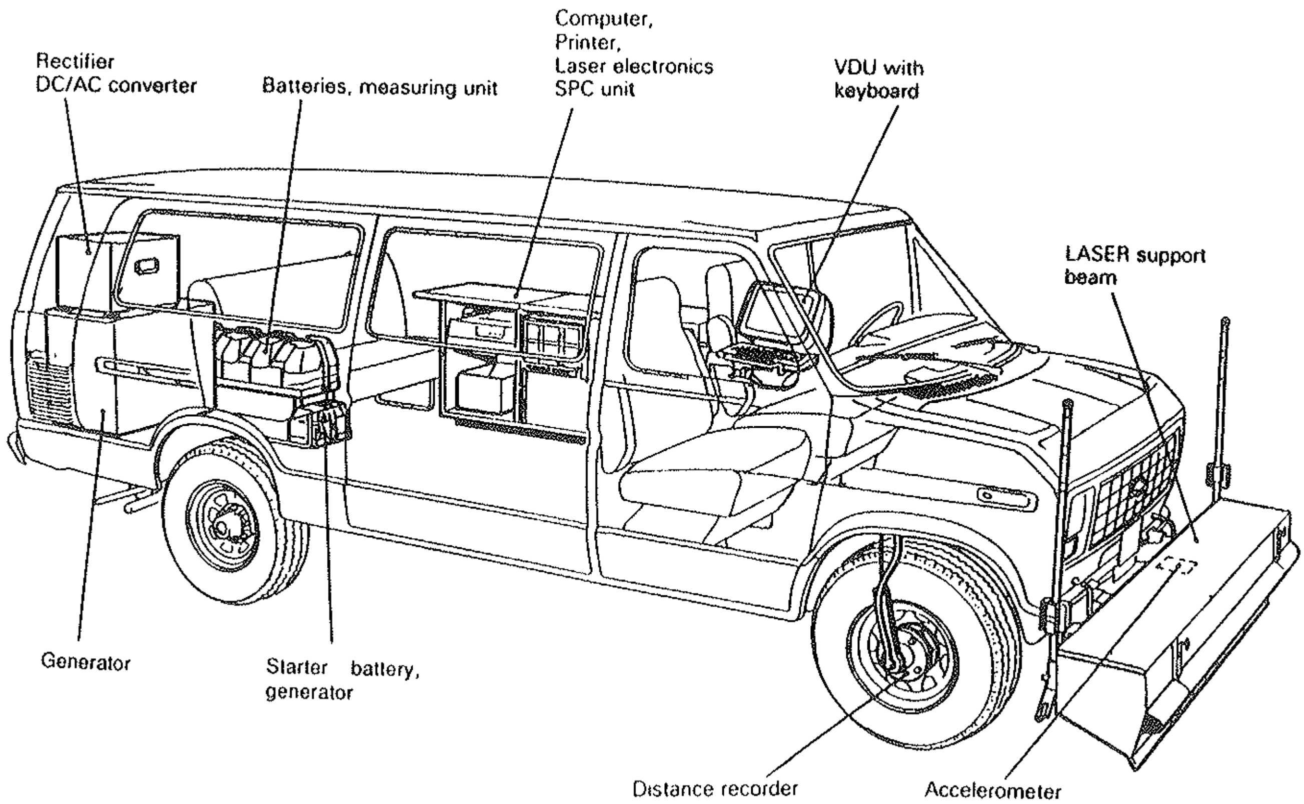

FIGURE 6 Schematic illustrating components of the Laser RST.

ing the field tests, (3) instrumentation evaluation and comparison of the performance based on hands-on experience and field tests, and (4) cost-effectiveness. Table 1 presents the criteria used for comparison and ranking of the selected methods.

Permanent Record of Pavement Surface

An image of pavement surface serves as a useful permanent record of pavement surface features. It facilitates fast and easy checking of the data without having to make a return visit to the field. Side-by-side comparisons of the images of a pavement surface, obtained during distress surveys performed at different times, allow investigation of the development of distresses. This is especially useful for long-term pavement performance research studies.

The detailed visual surveys and Laser RST do not create images of the pavement surface. Their output consists of numbers indicating the severity and extent of the observed distresses and characteristics of the pavement surface. Future investigations of the historical development of distress on a pavement section have no recourse but to rely on these ratings and measurements. Thus, these methods were rated "Very Poor" in terms of a permanent record of the pavement surface.

Reliability

The manual mapping method produces detailed maps prepared in the field. For reliability, this method was rated "Fair" because of the subjective nature of identifying distress types and severity, as well as inherent variation due to human factors. The GERPHO and PASCO ROADRECON-70 develop images from 35-mm film. Because this film, in the undeveloped state, is subject to loss due to improper handling and exposure, these devices were rated "Good" (rather than "Very Good") in terms of reliability. The ARAN video image can be viewed while it is being made and any problems can be detected immediately. Due to this feature, its reliability was rated "Very Good."

Field Productivity

Manual mapping is the most time-consuming and laborious method and was ranked "Very Poor" in field productivity. PASCO, GERPHO, and ARAN all use objective procedures at relatively high speeds to produce an image of the pavement surface and were rated "Very Good."

Usefulness

PASCO's and GERPHO's films are very sharp and were judged adequate for interpretation of distresses. The photographs from the PASCO device were slightly clearer than those from the GERPHO, although both were very acceptable. The usefulness of both of these devices' photographs of the pavement surface were rated "Very Good." The video images produced by the ARAN were judged "Poor" and not adequate for interpretation of all types of pavement distress. Its usefulness was ranked "Poor."

TABLE 1 A SUMMARY OF COMPARISON AND RANKING OF THE SELECTED METHODS

CRITERIA	Manual Mapping	GERPHO	PASCO ROAD RECON	ARAN	Laser RST	DETAILED VISUAL SURVEY	
						Manual Recording	Automated Data Logger
1. Permanent Record of Pavement Surface							
Reliability	3	2	2	1	5	5	5
Field Productivity	5	1	1	1	5	5	5
Usefulness	3	1	1	4	5	5	5
2. Field Data Collection, Processing, Interpretation, and Summary							
Level of Automation	5	2	2	2	1	4	3
Accuracy	2	2	2	4	4	3	3
Quality of Rut Depth Data	1	5	1	2	2	3	3
Repeatability	2	1	1	3	3	3	3
Ease of processing	2	3	4	2	2	2	3
Ease of interpretation of outputs	1	1	2	3	3	1	1
3. Operating Restrictions							
Environmental Effects	2	2	2	3	2	2	2
Traffic Interference	5	1	1	1	1	5	5
Operating Speed	5	1	1	1	1	5	4
4. Equipment Durability and Robustness	1	1	1	2	2	1	1
5. Cost Effectiveness	5	1	2	2	1	4	3

Rankings: 1 = Very Good 2 = Good 3 = Fair 4 = Poor 5 = Very Poor

The usefulness of the manually prepared maps was judged "Fair," because of the subjective nature of the distress interpretations and the possibility that pavement features are not recorded which appear insignificant, but which may become important at a later date.

Field Data Collection, Processing, Interpretation, and Summary

Criteria in this category include level of automation, accuracy of surface distress data, quality of rut depth data, repeatability, ease of processing, and ease of interpretation of outputs.

Level of Automation

Automation is a primary consideration for cost-effective distress survey procedures. Mapping is not an automated method and was rated "Very Poor." In detailed manual visual survey methods, field data collection, processing, and interpretation are done manually, although the data can be input into the computer and used to generate reports. Therefore, they were ranked "Poor." The automated data logger was given a "Fair" rating, due to the reduction in time and cost to transfer the field data to an office computer for processing. The GERPHO, PASCO, and ARAN instrumented vehicles were rated "Good" because data collection is automated, but further processing of the field data is required in the office. The automation of the Laser RST was rated "Very Good" because all of the information collected with this device is processed in the field with the on-board computer.

Accuracy of Surface Distress Data

Accuracy of the distress survey data was defined as how close the reported distress data corresponded to the distresses actually on the test sections. The "truth" was taken as the ratings from the three manual methods when they were all in agreement. Where conflicts in the data from the manual methods existed, return trips to those sites were made by the members of the study team to resolve the conflicts.

No single method was found to be totally correct for all sections. The manual mapping method yielded results that approximated what the truth was judged to be and was given a "Good" rating. The information from the GERPHO was also in close agreement with the observed distresses and given a "Good" rating. The form of distresses reported from the

PASCO ROADRECON-70 were somewhat difficult to directly compare, but was judged to be of "Good" accuracy. The accuracy of the detailed visual surveys was judged "Fair," even though the surveys were used, in part, to help define the actual conditions. As might be expected, the accuracy of the surface distress information collected through the windshield of the ARAN and Laser RST were not as accurate as the other methods and was judged "Poor."

Quality of Rut Depth Data

Quality of the rut depth measurements was based on the accuracy of the measurement and the amount of detail provided for the transverse profile. Accuracy of the rut depth measurements was determined by comparison against transverse rut profiles manually measured with a 10-foot (3-m) straightedge. The amount of detail was judged "Good" if both a transverse profile and maximum rut depth were produced.

Since the GERPHO does not measure rut depth, it was rated "Very Poor" in this category. The manual mapping method was rated "Very Good" because the 10-foot (3-m) straightedge was considered as a part of this technique.

Since the PASCO ROADRECON-75 rut depth measurements corresponded very well with the straightedge measurements, and detailed transverse profiles were produced, it was rated "Very Good."

The maximum rut depth measurements made with the ARAN and Laser RST were less than those measured with the straightedge. However, due to differences in measurement intervals, the accuracy of these rut depths could not be directly evaluated against the straightedge measurements. Although the ARAN measured a transverse profile using sensors spaced at 1-foot (0.3-m) intervals, only the maximum rut depth was reported. The Laser RST gave the average and standard deviation of the depth measurements made with each laser, which gives some information on the transverse profile shape, but did not give profiles for each measurement made. Since the Laser RST made approximately 3,000 measurements on each section, if transverse profiles were produced the amount of information would be overwhelming. Based on these considerations, the ARAN and Laser RST quality of rut depth measurements were rated "Good."

The accuracy and detail provided with the detailed visual surveys were rated "Fair." Some discrepancies were found in both the extent and severity of rutting reported by these methods. These survey techniques are not designed to produce information on the transverse profile of the pavement.

Repeatability

This criterion is related to the differences between the reported distresses from initial surveys and from surveys performed immediately following or several days later. The PASCO measurements showed excellent agreement between initial and repeat measurements and was therefore ranked "Very Good." The distresses from the GERPHO photographs were not interpreted for the repeat measurements. Since the repeat photographs of the test sections made with the GERPHO were judged by the study staff to be equal in quality to the initial photographs, the repeatability of this device was also rated "Very Good." The rut depth measurements made with the ARAN and Laser RST had "Good" repeatability. However, significant differences were found in the ratings of the othersurface distresses. Since rut depth is only one distress category, these two devices were rated "Fair" in overall repeatability.

Detailed survey methods showed discrepancies between raters, but repeat measurements with the same rating team yielded "Fair" repeatability. The repeatability of the manual mapping technique was rated "Good."

Ease of Processing

The ease of processing the raw data is rated based on the required background and training for the technician(s) and the complexity involved in the processing. The lower the requirements for operator training and the less complex the process, the higher the rating. These ratings are relative to each other and should not be considered as an absolute measure, that is, a method rated as "Poor" was judged to require more operator training and be more complex than one with a "Fair" rating. Mapping was rated "Good" even though it is laborious and time-consuming. It is a straightforward process requiring technicians to summarize, from the prepared maps, the distresses which have been interpreted in the field. The ease of processing the GERPHO photographs was rated "Fair" because a technician trained to interpret the photographs with keyboard skills is required.

The PASCO techniques were rated "Poor" overall in the ease of processing because of the complexity of the procedures and the following requirements for technicians: that they operate a digitizing computer for rut depth measurements, that they be trained for interpretation of the distresses from the photographs, and that they have keyboard skills for entry of the interpreted data into a computer. Because the technicians who process the raw data from the ARAN and Laser RST are not required to interpret the distresses, the ease of processing was rated "Good." The ease of processing the data from the detailed condition survey was also rated "Good." Although keyboard entry skills are required to enter the data into the computer, the technicians processing the data are not required to interpret distresses. The automated data logger was rated as "Fair" because it was slightly more complex due to the need to have the technician transfer the field data to the office computer prior to final processing.

Ease of Interpretation of Outputs

The ease of interpreting the reports or final output from each method was rated according to how easy it was to understand the outputs. All of the manual methods and GERPHO were ranked "Very Good" because the reports were given in terms of severity and extent of distresses in clearly distinguishable categories. The reports from the PASCO ROADRECON device were only rated as "Good," primarily because they were produced on an output format printed in Japanese and because cracking, patching, and potholes were grouped into one category. It should be noted that a user agency should be able to reformat reports into its desired format, using the ROADRECON equipment. The ARAN and Laser RST devices were ranked "Fair" because interpretation of their output was complex and not straightforward. The manuals and written procedures which accompanied their reports were also found to be complex and required more effort to understand than the other methods.

Operating Restrictions

The three criteria in this category are summarized in table 1 and discussed below.

Environmental Effects

No method can be used during all weather conditions, or at all times of the day and night. All methods are rated "Good" except ARAN, which was rated "Fair" due to the problems caused by the rain with the ultrasonic sensors during field tests.

Traffic Interference

Traffic interference during distress surveys affects the quality and quantity of distress data. None of the four instrumented survey vehicles interrupts traffic, poses hazards, or requires lane closure or other traffic controls for routine use. These were ranked "Very Good." All manual methods are subject to potential conflicts with traffic because of the presence of the rating team taking measurements on the side of the road or in the traffic lane. Therefore, the manual mapping and visual condition survey methods were ranked "Very Poor."

Operating Speed

The operating speed is related to productivity and cost-effectiveness of the complete system. Labor-intensive methods (mapping and manually-recorded detail survey) were ranked "Very Poor," followed by the automated data loggers, which was somewhat faster but rated "Poor" in comparison to the instrumented survey vehicles. The instrumented survey vehicles were all rated "Very Good."

Equipment Durability and Robustness

Equipment durability and robustness are important considerations for the long-term performance of a device. The manual mapping and detailed visual distress survey methods use equipment that is not subject to breakdowns or that requires little maintenance and were, therefore, rated as having "Very Good" equipment durability and robustness. The GERPHO and PASCO ROADRECON devices, which also rated "Very Good," have a long history of use in their respective countries and performed without problems during the field tests. The ARAN device tested in this study had two malfunctions during the testing period that were corrected without great delay. Although it was a new machine which had not had all of the "bugs" worked out, it was assigned a "Good" reliability rating in comparison to the other methods. The Laser RST was also given a "Good" rating is equipment reliability and robustness, because the instrumentation involved with the use of lasers and interfaces with the on-board computers could be subject to more potential problems than the equipment rated as "Very Good."

Cost-Effectiveness

Cost-effectiveness involves costs associated with several parameters: field productivity, operating crew size, office data processing time, manpower requirements, and usefulness of data. Cost analyses based on these criteria (*1*) resulted in the GERPHO and Laser RST ranked "Very Good," followed by the other two instrumented survey vehicles. The automated data logger was rated "Fair." The manual recording of visual survey method and manual mapping were ranked "Poor" and "Very Poor," respectively.

CONCLUSIONS

Distress surveys for pavement management purposes are conducted at two levels, network- and project-level evaluations. Network-level evaluations are conducted over a road or highway network to determine its condition and establish priorities for improvements to the sections competing for limited funding. Project-level evaluations are conducted to provide information with which to design specific improvements or "4R" measures (resurfacing, rehabilitation, restoration, and reconstruction). There is a wide variation in the type and application of distress surveys for network- and project-level evaluations. A great deal depends on the magnitude of the network, the type of pavement structures, the type of agency, and the available funding.

The PASCO and GERPHO photographic survey vehicles can be used for both network-level and project-level distress surveys. The GERPHO and PASCO devices are also well suited as high-speed distress survey devices for research studies. They are capable of covering extensive networks in a relatively short time. Either summary or detailed distress information can be interpreted from the photographs as desired. Photographs taken over time can yield useful information on the development of distress to update distress prediction models. The additional rut depth and roughness measurement equipment contained on the PASCO vehicle gives it additional utility for both network- and project-level surveys. While these vehicles provide the basis for good quality distress information, the costs associated with film development, office interpretation, and film storage may offset their advantages for some agencies. Although a permanent visual record of a pavement surface has many advantages, these records may not be necessary for a network-level pavement management system.

The other two distress survey vehicles investigated in this study, the ARAN and Laser RST, lend themselves to network-level distress surveys. They both supplement windshield-type distress ratings with measurements of rutting and roughness. They are capable of covering networks in a relatively short time. Since the distress information and pavement surface measurements are recorded on on-board microcomputers, the turnaround time on completion and assembly of the processed information is relatively short.

The video cameras on the ARAN provide additional information that may be useful to an agency. The through-the-windshield view of the road environment provides information useful for inventory purposes. Although the image of the pavement surface from the shuttered video camera was not adequate for interpretation of all distresses, it does provide a record of major distresses, such as potholes, that can be useful to the engineer in the office as a check on questionable ratings, or to investigate a section of road that is of interest, prior to making a field trip.

Manual surveys are the traditional approach to distress surveys. Automated data loggers are more cost-effective than manual recording, and thus it is recommended that an agency performing manual surveys use an automated data logger to record the distress survey information in the field and for transfer to an office computer. Because manual mapping is laborious and time-consuming in the field, as well as during office data reduction, it is not recommended for network- or project-level distress surveys for pavement management purposes.

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