Video Image Distress Analysis Technique for Idaho Transportation Department Pavement Management System

JIM BAKER, BASIL DAHLSTROM, KEITH LONGENECKER, AND TRI BUU

The Idaho Transportation Department (ITD) is developing and implementing an automated highway management system, the Pavement Performance Management Information System (PPMIS). The system consists of structural adequacy data, present serviceability data, and surface distress data. Field data for the first two modules are obtained using automated collection techniques. However, surface distress data are still gathered manually and are incorporated into a visual and subjective methodology. The ITD is pursuing a low-cost, technically sound methodology to automate the collection and analysis of surface distress data. The primary objective is to investigate the feasibility of automating the acquisition and subsequent analysis of pavement condition data. Two basic questions are being examined: First, can high-quality video images of road surfaces be filmed at average highway speeds? Second, can computer software be developed to use those images to calculate crack size and crack type, and to assign a severity rating to specific sections of road surface? VideoComp, an Idaho corporation, is assisting the ITD in efforts to answer these and related questions. Preliminary findings indicate that automation of the distress data module is feasible. During 1985 and 1986, VideoComp videotaped more than 2,400 lane-mi of Idaho's Interstate highways and 380 lane-mi of principal arterial highways. In addition, computer software capable of determining crack type and size has been successfully demonstrated.

Transportation departments throughout the United States are faced with a growing problem: the adequate maintenance of the nation's highways in the face of severely restricted maintenance budgets and shrinking maintenance staffs. Simply put, the nation's transportation departments are being asked to do more with less.

The response of the Idaho Transportation Department (ITD) to this challenge is the aggressive development and implementation of an automated pavement management system. The Pavement Performance Management Information System (PPMIS) is an automated highway maintenance model used for annual analysis and programming of projects and budget requirements for the maintenance and rehabilitation of the Idaho highway system.

The PPMIS consists of three major data elements: structural adequacy data, present serviceability data, and surface distress data *(1)*. To satisfy the data requirements of these three elements, the ITD is continuing efforts to implement a fully automated field data collection system. Data collection and analysis for two of the elements (structural adequacy and present serviceability) are fully automated. However, surface distress data collection and analysis remain manually based techniques relying on visual and subjective ranking methodology.

In this paper, efforts underway by VideoComp and the ITD to automate the surface distress data element of the PPMIS are examined. Specifically, the use of video image equipment to collect field data and computer-assisted analysis of those data are discussed.

The major feature of the video image system is that field data are collected, processed, analyzed, and passed on to the PPMIS in a totally automated fashion. The video image process reduces human intervention in the data collection required for surface distress analysis, reduces measurement error associated with labor intensive data collection techniques, and leads to significant cost savings.

BACKGROUND INFORMATION

The Idaho state highway system consists of approximately 5,000 mi of paved or oiled highways including about 612 mi of Interstate highways. During the past several years, the Transportation Management Services Section of the ITD has been developing and implementing new management information systems designed to enhance the ability of managers to make timely, well-informed decisions regarding the construction and maintenance of Idaho's roads and highways.

These efforts have led to the development of a number of interrelated information management subsystems. Together, these subsystems form the ITD program analysis system including computer programs and models such as PPMIS, HWYNEEDS, and HIAP, which can be used to provide the ITD with a very flexible and powerful set of program planning and budgeting analysis tools. For example, PPMIS is used to develop resurfacing, restoration, and rehabilitation (3R) improvement proposals; HWYNEEDS is used to develop capital improvement proposals; and HIAP is used to analyze funding allocations. Funding allocation options are analyzed by types of improvement within both the 3R and capital program improvement categories, federal-aid systems, and state districts.

Pavement Management System

The focus of this paper is the Pavement Management System (PMS) currently in use by the ITD. PMS ranks highway sec-

J. Baker and B. Dahlstrom, VideoComp, Boise, Idaho 83709. K. Longenecker and T. Buu, Idaho Transportation Department, Boise, Idaho 83707.

tions based on the severity of pavement deflections, roughness, cracking, and friction deficiencies. A composite index of deflection, roughness, and cracking for each highway section is also produced as a measure of overall performance.

At the heart of the PMS is the PPMIS, a computerized pavement evaluation information system *(2)*, developed to aid the ITD maintenance and district personnel in making the most appropriate rehabilitation decisions and in estimating the volume of work and cost of improvement on pavement condition problems.

The PPMIS model consists of three main computer programs: SYSTDY, SUMMARY, and POD *(2)*. SYSTDY and SUMMARY are used for network level analysis, whereas POD is used for analysis at the project level. SYSTDY and SUMMARY programs are designed to use any combination of structural adequacy, present serviceability, and distress data, whereas the POD program is limited to structural adequacy data.

Analysis at the network level begins with the program SYSTDY, which edits and processes the deflection, present serviceability, distress, and friction database information of the pavement network. SYSTDY transforms these inventory data into indices such as structural index (SI), present serviceability index (PSI), and cracking index (CI) and produces a report for each pavement section in the network. Summarized data are then passed to the SUMMARY program. This program combines the SI, PSI, and CI into a composite index (final index, FI), which represents the overall pavement condition of each section. Currently, data are collected for approximately 1,700 distinct sections of Idaho roadways. Pavement sections are logical units based on a number of selection criteria as identified by ITD. Criteria include jurisdictional boundaries (i.e., city and county), changes in pavement type (from concrete to asphalt), functional classification (e.g., principal arterials and secondary roads), time period of construction, terrain, and a number of other geometric characteristics. Pavement sections, as defined by the ITD are variable in length ranging from a minimum length of 0.3 mi to a maximum length of 9.3 mi.

Pavement sections form the basic units of analysis for ITD pavement management decisions. In comparing and assessing identified pavement sections, weighting factors are introduced on the various indices with functional classification, traffic volumes, and speeds being the influencing factors. In-depth descriptions of PSI, SI, CI, FI, and criteria used to establish pavement sections are available from the Management Services Section of the ITD *(3)*.

SUMMARY produces a ranked list of sections that can be used for programming improvement priorities. The POD program at project level is used to estimate overlay requirements for sections of highway that have a structural adequacy problem. The overall PPMIS model output is used in the yearly analysis and programming of projects and budget requirements for maintenance and rehabilitation of the Idaho state highway system.

Data Collection for the PPMIS Model

The PPMIS model requires a significant level of data acquisition. Pavement condition surveys include pavement deflection (Dynaflect measurements), pavement roughness (Cox roadmeter), pavement cracking (subjective evaluation using reference photographs), and pavement friction (locked-wheel tests). Supplementary data such as temperature, date, and route number are added through a Hewlett-Packard 85 microcomputer in the field.

Although the amount of data required to support PPMIS is quite large, the ITD has a small staff available to collect those data. Accordingly, the ITD has acquired several automated data collection and processing systems to provide computerized data management capabilities. All of the data necessary to support PPMIS with the exception of cracking (distress) data are collected and processed using automated techniques. At present, the PPMIS cracking index is a modification of a cracking rating scheme developed by the Arizona DOT. The rating crew has a series of pictures that are compared to the pavement. Different ratings correspond to different types (transverse, longitudinal, and alligator) and different degrees of cracking. The rater records the index from the pictures that most resemble the pavement in question; the averaging of ratings is allowed when appropriate.

ITD personnel perceive this manual and subjective data collection process as a weakness in the overall data collection methodology of PPMIS. Problems associated with the current system of data collection include a high cost of acquiring data, difficulty in replicating the collection efforts over time, and in general accumulation of data that are not as accurate or reliable as deemed necessary. The ITD, through a series of contracts with VideoComp, an Idaho consulting firm, is attempting to resolve this problem. VideoComp has developed a data collection and analysis system that helps ensure more cost-effective, timely, and accurate data for input into the PPMIS model.

The remainder of this paper describes the data collection system developed by VideoComp, examines how those data are analyzed, and discusses future research efforts to be undertaken by the Idaho Transportation Department and VideoComp.

SURFACE DISTRESS DATA ACQUISITION: AN AUTOMATED APPROACH

As discussed earlier, the ITD is vigorously pursuing the development of a low-cost, technically sound methodology for the automated collection and analysis of surface distress data. Four basic objectives have guided development of the ITD research agenda:

Objective 1. To determine if video image processing techniques can be used to provide severity measures (distress index) on the extent of the distress-cracking problem of any given pavement section.

Objective 2. To determine the capability of an automated system to classify, measure, and record the area and extent of a crack problem for any given pavement section.

Objective 3. To ensure that automated data collection techniques satisfy data reliability requirements, and that they can be replicated over time.

Objective 4. To determine the cost-effectiveness of automated data collection compared to more traditional manual surveys.

In the fall of 1985, VideoComp began work designed to meet the first two objectives. Those efforts, as well as subsequent work performed in 1986, are examined in more detail in the following paragraphs.

Data Acquisition

During the spring and summer of 1985, VideoComp designed and constructed a prototype vehicle for use in videotaping the travel lane of Idaho's Interstate highways. Since that time, the prototype vehicle has been used to videotape more than 2,400 lane-mi of Interstate highway for the travel lane as well as 380 lane-mi of principal arterial highways. In addition, project level taping has been performed on selected sections of Interstate highway.

The prototype, a trailer towed by a truck, features a video camera, video recorder, and controlled lighting. The initial videotaping project focused on four major activities:

1. Capture pavement surface images while traveling at highway speeds.
2. Film the outside wheelpaths of the outside (travel) lane with images of pavement surface covering at least 5 ft (width) of the outside lane starting from the lane-shoulder joints.
3. Edit the videotapes to provide a continuous record of the Interstate surface as it existed in October 1985 (with images recorded on videotapes that can be shown frame-by-frame on a television screen).
4. Preparation of a final report that discussed project methodology and findings.

Videotaping was completed in October 1985; a report documenting the project was presented to ITD in November 1985 *(4)*.

After reviewing results of the initial videotaping, ITD personnel determined that a width of 8 ft was more desirable than that of 5 ft as originally selected, and that location and distance information such as mile post location and direction of travel should be encoded on each videotape during subsequent videotaping projects.

In response to these requests, VideoComp modified the prototype vehicle. The modified vehicle (Figure 1) features two cameras and two recorders, and supports the videotaping of a field 8 ft wide. In addition, the vehicle supports a sophisticated distance-measuring scheme (in thousandths of a mile), and allows for character insertion through a keyboard directly on to each videotape that provides the viewer with critical information such as name of road, direction of travel, MACS code, and other required or desirable information (Figure 2).

Data acquisition using the original and modified prototype vehicles enabled ITD and VideoComp to acquire 2 years of visual analog benchmark data for Idaho's Interstate highways. ITD plans to use the data in a number of ways including studies of change of pavement condition over time. More importantly, the project served as a field demonstration of the concept of acquiring high-quality visual pavement surface condition data at highway speeds. Important findings from the project included

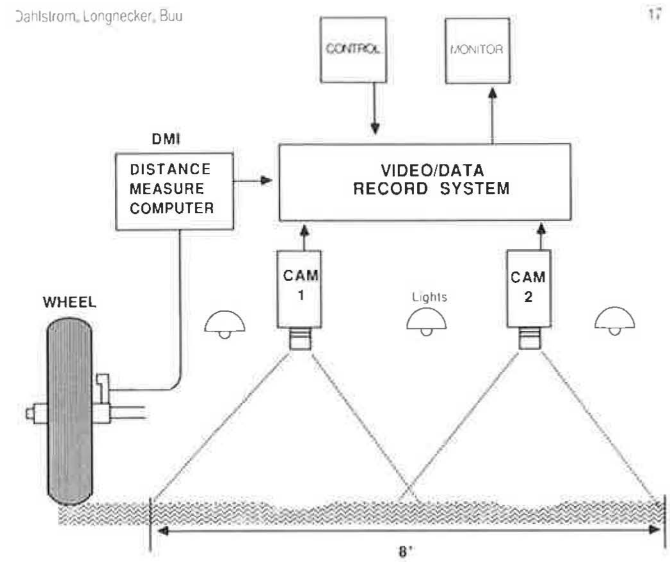

FIGURE 1 System overview.

1. Acquiring pavement condition data at highway speeds even in heavy traffic is relatively simple.
2. Visual data acquired are of a quality that allows surface images including cracking to be well defined and stable. Image quality tends to be better if videotaping occurs during the night. The angle of the sun in early morning and late afternoon results in some minor lighting problems.
3. Most of the prototype equipment used in the project is readily available for over-the-counter purchase. The mobile equipment used to gather data proved to be sturdy, dependable, and tolerant of a wide range of environmental conditions such as varying temperatures and dust.
4. Time and costs involved in gathering data appear to be quite reasonable.
5. It is apparent that the technology exists that will allow for the cost-effective, objective, and consistent collection of highway pavement condition data.
6. Collected data is of sufficient quality to be used as input data converted to digital data for computer software being developed to analyze the type, extent, and severity of cracking.

In all, 53 videotapes produced in Beta II format have been taped since 1985. Those tapes are currently archived at the Management Services Section of the ITD.

Data Analysis

After successfully demonstrating the ability to videotape road surfaces at highway speeds, VideoComp began the process of developing computer software necessary to analyze those videotapes. The software was designed to (a) accept videotaped frame-by-frame images as input; (b) digitize and store frames that exhibit evidence of cracking; (c) determine the type of crack (i.e., longitudinal, transverse, or alligator); (d) calculate the size of existing cracks; (e) classify the extent and severity of cracking; (f) incorporate findings from individual frames into an algorithm designed to classify the extent of cracking from the crack index for any given pavement section; and (g)

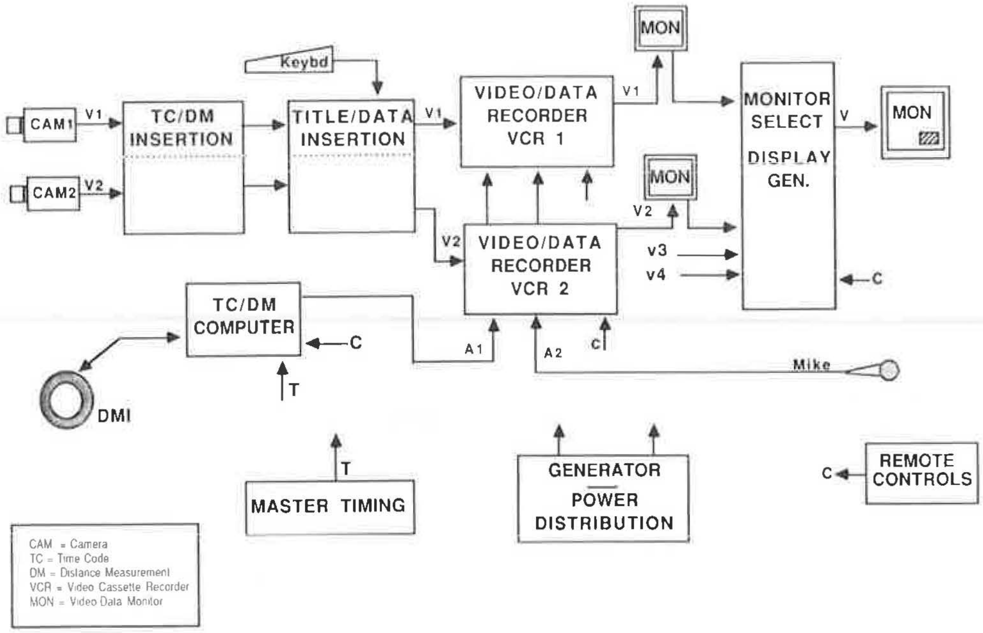

FIGURE 2 Highway data capture system.

pass the assigned crack or distress index on for use as input into PPMIS.

Figures 3 and 4 are reproductions of printouts taken from a randomly selected section of videotaped Idaho Interstate highway. Figure 3 is the digitized image of one frame of the selected videotape. The frame for concrete surface exhibits both transverse and longitudinal cracking. Figure 4 is the product of computer software that extracts the crack features, determines crack type, calculates the length of the cracks, and calculates total area for each of the cracks.

Ongoing Research and Development

Two of the four objectives of the ITD-VideoComp research agenda, automated data collection and computerized data analysis, formed the bulk of the research and development efforts of VideoComp to date. Over the next several months, efforts were to be directed toward the improvement of existing data collection and analysis processes. Work was also to begin on Objectives 3 and 4. To satisfy Objective 3, VideoComp was to assess the reliability of data and findings when an automated approach is used. Specifically, sections of Idaho Interstate highway designated as "long-term pavement monitoring sections" (LTMs) were to used for calibration studies. VideoComp has videotaped both lanes in one direction of four LTMs located in southern Idaho for project level analysis. Computer software developed by VideoComp was being used to establish a crack index for each LTM. Results were to be compared with existing pavement condition records for calibration purposes. The final objective of the ITD-VideoComp effort was to determine if automated collection and analysis is more cost-effective than current practices.

Included in the calibration efforts was to be a thorough examination of sampling techniques and strategies to be followed. A fundamental issue is the sample size necessary to develop a crack index at the network level. Each mile of

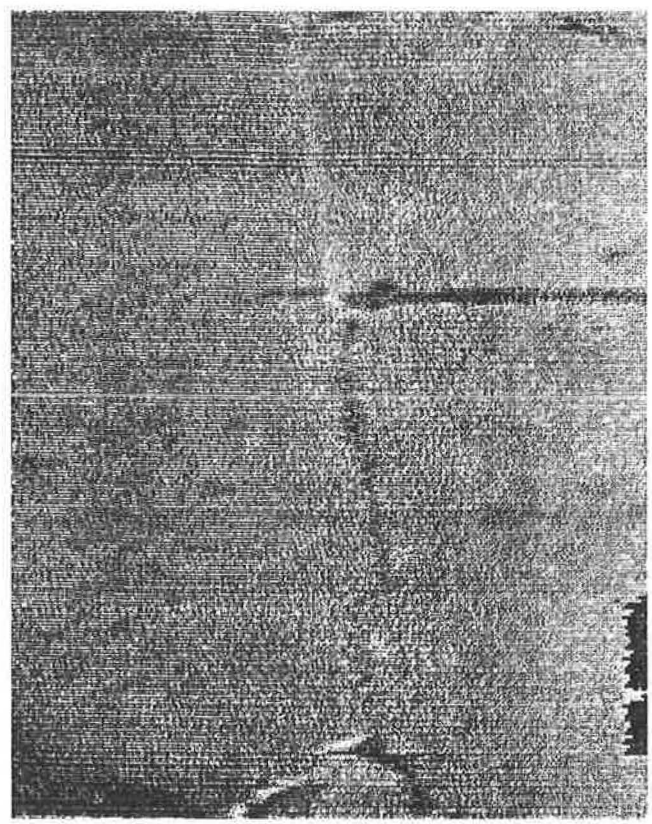

FIGURE 3 Digitized image—Idaho Interstate highway.

videotaped road surface is uniquely identified and each frame on the videotape has a reference distance measure. This measurement of distance is crucial for subsequent sample selection, especially for repeated sampling techniques; data analysis such as conversion of mileage data to pavement section data; and for replication studies over time. In playback mode, a cut-in win-

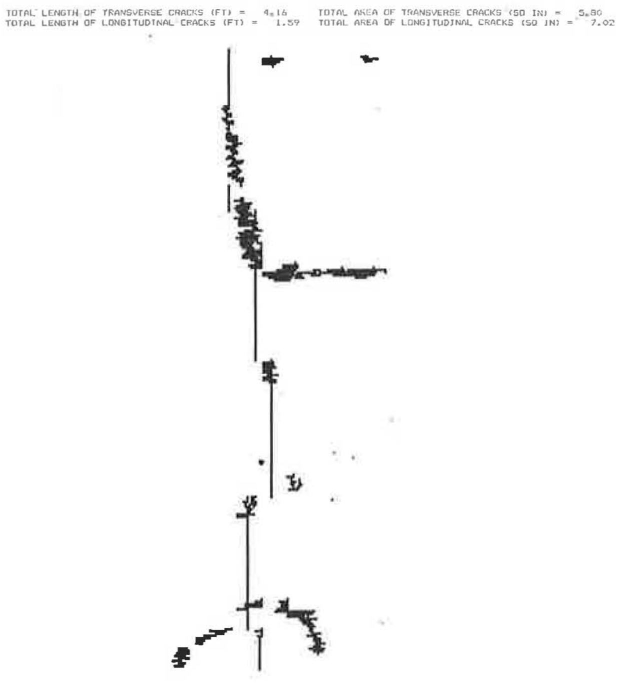

FIGURE 4 Computer-generated image of pavement surface cracking.

dow serving as a distance indicator appears on the screen. ITD data analysts have the option of using the window or simply turning it off. The window should prove useful during visual examination of various road surfaces.

Developing a sampling strategy is a crucial element of the ITD-VideoComp research agenda. VideoComp was to continue to develop and assess sampling strategies to be employed for network analysis. For example, the adequacy of a sample 100 ft long by 8 ft wide for classifying 1 mi of road surface in a statistically meaningful way was to be assessed. Numerous sample sizes and sampling techniques were to be examined during this phase of the research project. Using VideoComp computer software, a number of samples were to be selected from the LTM videotapes. Sample data were then to be compared with population data, and confidence intervals and levels calculated for various sample sizes. The product of this phase of the research was to be a detailed set of recommendations for the ITD to follow when using sampling procedures to assess the conditions at network level of Idaho's highways.

A second and related aspect of work to be undertaken in completing Objective 3 was to be the use of VideoComp computer software in conjunction with computer-assisted drafting (CAD) software to produce computer-generated maps of selected road surfaces. Those maps were to include features such as mileage markers and were also to include the location, type, and size of cracks on any given road surface. In addition to the detailed maps, a crack index was to be calculated for the entire road surface. VideoComp analysts were to work with ITD analysts to assess the reliability and usefulness of the output generated during this research phase.

Work on cost-effectiveness, the final objective of the ITD-VideoComp research agenda, was to focus on the costs associated with collecting and analyzing data using automated techniques versus the costs incurred in using manual collection and analysis techniques. Also addressed in this assessment was to be the reliability of data collected by automated processes versus manual collection techniques.

SUMMARY

The ITD is developing and implementing an automated highway management model, the PPMIS. A key input into the model is surface distress data. At present, those data are gathered manually and incorporated into a visual and subjective methodology. Department personnel consider the current collection and analysis techniques inadequate.

As a result, the ITD, in cooperation with VideoComp, is pursuing development of a low-cost, technically sound methodology to automate the collection and analysis of surface distress data. The research agenda jointly formulated by ITD and VideoComp is designed to answer two basic questions. First, can high-quality video images of road surfaces be collected at average highway speeds? Second, can computer software be developed to use those images to determine crack characteristics such as type and size and assign a reliable severity rating to specific sections of road surface?

In preliminary research efforts, the answer to both questions is yes. The next level of work is to refine existing data collection and analysis techniques, conduct numerous reliability calibration studies on various road surfaces in varying environmental conditions, and develop a sampling strategy for network level analysis. Finally, efforts will be focused on a thorough assessment of the costs and benefits associated with the automated collection and analysis of pavement surface condition data.

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