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PAVEMENT CRACKING INVENTORY STUDY

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16. Abstract

The purpose of this project is directed at reviewing available techniques and equipment in selecting and developing a video-logging system used in obtaining a crack index for use in Arizona Department of Transportation Pavement Management System. During the first phase, a literature search was accomplished to evaluate all the electromagnetic means to gather the surface defect inventory including cracking. It was concluded that the video technology provided the best means of gathering this information and field tests were conducted with individual types of video cameras. High resolution color cameras provided the best means of computer enhancement of the video images were explored.

In Phase II, field tests were conducted on four one-mile test sections of asphalt pavement in various states of distress. The field video images and the standard ADOT crack reference pictures were computer enhanced and a methodology was developed to directly compute the area of cracking.

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INTRODUCTION

Arizona Department of Transportation (ADOT) has been a leader among the several states that have developed pavement management programs. Pavement management programs determine and justify the proper funding levels to provide a safe and well maintained highway network for the traveling public. Within the Arizona pavement management system, ADOT has been able to use pavement test equipment to measure the pavement's surface roughness and skid resistance. However, the third factor, pavement cracking, is not measured by some standard mechanical-electrical test device.

Pavement cracking and the rate of change in cracking appears to be a very reliable and consistent indicator for pavement maintenance. Cracking indicates distress due to either traffic or climatic factors or a combination of both. Once cracking appears, the factors which influence its appearance will continue to operate and accelerate. The more extensive or severe the cracking, the sooner some form of rehabilitation must be initated.

The heart of the pavement management system is the predictive relationship that determines the future pavement condition of each highway pavement section. Cracking, caused by thermal or traffic fatigue and aging, is an important factor that must be included in the predictive relationships. The ADOT has developed a crack index system to determine the percent cracking by area. The system is based upon comparing standard test photographs (on which the percent of cracking has been calculated) to the cracking actually found in the field on the first 1000 sq. feet (90 m^2) of pavement surface at each milepost. Annually, the program is updated with the crack index and percent change in cracking from the previous year for each mile of pavement.

The system is slow with an annual expenditure of $30,000 to gather the pavement crack index information. New technology has been developed over the past several years that offers great promise for developing quicker more reliable systems from which the cracking index can be developed for the ADOT pavement management system (ADOT PMS).

SCOPE

The scope of this project was to review available techniques and equipment, select and develop a video logging system from presently available video equipment, and obtain the crack index for use in the ADOT PMS. The project was divided into two phases to accomplish the overall program scope.

Phase I

During Phase I, a review was made of the techniques and equipment available to determine the most cost effective system for visually recording and evaluating pavement cracking. A feasibility study was made to determine if computerized video image enhancement could be used to measure the amount of cracking in pavement test areas.

Phase II

The second phase of the project was a field test to demonstrate that the selected video system is operational and how to produce the cracking index for the ADOT PMS. An adjunct to this phase would be the field testing of various types of video equipment to determine the best operational procedures, camera angles, lighting, camera height, and various video techniques to be used within the system.

Task List

The following tasks were accomplished to complete both phases of the project:

(1) A review was accomplished of various types of video equipment along with preliminary field testing for suitability in the pavement cracking study.

(2) A literature review was accomplished on pavement surface distress measurement and recording systems with special emphasis on cracking.

(3) Electronic equipment that provides enhanced images through new computer programs was studied for possible utilization in determining the ADOT crack index.

(4) A detailed field test was conducted using various quality levels of video equipment to determine the feasibility of the use of video technology and the quality level required to obtain the ADOT crack index.

(5) The final task was to demonstrate computer enhanced video image capability in conjunction with calculating the percent cracking of the pavement test sections.

DISCUSSION

Video Equipment

After a survey of the available video equipment, four companies were invited to demonstrate their equipment. These were JVC, Panasonic, Hitachi, and Ikegami. Each of these companies demonstrated its newest color and black and white television cameras and recorders. From the field demonstrations that were performed in the Chicago area, it was determined that the current models of video equipment will provide sufficient resolution and clarity to view the surface cracking, distortion and texture. The surface texture was particularly clear on color television cameras that had resolution greater than 500 lines. The highest resolution cameras are black and white with up to 1,000 lines. However, with a black and white camera the surface texture is not as clear as it is with a high resolution color camera.

The literature review, discussions with knowledgeable engineers and field tests confirmed the original hypothesis, that the video methodology was the most productive means of gathering the pavement cracking information

Pavement Surface Distress Measurement & Recording Systems

Both manual and automated literature searches for the current practices for measuring and recording pavement surface distress were used. Manual literature searches were made in the libraries of Northwestern University Transportation Center, Evanston, Illinois and Novak, Dempsey & Associates, Palatine, Illinois. These were used to refine the list of key subject areas subsequently used for the automated search in the National Technical Information Service & Highway Research Information System. The key words of Pavement Management, Highway Pavement Evaluation, Surface Defects, Roughness and Cracking were most productive. The literature search showed that the majority of the information was found under pavement management systems or in the various handbooks developed by the local state agencies to accomplish their own surface evaluation surveys.

Since the mid 70's no additional pavement distress mechanisms have been added to the state of the art of pavement surface condition rating systems nor have any new methods for determining crack counts been developed other than photographic methods (1).

Each state has implemented its own surface condition rating system to satisfy its own requirements for its pavement management system (1).

All of the surface study methods have a commonality of recording the following major surface distress categories.

a. Cracking (longitudinal, transverse, alligator, map, reflection, corner, edge).

b. Disintegrations (ravelling, stripping, spalling, scaling).

c. Permanent Deformation (Rutting, Faulting)
d. Distortion (Settlement, Heaving)
e. Surface Conditions (Flushing, Polishing)
f. Repairs - (percent patching, or destruction)

The majority of the surface condition rating systems rate only the severity of each distress category. The severity refers to the size or degree of the distress manifestation, i.e., a 1/16 inch or a 1/4 inch crack. The severity is normally rated either with a word scale (low, medium or high) or a numerical value ranging from zero to five or zero to ten. The density is rated as how often the distress occurs over the area of the test section. Two schools of use of this information on the severity and density have evolved. The first is a one number rating system which combines both severity and density and then deducts this value from 100 to arrive at a pavement condition index. This is similar to the Asphalt Institute method (2) and the method used by the United States Air Force for air field pavement condition index (3). The second technique is a two number rating system in which the severity and density are added and the sum is deducted from 100 to give a surface condition number. This is the method used by the Ontario Ministry of Transportation and Communication (4). A further refinement of this method is to also deduct a factor for the location of the distress on the test section, e.g. if it is in the wheel path.

While some agencies have used photologging to accomplish limited surface evaluations, the visual method has remained the predominant means of gathering the surface condition information. Visual surveys continue to be plagued by undesirable subjectivity on the part of the raters, the absence of valid workable statistical sampling procedures and the lack of uniformity and severity weighting techniques for the distress types (1). While there is general agreement on what to look for during the surface evaluation, particularly for cracking, new survey methods would be helpful to quickly gather the field data and produce a uniform surface evaluation system free of rater bias.

Surface Evaluation Utilizing Video Technology

The use of television by highway agencies has been limited to video logging the street scene and traffic sign inventories. Some municipalities have also kept a video record of the existing street scene for use in any potential lawsuits. However, very little has been done with video in conducting surface condition evaluations.

Video Equipment

In general a video system will consist of the video camera; lens; lens or camera body stabilizing equipment; video image recorder and monitor; lighting and distance measuring information equipment. Recent technological improvements have made video equipment, particularly the new cameras, highly portable and compact.

a. <u>Color Video Camera</u> Color video cameras are manufactured with either a single tube or a three tube color system. Within the single tube camera the three color elements, red, green and blue are combined together in a single tube arrangement. This type of camera has resolution of between 250 and 300 lines with a price range that is comparable with that of a black and white camera ($2,000 to $5,000). In a three tube color TV camera each color element has its own corresponding color tube arranged along the X,Y, and Z axis. This camera gives about 500 lines of resolution and has a very clear picture. Three tube color cameras are available in both medium price ranges ($12,000 to $15,000) and expensive price ranges exceeding $35,000+. The quality between three tube cameras is measured in the amount of gain (the ability to amplify light) and the signal to noise ratio. These properties have a significant effect on the overall quality of the picture. The field tests of the JVC and Hatachi Three Tube, Color Video Cameras showed remarkably clear images of the pavement surface cracking, distortions and texture.

b. <u>Television Recording Tapes</u> The 1/2 - 3/4 inch (12.7 to 19 mm) tapes have a resolution capability up to 400 lines. The one inch (25.4 mm) tape can record up to 500 lines of resolution. The tape size selected will be governed by the recorder that is selected for the system.

c. <u>Video Recorders</u> The new video tape recorders (VTR) come with a multitude of features that include the normal forward and reverse, as well as frame by frame monitoring and variable speed recording. High quality 3/4 inch (19 mm) VTR as well as studio quality recorders were selected for the field test. The standard recording rate for VTR's is 30 frames a second. The recording rate will permit the taping of the pavement surface from a moving vehicle.

d. <u>Video Monitors</u> Although there is a small TV screen on each of the TV cameras, a monitor (i.e., a TV set) is required in the test vehicle to insure that the proper information is captured. A 9 inch (228 mm) color monitor was selected and mounted on the dash for viewing by the driver.

e. <u>Video Camera Support</u> The initial field experiments showed that it was necessary to stabilize the camera to reduce the large scale vibrations inherent in a moving vehicle. Accessories have been developed to overcome this problem. Either a spring stabilized camera stand, which can be either hand held or mounted on the vehicle, or an image stabilizer may be used. The image stabilizer uses a gyroscope and mirror configuration which stabilizes the lens image taken by the camera and produces a quality picture free from vibrations. The image stabilizer has an inherent problem with wide angle lenses (35 mm or lower), in that it vignettes and loses quality around the edge of the image.

f. <u>Camera Angle</u> The recommended camera angles and lens elevations were determined during the initial field evaluations of the video equipment.

The camera angles were run from a direct vertical downward (90°) to slightly depressed position (10°) from the horizontal. The lens elevation was run from 39 inches (100 cm) to 120 inches (304 cm) above the pavement surface. From these preliminary tests, it was determined that the camera angle should be 45 degrees from the horizontal at an elevation of 120 inches (304 cm).

g. Lens The best configuration for focal length and angle inclination was an eight milimeter wide angle lens mounted at 45 degrees from the horizontal, which provides the desired 14 foot (426 cm) wide by 14 foot (426 cm) deep picture image. This also can be obtained by using zoom lenses on the TV camera.

h. Mounting Supports and Lighting The video cameras were supported to provide an elevated viewing position of at least teñ feet (304 cm) above the road surface. Lighting should be used to provide continuous contrast to highlight surface cracking.

Video Image Enhancement Using Computer Technology

Computer enhancement holds great promise in automating the calculation of the ADOT cracking index. Computer enhancement has already been used in studying very small cracks associated with fatigue cracking in steel bridges (5).

The first step in computer enhancement is to digitize the video image. In digitizing, the image is broken up into dots called pixels, much like a photograph is printed on newsprint. The pixel is the basic element of picture resolution in computer enhancement. It is operated on an X and Y coordinate system where X is 640 horizontal columns and Y is 480 vertical rows. The Z axis is the gray scale value which ranges from 0 to 256. Zero is black and 256 is white (6).

There are approximately 13 different functions available for computer enhancement (7). The two main activities that image processing accomplishes are to either enhance reconstruction of the original image which produces a new image or to develop a numeric report which produces numbers representing the image.

The enhancement processes take this basic data and, by working it mathematically, enhances the image by magnification, averaging the gray level or modifying the gray levels. The image enhancement processes that hold the greatest promise for the crack index study are contrast enhancement and edge enhancement (difference, gradient and laplacian).

a. Contrast Enhancement The human eye is more sensitive to the high contrast picture. Therefore, by expanding the middle level gray scale into a wider band of gray while making the low level blacker zone black and the high level all white, small details become more defined. The contrast enhancement algorithm can also be reversed to enhance the darker areas instead of the lighter areas. This last method may be very good for crack studies.

b. Edge Enhancement (Difference) - The original picture is shifted by one pixel in both the horizontal and vertical direction. The two pictures are then compared and one is subtracted from the other. If there is a difference in the gray level, as around the edge of certain features in the picture, then these will be enhanced through subtraction.

c. Edge Enhancement (Gradient) - In gradient methods the same subtraction as for the edge enhancement (difference) is calculated. Since these differences are the first derivatives of the gray level, a gradient is calculated as the square root of the sum of the squares of the vertical and horizontal derivatives. This produces an edge enhanced picture where the edges are calculated without regard to shifting direction of the image, i.e., a picture with white lines on a dark background.

d. Edge Enhancement (Laplacian) - This is based on the second order derivative. Maximum values or peaks within the image are emphasized. This is very much how the human eye sees an object. This gives a much more natural and detailed image. When combined with the original picture, a very clearly detailed picture of the original image is obtained.

A comparison software program could be developed to determine the ADOT crack index (5). The digitized video images could either be compared against any number of standard cracking index pictures, or the precise area of cracking in the image can be determined. This can be accomplished any number of times along the one mile test section to more precisely measure the percent cracking and the annual change in cracking.

Field Tests of Video Equipment to Accomplish Surface Evaluation

Test Areas

The broad classifications of Arizona Highway Regions are desert, transition and mountain. The original test program for an urban and rural test section within each region was modified by ADOT to rural highways in the transition zone. Asphalt and portland concrete test areas were also modified to asphalt pavements, since the preponderance of ADOT highways are asphalt.

Surface Evaluation Procedures

The video surface evaluation information was correlated through regression analysis with existing surface evaluation methods. The following methods were used:

a. ADOT photo comparison method to provide comparison with existing methods to determine the ADOT crack index.

b. The Asphalt Institute Pavement Evaluation Rating System - A numerical survey combining severity and density of different distress manifestations.

c. Ontario Ministry of Transportation and Communications (Novak, Dempsey & Associates) condition rating system for flexible pavements. A comprehensive two number rating system reflecting both severity and density of different surface distress manifestations particularly cracking.

Video Equipment for the Field Test

Video equipment representing three levels of sophistication (high, med, low) was used in the field test. This performance range would permit the selection of the most economical ADOT video logging system. The video equipment selected for the field test by level of sophistication was as follows:

a. Video Cameras

1. High: Hitachi SK 91-Color, three tube, high resolution, 500 lines, dichroic prism optics, Cost $40,000.

2. Medium: JVC KY 2700-Color, three tube, high resolution, 500 lines, dichroic mirror optics, Cost $14,000
JVC KY1900-color, three tube, medium resolution, 300 lines, dichroic mirror optics, Cost $7,200.

3. Low: Panasonic WV 1850, black and white, high resolution, 800 lines, cost $1574.

b. Video Tape Recorders

1. High: Hitachi HR-100, 1 inch (25.4 mm) tape, high resolution, $33,000.

2. Medium: JVC CR 8200 U, 3/4 inch (19 mm) tape - medium resolution, stop frame. Monitor, $5,600.

c. Video Monitors

1. Vehicle: JVC 9 inch (228 mm) color. Model S100, $400.

2. Office

a. High - Ikegami - 17 inch (432 mm) color, high resolution precision quality monitor, Model No. PM171P, $600.

b. Medium - Sony Trinitron 19 inch (432 mm) medium resolution, Model No. KV1713G, $550.

c. Low - Ikegami 17 inch (432 mm) B/W -high resolution, Model No. 125A, $345.

d. Video Image Stabilizing Equipment Steadicam - Hand held or mounted spring-stabilized camera mount, $25,750. For the normal operation in video logging, the spring-stabilized camera mount would be required at cost of $6,000.

e. Distance Measuring Equipment to Provide Date and Mile Post Information on the Video Tape

1. Measuring equipment: Numetrics Model No. K 145 with Binary coded Decimal Generator, $725.

2. Video Character Generator - Chrono-Log Corp., Model No., S92, 131-X-11, $1,658.

NOTE: For the field test, the mile-post (MP) information and the test speed were recorded on the video tape.

f. Vehicle and Equipment Set Up

A 25 foot (762 cm) recreational vehicle with a built-in 125 volt power source was used for the test program. A platform was mounted on the top of the front of the vehicle to support the camera operator and the various video cameras. The height of the camera lens was 10 feet (304 cm). The Steadicam system and the rigid camera mount were mounted on the front of the platform. The general view of the camera arrangement is shown in Figures 1 and 2. The Steadicam system, which is designed to steady the camera in any position, was hand supported by the operator. A video console system and VTR's were installed in the vehicle. An intercom system was used by the video technician to monitor and direct the video taping. The driver had a nine inch color monitor mounted on the dashboard to view the recorded scene and comment on the pavement conditions as the tests progressed.

Speed

Speed of the test was measured by the vehicle speedometer. The speed for each test was superimposed on the video image by use of the special effects generator for the first 200 feet (61 m) of the test run.

Recording

During each test run, the recordings were taken on the Hatachi HP 100, 1 inch (25.4 mm) tape, and the JVC CR 8200U, 3/4 (19 mm) tape, VTR's.

FIGURE 1.
SIDE VIEW,
VIDEO CAMERA
SET UP.

FIGURE 2.
FRONT VIEW,
VIDEO CAMERA
SET UP.

Field Test Sites

The asphalt pavement test sites were selected by ADOT. There were four 1-mile test sections (located on Figure 3) described as follows:

(a) The first test site was on State Route 87, a north-south rural inter-city highway south of Chandler, Arizona between Mileposts 160 and 161. This is a 4-lane asphalt highway. The pavement surface cracking condition is characterized by fine to medium alligator cracking with some longitudinal cracking in the wheel tracks as shown in Figure 4. The video test was taken on the morning of the 15th of December shooting with the sun behind the vehicle which was proceeding in the north bound direction.

(b) The second test site was on State Route 287, from Mileposts 135 to 136. This is an east-west route located west of the city of Florence, Arizona. The pavement is characterized by transverse cracking, block cracking and random cracking as shown in Figure 5. The video test was taken in the afternoon of the 15th of December in the east bound direction with the sun at the right rear of the vehicle.

(c) The third test site was on U.S. Route 89, from Milepost 130 to 129. This is a north-south route south of Florence, Arizona. The pavement is characterized by transverse and random cracking and some patching as shown in Figure 6. This test site was selected for the detailed surface evaluation study because of the clarity of the video images obtained at this test site. The video test was conducted on the morning of the 16th of December on the south bound lane shooting into the sun.

(d) The fourth test section was on State Route 87/287 from Milepost 125 to 126. This is a north-south route located south of Coolidge, Arizona. The pavement is characterized by transverse cracking with sealed joints as shown on in Figure 7. The video test was taken on the south bound lane with the sun position ahead and to the right. This test section also had one area of cracked portland cement concrete pavement. This cracking was seen on the video tapes quite clearly.

Video Test Procedures

Test Lane Layout

Each test was conducted in the same manner. First, each mile (1.6 km) of pavement was laid out in 200 foot (61 m) increments in the test lane using a measuring wheel. Each section was then numbered from 1 to 26 to accurately locate each of the video images for that test run.

Test Speeds

The test runs were made at speeds of 5, 10, 25 and 35 miles per hour (8,16,40 and 56 km/hr). The variable speeds were used to determine the

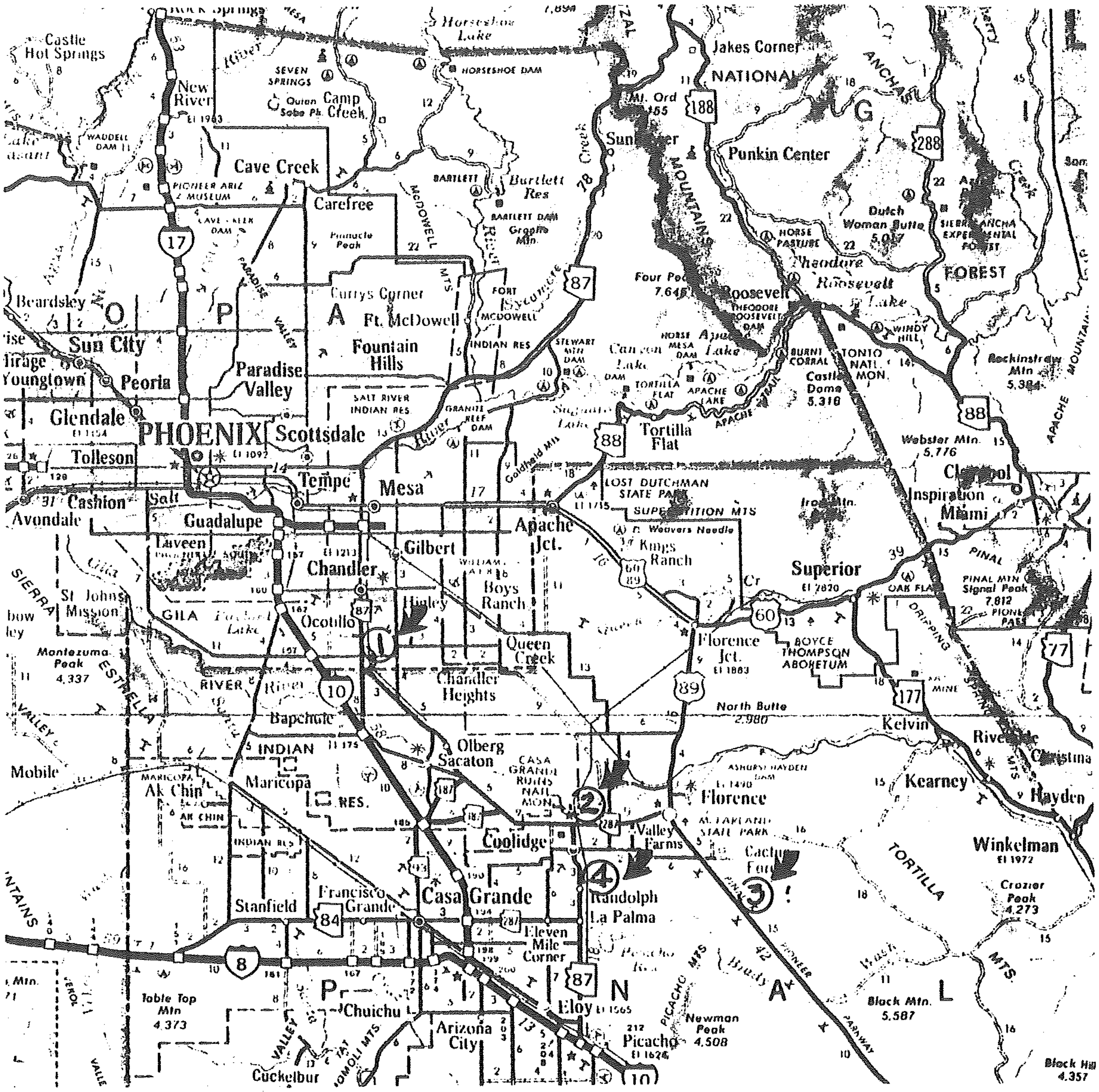


FIGURE 3
TEST SITE LOCATIONS

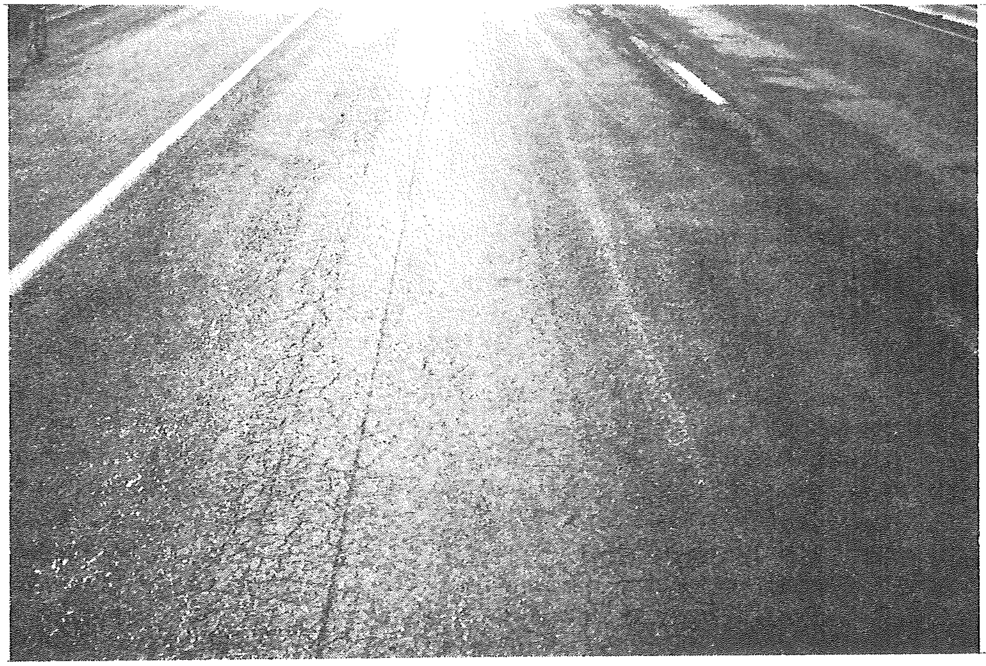


FIGURE 4.
TEST SITE 1, SR 87-OUTSIDE N BOUND LANE.

FIGURE 5.
TEST SITE 2, SR 287-E BOUND LANE.

FIGURE 6.
TEST SITE 3, US 89 SE BOUND LANE.

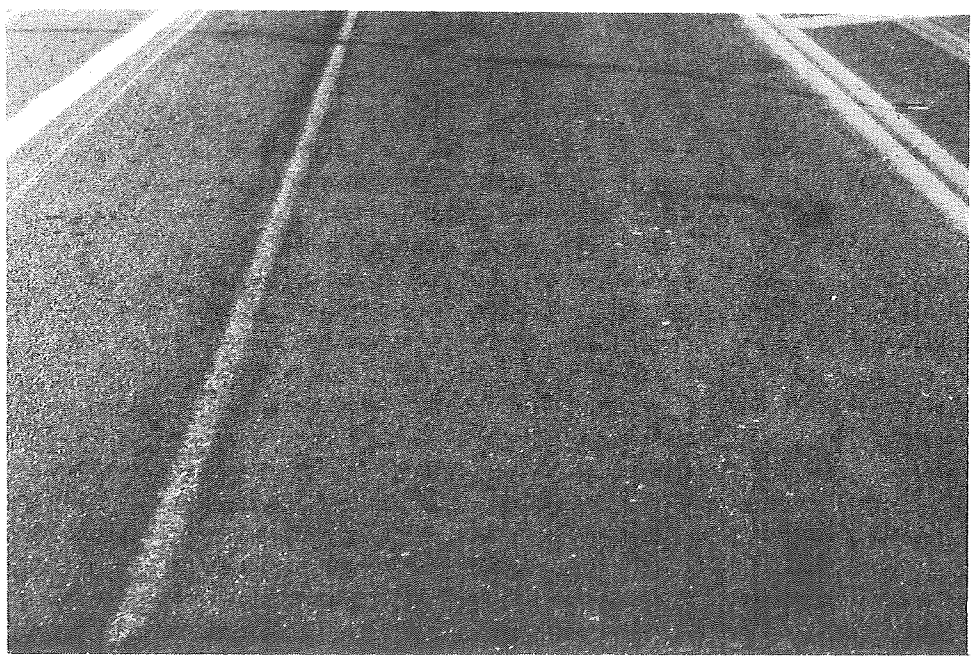


FIGURE 7.
TEST SITE 4, SR 87/287 S BOUND LANE.

maximum speed at which a clear video image could be captured for various types of pavement defects.

Test Lighting Conditions

During the tests, the weather was clear with brilliant Arizona desert sun. No artificial lighting was used. The tests were taken shooting into the sun, away from the sun and across the sun's direction to measure the effects of the sunlight and sun direction on the video images.

Comparison Manual Surface Study Methods

In addition to the video images, manual surface study methods were utilized for each test section. These were the Arizona Crack Index, using the photo comparison method; the Asphalt Institute method; and the Ontario comprehensive surface study method. The comprehensive surface evaluation method evaluated the pavement cracking and recorded the location, type of severity and density of the cracking for each 200 foot (61m) increment in each test section. The Asphalt Institute method was used for the whole 1-mile (1.6 km) section. The surface study results are summarized in the Appendix.

Test Video Camera Operations

The Hitachi SK91 was used on the first day of shooting . On the second day, the JVC KY2700 and the KY1900 were used. Each day the cameras were calibrated to insure the highest resolution obtainable. The JVC KY2700 obtained a resolution of 525 to 550 lines and actually gave us the best resolution of all cameras tested. The Hitachi SK91 and JVC KY2700 cameras were used with the Steadicam stabilizing camera mount. The JVC KY1900 was mounted on a fixed mount. At speeds of 5 miles an hour it provided a satisfactory picture, but at higher speeds, it lost some of the clarity due to vibrations. While the black and white camera was mounted, no images were recorded because of technical problems. However, the JVC KY 2700 was operated on the Steadicam as a black and white camera on test site 4 for one run. The evaluation of the black and white images clearly shows that the color image was far superior to that of the black and white for viewing cracking patterns.

Field Tests Observations and Results

The following general conclusions can be reached based upon the field tests and detailed observation of the resulting video tapes in the studio:

Video Camera

The JVC KY 2700 medium price range camera gave excellent results in the test and there is no requirement to go to a more expensive camera. It should be pointed out that new video cameras are coming on the market almost monthly. A new video camera that was not available for the test is the Hitachi FP21. It has improved prism optics rather than mirror optics and is in the medium price range for video cameras.

Video Tape Recorders

The JVC CR 8200U 3/4 inch (19 mm) tape also produced excellent resolution and would be satisfactory for gathering of the field information and reviewing the information in the office.

Video Camera Support

A detailed examination was made of the solid mount versus the use of the Steadicam camera stabilization system. The Steadicam was far superior to the solid mount; in fact, on one test run the split screen image was used to compare side by side the Steadicam supported TV image versus the solid mount supported image. They were similar up to 10 miles an hour (16 km/hr) , at about 12 miles an hour (19 km/hr), on pavement with class 2 cracking, the solid mounted camera started to lose a stable image. Therefore, some methodolgy of camera stabilization will be required if the tests are going to be conducted at any speed other than 10 miles an hour (16 km/hr) or less. The Steadicam system can be modified to use only the arm support so that the camera only moves in the vertical plane and remains pointed straight ahead. An operator would not be required to hold the camera, but direct mounting of the Steadicam to the vehicle may result in a slight reduction in vehicle speed for a stable image.

Lighting

Of all the variables other than speed, lighting is the most critical in capturing clear video images of the pavement. The best video images were taken shooting into the sun. The sun reflected across the pavement cracks and highlighted the cracking pattern. The lighting problem is a particularly difficult one to solve. It would be the one area other than speed that would possibly limit the suitability of a video logging system for cracking inventory program. For example, on the first test runs on State Route 87, the pavement distress was a very fine alligator cracking. Shooting away from the sun, it was very difficult to pick up this very fine alligator cracking on the video image even though the studio quality Hitachi SK 91 camera was used. On a return test shot on the same highway with the same distress pattern and shooting into the sun, the crack pattern was discernible but the very fine alligator cracking was again difficult to pick up on the video image. The very best video images in natural sunlight were taken on Test Site No. 3 on U.S. 89 shooting into the sun. This problem with the orientation of the sun and the natural sunlight in Arizona may possibly be resolved by further testing at night. The lighting should be positioned out approximately 25 feet (762 cm) in front of the camera shining back across the cracks to simulate the effect of sun. Another possibility is the use of strobe lights with a special video camera with a high speed (60 frames/second) spinning disk lens shutter that can utilize the effect of the strobe light. The best solution would be to provide high intensity lights at a low angle shining across the pavement toward the video camera to highlight the cracking pattern. This could be accomplished by using an open bed trailer with the lighting mounted on the front and the video camera mounted on the rear. The open bed of this trailer would permit viewing of the pavement surface.

Speed

Speed was the other critical variable in obtaining a clear video image of the pavement. The images were taken at the standard rate of 30 frames/second. Tests were run from a creep speed of 5 miles an hour (8 km/hr) up to 40 miles an hour (64 km/hr). The maximum speed at which the pavement cracking pattern could be accurately viewed on a video monitor was 28 miles an hour (45 km/hr). Above this speed, the resolution of the picture started to degrade and was not usable. This was based upon the geometrics of the camera height being 10 feet (304 cm) above the pavement surface.

Correlation with ADOT Crack Index System

The ADOT normally records the actual percent cracking and would use this information in their system. Their pavement management system further classifies (indexes) the actual percent cracking into three broad classifications: class 1, 0 to 10 percent cracking; class 2, 11 to 29 percent cracking and class 3, 30 percent plus cracking. With these broad classification ranges, there was only slight correlation between the class of cracking and the other surface study methods.

However, on US 89, Test Site No. 3, a high degree of correlation was obtained when the Ontario (NDI) surface study method was compared against the actual percent cracking for 18 test sections. The correlation coefficient was $r = -0.8951$. With 16 degrees of freedom, this correlation coefficient can be considered over 99% valid.

On the remaining test sites, there was general agreement with the results from test site No. 3 when the ADOT estimated percent cracking was compared against Ontario (NDI) surface study for the first 200 foot (61 m) section.

Computer Enhancement of Field Video Images

The computer image processing was accomplished by Spatial Data Systems of Goleta, California. To work out an image enhancement process and test its validity, the standard ADOT photographs for percent cracking were utilized. This image processing went through three phases. First, the picture, Figure 8, was digitized. A software program (BOXCAR) was used with a 32 by 32 matrix to remove the fine detail (cracks). The filtered picture was then subtracted from the original image to yield the image shown in Figure 9. The shading in the picture is due to the uneven lighting and broad tire marks. The enhanced image shown in Figure 9 clearly defined the areas of cracked pavement.

A more difficult problem was how to quantify or establish a numerical value for the digitized image that represented either the physical area of cracking or, as is used in the ADOT system, the area of the image that contains cracks. This problem was solved by using an additional software program contained in the EYECOM 2 picture digitizer and display unit, Model 109PTS. This software program is called HISTO: histogram. This histogram depicts the various gray levels contained in the image, Figure 9. The horizontal axis of the histogram represents the various grey levels (black-left to white-right). The vertical axis shows the number of pixels of each gray level contained within that histogram. The histogram has the general shape of a normal distribution curve, caused by the random distribution of the gray scales in the picture. However, the dark cracks in our computer enhanced image produce an unsymmetrical tail on the black (left) side of the graph. With the histogram program, the area or number of pixels contained in the tail can be measured to give an indication of the pavement quality.

The pixels contained in the tail are shown in black in the image in Figure 10. The crack patterns correspond well with the locations of cracks in the original image. The number of interest is the percent area of cracks of 14.39 percent. A similar analysis of the standard 35 percent cracking photo yields an area of 10. 09 percent. The importance of using this histogram program is that a numerical value is assigned to each image. This numerical value can then be modified to produce the Arizona Crack Index; for example, the factors obtained in this original study multiplied by a factor of 4.5, yields the surface areas containing cracks for the photo series of 64.7 percent versus 64.8 percent for the original, 45 percent versus 35 percent for the original and for the 7.7 percent versus 10.8 percent for the original photos for the 3 series of the ADOT cracking photos.

A similar program was used for the video images from test site No. 3, section 8 taken on Route 89 as shown in Figure 11. A BOXCAR program using a 2 x 2 matrix, then a 64 x 64 matrix was performed. The original image was subtracted from the filtered image producing the image in Figure 12 with the enhanced crack patterns. Again, the histogram program was used, which produced an area of cracking of 4.5 percent for this image.

The area of cracking depends upon where the unsymmetrical tail of the histogram is sliced. This can be accomplished by placing the + cursor, as shown Figure 10, in the black cracked area of the image and measure the relative gray scale of the pixel at the particular point. Using this as a

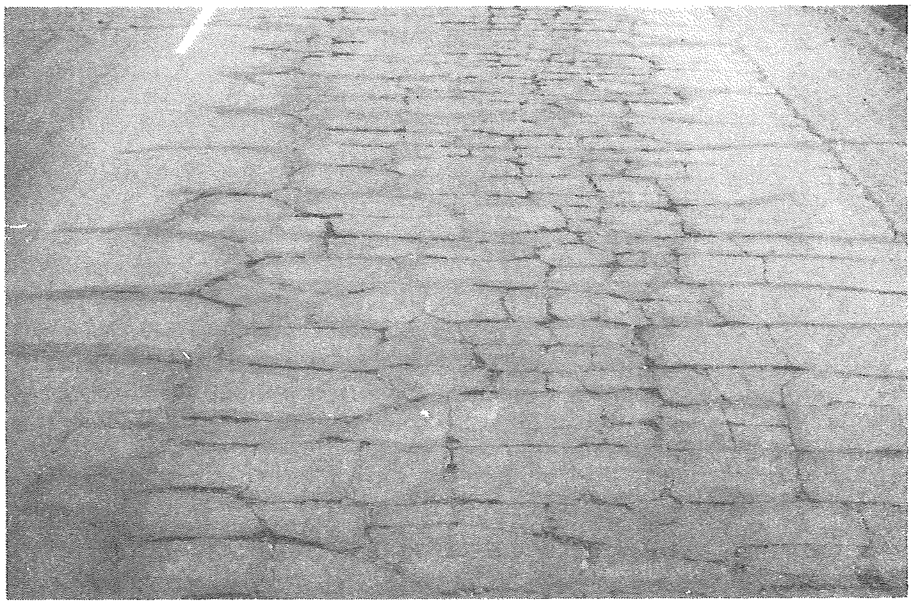


FIGURE 8.
ORIGINAL ADOT REFERENCE PICTURE
64.4% of IMAGE CONTAINS CRACKING.

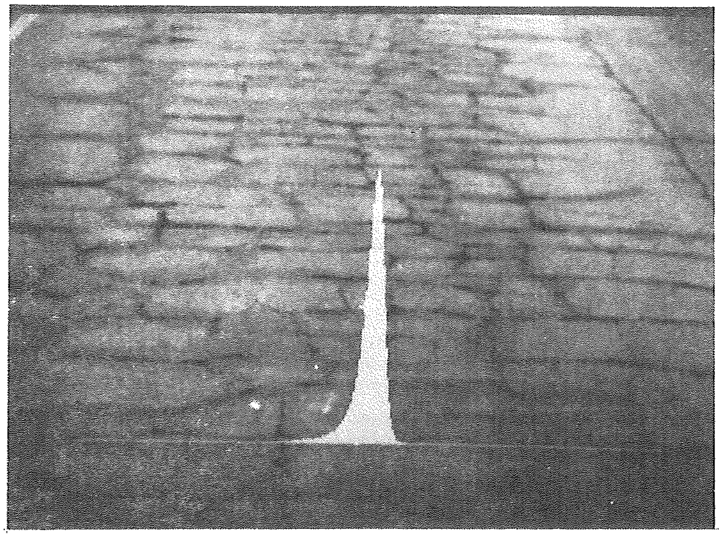


FIGURE 9.
ENHANCED IMAGE WITH HISTOGRAM
ADOT REFERENCE PICTURE.

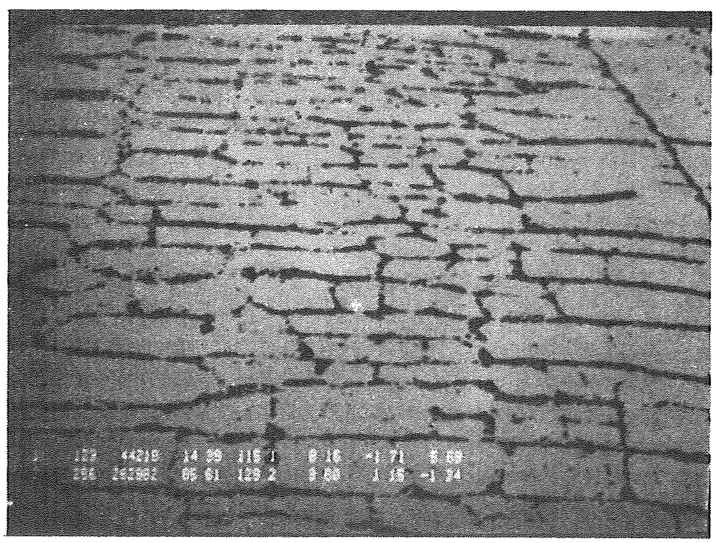


FIGURE 10.
ENHANCED IMAGE AT GREY LEVEL 123
PHYSICAL AREA OF CRACKS 14.4%.

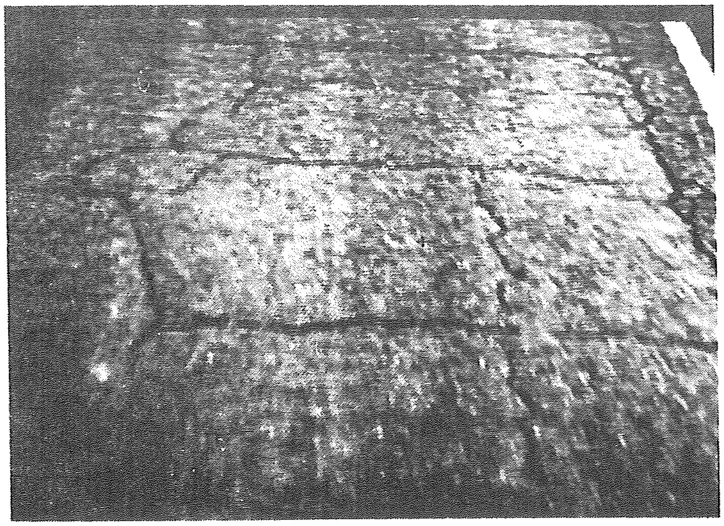


FIGURE 11.
COMPUTER ENHANCED VIDEO IMAGE
TEST SITE 3-SECTION 8 to 9, US 89-MP 130.

FIGURE 12.
CRACK IMAGE AT GREY LEVEL 114
TEST SITE 3- SECTION 8 to 9, US 89-MP130.

reference, the operator can accurately determine where to slice the black tail of the histogram to actually obtain the number of pixels that are the reference shade of gray or darker. This value represents the cracked areas of the pavement. Using this software program, the actual area of cracking in the pavement can very be easily be determined. A similar software program could be developed to determine the area of the test section containing cracks such as is presently utilized by the ADOT. A grid system as shown in Figure 14 could be overlaid on the image. Those areas within the grid that contain a dark image greater than or equal to the gray scale selected to determine what is and what is not a crack would determine the percentage area containing cracks. So a crack count can be accomplished by either of two methods, either determine the actual area of the cracks on the pavement section or determine the area of pavement that contains cracking.

In the case of the video image in Figure 13 from test site No. 3 that was digitized, using the conversion factor of 4.5, the cracking factor of 4.5 percent converts to an ADOT percentage cracking of 20 percent. This agrees with the field data of 20 to 25 percent for this section.

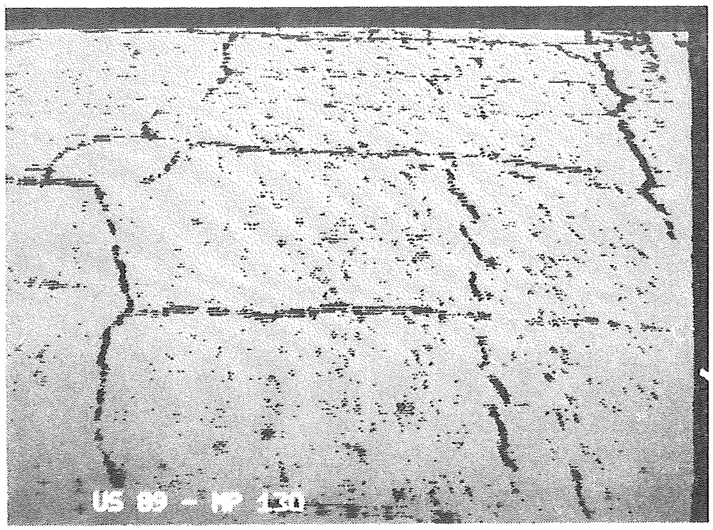
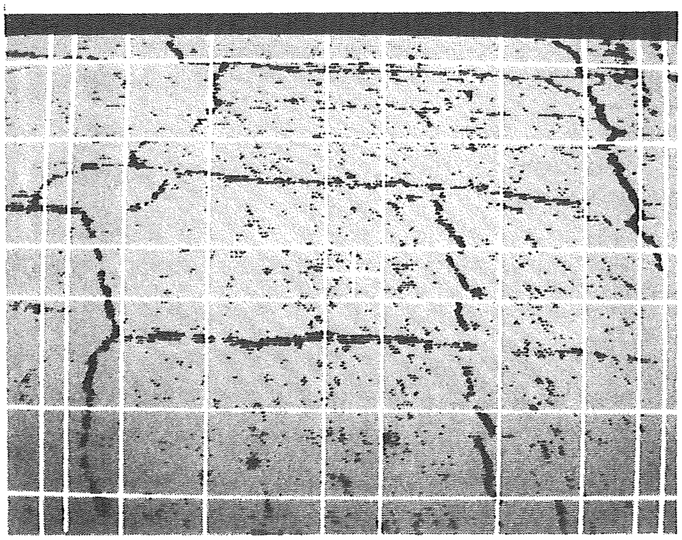


FIGURE 13.
COMPUTER ENHANCED IMAGE
TEST SITE 3-SECTION 8 to 9, US 89-MP 130.



ECONOMIC ANALYSIS OF VIDEO LOGGING SYSTEM

The current costs for collecting the crack inventory using the photo comparision method is approximately $30,000 a year or $4.25/mile ($2.68/km) for the 7,000 mile (11,200 km) system with a two man crew in the field for six months.

The investment costs to start the video system would be:

a.	Camera and lens (JVC 2700)	$ 14,000
b.	VTR (JVC CR 8200U)	5,600
c.	Camera Mount (Steadicam)	6,000
d.	Image Enhancement Equipment, Software, micro computer, Eye Com II, picture digitizer and display, tape storage cabinets, and 1000 video tapes.	62,750
e.	Distance measuring Equipment and video character generators	2,400
f.	Vehicle modifications, driver video monitor and the lighting trailer	30,500
		$121,250

The present two man field crew would be retained if the video logging trailer was used. The annual cost for the office technician to process the video tapes would be $15,000.

Using a six year equipment amortization period, the annual operating costs of the video logging system would be:

a.	Field Personnel (2)	$ 27,000
b.	Office Technician (1)	15,000
c.	Video and Digitizing Equipment	15,000
d.	Vehicle and Lighting Trailer	5,000
e.	Vehicle Operating Costs	5,000
f.	Traffic Control (joint use vehicle and operator)	20,000
		$ 87,000

The annual costs for existing photo comparison method for cellecting the crack inventory information is:

a. Field Personnel (2)	$ 27,000
b. Vehicle	2,000
c. Operating Costs	1,000
	$ 30,000

The existing manual system is clearly more economical than the proposed video logging system. Even if the frequency of testing was increased to twice a mile (1.6 km) and the traffic control was eliminated by improved speed of video logging, the manual system collection cost of $60,000 would still be less than the video logging system collection cost of $67,000.

CONCLUSIONS

Video Systems Capability

The current state of the art of video equipment can produce video images that clearly show the pavement cracking.

Test Vehicle Speed While Recording

The maximum speed that produced clear video images, even when viewed with the stop frame VTR, was 28 MPH (45 km/hr). This is a relatively low speed for gathering pavement inventory information. It would also create a major safety hazard for other vehicles traveling at freeway speeds. A major effort for moving traffic control would be required to protect the video test vehicle from other vehicles. Is is a major technical obstacle that must be solved before video logging procedures can be implemented.

Field Lighting Condition

The position of the sun in relation to video camera was a major factor in recording a clear pavement cracking pattern. The clearest images were recorded shooting into the sun with sunlight highlighting the cracking pattern.

Computer Enhancement

The Computer Enhancement programs clearly produced the most promising results for calculating the ADOT cracking index. Existing computer systems and software can accurately determine the actual area of cracks within the image area.

ADOT Crack Index Correlation With Other Methods

There was a high degree of correlation between the ADOT percent cracking by area measurements and the Ontario method (comprehensive) surface study methodology. The ADOT crack index system did not develop the same high degree of correlation.

Economic Benefits

The existing ADOT methods for collecting and determining the percent cracking in the pavement surface is more economical than using video images with computer enhancement. Even if the video collection speed was increased to eliminate the traffic control requirement and the sampling frequency was doubled to twice a mile (1.6 km), the present method would still be more economical.

RECOMMENDATIONS

Video Systems

Of the evaluated video equipment, the midrange cost equipment is recommended for the ADOT Video System. This would include the JVC KY2700 camera with lens, JVC CR 8200-U VTR, the camera stabilizing equipment, and associated monitors and support equipment. The use of color video cameras with high speed shutter systems (60 frames/second) should be explored.

Test Vehicle Speed

The speed of video test collection vehicle must be increased to operate safely in freeway traffic without additional safety vehicles. The 60 frames/second high speed video camera shutter should permit video logging at speeds of 45 to 50 miles/hour (72 to 80 km/hr). It should be field tested during the night lighting tests.

Field Lighting

Further field testing at night is recommended to improve the lighting of the pavement cracking pattern so that all levels of cracking can be recorded at high speeds and eliminate the effect of the sun's position relative to the camera.

The field lighting must be projected towards the video camera from a point approximately 20 to 25 feet (610 to 762 cm) in front of the video camera. An open frame trailer could provide this support for both the video camera and lighting systems. This arrangement will allow the light source to be ahead of the normal horizontal viewing plane of the video camera yet provide the lighting across the crack pattern.

Use of Computer Enhancement

Since the ADOT crack inventory is based on the area of pavement containing cracks, a software program will have to be written to compute the area of the pavement that contains cracks.

However, it would appear that if the video method with computer enhancement is adopted, using the direct measurement of actual area of cracking would be preferable.

In either event, additional software will have to be written and validated to directly produce a crack index or percent cracking from the field video tapes for insertion into the ADOT pavement management system data base.

In addition, this would permit greater testing frequency for a given mile (1.6 km) section with the corresponding increased accuracy of the percentage cracking calculation. This would make the video system a possible viable economic alternative to the present ADOT system.

APPENDIX

TEST SITE NO. 3
US 89 MP 130 to 129

Test Section	Novak, Dempsey Surface Condition No.	ADOT Percent Cracking by Area
1	63	12
2	63	18
3	68	10
4	67	15
5	58	20
6	58	22
7	55	28
8	57	32
9	55	27
10	60	28
11	66	15
12	68	11
13	54	35
14	56	29
15	54	29
16	62	18
17	63	22
18	58	28

TABLE 2-A.
TEST SITE 3 SURFACE CRACKING COMPARISON.

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