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AUTOMATED DATA ACQUISITION FOR LOW-VOLUME ROAD INVENTORY AND MANAGEMENT

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ABSTRACT

Local governments need suitable inventories and condition surveys to accurately determine and prioritize their funding needs. An efficient method of performing an inventory of the roads and subsequently determining the condition of major system components is to use an automated data-acquisition system to measure and record essential data. The data may be collected and processed by a central inventory management group. The inventory should include pavement characteristics, roadway geometrics, and roadside features. Pavement condition may include structural integrity, road roughness, and skid resistance. Roadway geometrics include horizontal curvature, length, width, superelevation, and grade. Roadside features include signing, intersections, guardrails, and obstacles.

This paper presents a concept for a second-generation vehicle-mounted photologging system that may, in a single-pass, photolog the roadway and automatically record measurements necessary for inventoring

and rating. Also, major functions of a central inventory management group are described.

Second-generation photologging systems use either camera or video systems for visual data recording. Particulars of those methods are presented and compared. Sensors for additional data measurement including grade, superelevation, and road roughness will be described. Data-recording methods are discussed with emphasis on future data-storage technological improvements.

The function of the inventory management group is to obtain data and convert it to a usable form. This consists of five basic activities: operations management, data acquisition, data reduction, data interpretation, and inventory preparation.

Data reduction includes sorting and editing visual records (film or video tape) and digitizing analog recordings. Several methods for addressing those records and cross correlating visual and sensor data are discussed. They range from manual sorting techniques to computerized laser-disc data-processing systems.

Data interpretation requires review of acquired data in its formatted, addressable form. Analyses may include a combination of visual and sensor analysis (for pavement condition and roadway geometrics). Other geometric-related analyses may be based almost entirely on visual recordings (roadside features). In some instances such as unpaved roads, where few accepted standards exist, new standards or criteria should be formulated for evaluation. Otherwise, accepted standards will be used.

The road rating process is described along with methods employed to rank or prioritize pavement and traffic safety-related rehabilitations.

Interaction between the central inventory management group and the low-volume road agency in preparing the final compiled inventory also is discussed.

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INTRODUCTION

Management of local roads may be enhanced by use of an inventory of the physical elements of the roadways and a survey of their existing conditions. Such inventories are commonly used as tools in 1) determining future funding requirements, 2) assessing current funding needs, 3) allocating and managing limited funds, 4) prioritizing construction and repairs, 5) increasing safety, and 6) avoiding unnecessary accident-related litigation.

To obtain valid inventories, local agencies must send people to the field either to obtain information about the infrastructure or to verify data obtained from office files and records. Field work is an absolute requirement to obtain condition surveys. Field and office data must be condensed into a usable form and evaluated. Results must be reformatted for presentation for use by nontechnical users.

In performing inventories, local agencies often encounter problems. It is difficult to locate and train competent survey personnel. The cost of manual data acquisition is expensive. Processing field data also may prove costly and troublesome. It may be difficult at the local level to obtain technical expertise to evaluate and analyze the data. Finally, local agency personnel may not be sufficiently skilled or experienced to render the inventoried information/data and ratings in a manner that may be utilized by lay persons such as county judges, law-enforcement personnel, or other local government officials or employees.

One method of overcoming those difficulties is to employ automated drive-over data acquisition. Data acquisition is performed by a crew in a van or car equipped with photologging (or videologging) system(s) and often supplemented with other nonvisual data-acquisition systems that measure a variety of pavement parameters (Figure 1). The derived data are automatically stored in an addressable form and so they may be retrieved later. When the field data have been obtained, it may be delivered to a central inventory management group. That organization can economically and properly format and analyze the data and produce usable inventories and synopsized reports.

A number of companies manufacture assembled data-acquisition systems for pavement surveying and market fully equipped vehicles. Nationwide, several consulting firms possess or are preparing to offer pavement survey and inventory services.

Local agencies having large inventories (2,000 plus miles) might investigate purchasing an equipped data-acquisition vehicle. Road agencies having smaller inventories might consider employing a pavement survey and inventory consultant.

A third approach would be for local agencies to pool resources and contract with a university-associated transportation program, a technology-transfer organization, or a consultant to establish a central inventory management group. Either organization would likely have access to varied and specialized technical skills necessary to establish a competent roadway management team.

The road inventory should include a listing of the physical elements and their locations, pavement and road surface conditions, and roadway geometrics. Pavement condition should include pavement type, pavement structural integrity, road roughness, and skid resistance. Roadway geometrics include roadway length, pavement width, superelevation, grade, and roadside geometrics such as signing, intersections, guardrails, and roadside obstacles.

PHOTOLOGGING

The primary form of field data acquisition is photologging or videologging. Acquisition of roadway visual images is termed "first-generation" photologging and has been performed by state highway agencies for about 20 years (1). Considerable information related to pavement and general roadway environment may be acquired from photographs of the in-place road system. That process augmented by concurrent acquisition of nonvisual data is termed "second-generation" photologging. That practice provides for economical acquisition of data parameters over the entire route. As the visual image and nonvisual parameters are being recorded concurrently, often on the same data storage medium, it is a simple matter for central inventory management personnel to correlate individual visual records with attendant nonvisual data. This allows correlations to be made that would not be possible if the visual image inventory was conducted separately from a statistical sampling of the nonvisual data. It should be noted that

100-percent data acquisition by photologging is difficult to achieve and that some limited amount of more conventional field inspections should be anticipated. Presently, 43 states perform some type of photologging or videologging operation.

VISUAL DATA

Commercially available photologging (videologging) systems employ one or more vehicle-mounted cameras aimed forward, rearward, and/or downward, depending on the manufacturer. If more roadside detail is sought, as would be the case for low-volume roads, the camera(s) could be aimed slightly outward. If four-lane roads were being recorded, it would be possible to film or tape the two lanes in a given direction simultaneously with one camera. Also, if only visual inventoring was being done, it would be possible to film or tape a two-lane road in one drive-over pass. A front-mounted camera would record one lane and a rear-mounted camera would record the other. When very general visual records are desired, a single pass with one camera may suffice. Where second-generation photologging is conducted, one pass may be required for each lane, limiting the utility of additional cameras.

One use of visual data may be to determine distances. As shown in Figure 2, the height of a telephone pole may be determined by measuring the image height in successive film frames. Then the height of the pole may be computed from

$$D = d_1 d_2 \ S \cos \phi / (d_1 - d_2) fR,$$

in which D = dimension of the object (meters),

d_1 = size of the image on frame one (millimeters),

d_2 = size of the image on frame two (millimeters),

S = frame interval (meters),

ϕ = angle of skew of the camera to the roadway,

f = focal length of the lens (millimeters), and

R = enlargement ratio = ratio of size of image on screen to size of image on film.

Distances to the front and side of the image may be roughly measured using a perspective overlay (Figure 3). The road should be level if a front-viewing camera is used. Distances on hilly roads may be measured using the perspective overlay with a rear-directed camera.

Usually, color film or video tape is used. There are advantages and disadvantages with either cinematic or video image-recording methods. Camera film must be developed whereas video tape is immediately ready for replay. It is cheaper to copy video tape and it may be erased and reused when necessary. Also, several video images may be superimposed and displayed simultaneously as split-images on a video monitor. Camera film will show finer detail than video tape. Film may be necessary when small pavement flaws such as tight cracks are to be detected visually. Video images are usually taken continuously and are best reviewed at real-time recording speeds. However, motion picture film may be exposed at fixed intervals along the road (one frame approximately every 50 feet). When that film is replayed for data review and interpretation, central inventory management personnel will benefit from the derived "time-compression" gained during playback.

Even when employing first-generation photologging or videologging, it is desirable to log information such as the logging date, route, agency control number, odometer reading, vehicle speed, tape or film number, and operator comments. System manufacturers provide for superimposing information visually onto a portion of the film or video image (Figure 4). If second-generation photologging or videologging is performed, nonvisual sensor information may be digitized, encoded, and stored along with the conventional data on a portion of the visual image. If visual data storage is not desired, the sound track of either the film or video tape may be used to store analog or digitized data.

NONVISUAL DATA

Second-generation data-acquisition systems are capable of measuring and recording information that could not be determined visually. Among those parameters are 1) road roughness, 2) pavement surface side friction, 3) grade, 4) cross slope, 5) bearing, 6) horizontal curvature, and 7) vertical curvature.

Road roughness may be measured by the deflection of the rear axle of the data-acquisition vehicle. This may readily be measured by attaching an accelerometer to the axle (for small displacements). One manufacturer supplies a separate towed road-roughness measuring system capable of measuring roughness wavelengths from 1 inch to 300 feet (Figure 5). The road roughness system can be calibrated to national standards for comparison of data with other road agencies.

Side friction of the pavement surface may be measured using a ball-bank indicator having the angle of swing of a damped pendulum expressed as the tangent of the angle. This is a measure of sideways frictional forces between the tires and the road surface as the vehicle travels along a curve. When correlated with vehicle speed, that measurement ascertains whether the curve´s superelevation is safe for its posted speed.

Usually, grade measurements are made in reference to a gyroscope.

Readings are given in percent of grade with a plus or minus sign to indicate slope. Cross slope or transverse slope is measured in a similar fashion. A gyrocompass is used in one manufacturer's system to determine bearing. Combining bearing and odometer signals provides for determination of horizontal curvature. Grade (gyro) signals also may be combined with odometer signals to determine vertical curvature.

Some first-generation photologging or videologging systems may be "built-up" to second-generation systems as funding allows. All photologging, videologging, or nonvisual data-acquisition systems should be componentized to the maximum extent possible to provide for replacements when better technology becomes available.

A "third generation" of pavement data-acquisition vehicles is presently being evolved. Those systems will contain instrumentation to make "on-the-fly" analyses of pavements that presently do not lend themselves well to conventional data-acquisition or follow-up analysis. The vehicle shown in Figure 1 is equipped with sensors in an enlarged front bumper that detect rutting. Swedish and Japanese firms have developed laser sensors capable of detecting a number of types of distress in pavements, including cracking and rutting (2). An American firm is presently developing a fully automated system that will optically survey pavements and assess their conditions.

Structural evaluations generally are applied to pavement sections on the basis of perceived needs as determined from visual inspections of pavement distresses and the observation of load- and fatigue-related distresses. There are a number of devices and procedures available for collecting and processing deflection data for structural evaluations of pavements. Such equipment does not lend itself well to "on-the-fly" data-acquisition methods. Hopefully, in the future, more rapid test methods will be developed that potentially may be "piggy-backed" onto the second- or third-generation photologging vehicles.

OPERATIONAL REQUIREMENTS FOR DATA ACQUISITION

The ideal test vehicles for data acquisition are vans. They have sufficient internal space and may be serviced at most locations should the need arise. The test van should have space to house the camera(s), data-input devices, photologging or videologging control panel, electrical generating equipment, and spare film or tape. The vehicle will generally require a crew of two, a driver and a system operator. The system operator will log route information, tape numbers, and special events with the manual data-entry system. He will change the film and check system functioning during the tests. Also, he will serve to direct the driver.

Generally, the vehicle will be operated at speeds between 35 and 55 miles per hour. Depending upon travel time to the test site, the data acquisition crew may record 500 to 1,300 lane-miles of road per week. The lower figure is representative of city operations. The higher figure is possible for open high-type paved roads. The Connecticut Department of Transportation employs a photologging system. To complete inventory of their 4,000 miles of pavement, 8 months of second-generation photologging is obtained each year. Previously, this was done manually by six two-man field crews with an 11-year cycle to collect similar data.

For low-volume urban roads, film consumption would be one 100-foot reel for every 25 miles with an exposure interval of one frame per 35 feet. A week of city photologging could consume up to 20 reels of film.

If a video system was used, 20 two-hour tapes would be required for the same operation. A two-man crew could conceivably photolog about 50,000 lane-miles per year with an 80-percent duty cycle. In rural locations, the exposure interval could be increased to one frame per 70 feet, increasing the mileage of coverage on a can of film or a video tape.

Costs for different types of logging operations (including data reduction) varies with the category of road inspected and the number of data parameters to be inventoried. Typically, costs per mile may range from $134 for urban areas with high sign densities to $15 for rural areas with very low sign densities (3). Photologging and videologging have corresponding costs ranging from $67 and $69, respectively, for urban areas with high sign densities down to $23 and $16, respectively. However, those costs represent only one type of inventory (signing). If multiple data parameters are required, the photologging and videologging methods will be even more economical.

INVENTORY MANAGEMENT GROUP

A central inventory management group would consist of five teams: 1) the operations-management team, 2) the data-acquisition team, 3) the data-reduction team, 4) the technical review and rating team, and 5) the inventory-preparation team (Figure 6).

The operations-management team would supervise and coordinate the entire central inventory management group. They would interface with other units or agencies responsible for various aspects of the low-volume road system and determine test requirements. The operations-management team would schedule work and coordinate all operations and would review all compiled inventories and synopses before they were delivered to other units and staff.

Once the data-acquisition team had obtained data from the low-volume road system, the raw data would be transmitted to the data-reduction team. That team would consist of several technicians who would develop film and digitize and computerize analog sensor data. They would inspect photologged or videologged images to see if they were suitable for analysis. The technicians also would check to see if all sensor data were reasonable and would review the routing and identification information to ensure that data were complete. Finally, they would organize the data into a reduced formatted form to facilitate ratings and analyses by the technical review and rating team.

The technical review and rating team would consist of a few engineers and technicians with expertise in the fields of pavement analysis and rating, pavement management, and transportation engineering. They would review the reduced data and correlate those findings with visual records obtained by photologging or videologging. They would rate pavements, identify deficient areas, determine remedial measures, prioritize repairs, determine repair costs, offer alternative solutions to field problems, and provide other technical assistance that would be helpful to the low-volume road unit.

Pavement ratings, roadway analyses, and other data would be forwarded to the inventory-preparation team. They would organize a compiled inventory of the road system along with the required reports or synopses explaining in lay terms funding levels required and suggesting priorities for repair of deficiencies identified in the system. Once the final reports and inventory have been completed, the inventory, synopsis, and film or tapes would be sent to the operating unit for their use.

POST-INSPECTION DATA PROCESSING

NONVISUAL DATA

Due to the amount of information that must be assembled, retrieved, and analyzed, it would be cost effective to digitize as much nonvisual quantitative data as possible and then computer-process and correlate those data. This requirement favors field storage of data in analog or digital form on the sound track of the film or video tape. That data could be easily off-loaded from the completed film or tape, digitally formatted, and computer processed. Pattern-recognition computer programs should be developed to detect and identify problem areas in the pavement. The entire data set could be automatically scanned and evaluated on a preliminary basis with a low expenditure of manpower. Computer data-base management programs would be used to store and manipulate data sets. The final evaluations would be prepared using computer spreadsheet programs that may easily be incorporated into completed inventories and road-system synopses.

VISUAL DATA

If large visual data bases are accumulated, the many reels of film or video tape cassettes may be difficult to catalog and store. If the low-volume road agency desires to continually inspect or review the visual records, a more convenient means of storing and processing data should be adopted. The Connecticut Department of Transportation presently employs such a system (4, 5). In photologging its 4,000 miles of highways, 660 100-foot reels of cinematic film are used, storing 920,000 frames of 35-mm film. The film is sent to a professional processor and converted to laser video discs. During the conversion process, the image in each frame is enhanced by correcting for improper lighting. The laser video discs store four giga-bytes of data on a laser disc the size of a 12-inch photograph record. Each video disc stores about 110,000 frames of data.

The image-conversion process costs approximately $10,000 per video disc, and additional copies are about $20 each. This provides inexpensive backup of data. Also, laser discs are more durable than either film or video tape. Costs of image conversion may be recaptured through reduced expenditures for files, storage space, and time expended in locating the required data. Video discs also are formatted and combined with a data-retrieval system that allows three-second access to any location stored on the disc.

The visual-data analyses may be accomplished by projecting the cinematic film or video tape and reviewing the images. The exposition of nonvisual test parameters on a portion of the screen would greatly aid in concurrent evaluation of data (Figure 7). It would be useful to have a script of the preprocessed computer data to aid in rapid identification of problem locations. When the technical experts review the film or tape, they could be provided with digital encoding devices to record features and visually rate the pavement roadway and roadside. Ideally, such records could be incorporated with an adaptive-learning or artificial-intelligence computer program to reveal visual/quantitative relationships not readily discernible even to the technical experts. That process would eventually yield a higher order of data analysis, allowing engineers and technicians to perform some visual analyses, thereby freeing the technical expert to seek other significant parameter relationships. At least one data-acquisition firm offers laboratory equipment to perform some of these processes.

INTERPRETATION OF DATA

Interpretation of derived data by the technical review team requires input of specific types of visual, nonvisual, and qualitative and quantifiable pavement data. Broadly, the technical review is divided into two categories: 1) pavement/road surface evaluation and management and 2) traffic/roadside environment evaluation and management. Both reviews often need the same nonvisual data parameters as well as the visual images.

One necessary component required for either review will be complete geometric identification of each road, functional classification of the route, identification of section termini, block or section number, length of section, pavement type, pavement width, number of travel lanes, and type and width of shoulders or curbs. Other additional data not provided by the drive-over tests would include traffic data such as average daily traffic (ADT) and vehicle compositions, accident data such as frequency of occurrence, severity, and exact locations; and planning information such as impending zoning changes and land utilization.

PAVEMENT/ROADWAY DATA

For pavement/roadway surface condition rating, it is necessary to identify current situations and problems on the roadway requiring correction. Condition ratings may be compared with prior ratings to determine deterioration rates and to judge effectiveness of rehabilitation strategies that have been used. For example, condition ratings may be used to develop deterioration-versus-time or traffic volume (fatigue) curves.

Pavement condition ratings may be determined on the basis of a number of factors or combinations thereof. Factors involved in condition ratings for pavements are

1) ride quality,
2) observable distress,
3) findings from structural evaluations,
4) other factors such as accident records or skid-test results, and
5) a combination of the above (or other) factors.

Observable distresses vary with the pavement type. For bituminous-surfaced roads, these typically include alligator cracking, block cracking, reflection cracking, rutting, raveling, bleeding, shoving, corrugations, potholes, and patching (Figure 8). Observable distresses in rigid pavements include blowups, corner breaking, "D" cracking, faulting, spalling, transverse cracking, longitudinal cracking, popouts, pumping, polished aggregate, joint/seal deterioration, and patching. Observable distresses associated with aggregate-surfaced roads include rutting, corrugations, potholes, aggregate loss, slipperiness, surface erosion, and dusting.

The manifestation of distress of any pavement/road surface is an indication of defects in materials or overall structural integrity of the road. The photologging survey is an important portion of the pavement distress survey.

Once the roadway condition is established along with predicted rates of deterioration, repair strategies may be formulated. Those strategies may be selected knowing the identified deficiencies, wear rates, and maintenance funding available. The pavement management staff may offer a number of repair strategy "menus" from which the local agency may select. Various strategies could be prepared to show what work may be performed at various levels of funding. This is also necessary as it is difficult to immediately determine local needs. However, all pavement areas that constitute a motoring hazard would need to be identified and recommended for prompt repair.

TRAFFIC/ROADSIDE ENVIRONMENT DATA

The traffic engineers might analyze road geometry (obtained from visual-image analysis), traffic volume and accident data, and some nonvisual data obtained during the drive-over inspection. Traffic engineers would visually determine if the traffic volume warranted a higher standard of surface maintenance, traffic control (signing, marking, and delineation), and geometrics (stopping-sight distance, focusing-sight distance, etc.) than existing or planned. Also, traffic engineers would note local land use, planning, and zoning. They would provide recommendations of future traffic routing and updating of existing facilities. The visual and visually derived data could be used in conjunction with accident data to identify casual relationships and derive remedial changes in the roadway or signing. Obvious road hazards such as narrow steep shoulders could easily be detected. Also, significant hazardous roadside features or illegal access roads could be identified for follow-up action. Poorly placed, missing, damaged, or illegible signing could be identified for prompt replacement. Also, visual data could be used to identify locations where traffic codes were enforced, but where local conditions necessitated change. Numerous braking skid marks at an intersection would be a good indicator of the need to revise some roadway element.

Nonvisual data such as crown, grade, or superelevation correlated with visual images (to detect signing and sight distance) could be used to identify dangerous or substandard locations. In many cases, legal speed limits may exceed safe speeds. Speed-limit reduction will minimize such hazards.

The traffic engineer would recommend solutions for every substandard or hazardous location. He would assign a risk factor to each location based upon severity of the defect(s). He would determine the probability of accidents at the locations based upon traffic volumes and predict probable consequences of accidents.

Information on the traffic/roadside environment would be compiled along with a list of repair strategies for upgrading the signing and making geometric modifications to correct deficiencies. Areas requiring immediate action would be identified. Alternative strategies would be prepared, showing safety improvements that might be expected (in terms of accident or risk reduction) for various levels of funding directed toward different tasks. For a given level of funding, strategies necessary to achieve the maximum improvement in safety would be identified. Implementation of a rational safety-related roadway management program would render agencies less susceptible to accident-related litigation. Failure to perform safety maintenance due to ignorance of standards is not a legal defense. When safety-related work is not performed because of limited funding or because of the direction of available funds to other items deemed more critical, it could be argued that the agency was operating responsibly. Not every safety-related problem detected through the inventory process needs to be repaired immediately, especially if risks are assessed.

Agencies should balance expenditures among local needs with available funds. The technical review and rating team should provide recommendations for allocating the funds between the pavement and traffic sectors.

CLOSURE

It should be noted that, for appropriation purposes, only a statistical sampling of a local road system needs to be inventoried and analyzed. A complete inspection and analysis is necessary to assist in prioritizing remedial work. The primary purpose of automated data-acquisition and centralized inventory management is to determine desirable funding levels. A second purpose is to aid in directing available maintenance funds to the most severe and beneficial strategies. Once the inventory and condition survey system is in place, it may be used for a variety of additional purposes including cost-evaluation for purchasing special equipment, planning for upgrading unpaved roads, evaluating the long-term performance of specific repairs or designs, evaluation of roadside drainage conditions, community planning, monitoring utilities, recruiting new businesses, zoning, community planning and development, and even providing a historical record of the community served by the local road agency. If properly planned and implemented, this operation might provide additional unanticipated uses to the low-volume road agency and the community it serves.

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LIST OF FIGURES

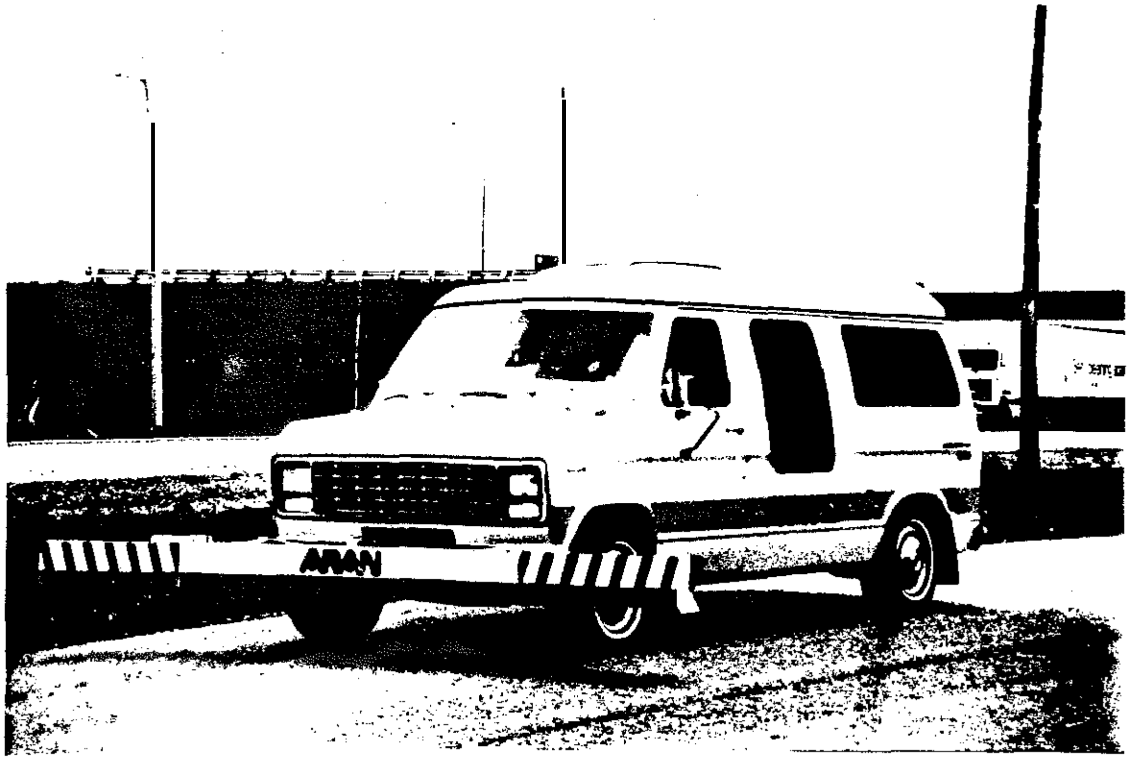
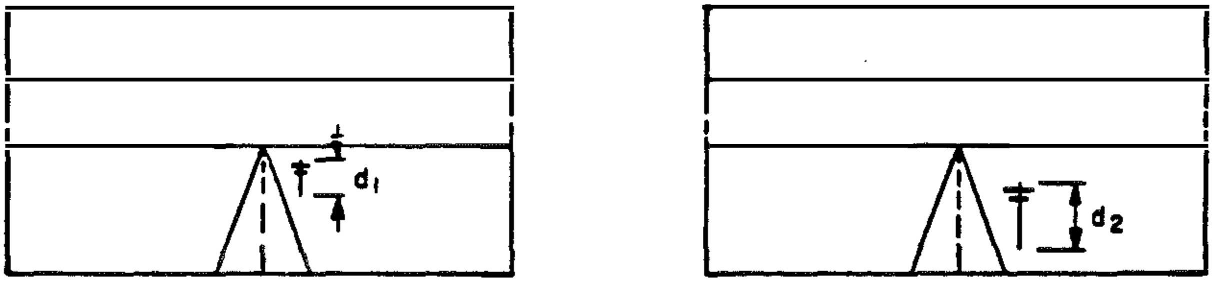


Figure 1. Modern Photologging Vehicle for Drive-Over Roadway Surveys (Photograph Courtesy of Highway Products International, Paris, Ontario, Canada).



FIRST FRAME

SECOND FRAME

Figure 2. Increase in Size of Visual Image (Telephone Pole) with Successive Picture Frames (Picture Courtesy of TECHWEST CO., Richmond, British Columbia, Canada).

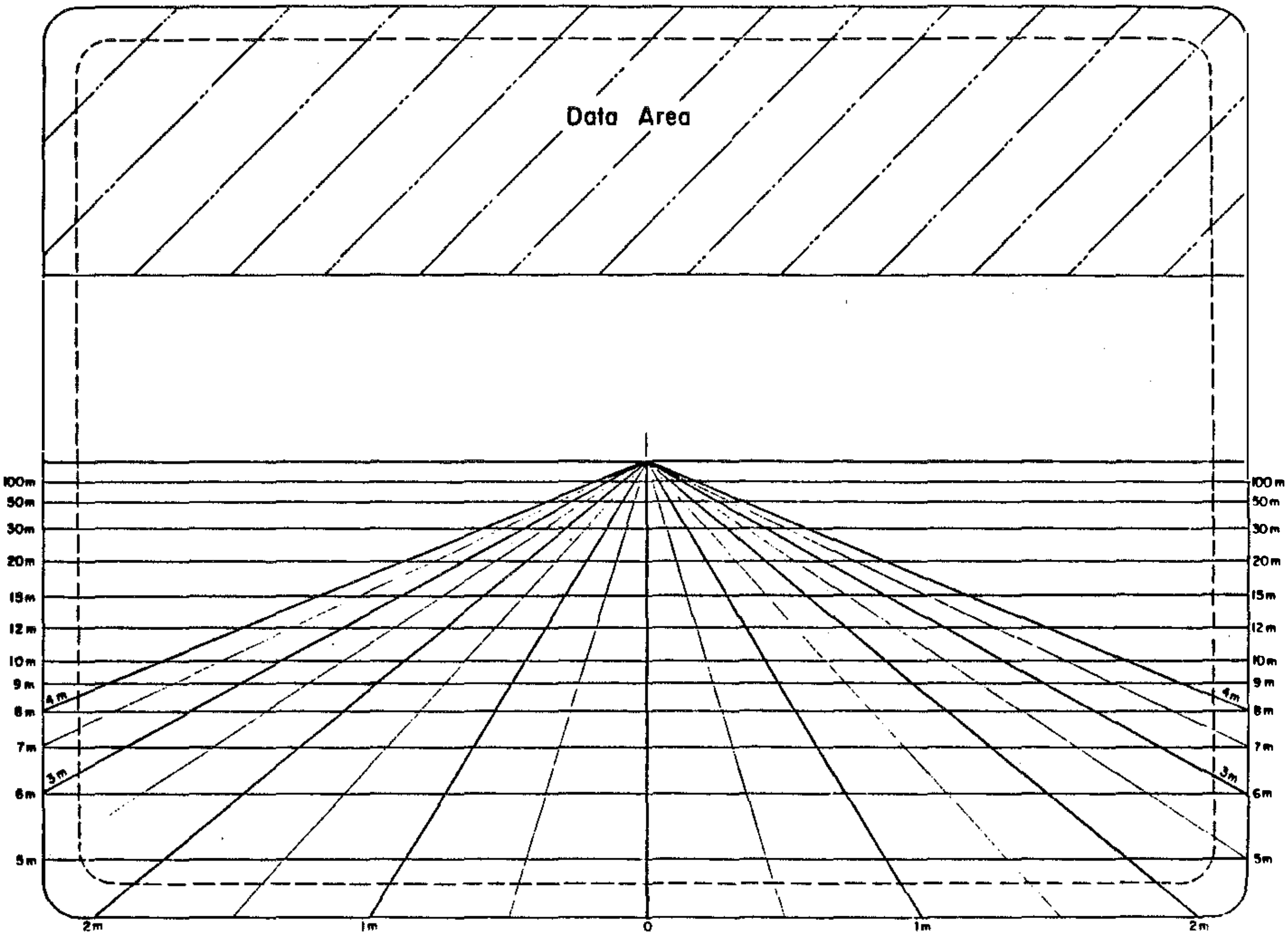


Figure 3. Perspective Overlay for Deriving Dimensional Data from Photologging Images (Courtesy of TECHWEST CO., Richmond, British Columbia, Canada).

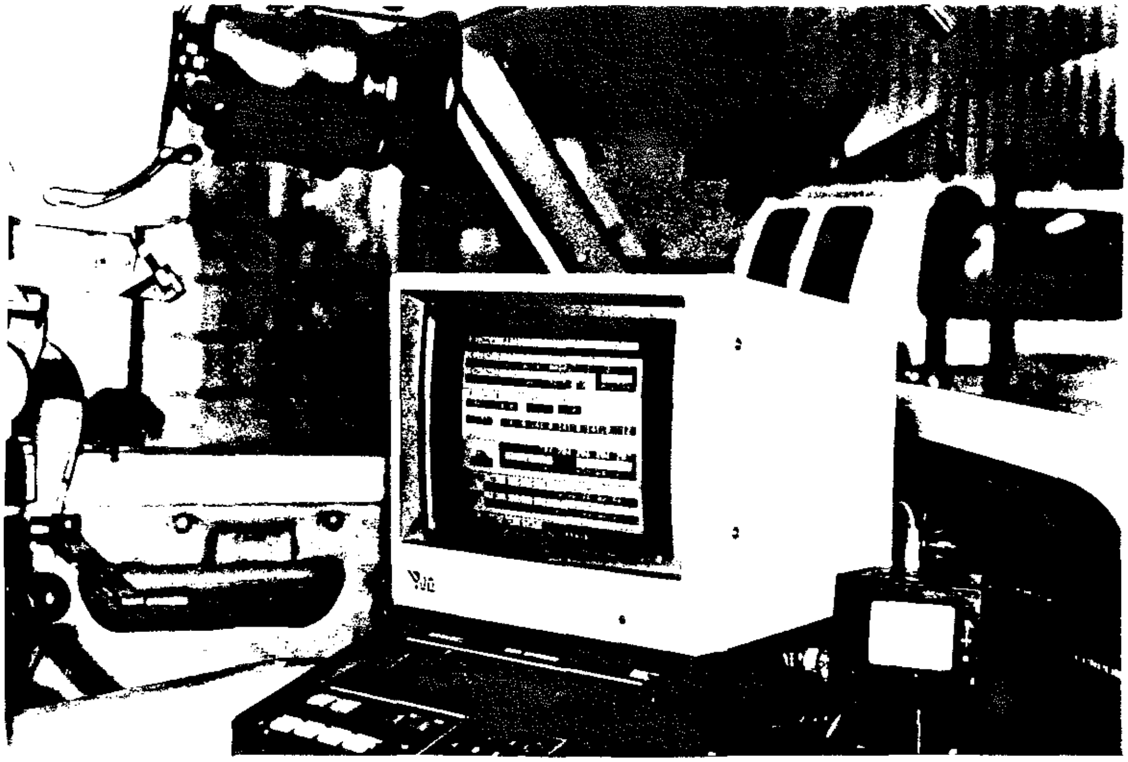


Figure 4. Visual Display of Coded Test Information in Videologging Vehicle (Courtesy of Highway Products International, Paris, Ontario, Canada).

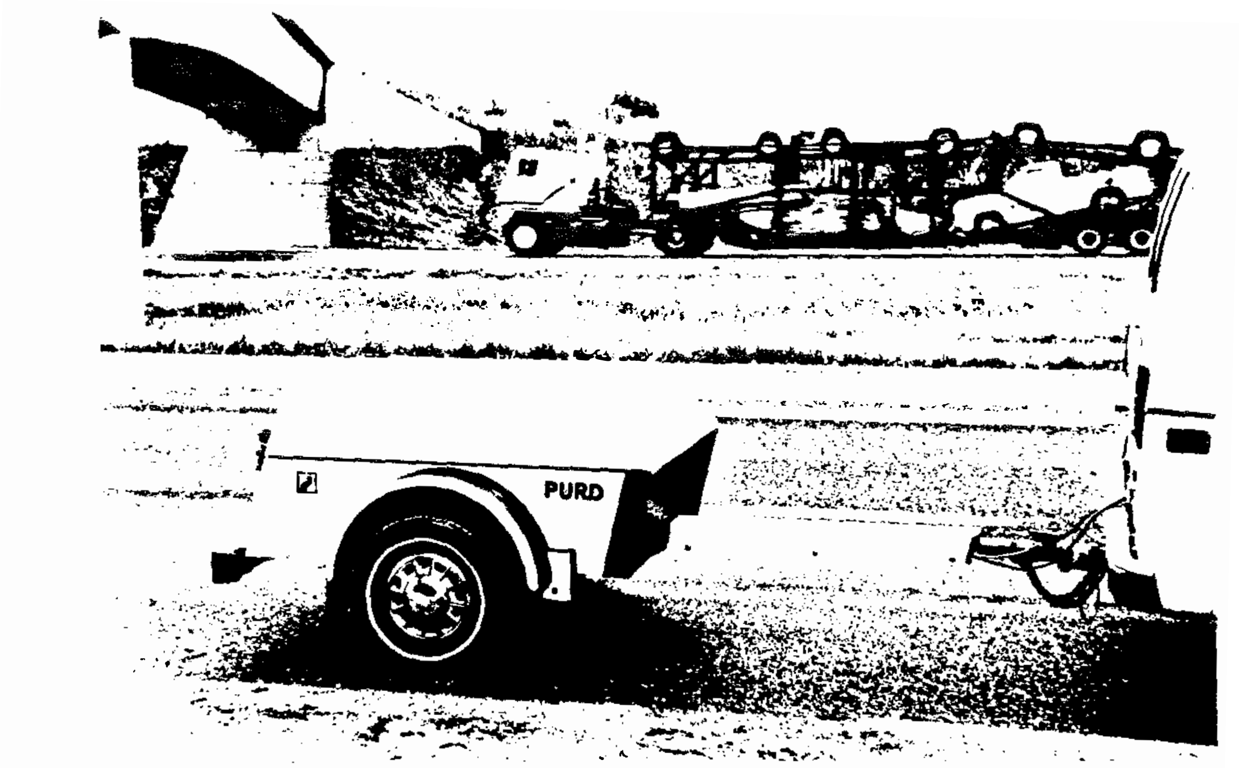


Figure 5. Towed Road-Roughness Measurement System (Courtesy of Highway Products International, Paris, Ontario, Canada).

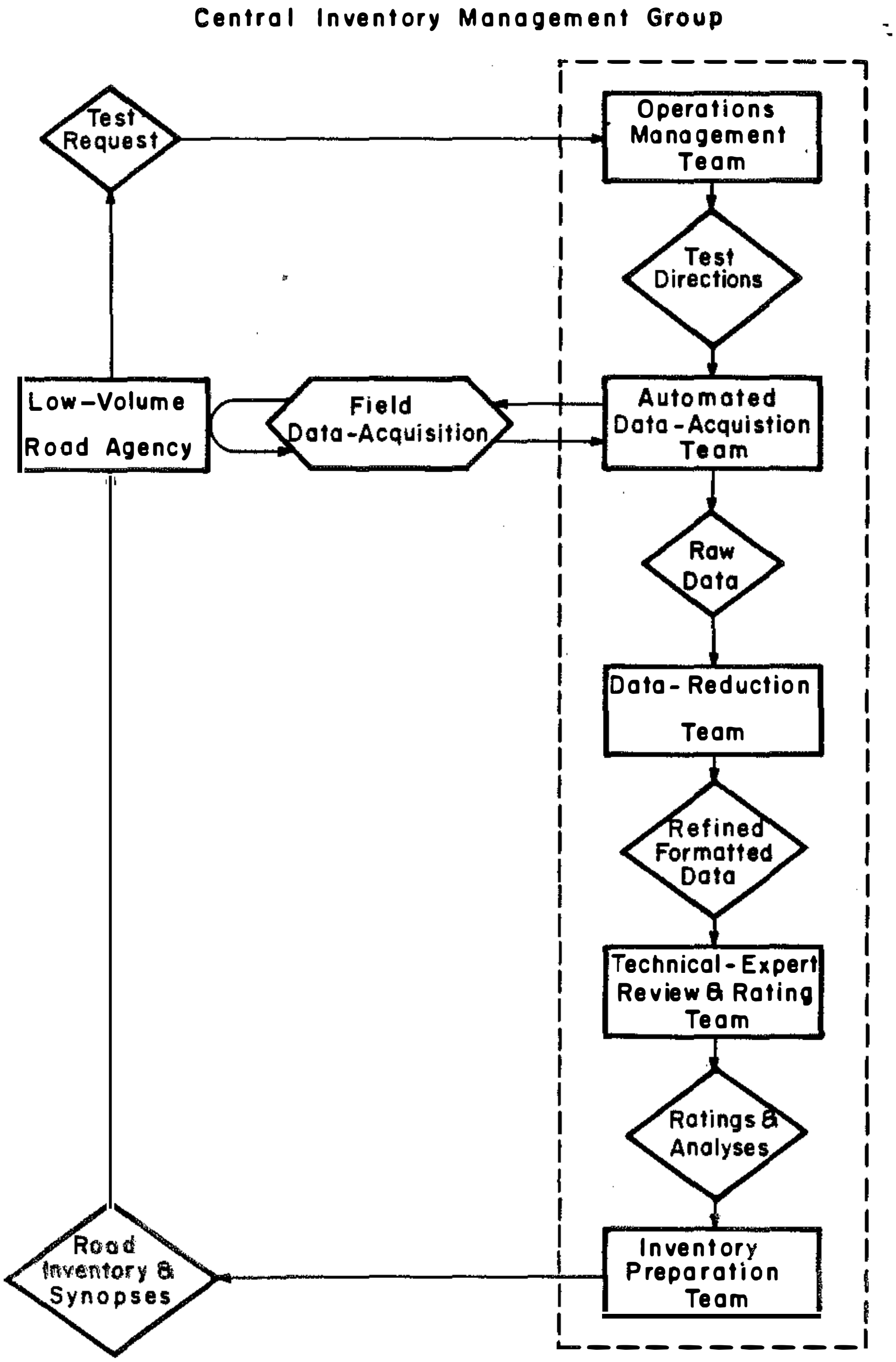
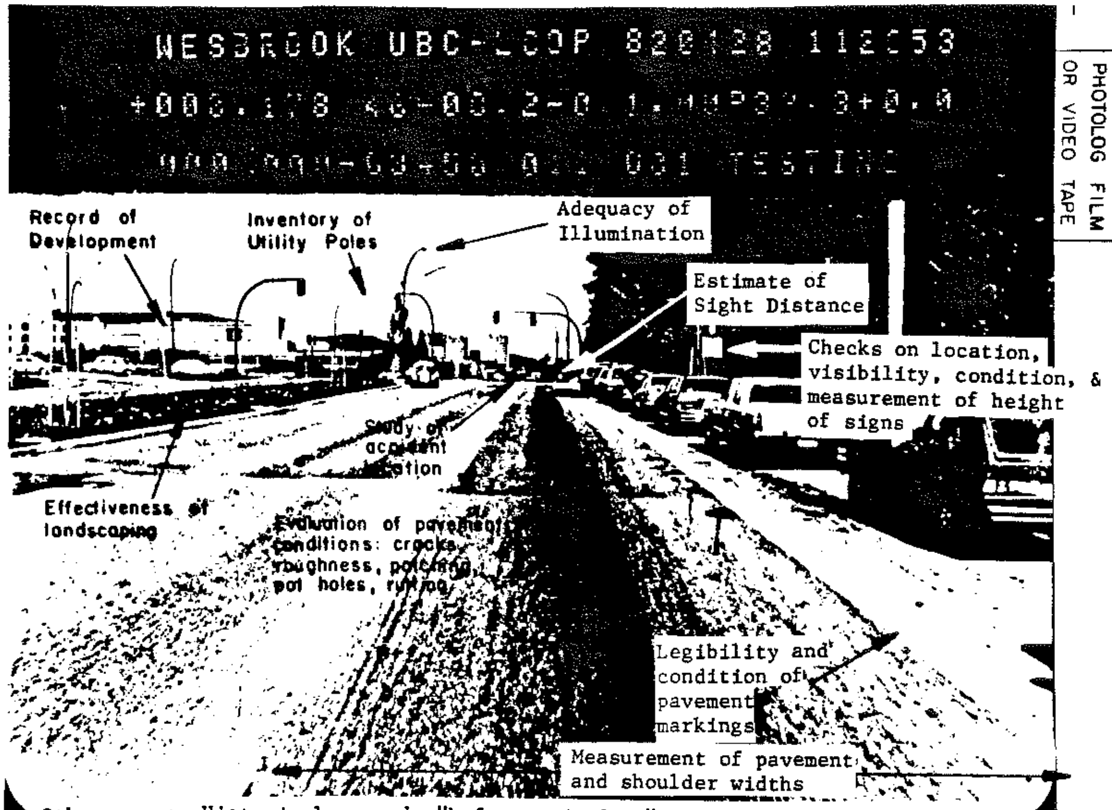


Figure 6. Organizational Chart for a Central Inventory Management Group.



<u>Other uses</u>: Historical record, "before and after" studies for public relations, evidence in legal cases, general evaluation for planning purposes.

Figure 7. Visually Detectable Information Provided by Photologging (Photograph Courtesy of TECHWEST CO., Richmond, British Columbia, Canada).

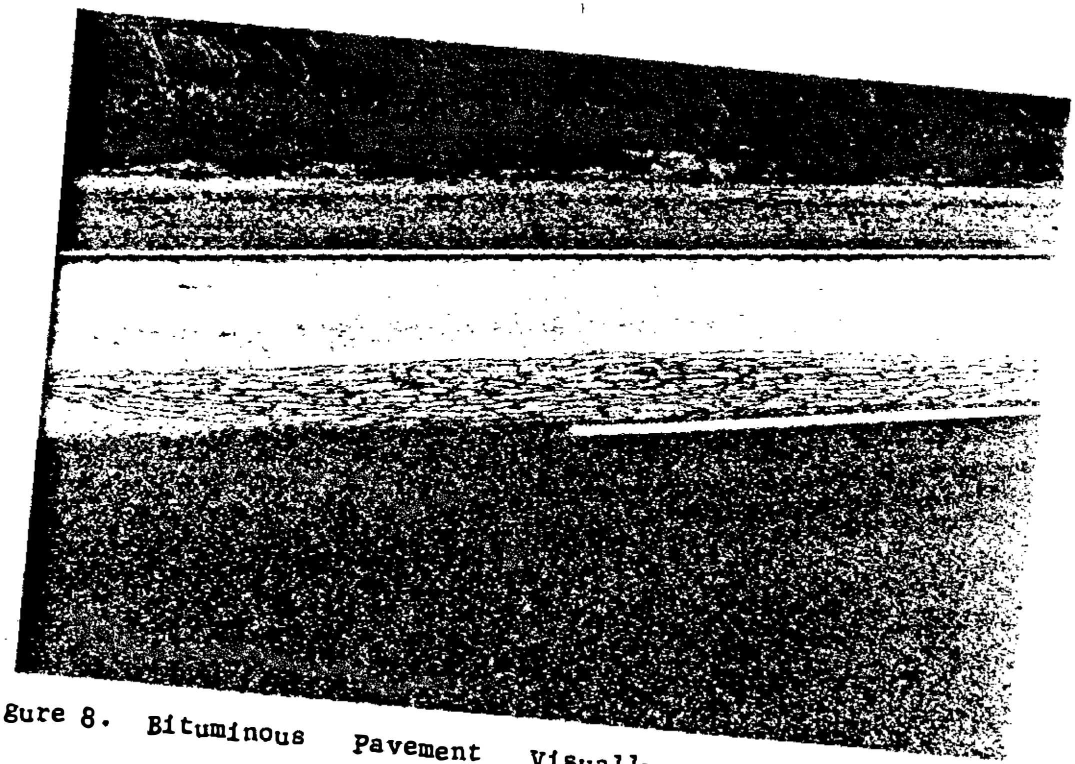


Figure 8. Bituminous Pavement Visually Exhibiting Alligator Cracking.