TEXAS Automation Opportunities in Highway Construction and Maintenance

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Automated road maintenance can directly improve safety, pavement quality, working environment, and productivity. Indirect savings can be achieved by reducing the disruption to normal road use caused by work crews. Because of the potential benefits offered by this technology, the conceptual feasibility of automating the major maintenance activities of the Texas Department of Transportation has been evaluated (*1*). This has involved a detailed analysis of TxDOT's maintenance budget, individual surveys of TxDOT personnel, and a broad-based technical investigation. As a result of the evaluation, automated crack sealing was identified as a high-need area and a review of the technical feasibility of implementing this procedure was undertaken. A discussion of automated crack-sealing equipment, developed on the basis of a graphically controlled, *XY*-table design, is presented here.

Evaluation of Technologies

Automation technologies exist along an evolutionary continuum from concept to commercial prototype. At the University of Texas (UT) at Austin, engineers have developed an automated road maintenance evaluation model through which maintenance activities or systems designed to automate those activities can be evaluated from quantitative and qualitative perspectives (*1*). Three phases of evaluation are defined to thoroughly address available opportunities: (*a*) needs assessment and conceptual feasibility, (*b*) technological feasibility, and (*c*) field testing. In each phase the potential benefits of automation are evaluated from economic and qualitative perspectives.

In the first phase, maintenance activities that are conceptually feasible for automation are identified and ranked in terms of the opportunities they present for automation. In the second phase, the anticipated feasibility of one or more selected prototype systems is evaluated. In the third phase, field trials for selected systems are recommended for compilation of performance data, bench marking for comparison, and training.

A needs assessment study for Texas focused on road maintenance activities. Twenty-five activities making up 75 percent of the state's maintenance budget were examined in detail and a cost-concern matrix was formed on the basis of the results of this study. The concern rating formula for deriving the *Y*-axis value incorporates productivity, quality, safety, and sociopolitical, technological feasibility, ergonomic, and user cost factors. TxDOT engineers consider safety the most important factor for indicating the need for automation. The X-axis of the cost-concern matrix is based on yearly maintenance expenditures, and this scale can vary from one public agency to another. Distance from the origin is a crude but effective measure of automation need or opportunity.

Leveling or overlays consume a significant portion of the maintenance budget. Related concerns about safety, quality, and user delay costs resulting from overlay operations indicate that there is a need to improve the technology of leveling and overlays. Similar concerns exist for milling and paving operations, and equipment manufacturers have responded by developing cable- and laser-guided automated level control systems. Recently multimillion dollar consortia have been formed in Japan and the United States to develop and then apply real-time three-dimensional positioning systems to the control of earth-moving and paving equipment. These procedures will eliminate the need for grade stakes and most related surveying work and will facilitate grading and laydown of complex curves directly from computer models.

Other identified needs are already being addressed by the Federal Highway Administration and state departments of transportation(2). Prototype automated equipment for line painting, marker placement, pothole filling, garbage pickup, and other procedures already exist. In Texas crack sealing has been considered an area of particular concern because of safety, productivity, and road user delays. A feasible approach for its automation has been identified and demonstrated.

Automated Pavement Crack Sealing

Need

Approximately $200 million is spent annually on crack sealing in North America. It is a widespread, dangerous, labor-

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intensive, and costly operation, and it imposes significant costs on road users because of the disruption of traffic. Removing workers from the process reduces their exposure to traffic and lowers operating costs. Automation could also result in increased process speed and decreased road user costs. Approximately 25 percent of crack-sealing operations nationwide is privately contracted. In Texas the figure is about 50 percent of the approximately $7 million spent annually. Labor costs average about 60 percent of total crack- sealing costs. These numbers give a broad indication of the potential impact of automated crack sealing.

In Texas, according to the most recent economic analysis, statewide implementation of automated crack-sealing methods would produce estimated savings of $2.4 million for TxDOT (at 4 percent minimum attractive rate of return) and $2.6 million for private contractors (at 20 percent minimum attractive rate of return) during a 6-year planning horizon. The user-cost savings based on an approximately 25 percent efficiency improvement are estimated using the QUEWZ-E model to be $11 million for the 5150 kilometers (3,200 miles) of Interstate highways in Texas. Total user-cost savings would be much higher because the savings on urban freeways and streets, farm-to-market roads, and secondary roads are not included. From a national perspective during a 30-year planning period, the net current worth of automated crack sealing could be in the hundreds of millions of dollars.

Development

Current crack-sealing methods (Figure 1) require a crew of five to nine laborers to perform a combination of the following tasks. Depending on the state, they would (*a*) rout the crack, (*b*) blow it clean with compressed and sometimes heated air, (*c*) fill it with sealant, (*d*) squeegee it clean, and (*e*) cover it with sand or other material. Blowing and sealing are the most common operations.

Several prototype automated crack-sealing devices have been built. Originally the automated crack-sealing system was envisaged as an equipment train that included an equipment trailer, a manipulator, and a large van containing computer and power equipment (Figure 2). Blowing and sealing operations were to be automated. Manipulator options were considered, and an *XY*-table configuration was selected because of its ease of control and robust physical characteristics. Multisensor machine vision was proposed for automated crack mapping with system autonomy as the end goal. A project to implement this design was started at Carnegie-Mellon University (CMU) in 1989, and a working system was demonstrated a year later (*3*).

On the basis of the success of the first laboratory prototype, development of a field prototype was funded with approximately $100,000 from the Strategic Highway Research Program IDEA (Innovations Deserving Exploratory Analysis) program and $20,000 from the California Department of Transportation. Design objectives were to consolidate control and data processing on a single Intel 386 PC and to demonstrate operation of the system, still connected by an umbilical cord to the laboratory, on random unrouted cracks in a parking lot. A more robust *XY* manipulator was fabricated (Figure 3), and a revised control loop was implemented. Although demonstrated successfully a year after beginning the second phase, the system was retarded by slow range scanning speed.

Since that time a number of studies have shed additional light on the problem. These studies include reviews of methods, practices, and productivity of crack sealing in Texas; sensor fusion methods; and the maintenance automation needs already described. The SHRP sealant materials study and the FHWA-sponsored highway robotics seminars in 1992 and 1993 are also relevant.

Key design objectives for automated crack sealing have been distilled on the basis of the knowledge and experience gained from the preceding development efforts. The goals are (*a*) flexibility to handle different practices, (*b*) operation at manual crew speed or faster, and (*c*) a unit cost of less than $100,000. To meet these objectives, a graphically controlled system using an *XY*-table manipulator has been designed. FHWA, TxDOT, a crack-sealing equipment manufacturer, and UT at Austin are providing more than $300,000 in support of a two-phased implementation of this modified design. Commercial sealing equipment is being integrated with modified hardware and software from the CMU/UT prototype. Field trials for the first phase will be conducted in June 1995. It is estimated that

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FIGURE 1 Conventional crack-sealing methods.

the system could be sold for considerably less than $100,000.

The new design combines computer-assisted manual control with the previously developed machine vision software and *XY*-manipulator hardware to implement a simple, high-speed automated system. The driver of the lead truck first moves the equipment train and stops over a cracked section. Presented with a high-resolution video image of the work area, the driver indicates the crack network graphically by using a light pen. Although some error is expected because of limited hand-eye coordination, machine vision software is used to center the manually drawn lines along the crack spines. The *XY* manipulator is used much like a plotter to draw the blowing and sealing tools over the cracks, and the driver moves on. Computer-assisted manual control circumvents problems previously associated with autonomous crack mapping, which required time-consuming range scans to differentiate cracks identified with machine vision from various road markings.

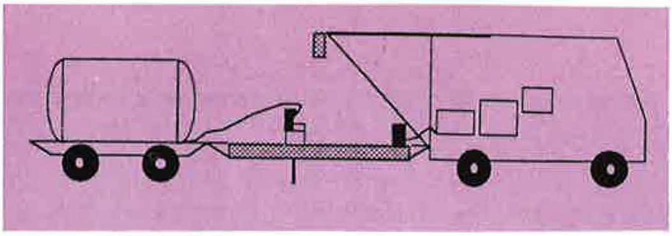

FIGURE 2 Conceptual prototype of the automated pavement crack sealer.

Significant technical challenges addressed in the first phase of this implementation effort include (*a*) optimization of the ergonomics, (*b*) calibration and alignment, and (*c*) dynamic control of the manipulator for high-speed movement. Technology and lessons learned from the first phase will be used in the second phase of the effort to develop a commercial prototype using off-the-shelf hardware and hardened components. Field trials and demonstrations of the commercial prototype are expected in July and August 1996.

Economic Feasibility

After all this effort, will anyone actually buy an automated pavement crack and joint sealing system? Only 16 percent of private contractors who perform crack sealing earn annual revenues of more than $1 million, and their revenues cannot be solely attributed to crack sealing. Only a small percent will be able to invest in automated systems initially; however, the associated benefits should increase their competitive advantage. These contractors will likely go on to dominate the market.

Government agencies may also purchase automated crack sealers. Twenty-five highway districts in Texas are authorized to purchase such equipment. Local municipalities and contractors augment the potential market. Impediments do exist, however. These include the practice of performing crack sealing with crews otherwise left idle when larger construction projects are threatened by inclement weather, or simple reluctance expressed by focus groups to spend large amounts of money because of perceived risk. Agencies are, however, becoming increasingly sensitive to safety and to the road user costs imposed by lane closures. Automated crack sealing will address these concerns and reduce operating costs.

In other areas of automated maintenance and construction, evolutionary developments in conventional overlay, patching, grading, and paving machines will continue to emerge. In the next decade automated, three-dimensional positioning systems based on global positioning systems and laser technologies will make a revolutionary impact, and innovative systems such as the crack sealer, pothole patcher, and line-painting machines will become commercially viable.

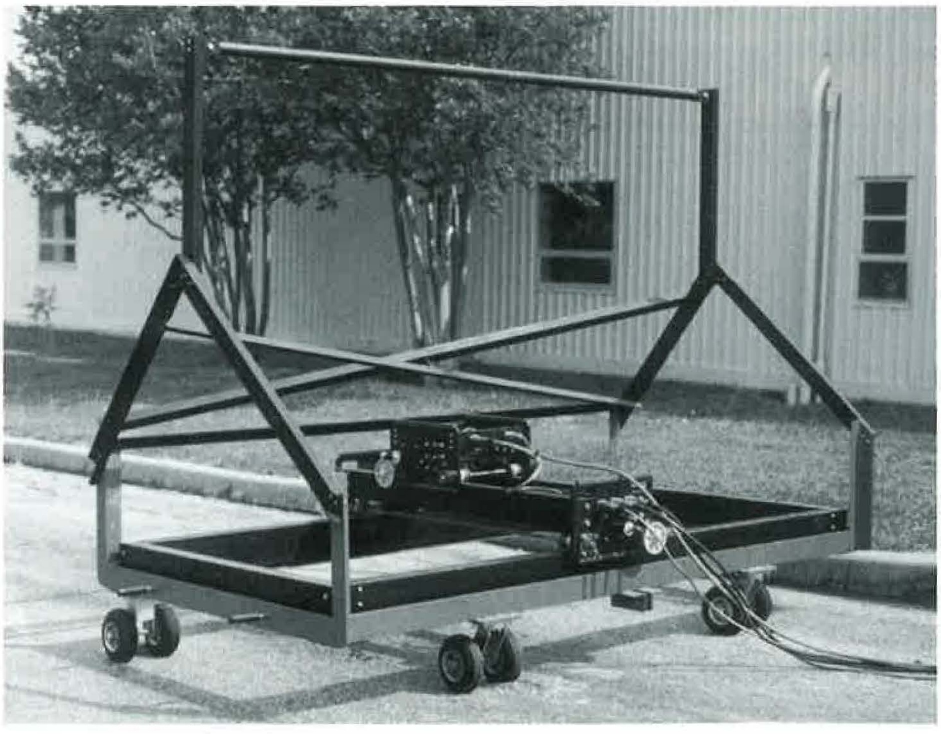

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FIGURE 3 First field prototype crack-sealing system.

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AUTOMATION IN DESIGN
NCHRP Activities

The move by the transportation industry toward increased automation of design activities has resulted in the need for research to better develop and incorporate automated processes. A number of projects are being conducted under the National Cooperative Highway Research Program to address these needs and will provide tools for faster and less labor-intensive performance of various design processes. The following are examples of NCHRP projects covering several functional areas that will lead to the creation of new tools for automated design.

Bridges and Structures

NCHRP Project 12-26/2: Distribution of Wheel Loads on Highway Bridges—Analysis Software

The anticipated distribution of wheel loads on a bridge has a significant effect on its design. Bridge engineers need fast, efficient tools to assist them with distribution analyses during the design process. NCHRP Project 12-26/2 is providing software to help in this work.

In the precursor to this project numerous variables affecting the distribution of wheel loads were considered, and recommended design provisions applicable to service load and strength design methods as well as the structural evaluation of existing bridges were developed. Results of the investigation were summarized in *NCHRP Research Results Digest 187: Distribution of Wheel Loads on Highway Bridges.* In addition the American Association of State Highway and Transportation Officials adopted the specification recommendations resulting from the project and published them as the AASHTO *Guide Specifications for Distribution of Loads for Highway Bridges.*

Under Project 12-26/2, a PC-based wheel load distribution software program was developed on the basis of grillage analysis methods. Modifiable for incorporation as a self-contained module into a complete bridge design and analysis package, the program should assist bridge offices in the automation of design.

NCHRP Project 24-6: Expert System for Stream Stability and Scour Evaluation

Many structures maintained by transportation agencies are constructed over waterways that are susceptible to various degrees of scour and stream instability. If not prevented or arrested, scour and instability can ultimately lead to failure, with possible loss of life and high cost of facility replacement. Relatively few experts exist who can use their judgment and experience to effectively address scour and stream stability problems, yet the solution invariably relies on such individuals. The objective of this research is to develop an operational, microcomputer-oriented, knowledge-based expert system to aid field personnel in evaluating current and potential scour and stream stability problems and identifying the need for countermeasures or additional detailed analyses. Much of this information may be applicable to automated design processes.

Pavements

NCHRP Project 1-32: Systems for Design of Highway Pavements

Pavement design requires consideration of many factors, including the effects of roadbed soil, climate, traffic loading, construction materials, and other design details and features on pavement performance and life-cycle costs. These considerations are being addressed through NCHRP Project 1-32 with a feasibility study on the development of a catalog of design features and an expert system. The objective of the design process is to identify pavement structures that will provide acceptable performance and economy over the intended design life.

Traffic

NCHRP Project 3-55: A Highway Capacity Manual for the Year 2000

Many NCHRP projects in the traffic area have a direct effect on the *Highway Capacity Manual.* Because the HCM can be laborious to use, many design offices use the Highway Capacity Software that is available through McTrans.

NCHRP Project 3-55 may provide a more automated approach to capacity analysis. The goal of the project is to make recommendations to the Transportation Research Board's Highway Capacity and Quality of Service Committee on the most effective formats and delivery systems for the next edition of the HCM.