Automated Data Acquisition for Low-Volume Road Inventory and Management

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Local governments need suitable inventories and condition surveys to accurately determine and rank their road funding needs. An efficient method of performing an inventory of the roads and determining the condition of major system components is to use an automated data acquisition system to measure and record essential data. The data can be collected and processed by a central inventory management group. The inventory should include pavement characteristics, roadway geometrics, and roadside features. Pavement condition can 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. A concept is presented for a second-generation vehicle-mounted photologging system that can, in a single pass, photolog the roadway and automatically record measurements necessary to inventory and rate roadways. The major functions of a central inventory management group are also described. Second-generation photologging systems use either camera or video systems to record visual data. Particulars of those methods are presented and compared. Sensors for additional data measurement, including grade, superelevation, and road roughness, are described. Data recording methods are discussed with emphasis on 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 videotape) 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 a review of acquired data in its formatted, addressable form. Analyses can include a combination of visual and sensor analyses for pavement condition and roadway geometrics. Other geometric-related analyses can be based almost entirely on visual recordings of roadside features. In some instances, such as unpaved roads, in which few accepted standards exist, new standards or criteria should be formulated for evaluation. Otherwise, accepted standards should be used. The road rating process and methods employed to rank pavement and traffic safety-related rehabilitations are discussed. The interaction between the central inventory management group and the low-volume road agency in preparing the final compiled inventory is also discussed.

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The management of local roads can 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 to (a) determine future funding requirements, (b) assess current funding needs, (c) allocate and manage limited funds, (d) rank construction and repairs, (e) increase safety, and (f) avoid unnecessary accident-related litigation.

In order 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. The results must be reformatted for presentation to nontechnical users.

Local agencies often encounter problems when performing inventories. It is difficult to locate and train competent survey personnel. The cost of manual data acquisition is expensive. Processing field data may also prove to be 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 data and ratings in a manner that can be understood by laypersons such as county judges, law enforcement personnel, and other local government officials and 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 systems, 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 so that they can be

FIGURE 1 Modern photologging vehicle for drive-over roadway surveys. (*Photograph courtesy of Highway Products International, Paris, Ontario, Canada*)

retrieved later. When the field data have been obtained, it can 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. Several consulting firms nationwide offer or are preparing to offer pavement survey and inventory services.

Local agencies that have large road inventories of 2,000 or more miles might investigate purchasing an equipped data acquisition vehicle. Road agencies that have smaller inventories might consider employing a pavement survey and inventory consultant.

A third approach is 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 be likely to have access to the varied and specialized technical skills necessary to establish a competent roadway management team.

The road inventory should include a list 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 should 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 can be acquired from photographs of the in-place road system. This process, augmented by concurrent acquisition of nonvisual data, is termed second-generation photologging. It 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 easy 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 a limited amount of more conventional field inspections should be anticipated. Forty-three states currently perform some type of photologging or videologging operation.

Visual Data

Commercially available photologging or videologging systems employ one or more vehicle-mounted cameras aimed forward, rearward, 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 are being recorded, it is possible to film or tape the two lanes in a given direction simultaneously with one camera. If only a visual inventory is being performed, it is also possible to film or tape a two-lane road in one drive-over pass. A front-mounted camera could record one lane and a rear-mounted camera could record the other. When very general visual records are desired, a single pass with one camera may suffice. When second-generation photologging is conducted, one pass may be required for each lane, which would limit the utility of additional cameras.

One use of visual data is to determine distances. As shown in Figure 2, the height of a telephone pole can be determined by measuring the image height in successive film frames. The height of the pole can then be computed from the following equation:

$$D = d_1 d_2 S \cos \phi / (d_1 - d_2) f R$$

where

D = dimension of the object (m),
d_1 = size of the image on frame one (mm),
d_2 = size of the image on frame two (mm),
S = frame interval (m),
ϕ = angle of skew of the camera to the roadway,
f = focal length of the lens (mm), and
R = enlargement ratio, which is equal to the ratio of the size of the image on screen to the size of the image on film.

Distances to the front and side of the image can 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 can be measured using the perspective overlay with a rear-directed camera.

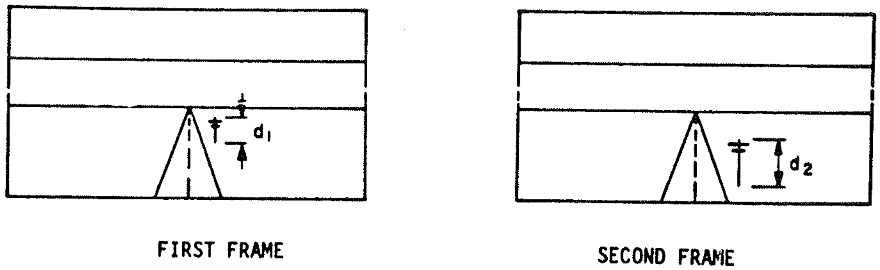

FIGURE 2 Increase in size of visual image (telephone pole) with successive picture frames. (*Illustration courtesy of TECHWEST Co., Richmond, British Columbia, Canada*)

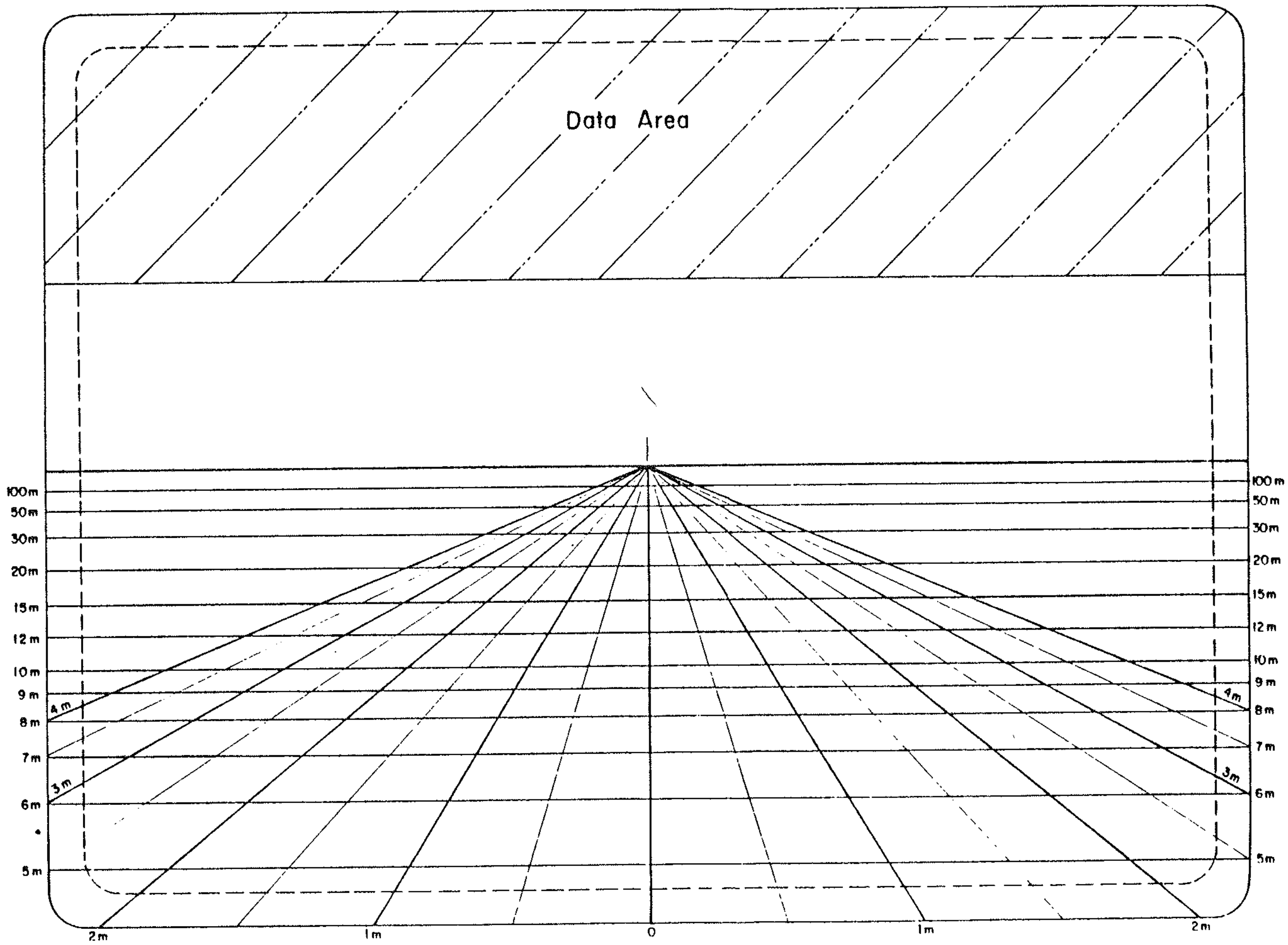

FIGURE 3 Perspective overlay for deriving dimensional data from photologging images. *(Courtesy of TECHWEST Co., Richmond, British Columbia, Canada)*

Color film or videotape is usually used. There are advantages and disadvantages to both film and videotape recording methods. Camera film must be developed whereas videotape is immediately ready for replay. It is cheaper to copy videotape and it can be erased and reused when necessary. In addition, several video images can be superimposed and displayed simultaneously as split-images on a video monitor. Camera film can show finer detail than videotape. Film could 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 can be exposed at fixed intervals along the road (one frame approximately every 50 ft). 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 first-generation photologging or videologging is employed, 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 the visual superimposition of information onto a portion of the film or video image (Figure 4). If second-generation photologging or videologging is performed, nonvisual sensor information can be digitized, encoded, and stored together with the conventional data on a portion of the visual image. If visual data storage is not desired, the soundtrack of either the film or videotape can be used to store analog or digitized data.

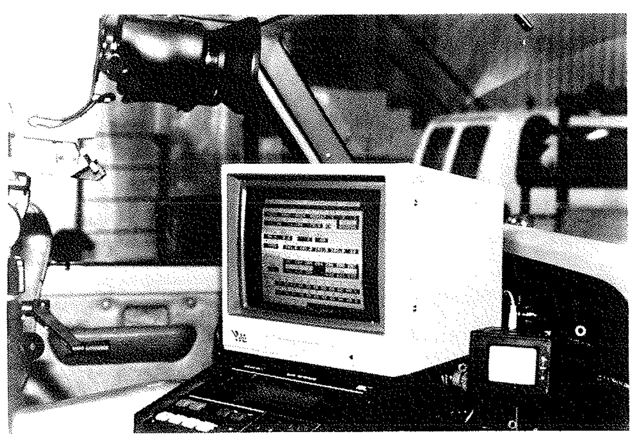

FIGURE 4 Visual display of coded test information in videologging vehicle. *(Courtesy of Highway Products International, Paris, Ontario, Canada)*

Nonvisual Data

Second-generation data acquisition systems are capable of measuring and recording information that cannot be determined visually, such as road roughness, pavement surface side friction, grade, cross-slope, bearing, and horizontal and vertical curvature.

Road roughness can be measured by the deflection of the rear axle of the data acquisition vehicle. This can 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 in to 300 ft (Figure 5). The road roughness system can be calibrated to national standards to compare data with that of other road agencies.

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

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

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

A third generation of pavement data acquisition vehicles is currently being evolved. Those systems will contain instrumentation to make impromptu analyses of pavements that currently 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 that are capable of detecting a number of types of distress in pavements, including cracking and rutting (*2*). An American firm is currently developing a fully automated system that will optically survey pavements and assess their condition.

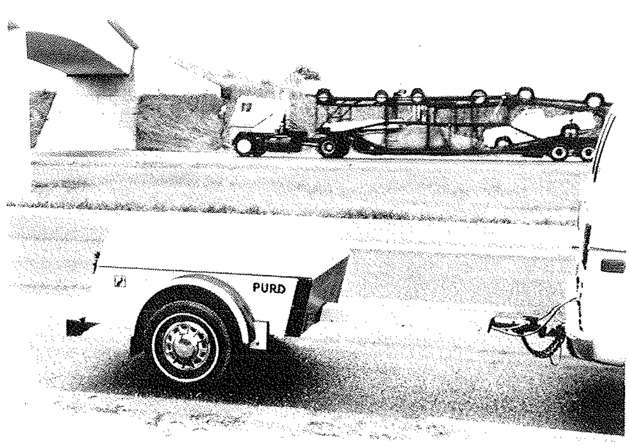

FIGURE 5 Towed road roughness measurement system. (*Courtesy of Highway Products International, Paris, Ontario, Canada*)

Structural evaluations are generally 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 to collect and process deflection data for structural evaluations of pavements. Such equipment does not lend itself well to impromptu data acquisition methods. It is hoped that more rapid test methods will be developed that potentially could be "piggy-backed" onto the second- or third-generation photologging vehicles.

OPERATIONAL REQUIREMENTS FOR DATA ACQUISITION

Vans are the ideal test vehicles for data acquisition. They have sufficient internal space and can be serviced at most locations should the need arise. The test van should have space to house the cameras, data entry devices, the photologging or videologging control panel, electrical generating equipment, and spare film or tape. A crew of two, a driver and a system operator, is generally required. The system operator logs route information, tape numbers, and special events on the manual data entry system. He changes the film, checks how well the system is functioning during the tests, and directs the driver.

The vehicle should generally be operated at speeds between 35 and 55 mph. Depending on the travel time to the test site, the data acquisition crew could record 500 to 1,300 lane-miles of road per week. The lower figure is representative of city operations. The higher figure is possible on open high-volume paved roads. The Connecticut Department of Transportation employs a photologging system. In order to complete the inventory of the 4,000 mi of pavement in Connecticut, 8 months of second-generation photologging is accomplished each year. This had previously been done manually by six two-man field crews in an 11-year cycle.

For low-volume urban roads, 100 ft of film is taken every 25 mi with an exposure interval of one frame every 35 feet. A week of city photologging could take up to 20 reels of film. If a video system is used, 20 2-hr tapes are required for the same operation. A two-man crew could conceivably photolog about 50,000 lane-miles each year with an 80-percent duty cycle. In rural locations, the exposure interval could be increased to one frame every 70 feet, which would increase the total amount of miles covered on a can of film or a videotape.

Costs for different types of inventory operations, including data reduction, vary according to the category of road inspected and the number of data parameters to be inventoried. Costs per mile typically 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 that range from $67 and $69, respectively, for urban areas to $23 and $16, respectively, for rural areas. However, these costs represent only one type of inventory: signing. If multiple data parameters are required, the photologging and videologging methods are even more economical.

INVENTORY MANAGEMENT GROUP

A central inventory management group normally consists of five teams: the operations/management team, the data acquisition team, the data reduction team, the technical review and rating team, and the inventory preparation team (Figure 6).

The operations/management team supervises and coordinates the entire central inventory management group. They interface with other units or agencies responsible for various aspects of the low-volume road system and determine test requirements. The operations/management team schedules work and coordinates all operations. They also review all compiled inventories and synopses before they are delivered to other units and staff.

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

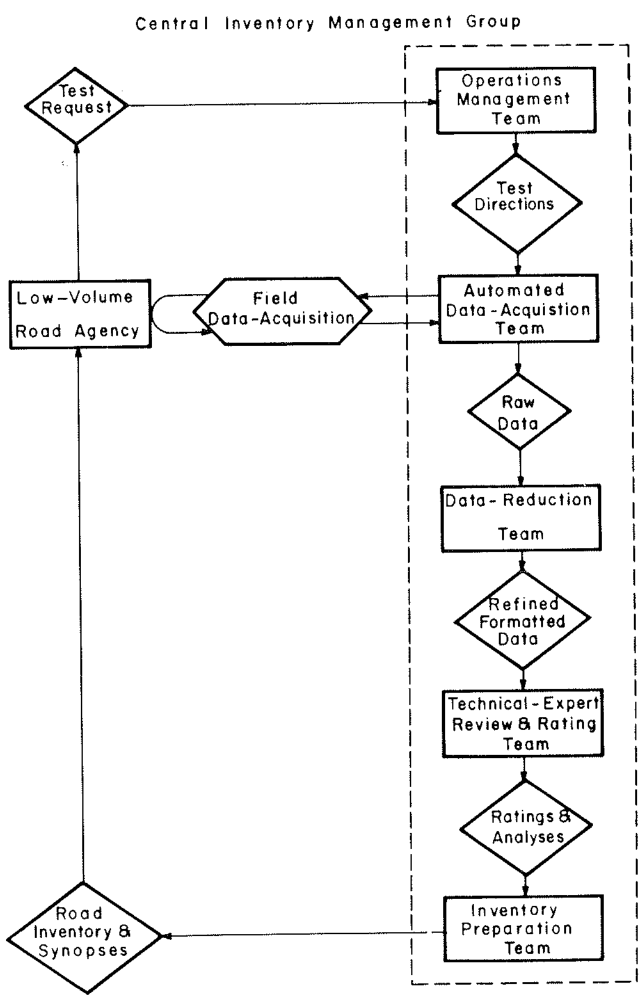

FIGURE 6 Organizational chart for a central inventory management group.

The technical review and rating team normally consists of a few engineers and technicians with expertise in the fields of pavement analysis and rating, pavement management, and transportation engineering. They review the reduced data and correlate those findings with visual records obtained by photologging or videologging. They rate pavements, identify deficient areas, determine remedial measures, rank 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 are then forwarded to the inventory/preparation team. They organize a compiled inventory of the road system that includes the required reports or synopses that explain in lay terms the required funding levels and suggested priorities for repair of deficiencies identified in the system. Once the final reports and inventory are completed, the inventory, synopsis, and film or tapes are sent to the operating unit for their use.

POST-INSPECTION DATA PROCESSING

Nonvisual Data

Because of 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 process and correlate those data by computer. Data should be stored in the field in analog or digital form on the soundtrack of the film or videotape. That data can then 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 should be used to store and manipulate data sets. The final evaluations should be prepared using computer spreadsheet programs that can easily be incorporated into completed inventories and road system synopses.

Visual Data

If large data bases are accumulated, the many reels of film or videotape cassettes could 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 currently employs such a system (*4, 5*). In the course of photologging 4,000 mi of highways, 660 100-ft reels, or 920,000 frames of 35-mm film, are used. The film is sent to a professional processor and converted to laser videodiscs. During the conversion process, the image in each frame is enhanced and improper lighting is corrected. The laser videodiscs store four gigabytes of data on a laser disc the size of a 12-inch phonograph record. Each videodisc stores about 110,000 frames of data.

The image conversion process costs approximately $10,000 per videodisc; additional copies cost about $20 each. This provides for inexpensive backup of data. Laser discs are also more durable than either film or videotape. The costs of image conversion can be recaptured through reduced expenditures for files, storage space, and time expended in locating the required data. Videodiscs are also formatted and combined with a data retrieval system that allows 3-second access to any location stored on the disc.

The visual data can be analyzed by projecting the cinematic film or videotape 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 also be useful to have a script of the preprocessed computer data to aid in rapid identification of problem locations. When 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. Such records could ideally be incorporated with an adaptive-learning or artificial-intelligence computer program to reveal visual and quantitative relationships not readily discernible, even to technical experts. This process would eventually yield a higher order of data analysis, and would allow 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.

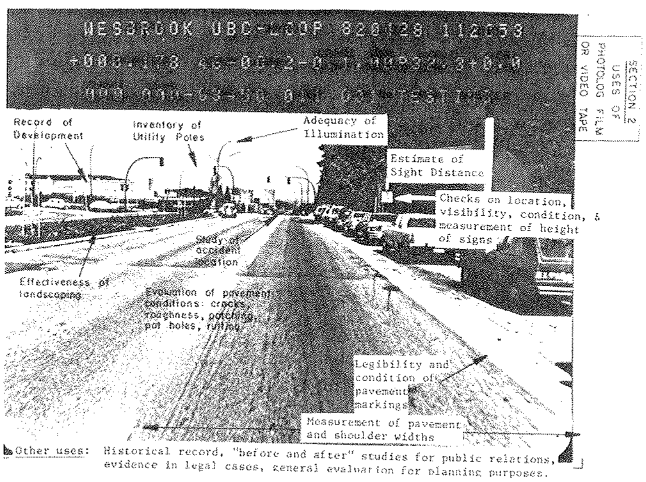

FIGURE 7 Visually detectable information provided by photologging. (*Photograph courtesy of TECHWEST Co., Richmond, British Columbia, Canada*)

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. The technical review is broadly divided into two categories: pavement and road surface evaluation and management, and traffic and roadside environment evaluation and management. Both reviews often need the same nonvisual data parameters and visual images.

One necessary component required for either review is complete geometric identification of each road; functional classification of the route; identification of section termini and 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 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 AND ROADWAY DATA

In order to rate pavement and roadway surface condition, it is necessary to identify the current problems on the roadway that require correction. Condition ratings can be compared with prior ratings to determine deterioration rates and to judge the effectiveness of rehabilitation strategies. For example, condition ratings can be used to develop deterioration versus time or traffic volume (fatigue) curves.

Pavement condition ratings can be determined on the basis of a number of factors or combinations thereof. The following are factors involved in condition ratings for pavements:

- Ride quality,
- Observable distress,
- Findings from structural evaluations,
- Other factors such as accident records or skid test results, and
- 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 and 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 or road surface is an indication of defects in materials or the overall structural integrity of the road. The photologging survey is an important part of a pavement distress survey.

Once the roadway condition is established and rates of deterioration are predicted, repair strategies can be formulated.

FIGURE 8 Bituminous pavement showing alligator cracking.

Those strategies can be selected with knowledge of the identified deficiencies, wear rates, and maintenance funding available. The pavement management staff can offer a number of repair strategy "menus" from which the local agency can select. Various strategies could be prepared to show what work can be performed at various levels of funding. This is also necessary because 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 AND ROADSIDE ENVIRONMENT DATA

The traffic engineers can 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 can visually determine if the traffic volume warranted a higher standard of surface maintenance, traffic control (signing, marking, and delineation), and geometrics (stopping sight distance and focusing sight distance) than is currently existing or planned. Traffic engineers could also note local land use, planning, and zoning. They can provide recommendations for future traffic routing and updating of existing facilities.

The visual and visually derived data can be used in conjunction with accident data to identify causal relationships and derive remedial changes in the roadway or signing. Obvious road hazards such as narrow steep shoulders could easily be detected. Significant hazardous roadside features or illegal access roads can also be identified for follow-up action. Poorly placed, missing, damaged, or illegible signing could be identified for prompt replacement. Visual data can also be used to identify locations in which traffic codes are enforced, but in which local conditions necessitate change. Numerous braking skid marks at an intersection are a good indicator of the need to revise a particular roadway element.

Nonvisual data such as crown, grade, or superelevation, correlated with visual images to detect signing and sight distance, can be used to identify dangerous or substandard locations. In many cases, legal speed limits may exceed safe speeds. A reduction in the speed limit would minimize such hazards.

The traffic engineer can recommend solutions for every substandard or hazardous location. He can also assign a risk factor to each location based on the severity of the defects. He can determine the probability of accidents at the locations based on the traffic volumes, and predict the probable consequences of accidents.

Information on the traffic and roadside environment can be compiled along with a list of repair strategies to upgrade the signing and make geometric modifications to correct deficiencies. Areas that require immediate action can be identified. Alternative strategies can 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 can 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 as a result of ignorance of standards is not a legal defense. When safety-related work was not performed because of limited funding or because the direction of available funds to other items was 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.

CONCLUSION

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 ranking 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 can be used for a variety of additional purposes, including a cost evaluation for the purchase of special equipment, a plan for upgrading unpaved roads, an evaluation of the long-term performance of specific repairs or designs, and an evaluation of roadside drainage conditions. The system can also be used to plan communities and development, monitor utilities, recruit new businesses, zone properties and districts, and even provide a historical record of the community. If it is properly planned and implemented, this operation could provide a number of unanticipated uses to the low-volume road agency and the community it serves.

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