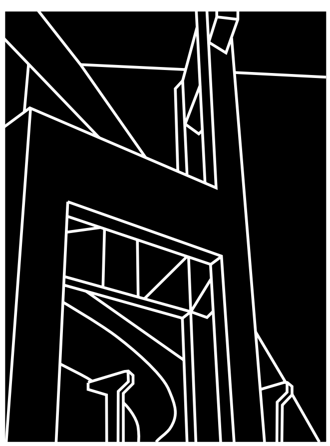
PROJECT SUMMARY REPORT 1515-S

IMPLEMENTATION OF AN AUTOMATED ROAD MAINTENANCE MACHINE (ARRM)

Carl T. Haas, Kamel Saidi, Yong-Kwon Cho, Walter Fagerlund, Hyoungkwan Kim, and Young-Suk Kim



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16. Abstract

Crack sealing is a hazardous, costly, and labor-intensive operation. In North America, approximately $200 million is spent each year on crack sealing. Prompted by concerns of safety and cost, The University of Texas at Austin, in cooperation with TxDOT and the Federal Highway Administration, has developed a unique computer-guided automated road maintenance machine (ARMM) for pavement crack sealing. The current ARMM prototype, first developed in 1997, was significantly upgraded this year (1999). The main upgrades included a new aluminum gantry to replace the older steel one; a computer system, which meets industrial requirements; and a new, spring-loaded turret design. This prototype has been thoroughly tested in field trials conducted in Texas and in nine other states. The prototype's productivity was also measured during controlled experiments. These experiments demonstrated that the device is able to seal 0.67 miles per workday or 444 linear feet of cracks per hour. The optimum sealing productivity possible with the current prototype was also estimated at 2.32 miles per workday or 765 linear feet of cracks per hour. With future improvements to several of the ARMM's components, further increases in productivity will be possible.

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by

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IMPLEMENTATION RECOMMENDATIONS

1. Perform more research on the manual crack sealing operation's productivity and standards at DOTs across North America.
2. Improve sealed crack quality to meet the standards of most potential DOT customers.
3. Improve workspace lighting to eliminate shadows and increase contrast.
4. Consolidate equipment into one vehicle to reduce mobilization steps and time.
5. Replace the XY-table's linear bearings to reduce friction and eliminate the gantry's alignment problems.
6. Change the squeegee design to a "U" or "V" shape to account for minor line-snapping errors and to provide better band-aid control.
7. Modify the line-snapping algorithm to allow line snapping to the center of a crack rather than to its edge.
8. Replace components that are susceptible to the elements with rugged, industrial-strength versions.

9. Perform extensive field trials on long stretches of road (10 or more miles) in order to validate the ARMM's productivity performance.
10. Actively recruit new potential vendors for possible future commercial development.

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CHAPTER 1. INTRODUCTION

Crack sealing, a routine and necessary part of pavement maintenance undertaken by all state departments of transportation, is a dangerous, costly, and labor-intensive operation. Within North America, about $200 million is spent annually on crack sealing, with the Texas Department of Transportation (TxDOT) spending about $7 million annually (labor alone accounts for over 50 percent of these costs). In pursuing the pavement operations, agencies must contend not only with the substantial personnel turnover and training problems associated with crack sealing, but also with the traffic disruptions that crack sealing operations typically generate.

In an effort to address these concerns of safety and cost, a man/machine balanced automated road maintenance machine (ARMM) (Figure 1.1) for automatically sealing pavement cracks has been developed, tested, and successfully demonstrated by The University of Texas at Austin. This cooperative project has been funded by the Federal Highway Administration's Office of Technology Applications, by the Texas Department of Transportation's (TxDOT) Maintenance and Construction Division, and by Crafco, Inc. (a crack sealing equipment manufacturer).

Figure 1.1. The ARMM Prototype Setup

The ARMM uses an XY-table gantry robot with a rotating turret to blow, seal, and squeegee cracks in one pass, thus greatly improving the productivity of the system. While the manipulator is moving within its work area, its frame remains stationary. Sealing cracks in one work area and then moving to the next work area is considered one work cycle. To control the ARMM through a work cycle, five steps are required: (1) image acquisition, (2) manual crack mapping and representation, (3) automated line snapping and manual line editing, (4) automated path planning, and (5) manipulator and end effector control.

Since the system performs well in its current configuration, demonstrations can be interspersed throughout the year with work on improvements and field trials. In 1999, the field trials with full-scale crack sealing were conducted in ten states: Texas, Pennsylvania, Oklahoma, Missouri, North Dakota, Wyoming, Colorado, Utah, California, and Arizona(see Figure 1.2).

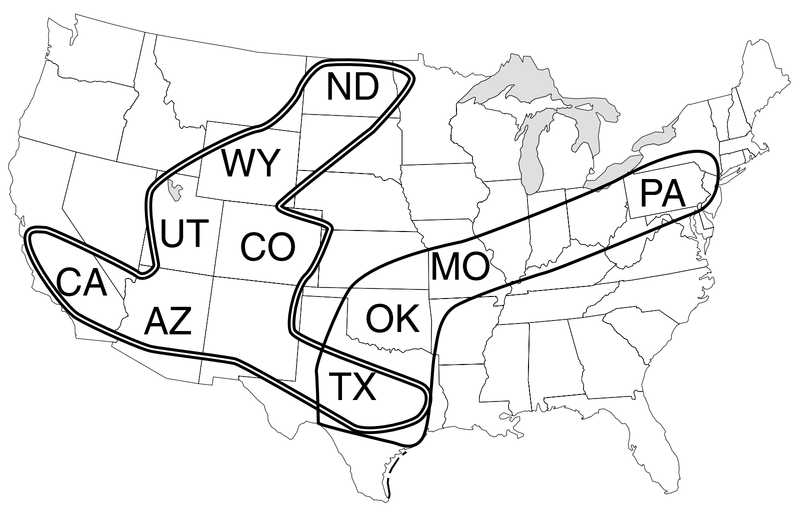

Figure 1.2. The ARMM's Field Demonstration Locations in 1999

The demonstration sites were selected based on meetings with ASCE, NCHRP, AASHTO, and WASHTO, and on research meetings with state highway departments. Other locations were also chosen according to the level of interest that was shown by each state. The objectives of the field demonstrations were to:

1. Gain additional field experience
2. Acquaint maintenance personnel around the country to the potential of automated crack sealing technology
3. Collect additional productivity data
4. Acquire more feedback from maintenance personnel
5. Perform further equipment testing under actual working conditions

This report describes the ARMM's development, system improvements, and productivity analysis method and results. The report also discusses current research efforts, field implementation, and improvements and modifications suggested through the field trial technology evaluation. The ARMM's future implementation and work plans are also presented.

CHAPTER 2. BACKGROUND

Originally, the automated crack sealing system was envisaged as an equipment train that would include an equipment trailer, a manipulator, and a large van containing computer and power equipment. Manipulator options were considered and an XY-table configuration was selected because of its ease of control and robust physical characteristics.

2.1. LABORATORY PROTOTYPE [1990]

Design objectives for the laboratory prototype focused on "proof of concept." Improving safety and productivity by working autonomously was the primary objective. Low cost was a secondary objective at this stage. An XY-manipulator was assembled in the lab and pavement test sections were fabricated. A video camera mounted above the work space was used to acquire images that were digitized and then combined with laser range data of surface contours using a specially developed multilayer quadtree model and image analysis algorithms. The combining of sensor data, a practice often termed *fusion* in robotics literature, is required because neither source of data is sufficient or fast enough in itself to provide completely accurate mapping.

Problems encountered in the first phase of development included unacceptably slow operation in the scanning, mapping, and work process cycle. In addition, calibration and alignment between the sensing and manipulator subsystems proved difficult because of the hasty assembly of the prototype. Despite these problems, a consensus existed that the approach was feasible and that the design cycle should begin anew.

2.2. FIRST FIELD PROTOTYPE [1992]

In 1992, Carnegie Mellon University (CMU) and, subsequently, The University of Texas at Austin developed the first field prototype. Design objectives for the first field prototype were to consolidate control and data processing and to demonstrate operation on unrouted cracks in a parking lot. A more robust XY-table was fabricated (Figures 2.1 and 2.2) and a revised control loop was implemented. However, the system was still hindered by slow range scanning speed, and development along this track by the associated personnel ceased temporarily [2].

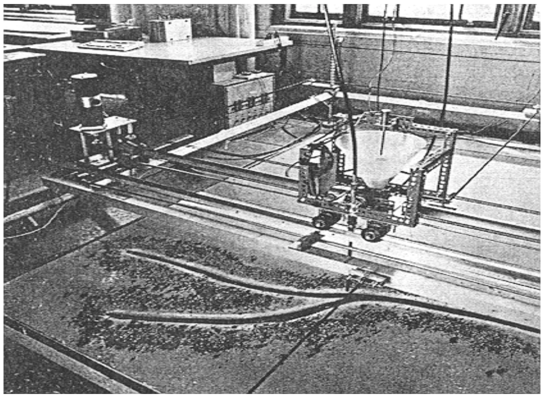

Figure 2.1. CMU Laboratory Prototype

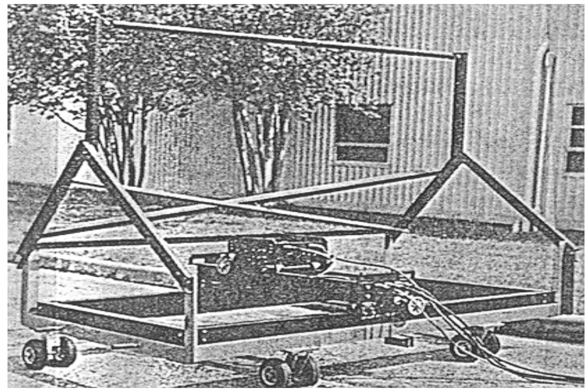

Figure 2.2. First Field Prototype

2.3. CAL-DAVIS FIELD PROTOTYPE [1993]

In a subsequent and related development effort, the Automated Crack Sealing Machine (ACSM) was developed by the California Department of Transportation (Caltrans) and the University of California, Davis (Cal-Davis). Figure 2.3 shows that the ACSM, a self-contained prototype vehicle, includes a three-axle truck with a line scan vision system mounted on the front and a robot positioning system mounted at the rear of the vehicle [3]. Computer systems are positioned on the truck bed, as are peripheral support systems.

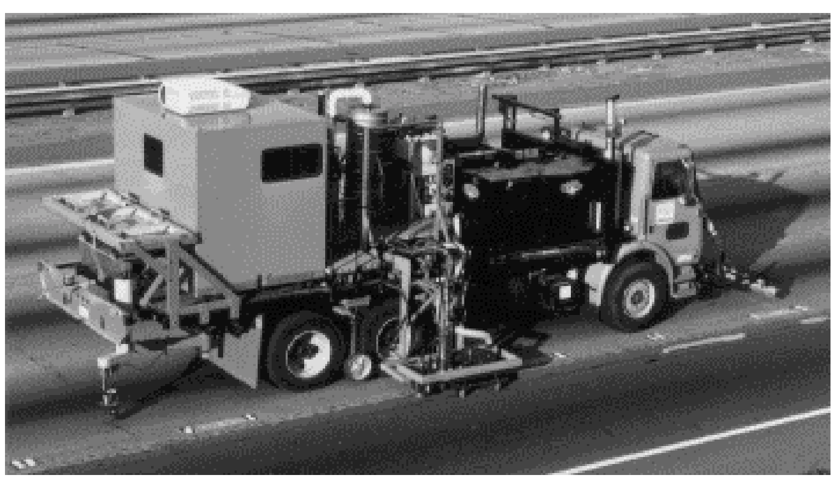

Figure 2.3. Cal-Davis ACSM Field Prototype

The Longitudinal Robot Positioning System guides the submachine that seals longitudinal cracks. It is mounted on the side of the vehicle and is used to seal joints between pavement and shoulder/median sections [3]. In demonstrations the device prepared and sealed longitudinal joints at 2 miles/hour [1].

In terms of cost, the Cal-Davis device is about 8 times more expensive than the ARMM,. If produced in volume, it is estimated that the Cal-Davis machine would sell for approximately $550,000 [4]. Market analysis indicates that such costs would be prohibitive to private contractors and to government agencies [4]

2.4. SECOND FIELD PROTOTYPE [1995]

Based on the experience gained from the preceding development efforts, a tele-operation approach was proposed and accepted as a modified objective. This next iteration of the design cycle was funded by the aforementioned consortium.

In this effort, a remote, graphically controlled system employing an XY-table manipulator was designed (Figures 2.4 and 2.5). Among other upgrades, this prototype featured manual graphical input (obviating range sensing) and a single application program that integrated all software. In addition, machine vision was used to correct for lack of operator hand/eye coordination, and automated path planning was used to minimize crack network traversal time, resulting in substantial cycle-time savings. Field trials conducted in June 1995 indicated that 5- to 10-second work cycles were achievable. It was estimated that the system could be manufactured from "off-the-shelf" equipment for as little as $70,000.

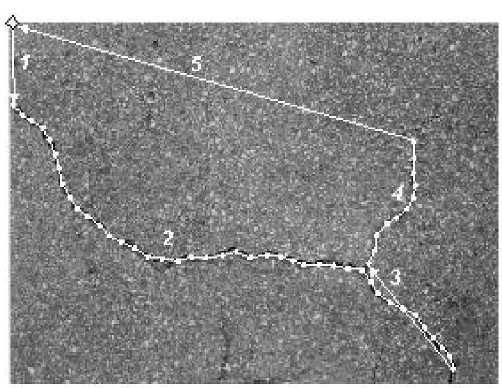

Figure 2.4. Automated Path Planning

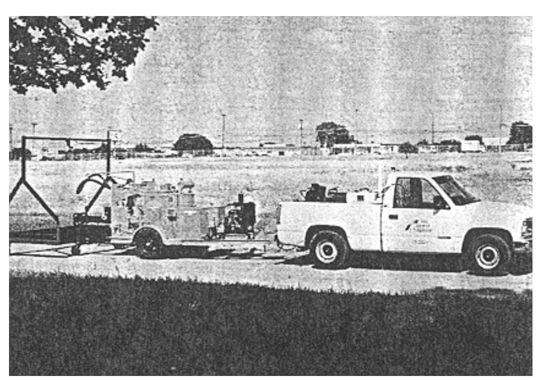

Figure 2.5. Second Field Prototype

2.5. CURRENT FIELD PROTOTYPE [1997]

New technology and lessons learned from implementation of the second field prototype were used in developing the current field prototype. The previous manipulator, which had a work envelope of 1 m × 2 m, was replaced with a manufactured manipulator having a 4 m × 2 m work envelope, enabling it to now cover a full lane width in one pass.

Key technical advances that have already been implemented in this phase include (1) a more efficient user interface (Figures 2.6 and 2.7), (2) an upgraded PC and a large flat-panel LCD touch-screen, (3) a lighter gantry design, (4) a new turret and squeegee design, and (5) a modified motion control system based on the new hardware design.

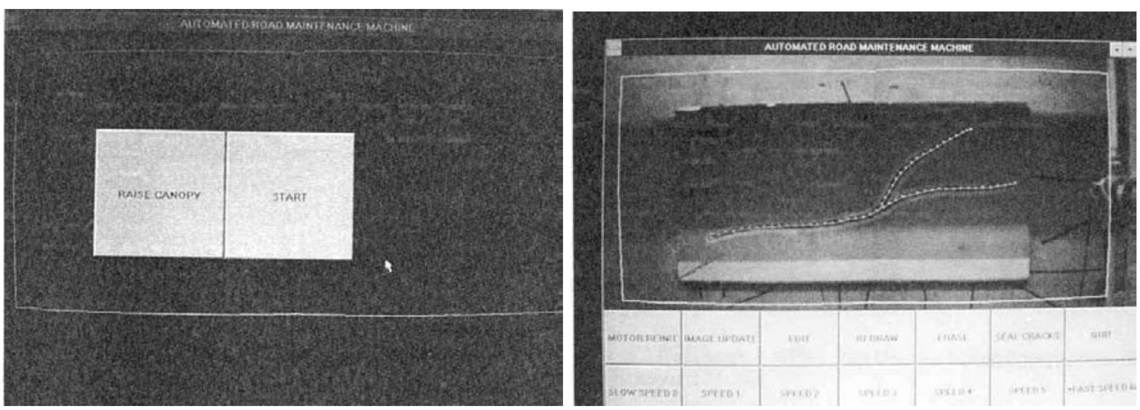

Figure 2.6. Graphical User Interface of the ARMM's Vision Software

CHAPTER 3. SYSTEM UPGRADES

This section describes how the physical components of the ARMM have been upgraded since the 1997 TxDOT report. There are three main components that have been significantly upgraded: the XY-table gantry, the computer system, and the turret.

3.1 THE XY-TABLE GANTRY

The original steel XY-table gantry was replaced with a new aluminum gantry (see Figures 3.1 and 3.2) that weighs about one-third of what the steel gantry weighs. The weight of the previous steel gantry had been the main obstacle in improving the productivity of the ARMM. The new aluminum gantry made it possible for the turret to move twice as fast as was possible with the steel gantry, which also increased the overall productivity of the ARMM by a roughly equivalent amount. The ARMM's motors had to be retuned in order to achieve optimum performance. The ARMM's software also had to be modified to incorporate the new performance parameters of the motors.

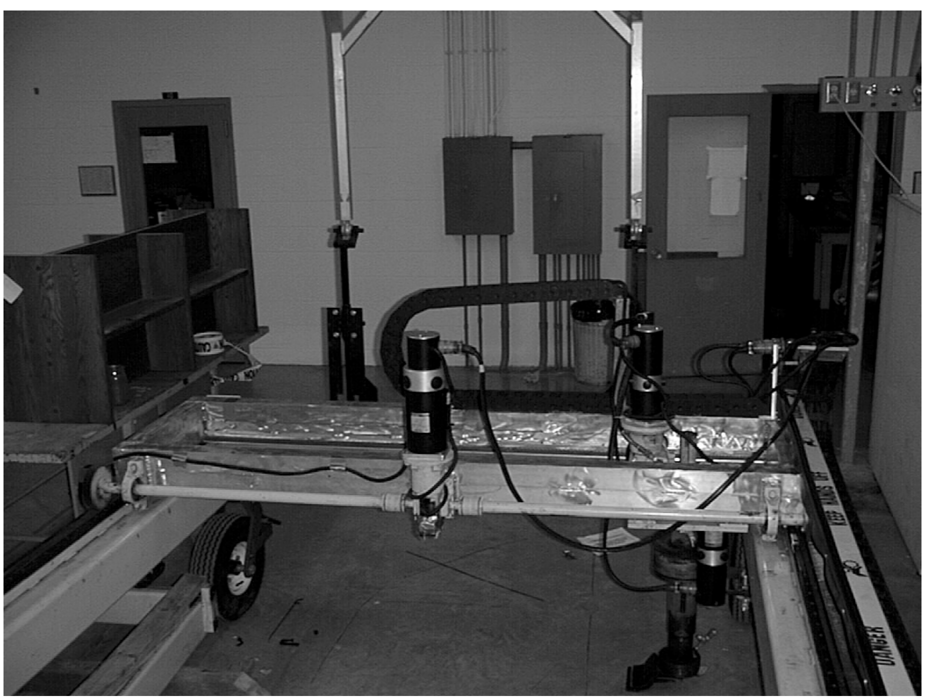

Figure 3.1. The Aluminum Gantry during Installation

Figure 3.2. The Aluminum Gantry during Operation

3.2 THE COMPUTER SYSTEM

In another upgrade effort, the ARMM's original computer (an Intel 486-based processor with a generic chassis) was replaced with a new system (an Intel Pentium II 233 MHz processor) specifically designed for industrial applications (Figure 3.3). In addition to being more powerful, the new computer is also better able to withstand vibrations and fluctuations in temperature and humidity, which are commonly encountered in actual work environments. The ARMM's older touch-screen monitor was also replaced with a flat-panel liquid crystal display (LCD) touch-screen, which makes much better use of the tight workspace inside the towing vehicle. The new LCD monitor was installed in the vehicle using a specialized mounting device that gives the operator the ability to orient the LCD to any position (Figures 3.4 and 3.5).

Figure 3.3. The New Industrial Computer and LCD Touch Screen

Figure 3.4. The LCD Mounted inside the Towing Vehicle

Figure 3.5. The LCD Oriented to a Preferred Position during Operation

3.3 THE TURRET

Finally, the ARMM's old turret was redesigned to better follow the uneven contours of a typical road surface. The new turret design is a spring-loaded, two-piece retractable turret; it also includes two wheels that provide rolling contact with the road surface. The new turret is able to retract a total of 3 inches, which assures a uniform contact between the road surface and the squeegee (Figures 3.6 and 3.7). The ARMM's software was also modified to ensure that the turret always moves in a specified direction so as to maintain proper alignment between the wheels and the direction of travel.

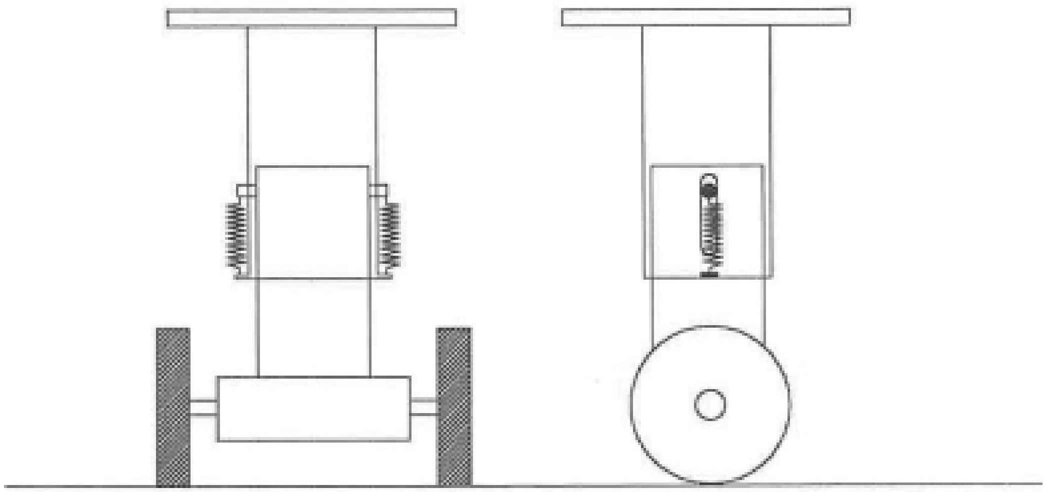

Figure 3.6. Design of the New Turret

Figure 3.7. The New Turret in Operation

3.4 MINOR CHANGES

In addition to the above-mentioned changes, the ARMM system also underwent the two minor changes listed below:

- The two cameras were enclosed inside boxes to protect them from the elements while the ARMM is in transit and while it is sealing cracks (Figure 3.8).
- Plastic handrails were installed along the length of the ARMM's XY-table to prevent workers from placing their hands close to the rack-and-pinion drive system (Figure 3.9).

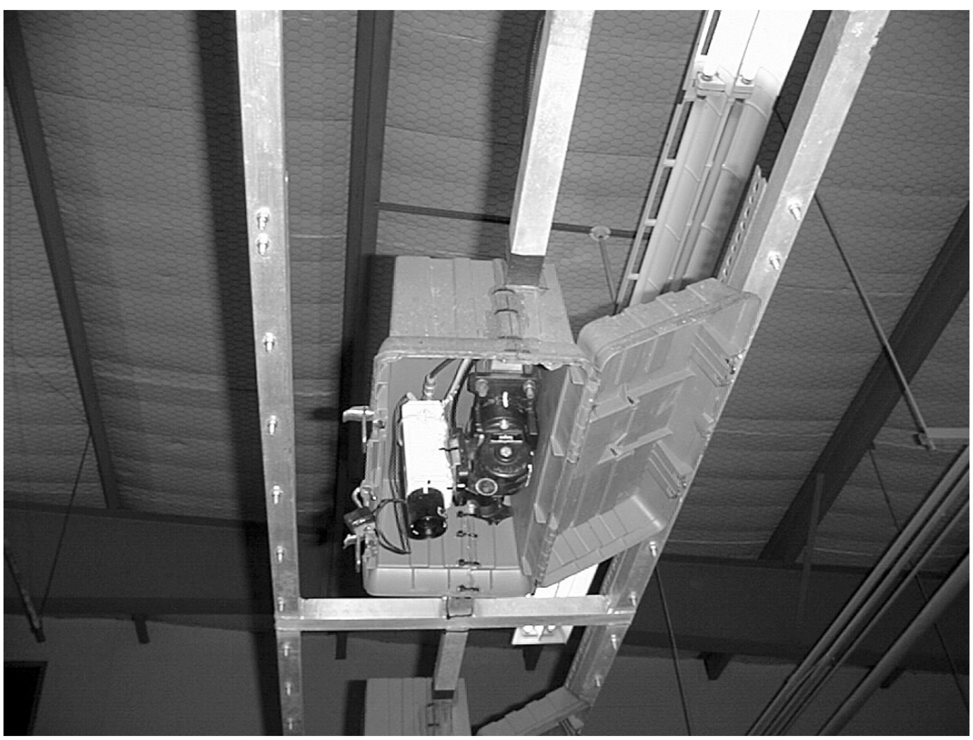

Figure 3.8. The Camera Enclosures

Figure 3.9. The Safety Handrails

Appendix A lists the updated costs of the ARMM system, including the cost of the above-mentioned changes, while Appendix B lists the manufacturers of most of the ARMM's components.

CHAPTER 4. TIME TRIAL

This section discusses the design, execution, and results of an experiment that the Field Systems and Construction Automation Lab (FSCAL) team conducted in order to measure the productivity of the automated road maintenance machine (ARMM.)

4.1 DESIGN — SIMULATING TYPICAL CRACK PATTERNS

First and foremost, the team was concerned with how to conduct the time trial using typical crack patterns found on an average road surface. Because the experiment had to be carried out in a controlled and measurable environment, conducting it on a busy public road was not an option. Moreover, several miles of road would have to be used so that the ARMM could seal a number of cracks sufficient to achieve some sort of statistical significance. Accordingly, in lieu of searching for a private road having a considerable number of cracks, the team decided to draw simulated cracks on a chosen length of road at the J. J. Pickle Research Campus. (To draw the cracks on the road's surface, the team decided to use a water-based black latex paint and to apply it using 1 in. wide paint rollers.) While drawing the cracks would allow the team to simulate any type of crack condition, it also dictated that no actual sealant material could be used to fill the simulated cracks. However, since the objective of the time trial was to measure the optimum productivity of the ARMM, not using sealant ensured that malfunctions of the sealant melter would not affect the overall productivity. Given that the sealant melter's flow rate was known to be sufficient to keep up with the highest speed of the ARMM, its omission from the experiment did not inflate the productivity results.

After considerable discussion and debate, the team concluded that there were three types of cracks that were of primary concern: longitudinal cracks, transverse cracks, and branched cracks. Figure 4.1 shows a representation of the branched crack type, while Figure 4.2 shows the longitudinal and transverse types. Using these crack types, the team then divided the length of test road into three 100 ft sections according to the type of cracks that were being sealed. By measuring the productivity of each type of crack, researchers could calculate an average value for the typical road surface. In turn, each 100 ft section was further divided into twenty 5 ft x 11 ft sections to represent the size of the ARMM's workspace. Hence, the ARMM would seal a total of 300 ft, stopping sixty times in the process.

The next issue was how to vary the density of the cracks over each test section (i.e., the number of linear feet of cracks per workspace). In order to obtain measurements of productivity for different crack densities, the team decided that medium, low, and severe crack densities could be represented by one, two, and three cracks per ARMM workspace, respectively. Although one crack per workspace initially seems like a low number to represent medium crack densities, having sixty consecutive adjacent workspaces creates an atypical situation more akin to a road of medium crack density. Since the ARMM's workspace can be approximated by a 5 ft x 11 ft rectangle, the team decided that each individual crack should not exceed the minimum ARMM dimension, namely, 5 ft. Thus, each crack length was set to 5 ft, which made it possible to fit one longitudinal crack in one ARMM workspace. In addition, setting each crack length to 5 ft simplified the task of calculating the linear feet of sealed cracks and the associated productivity. (Given that no sealant was to be dispensed during the experiment, the team decided not to vary the width of the drawn cracks.)

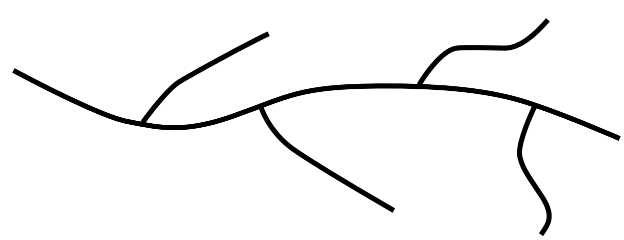

Figure 4.1. Representation of a Branched Type of Crack

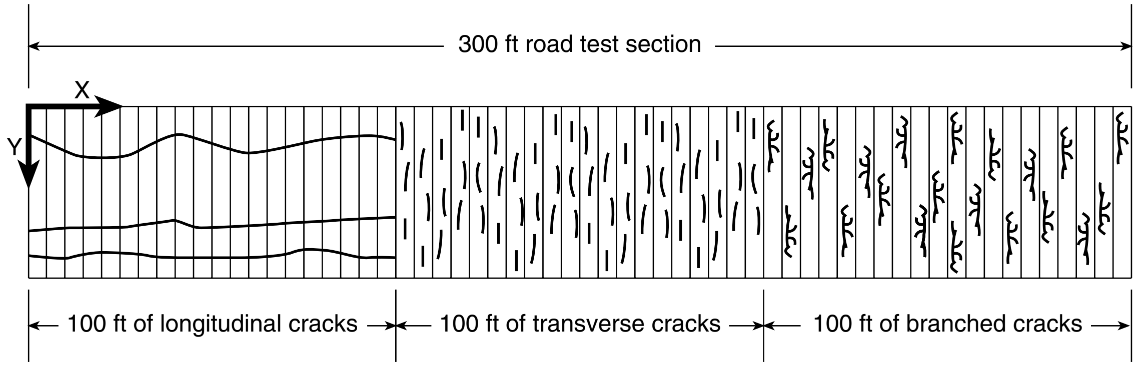

Figure 4.2. The Layout of the Test Road Section

In order to determine the location of each simulated test crack within an ARMM workspace, a random-number generator was used to construct a table of coordinates for each workspace. For each of the *x* and *y* directions in the workspace (refer to Figure 4.2), a random number between 1 and 5 was generated. For example, a value of 1 for the *x* direction meant that the crack should be located close to that axis' origin; a value of 3 meant that the crack should be located in the center of that axis; and a value of 5 indicated that the crack should be placed at the other end of the axis. A value of 2 or 4 meant that the crack should be located between the three prior positions, with 2 being closer to the axis' origin and 4 closer to the axis' other extreme. An identical scheme was developed for the *y*-axis. Because the test road was made up of sixty sections (each representing one ARMM workspace), the origin of the *x-y* coordinate system was shifted to a new section for each of the random-number calculations.

The random numbers were generated for the medium, high, and severe crack density conditions so that each pass across the test section would follow a random pattern of cracks. This meant that the cracks representing the different crack densities had to be identified as such. In the first pass over the test road surface, the operator would seal only those cracks identified as belonging to the medium density category. Therefore, only one crack per workspace would be sealed. In the second pass, the operator would concentrate on the medium- and high-density cracks, while in the final pass he would seal all the visible cracks.

The next issue was how to draw random branched cracks while allowing the operator to seal only 5 ft of crack during the first pass, 10 ft during the second pass, and 15 ft during the last pass. To do this, the team decided to divide a 15 ft length of rope into five sections — one 5 ft section and four 2.5 ft sections. The 2.5 ft sections were then tied to the 5 ft section, as shown in Figure 4.1. The idea was that this rope would then be thrown onto each ARMM workspace and its profile traced to simulate a branched crack. In order to ensure that the rope did not coil onto itself when it was tossed (a position that would not represent a realistic crack), the team decided to coat the rope with wood glue, allow the glue to dry, and then toss the rope. As the team members had hoped, the dried glue gave the rope rigidity, allowing it to form realistic-looking crack patterns. Figure 4.3 shows one of the simulated branched cracks on the test road section.

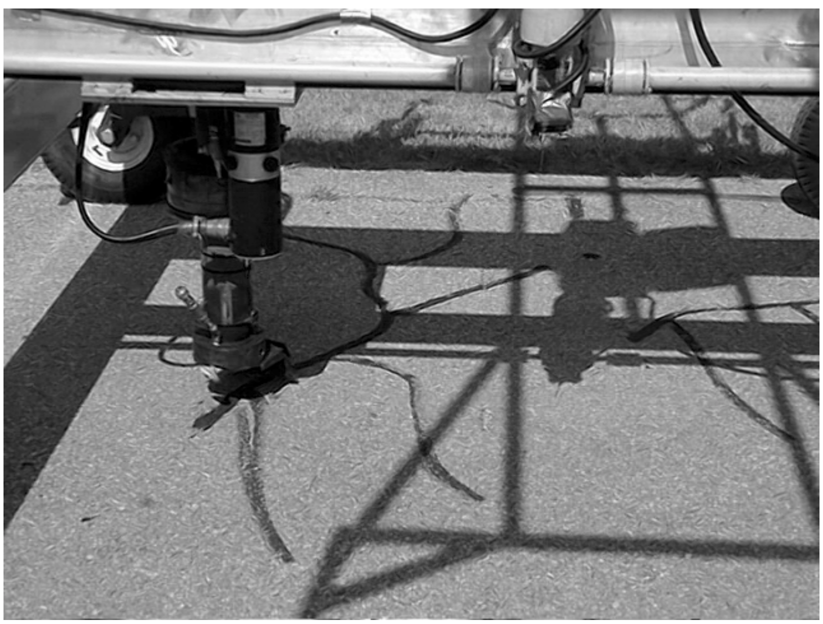

Figure 4.3. The ARMM Sealing a Simulated Branched Crack during the Time Trial

4.2 EXECUTION — MEASURING PERFORMANCE

The next aspect of the experiment involved determining what times needed to be measured in order to obtain meaningful productivity results. The team decided that, in order to quantify productivity completely, four different times had to be measured: moving time, drawing/snapping time, sealing time, and total time. Moving time measures the time the ARMM takes from the moment the turret returns to its home position after sealing a crack, until the operator moves to the next road section and begins to trace new cracks. Drawing/snapping time measures the time it takes for the operator to trace all the relevant cracks in one workspace, as well as the time that it takes the computer to snap the traced lines to the cracks and issue the command robot to start sealing. Sealing time measures the time it takes the turret to move from its home position, seal all the cracks, and then return to its home position. Finally, total time measures the total time it takes for the ARMM to complete each 300 ft pass.

4.3 RESULTS — PRODUCTIVITY OF THE ARMM

Based on the feedback obtained during the field demonstrations (discussed in Section 5), the most common measure of productivity for a crack-sealing work crew is either miles of road per work day or linear feet of cracks per hour. According to the results of the time trial (the data obtained during the time trial are presented in Appendix C), the average productivity of the ARMM is 0.67 miles of road per workday, or 444 linear feet of cracks per hour. Table 4.1 shows the measured productivity results for the different levels of crack density, while Table 4.2 shows the corresponding estimated productivity results of the ARMM.

Table 4.1. The Measured Productivity of the ARMM

Productivity (miles per 8-hour workday)			
Crack density			
Medium	High	Severe	Average
0.83	0.70	0.55	0.67

Linear feet of cracks per hour (ft)			
Crack density			
Medium	High	Severe	Average
546	460	363	444

Table 4.2. The Estimated Productivity of the ARMM

Productivity (miles per 8-hour workday)			
Crack density			
Medium	High	Severe	Average
1.43	1.20	0.95	1.16

Linear feet of cracks per hour (ft)			
Crack density			
Medium	High	Severe	Average
942	793	626	765

In the time trial design, the term *medium density* referred to 5 linear ft of crack per workspace. However, since each workspace was adjacent to the next one, this did not accurately reflect actual medium crack densities in a real-world situation. No empty workspaces were included in the test road section because the team wanted to maximize the number of cracks sealed while minimizing the overall length of the test road section. Realistically, the situations created by the medium, high, and severe crack densities along the test road section represent above-average crack densities. Since the density of cracks along typical roads is a function of several factors (such as climate, amount of traffic, type of traffic, geotechnical conditions, etc.), obtaining one value for the real-world average crack density is unrealistic. Nonetheless, based on experience gained through the field demonstrations undertaken by the FSCAL team (described in Section 5), the densities considered in the time trial were at least twice as high as what was encountered in the ten states visited during the demonstrations. Using a high density value effectively cuts the total time for each pass over the test road section by half, and in turn doubles the productivity to 1.34 miles per workday. This productivity does not affect the number of linear feet of cracks sealed per hour since the decrease in time is offset by an equivalent decrease in the amount of cracks sealed.

In addition to the above-mentioned limitation of the time trial owing to technical difficulties encountered during the trial, the speed at which the turret traveled over a crack had to be reduced to approximately 15 meters per minute. Since the maximum speed is 26 meters per minute, that meant that the turret was moving at approximately 58 percent of its maximum. Thus, under optimum circumstances, the productivity of the current ARMM could be as high as 2.32 miles of road per workday, or 765 linear feet of cracks per hour (Table 4.2). (All the above results are summarized in Appendix C.)

CHAPTER 5. FIELD DEMONSTRATIONS

5.1 INTRODUCTION

This chapter presents the findings and experiences of the Field Systems and Construction Automation Lab (FSCAL) team members, who embarked on two separate demonstration trips — a 9-day trip to Pittsburgh, Pennsylvania, and a 6-week tour of the western United States. The purpose of the trips was to demonstrate the potential of the automated road maintenance machine (ARMM) to the departments of transportation of various states and, at the same time, to gather valuable field data regarding the ARMM's performance and reliability.

5.2 TEAM MEMBERS

The team that traveled to Pennsylvania included YongKwon Cho and Kamel Saidi, two University of Texas at Austin graduate students. The members that made up the team that went on the 6-week U.S. tour consisted of two additional graduate students, Walter Fagerlund and Hyoung-Kwan Kim. All four of the team members are part of the Construction Engineering and Project Management (CEPM) program within the department of civil engineering of The University of Texas at Austin.

5.3 EQUIPMENT

The primary pieces of equipment used during both trips included the following:

- The ARMM and its accompanying computer and electronic components
- A 5000-watt electric generator
- An air compressor

For the Pennsylvania trip, a 1999 Ford F-250 extended cab diesel truck served as the mode of transportation, whereas for the 6-week U.S. tour, the following additional pieces of equipment were used:

- A Crafco, Inc. "Supershot 60" sealant melter
- A 1999 Ford F-350 crew cab diesel truck (rental)
- A 1999 Ford E-350 fifteen-passenger gasoline van (rental)

5.4 LOGISTICS

The Pennsylvania trip took place between April 30 and May 8, 1999. The objective of this trip was to demonstrate the ARMM at the Maintenance Executive Development Program (MEDP) Conference sponsored by the Pennsylvania Department of Transportation.

The demo dates and locations for the longer 6-week trip were planned so as to allow the tour to follow a circular path starting out north from Austin and returning to Austin from the west, after stopping in each of the nine cities listed in Table 5.1. The tour was scheduled to visit the departments of transportation (DOT) of eight different states over a 6-week period between May 31, 1999, and July 16, 1999. Table 5.1 below shows the schedule the tour followed and the various locations where the demos took place. The dates and times of each demo were coordinated with representatives of each DOT (also listed in Table 5.1).

Table 5.1. ARMM U.S. Tour Schedule

City	**Date**	**Location**	**Time**	Contact
Oklahoma City, OK	6/2/99	US 66 & HW 92	9:00 a.m.	Kevin Bloss
Kansas City, MO	6/7/99	I-80	12:00 p.m.	Clif Jett
Bismarck, ND	6/10/99	Bismarck Zoo	9:00 a.m.	Mike Kisse
Casper, WY	6/16/99	I-25	9:00 a.m.	Ken Sweden
Denver, CO	6/21/99	C-DOT HQ	9:00 a.m.	Werner Hutter
Salt Lake City, UT	6/29/99	UT-DOT HQ	10:00 a.m.	Craig Ide
Truckee, CA	7/1/99	I-80	7:30 a.m.	John Cottier
Tucson, AZ	7/7/99	I-10	10:30 a.m.	Arnold Gates
Crafco, AZ	7/9/99	Crafco Headquarters	10:00 a.m.	Vern Thompson

Section 5.5 includes photos taken during the field demonstrations; it also describes a few of the technical difficulties that were directly related to both the ARMM's design and its ability to seal cracks.

5.5 THE FIELD DEMONSTRATIONS

5.5.1 Monroeville, Pennsylvania

Date: 5/5/99
Time: 2:00 p.m.
Location: ExpoMart parking lot in Monroeville

Figure 5.1. The ARMM Setup in the ExpoMart Parking Lot

Figure 5.2. Participants at the MEDP Conference Observing the ARMM

5.5.2 Oklahoma City, Oklahoma

Date: 6/2/99
Time: 7:30 a.m.
Location: Route 66 and US 92 (later moved a few miles away)

Figure 5.3. The Demo Location on Route 66

Figure 5.4. The ARMM Being Readied for Unloading

5.5.3 Kansas City, Missouri

Date: 6/7/99
Time: 12:00 p.m.
Location: I-80

Figure 5.5. The ARMM Setup on the Frontage Road to Highway 80

Figure 5.6. The ARMM Demo Team Briefing the MO-DOT Representative

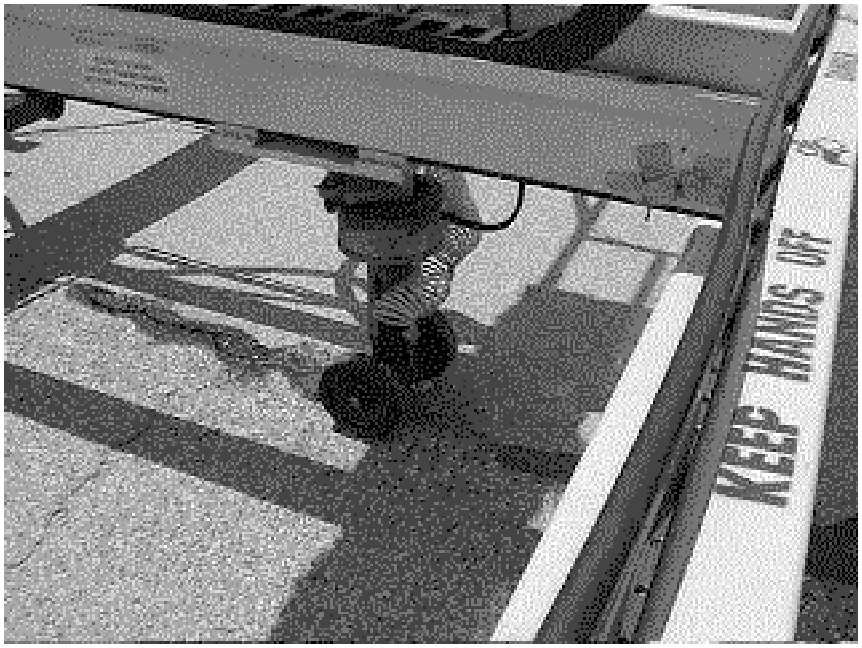

Figure 5.7. The ARMM Sealing a Longitudinal Crack

5.5.4 Bismarck, North Dakota

Date: 6/10/99
Time: 9:00 a.m.
Location: Urban road next to the Bismarck Zoo

Figure 5.8. The Demo Location close to the Bismarck Zoo

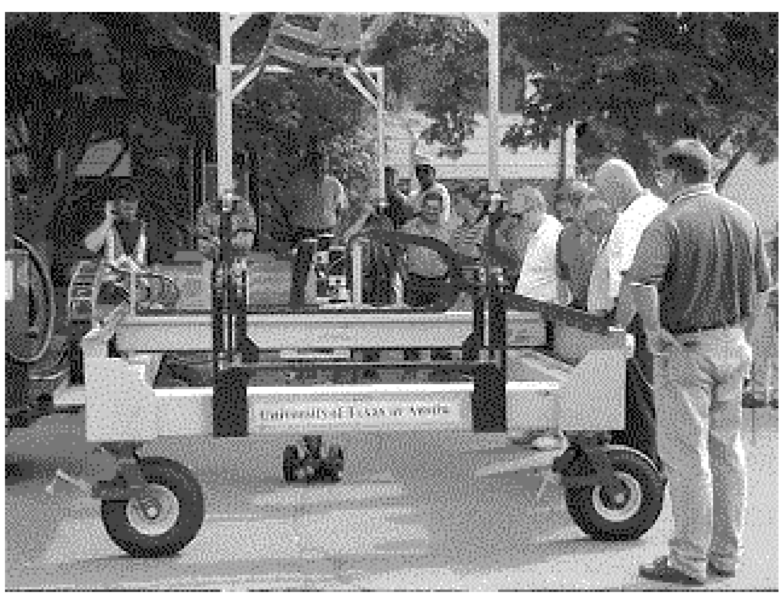

Figure 5.9. The ND-DOT Representatives Observing the ARMM in Operation

At the beginning of the demonstration, the ARMM team discovered that the melter's electric hose was not functioning. Although the team consulted with the Crafco, Inc., representatives, the hose could not be repaired until after the demonstration. Consequently, the demo proceeded with the melter hose connected to, but no sealant flowing to, the ARMM. The hose ultimately had to be replaced a few days later.

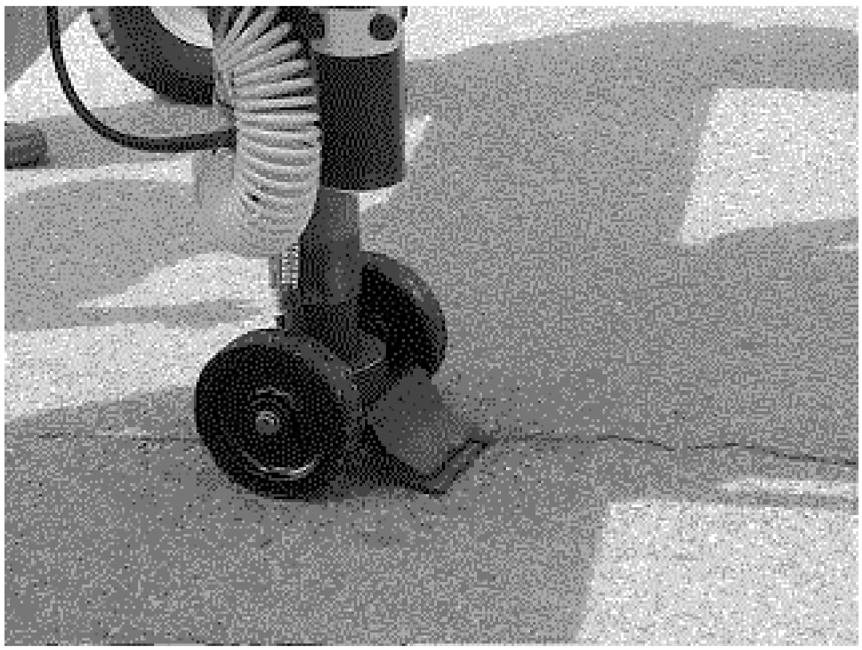

Figure 5.10. The ARMM Sealing Cracks without the Sealant Material

5.5.5 Casper, Wyoming

Date: 6/16/99
Time: 9:00 a.m.
Location: I-25

Figure 5.11. The Demo Location on Interstate 25

Figure 5.12. The WY-DOT Representative Observing the ARMM

Some of the cracks that were encountered were very deep and wide. It was often difficult to judge the width and depth of the cracks simply by looking at the computer monitor. It was even more difficult to determine when a crack had been filled in completely.

However, the greatest problem associated with the wide cracks had to do with the fact that the line-snapping algorithm would snap not to the center of the crack, but rather to the edge of it (where it is usually darker). Thus, the line-snapping algorithm should be modified to snap to the center of a crack, regardless of the crack's width. It would also be useful if the ARMM program could determine the average width of a crack automatically.

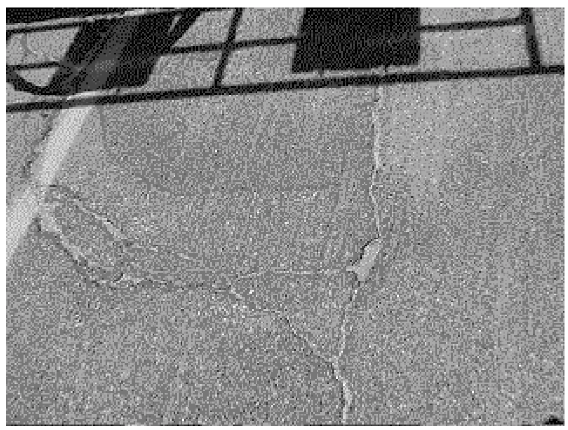

Figure 5.13. The Wide and Non-Uniform Cracks before Sealing

Figure 5.14. The Wide and Non-Uniform Cracks after Sealing

In addition, if a certain crack needed a second pass to fill it with the correct amount of sealant, the air nozzle would blow out some of the sealant that had already been laid down in the first pass. This caused the turret's wheels to accumulate sealant and debris, which, in turned, caused the motors to overload in some situations (see Figure 5.15). Thus, it is important to fill a crack properly during the first pass by adjusting the turret speed appropriately. However, if the first pass is not sufficient, the air should be switched off for the duration of all subsequent passes.

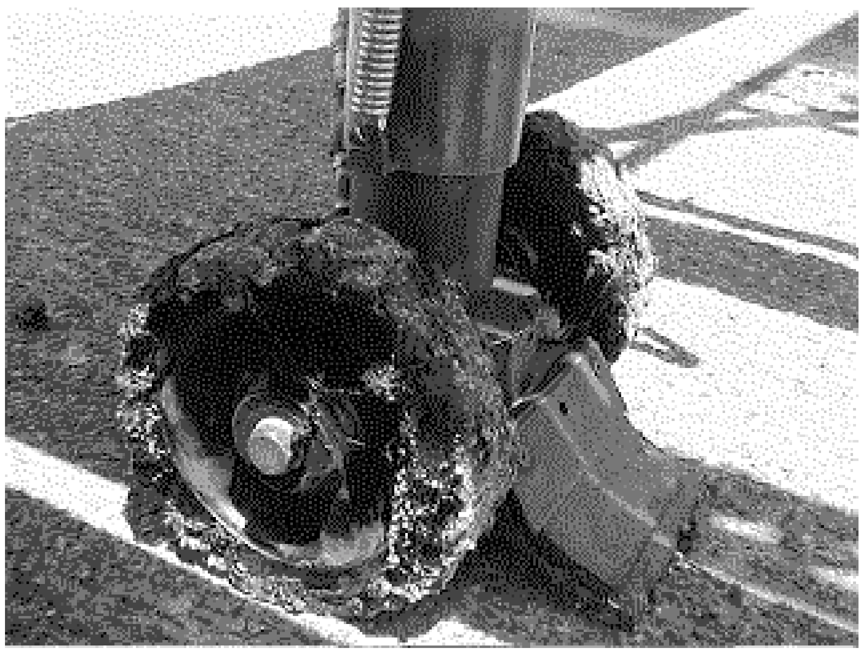

Figure 5.15. The Turret Wheels with Accumulated Sealant

5.5.6 Denver, Colorado

Date: 6/21/99
Time: 7:00 a.m.
Location: Colorado DOT yard

Figure 5.16. The ARMM Setup in the CO-DOT Parking Lot

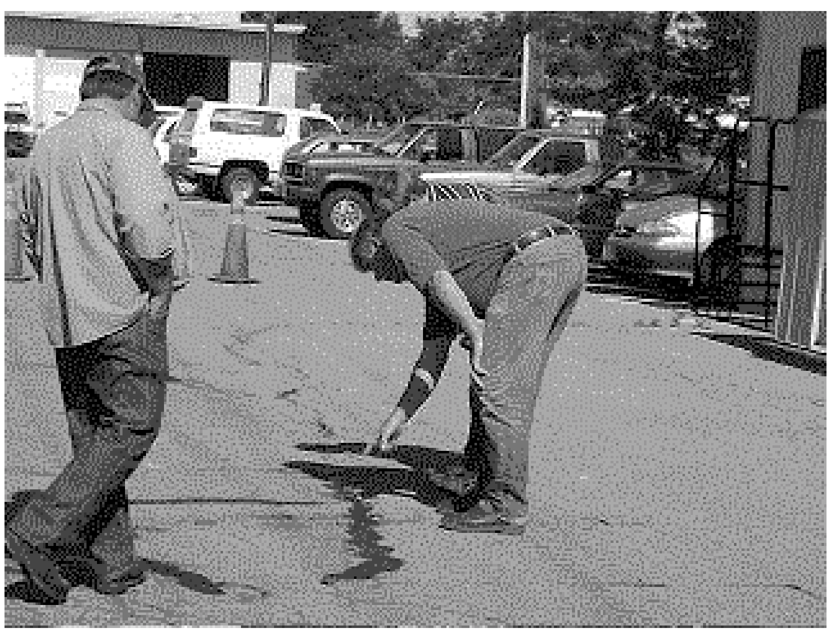

Figure 5.17. A CO-DOT Representative Observing the Quality of the Seal

Figure 5.18. The CO-DOT and ARMM Team during a Classroom Discussion

At the beginning of the Denver demonstration, the melter did not immediately start because of the cold weather — the coldest the ARMM had experienced during the trip. Thus, more time for setting up should be allowed when temperature extremes are encountered.

5.5.7 Salt Lake City, Utah

Date: 6/29/99
Time: 10:00 a.m.
Location: Utah DOT headquarters parking lot

Figure 5.19. The ARMM Setup in the UT-DOT Parking Lot

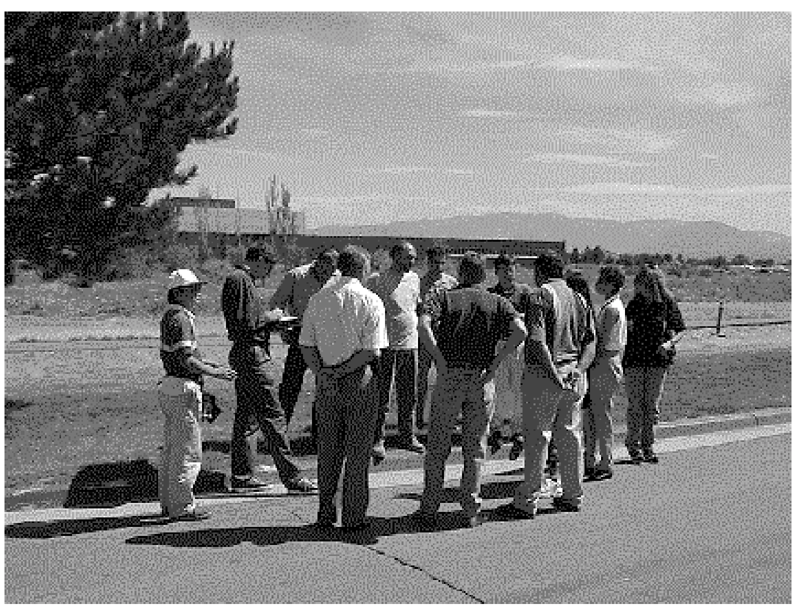

Figure 5.20. The ARMM Team Briefing the UT-DOT Representatives

Overall, the Utah demo went well. However, it seemed that Utah DOT representatives were more interested in the ARMM's productivity than anything else. They were even measuring the crack lengths and the time required to seal them. Of course, during the briefing, the team explained to the representatives that the ARMM was not operating at its optimum output and that there remained several improvements to be implemented before a commercial version could be developed.

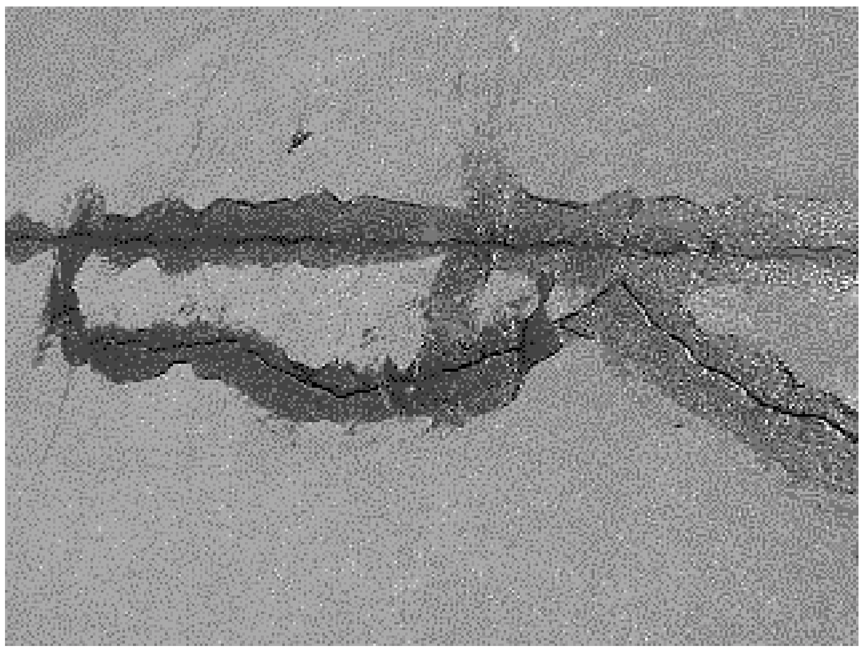

Figure 5.21. A Sealed Branched Crack at the UT-DOT Parking Lot

5.5.8 Truckee, California

Date: 7/1/99
Time: 7:00 a.m.
Location: On-ramp to I-80 at US 89

Figure 5.22. The ARMM Setup on an Access Ramp to Interstate 80

Figure 5.23. A Deep and Wide Crack before Sealing

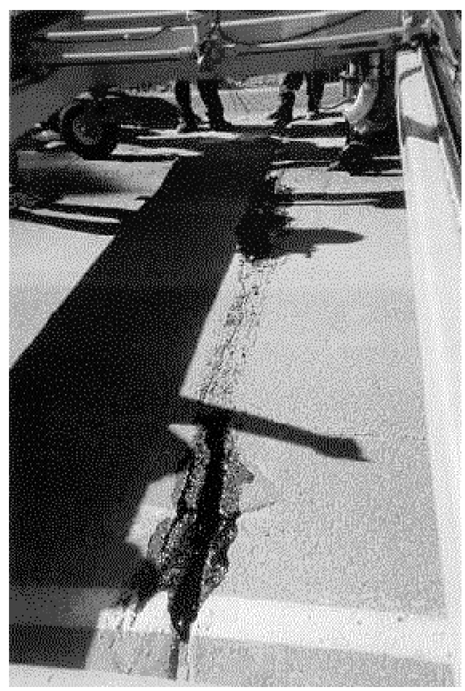

Figure 5.24. A Deep and Wide Crack Partially Sealed

The cracks on the access ramp were rather large. The ARMM successfully sealed three of the large cracks on the AC pavement, with the device getting progressively better after each crack. However, because the cracks were so wide, it was difficult for the ARMM's squeegee to work properly. The demonstration then proceeded down toward I-80, where the ARMM sealed several regular cracks on PCC pavement. The PCC pavement in the right lane (where the demo took place) had visible aggregates of several different shades of gray. The aggregates had apparently been exposed as a result of the right lane being used for chain control during the winter months. The line-snapping algorithm had no difficulty recognizing cracks on this surface.

Figure 5.25. The ARMM in Operation on Interstate 80

5.5.9 Tucson, Arizona

Date: 7/7/99
Time: 10:30 a.m.
Location: I-10 Frontage Road at Congress Ave.

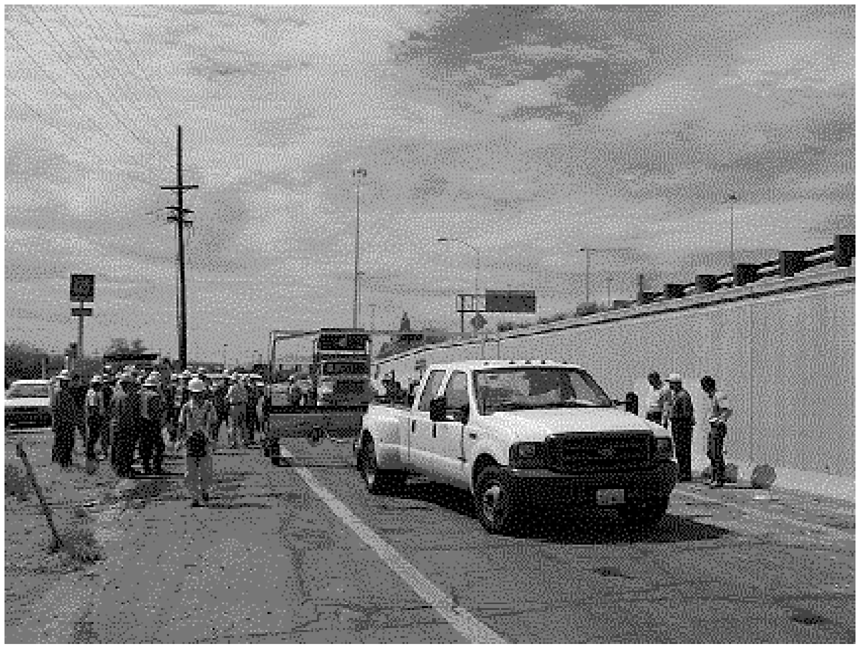

Figure 5.26. The ARMM Setup on the Frontage Road to Interstate 10

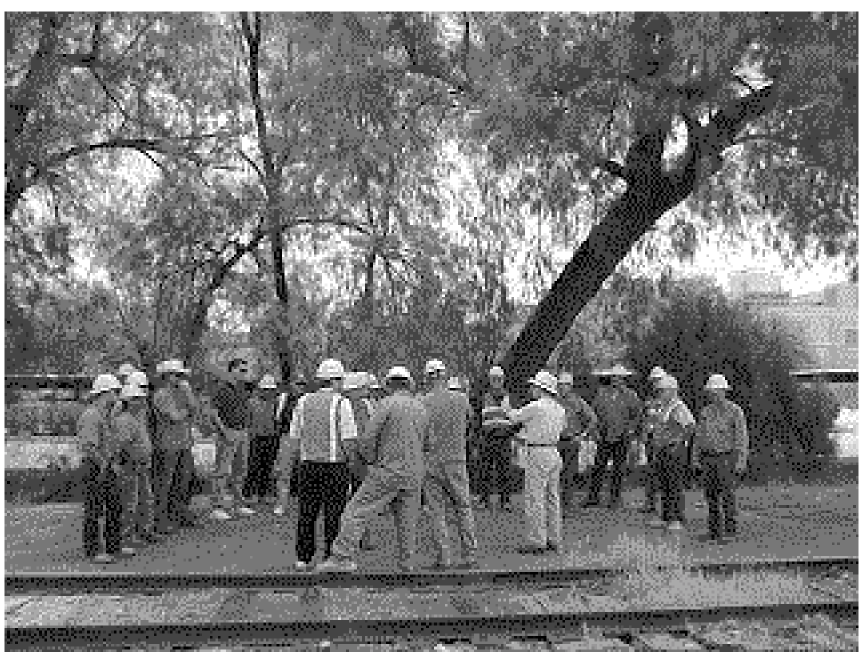

Figure 5.27. Dr. Haas Briefing the AZ-DOT Representatives

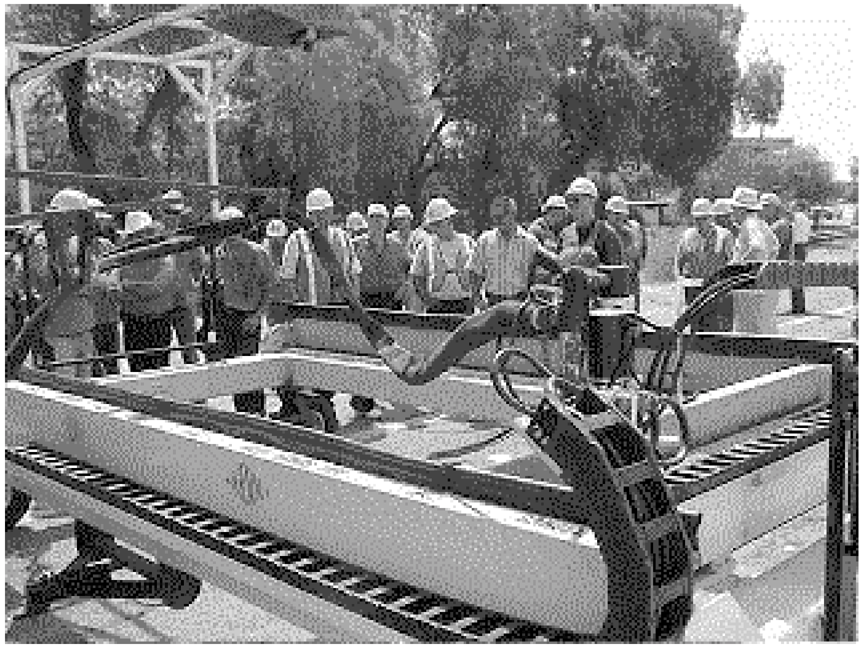

Figure 5.28. The AZ-DOT Representatives Observing the ARMM in Operation

5.5.10 Phoenix, Arizona

Date: 7/9/99
Time: 10:00 a.m.
Location: Urban road in Mesa, AZ, close to Crafco, Inc.

Figure 5.29. The Demo Location close to Crafco Headquarters

Figure 5.30. Crafco, Inc., Representatives Observing the ARMM

Figure 5.31. The Crafco, Inc., Engineers Learning about the ARMM's Software

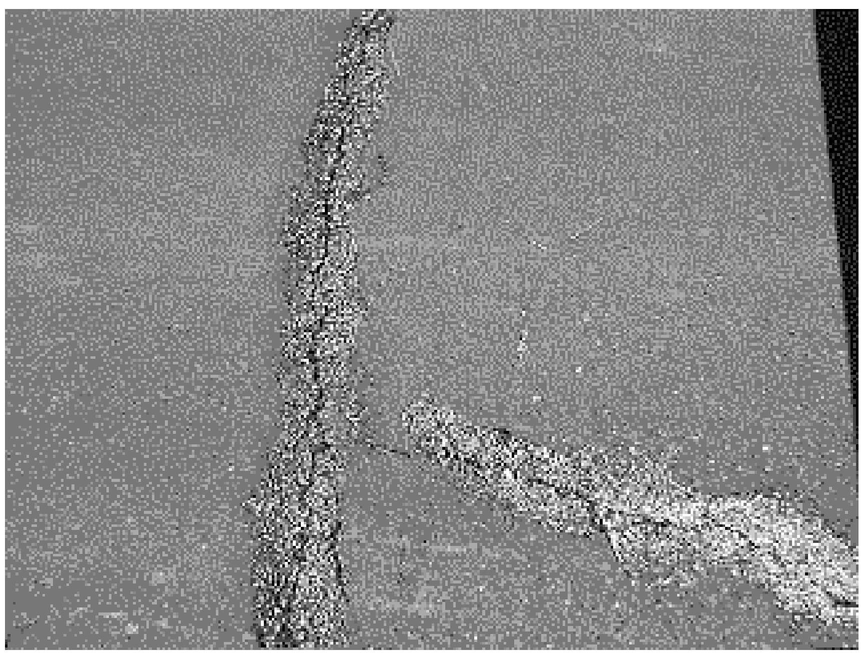

Figure 5.32. A Sealed Branched Crack

5.6 COMMENTS AND SUGGESTIONS OBTAINED FROM THE DOT s

The following is a list of common comments and suggestions that the ARMM team encountered during the demonstrations:

- Minimize the minute and numerous turret direction changes when following a crack
- Eliminate need for turret to return to its home position after each crack
- Have emergency switches on the ARMM accessible to the workers around the robot
- Install lights for nighttime operation
- Change the shape of the squeegee to a circular design that can contain the sealant
- Change the shape of the squeegee to a “V” or “U” shape
- Implement an interactive calibration procedure from within the ARMM software
- Signal the operator inside the truck when the turret has returned to home position
- Implement a floating turret design that can maintain a constant height off the ground and eliminate the wheels
- Redesign the ARMM so that it can be towed (obviating a trailer)
- Implement a telescoping frame design that can be adjusted to different widths depending on requirements
- Increase air pressure/flow
- Include all the equipment in one self-contained unit
- Investigate using either thinner wheels or different wheel material/coating to prevent them from getting gummed up
- Increase work speed
- Implement ability to seal cracks continuously (i.e., without stopping)
- Account for increase in a crack’s width and depth after it is blown out
- Implement the ability to control the flow of sealant or the speed of the turret on the fly (i.e., while it is sealing a crack) to account for variations in crack width and depth
- Eliminate the shadows that confuse the line-snapping algorithm
- Increase mobilization speed

- Consider using multiple air nozzles that can cover an entire lane width in one pass and possibly install a second one that will clean up after the first pass

Some Quotes

- The Colorado DOT melters are down approximately 30 to 40 percent of the time.
- Arizona DOT can seal an average of 4.5 miles of road per day using a crew of six to nine (including two on air nozzle, two to three on squeegees, one on the melter wand, one for driving the melter and maintaining the proper level of sealant, and possibly two flag men, depending on traffic conditions).
- David Nicholas (AZ-DOT) considers a machine that can seal cracks at 5 miles per day with an 85 percent accuracy to be pretty good.
- AZ-DOT agrees that keeping the workers away from the hot sealant is a valid safety consideration.

CHAPTER 6. FUTURE IMPROVEMENTS

This section of the report discusses possible improvements that can be made to the automated road maintenance machine in the future. The improvements were determined through several years of experience with the current ARMM prototype (and previous versions), as well as through the numerous field trials and demonstrations that were conducted. As mentioned in Section 5 of this report, the representatives of the departments of transportation (DOT) of several states provided many suggestions and recommendations regarding the future direction of the ARMM. These representatives included people from management *and* from the field, which makes this type of feedback significant, insofar as it reflects the needs of the ARMM's primary customers. Accordingly, the improvements suggested in this section should be seriously considered for implementation in a commercial version of the ARMM.

The improvements that are discussed in this section can be divided into two categories as follows: (1) improvements in crack sealing technologies and (2) improvements in overall machine design.

6.1 IMPROVEMENTS IN CRACK SEALING TECHNOLOGIES

6.1.1 Improved Squeegee Design

The current squeegee design includes a straight-edged piece of hard rubber that allows the overflow of sealant to spill out at the edges and onto the road surface. Although some states require a certain amount of sealant to be deposited on either side of the crack (often referred to as "bandaging"), it is generally not a desirable outcome of most crack sealing operations. Most states recommend that the sealant in a crack remain flush with the road surface, or that it form a very thin bandage along the edge of the edges of the crack. Excess sealant on the surface of the road will cause the sealant inside the crack to be pulled out when the material sticks to the tires of passing vehicles or, as is the case in some northern areas, a snowplow scrapes up the bandage and seal. Thus, the design of the current turret must be corrected. A commonly used shape for a squeegee in crack sealing operations is the "V" shape. Accordingly, it was this design that was most often recommended by individuals with extensive field experience. The "V" shape helps to produce a consistent seal, to contain any excess sealant, and to correct for any line-snapping errors. A few DOT representatives suggested a circular design — one that would completely contain the sealant and sense the pressure over the crack as a means of regulating the flow of sealant into the crack.

6.1.2 Smart Turret That Doesn't Return Home

One of the most frequent criticisms expressed to the field demonstration team was that the turret wasted a lot of time returning to its home position after each sealing operation was completed; that is, the operator had to wait for the turret to complete its journey before moving to the next section of road. There are three ways to eliminate this time delay: (1) by creating more than one home position; (2) by lifting the turret off the ground; or (3) by obviating a home position.

The first alternative would be to create two turret home positions on either end of the ARMM to which the turret could return after completing its operations. The computer software would identify the home position closest to the end of the last crack to be sealed and instruct the turret to go there once it has finished sealing that crack.

The second alternative involves modifying the design of the turret to allow it to be raised off the ground at the end of its operations. This would enable the operator to start driving to the next road section to be sealed while the turret was still returning to its home position. A combination of the first and second alternatives could also be of some benefit.

The last alternative involves redesigning a significant portion of the ARMM so that the location of the turret could be measured more accurately. Because the main purpose of instructing the turret to return to its home position is to keep track of its location within the XY table, a more accurate means of measuring the location of turret and moving it would eliminate the need for a home position. In this alternative, a home position might still be useful when the ARMM is switched on at the beginning of its daily operations.

6.1.3 Solutions for Improved Crack Identification and Sealing

Although less obvious than minimizing the excessive time spent returning the turret to its home, another clear improvement in productivity and quality could be achieved through improved crack identification. Suggested ideas in this area involved solutions of varying complexity and cost, ranging from software and lighting design to laser scanning.

Currently, the lack of adequate lighting can result in difficulties in computing crack location. Because the software is designed to adjust the operator-drawn line to the area of darkest contrast, sometimes the line is snapped to the edge of a large crack rather than to the center. Shadows also can introduce problems when they overlap a crack. The shadows reduce the contrast between the crack and the surrounding pavement, making exact crack identification difficult. Both problems need to be addressed.

First, a uniform lighting source needs to be provided. A covered canopy over the XY-table would eliminate the shadows. If the overall canopy decreases the interior light level, an artificial light source could be included to provide uniform lighting. This would also allow for nighttime operation. The effectiveness of this method was verified on the tour during a nighttime demo that used a pair of 150W off-the-shelf outdoor lights. The lighting not only provided sufficient illumination to ensure proper contrast for crack identification, it also illuminated the workspace in such a way as to make it easily visible to the operator.

Second, line location on larger cracks could be identified at the center of the crack rather than at the edge. This would require modifying the current software to go beyond areas of highest contrast and to select the center of the darkest region. While this could prove to be a challenge, there is a possibility that a properly designed V- or U-shaped squeegee could help distribute the sealant across a wider area, thus compensating for the error.

Difficulties in identifying the crack location and in delivering proper amounts of sealant can also result from poor calibration of the turret or cameras. Transporting and mobilizing the ARMM system can, at times, misalign the cameras that are mounted on the canopy. Transporting the ARMM over rough roads can move the cameras slightly out of position. If the cameras move even a slight amount, the turret can easily be misguided to the left or right of a crack. Current calibrations are performed by hand (to adjust the camera mount) and through the C++ development program (to adjust the turret location). Adjusting the camera alignment is a tedious process, requiring one worker to move the camera mount while another watches the video screen to confirm the realignment of the two cameras. There are several ways to approach this problem in order to expedite the process.

The cameras could be mounted on a sturdier frame, or mounted together on a single rigid bar. Such positioning would minimize the misalignment caused by the mounts. If reinforcement proves to be ineffective, then better adjustable mounts could be designed. The current camera mounts are extremely sensitive to vibrations and are very difficult to adjust. If the mounts could be adjusted in small increments using some sort of spring-loaded locking mechanism, the calibration could be performed much more rapidly. The ultimate control would be through remote adjustment of the camera mount from within the ARMM's software. This would be a costly, but very efficient, method of calibrating the camera alignments. Other camera features, such as focus and shutter speed, could also potentially be adjusted using this method.

Once the cameras are aligned with one another, the next step is to calibrate the turret with the cameras. Current adjustments are made by measuring the amount of turret misalignment and then adjusting the turret location from within the programming software. This requires time-consuming changes to values within the program itself. It also requires knowledge of programming, which is an unreasonable expectation of the operator. Improvements could include allowing adjustments to be made through the ARMM's software. The operator could simply type in the new offsets to update the program. In this case, the operator would need only to be able to measure the amount of the offset; the operator would not need to edit program code.

Beyond the issue of camera and turret alignment, however, lies a deeper concern, namely, the identification of crack width and depth. While the squeegee can help make up for some variations in crack size, a better identification of the size could help deliver the proper amount of sealant, allowing more efficient use of material and producing a higher quality seal. To a certain degree, width could be determined by the cameras. The line-snapping algorithm could also identify the width of the darkest region (i.e., the crack). However, determining the depth of a crack and subsequently the volume of sealant required to fill the crack is a more complex problem. A single laser or ultrasonic sensor could read directly ahead of the turret and determine the depth of the crack. The computer could then adjust the speed of the turret and/or the flow of sealant material from the pump to correspond to the crack size. This would require sensors, possibly increased computing power, and servo control of the material pump. While the upgrade could prove costly initially, the value of the improvements in quality and productivity could make the investment profitable. The next level of crack identification and sizing would be the use of prescanning lasers for the entire workspace. Multiple lasers would read ahead of the turret, or even the vehicle, to determine crack locations and sizes. This solution would be very costly because of the necessary computing power (and might even be constrained by current technology). If the lasers took too long to prescan, the entire operation could be delayed. Nevertheless, prescanning would be required for an in-motion crack sealing operation.

6.2 IMPROVEMENTS IN OVERALL MACHINE DESIGN

6.2.1 Improved Turret System

One problem encountered during the field demonstrations was related to the design of the turret wheels. The large plastic wheels, while effective in maintaining the height of the turret at a consistent level, sometimes became impaired by the accumulated sealant. The wheels would track through the fresh sealant and hinder the motion of the turret. Two solutions could improve the design: (1) thinner wheels or (2) a floating turret.

The first alternative would be to design thinner wheels (e.g., metal-disc wheels) that are not as likely to accumulate sealant. The second alternative, a floating turret, would eliminate the need for wheels altogether. A height sensor mounted on the turret and a mechanism to control the turret height would help maintain the desired distance above the pavement. The height sensor could be an ultrasonic or laser sensor. Ultrasonic sensors are already used in paving and earthwork technology to maintain screed and blade heights. The height sensor would send signals to an actuator that controls the height of the turret. A pneumatic actuator would be relatively inexpensive and, coupled with an ultrasonic sensor, would eliminate the problem with the turret wheels.

6.2.2 XY-Table Size

Another common observation during the field demonstrations relates to the size of the ARMM's XY-table. While the XY-table workspace was originally designed to fill an entire lane width, the overall size of the machine was criticized for being too large. Some suggested a smaller frame that could work within situations of tighter traffic control or in urban areas. Since the present design is wider than a standard 12 ft lane, traffic control requires the closure of two lanes or a lane and a shoulder. While a smaller size would require multiple passes to complete a single lane, most officials would prefer to make the extra pass rather than close the extra lane.

Another solution to the size problem would be a function of an adjustable frame. This complex design would require large actuators and a possible increase in mobilization time. The design of the bearings that maintain the alignment of the gantry within the XY-table would also be complicated. Currently, many concrete pavers possess such a technology. While the initial cost may be high, the possibility for more applications and reduced traffic impact could potentially justify the upgrade costs.

6.2.3 Canopy Telescoping Height Adjustment Design

Currently, the canopy containing the cameras is raised manually through a swinging hinge design that requires that the ARMM software move the gantry out of the way. To improve this design, the swinging hinge could be replaced with telescoping poles. The poles could be adjusted manually or powered by actuators. A manual system could use a crank or ratchet system to raise and lower the canopy. Likewise, actuators could perform the same task, requiring only a single command from the cab of the truck. Either design would reduce the mobilization time and, possibly, the number of workers required for the operation. The actuated system would also reduce the crew's exposure to traffic during mobilization.

6.2.4 Bearing Design

A critical limitation to the overall speed of the sealing operation lies in the design of the bearings. Decreasing the friction within the bearings could increase machine and sealing speed. While the current motors have the potential to travel faster, they are presently limited by the bearing friction. Several solutions are possible: (1) better alignment of the current pillow block system, (2) cylindrical linear bearings, or (3) a floating air cushion system.

The first and least costly design would be the exact alignment of the current pillow block design. This process is difficult and requires exact positioning of many screws in the tracks and the pillow blocks. Adjusting these components simultaneously while maintaining a certain degree of precision (while also accounting for material variability caused by temperature) is a very difficult task. Even with precise positioning, accounting for the material variability and the overall contact area produces a friction that limits the overall speed.

The second alternative is to replace the current pillow block design with an improved bearing system, such as a cylindrical linear bearing design. These bearings have less friction and possibly align more efficiently. In terms of faster sealing operations, the cylindrical linear bearing design represents an upgrade over the old pillow block method.

The third and most radical method would be a system that uses frictionless air bearings instead of traditional friction bearings. A heavy-duty air compressor would be needed to provide the air pressure sufficient to support the weight of the gantry and the turret. In this instance, given that the bearings are virtually frictionless, any limitations in crack sealing speed would be owing to motor limitations. Special engineering challenges would include the design of the air delivery system and some sort of braking mechanism to stop the gantry when required. Economic challenges would include deciding whether the improvements in speed justify the cost.

Improving the bearings is the quickest way to increase production of the whole system. For this reason, bearing improvement will be a critical consideration in future designs.

6.2.5 Mobilization Issues

Decreasing the mobilization time was also a main concern of many of the representatives of the various departments of transportation. Unloading the XY-table from the trailer and connecting the system was time consuming and required more labor than the actual sealing process. Four workers can efficiently mobilize the ARMM, though only one is required for operation. Several variations of the system could improve mobilization: (1) a trailer-free XY-table, (2) a trailer-free XY-table and a single-unit truck with all the other equipment, and (3) a single unit containing all of the components.

A trailer-free XY-table would reduce mobilization time by eliminating the need to unload the ARMM from the trailer. The present XY-table is large, cumbersome to maneuver manually, and challenging to load and unload in crowded or sloped locations. While a trailer-free ARMM system would reduce mobilization time, it still would require hooking it up to the truck and melter combination.

A solution to the docking of the three components (truck, melter, and table) could be to design two or all three components as a single unit. Combining the melter with the truck would involve a large truck with the melter mounted on its bed. Combining the XY-table with the truck would require a greater design effort, since the XY-table would have to be mounted directly above the road. One possible design approach would be to cantilever the XY-table from the back of the truck, placing it between the front and rear axles.

6.2.6 Onboard Electronics

Improvements could be made to some of the onboard electronics and to the air compressor. The current electronics are not completely impervious to the extreme weather conditions that may be encountered in the field. During transport, critical components had to be wrapped in plastic for protection. Future improvements could include water and dirt protection for the wires, motors, and connectors. (Covering in the form of watertight tubing or boxes would provide such protection.) Electronic components capable of withstanding extreme temperature variations could also be installed to improve the system's reliability.

Since the crack blowing capability of the current air compressor was not adequate to clear debris out of the larger cracks encountered during the field demonstrations, a larger air compressor could also be mounted on the bed of the truck. The current 100-psi compressor is not sufficiently powerful to provide high pressure air at an elevated flow rate for long periods of time.

6.2.7 Emergency Stops

To enhance safety, future models should include emergency gantry-motor stop buttons around the XY-table and inside the cab. This precaution would reduce the risk of accidents in and around the machine.

CHAPTER 7. TXDOT PROCUREMENT PLAN

Although TxDOT attempted to initiate commercial procurement of the automated road maintenance machine (ARMM), time constraints and communication problems resulted in no bidders responding. All parties agreed that such lack of response could be avoided in the future if the bid were to be re-issued with minor modifications. The request for proposals is included in Appendix D.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The automated road maintenance machine (ARMM) has been in development for almost 10 years. The most recent prototype, originally developed in 1997, has undergone several major improvements in the last 2 years. The current ARMM's computer system was replaced with an industrial computer and a flat-panel LCD touch screen. A new spring-loaded turret equipped with wheels was designed and implemented to improve the ARMM's response to varying road conditions. Finally, the XY-table's older steel gantry was replaced with a lighter aluminum design that allowed the turret to move twice as fast as before.

Between May and July of 1999, team members from the Field Systems and Construction Automation Lab (FSCAL) took the ARMM on a tour of ten U.S. states. The purpose of the tour was to gain field experience, show the potential of automated crack sealing technology to the departments of transportation (DOT) of the visited states, obtain feedback from road maintenance personnel, and proof-test the equipment under actual working conditions. During these field demonstrations, the vast differences in crack sealing standards that different states have adopted became apparent. Learning of these practices and obtaining feedback about the design and performance of the ARMM proved insightful and useful for further design developments. In general, the ARMM was well received during the tour, with a consensus of the validity of the concept achieved by all the DOTs visited.

The productivity of the ARMM (with all the improvements discussed above) was measured during a time trial that was conducted in August 1999. In the controlled experiment set up for the time trial at the FSCAL's facilities, three types of cracks were simulated. **The results of the time trials showed that the current ARMM prototype is capable of sealing 444 linear feet of cracks per hour or 1.34 miles of road per workday. The ARMM also has a potential of sealing 765 linear feet of cracks per hour or 2.32 miles of road per workday (if minor technical issues are resolved). Furthermore, if the ARMM's XY-table bearing system could be redesigned to reduce the alignment problems and the coefficient of friction, higher productivity values could be obtained.**

8.2 RECOMMENDATIONS

The next phase in the evolution of the automated crack sealer would be to develop a commercial prototype, either through private or public channels. The ideal situation would be a joint venture of industry and a research institute, which would combine the state of the art in construction automation technology with extensive experience in pavement maintenance.

A viable commercial prototype should have a productivity comparable to or higher than manual crack sealing productivity. Further analyses of the productivity of the manual crack sealing process and the quality of sealed cracks across the country should be performed to establish targets for the commercial prototype.

The following is a list of the minimum improvements that must be included in a new prototype to make it commercially feasible:

1. Better bearings (lower friction, easier alignment, etc.)
2. Improved squeegee design
3. Improved crack identification algorithm
4. Simpler setup process (maybe single unit or truck and one trailer)
5. More rugged components for varying environmental conditions
6. Better lighting

In addition to the above recommendations, which mainly address the design of the ARMM, the following two recommendations address the issue of the ARMM's marketability. First, any new developments in automated crack sealing must include extensive field demonstrations that will assist in convincing public agencies and private contractors of the feasibility of the technology. The demonstrations should entail the uninterrupted sealing of several continuous miles of road. Second, any future work should also include active recruitment of new vendors so as to disseminate information on the benefits of automated crack sealing.

The Field Systems and Construction Automation Lab team members, who have been involved with the ARMM project in various capacities, strongly believe that the future of crack sealing lies in automation.

REFERENCES

[1] Haas, C., "Evolution of an Automated Crack Sealer: A Study in Construction Technology Development," *Automation in Construction,* April 1996, pp. 293–305.

[2] Haas, C., C. Hendrickson, S. McNeil, and D. Bullock, "A Field Prototype of a Robotic Pavement Crack Sealing System," *Proc. 9th Int. Symp. on Automation and Robotics in Construction*, Tokyo, June 1992, pp. 313–322.

[3] Jazbec, Willikam C., and Steven A. Velinsky, "A Pavement Crack Cleaning and Heating System for Automated Sealing Machinery," *UCD-ARR-92-03-26-01*, 118 pp, March 1992. Automated Crack Sealing Machine, University of California at Davis, http:\\www.ahmct.ucdavis.edu/AHMCT_projects/asdm.html.

[4] Velinsky, S. A., "Fabrication and Testing of an Automated Crack Sealing Machine," National Research Council, SHRP-H-659, Washington, D.C., 1993.

[5] Kim, Y. S., C. Haas, K. Boehme, and Y. K. Cho, "Implementing an Automated Road Maintenance Machine (Armm): Lessons from the Field," The 16th International Symposium on Automation and Robotics in Construction (ISARC), Madrid, Spain, Sept. 22–24, 1999.

APPENDIX A. COST OF THE ARMM SYSTEM

Item Description	Qty	Model #	Cost (each)	Total Cost
AEROTECH				
410 oz-in motor	2	1410LT-MS01-E500LD	$1,000.00	$2,000.00
960 oz-in motor	1	1960LT-MS01/E500	$1,435.00	$1,435.00
Motion controller	1	U500ULTRA	$2,390.00	$2,390.00
Three axis of amplifiers	1	BB501/X4-BA20-80/X4-BAC/TVO.4	$5,290.00	$5,290.00
Interconnection cable	1	OP500-12	$195.00	$195.00
Feedback cable	3	DC-MSO	$250.00	$750.00
Double-shielded cable	1	ECX413	$800.00	$800.00
BEARINGS INC.				
Swiveling end bearing	8	TRE12	$19.66	$157.28
Pillow block bearings	8	P2BSC012	$22.06	$176.48
CYBO ROBOTS				
XY-table	1	Custom	$26,950.00	$26,950.00
DATA TRANSLATION				
Frame grabber board	1	DT3852B-20	$3,805.20	$3,805.20
DAYTON				
Generator (5000W)	1	3W795B-20	$1,078.69	$1,078.69
HAMILTON CASTER				
Wheel assembly	2	S-70188-4SL-FCB	$361.68	$723.36
K&K WELDING				
Canopy	1	Custom	$950.00	$950.00
Aluminum gantry	1	Custom	$750.00	$750.00
LOVEJOY				
Shaft couplings	1	U62X5/8	$80.00	$80.00
PELCO				
½-in. camera	2	PCHM575	$468.00	$936.00
Camera lens	2	TV6EX-1	$236.00	$472.00

Item Description	Qty	Model #	Cost (Each)	Total Cost
SKB				
Equipment racks	2	544635	$319.88	$639.76
SPEEDAIRE				
Air compressor	1	4BB20	$549.99	$549.99
SPILLAR HITCHES				
Drop hitch (3-in.)	1	Custom	$400.00	$400.00
PIXELL				
Touch-screen monitor	1	AGM-15T	$5,025.00	$5,025.00
TRIPPLITE				
Line conditioner	2	LCR-2400	$574.00	$1,148.00
INDUSTRIAL COMPUTER SOURCE				
Industrial computer	1	Pentium SBC 233MHZ PC	$3,833.50	$3,833.50
Miscellaneous items			$500.00	$500.00
Approximate Total System Cost				$61,035.26

APPENDIX B. EQUIPMENT MANUFACTURERS INDEX

Aerotech, Inc.
101 Zeta Drive, Pittsburgh, PA 15238-2897
Tel : (412) 963 7470, Fax: (412) 963 7459
URL : http://www.aerotechinc.com/

Bayside
27 Seaview Boulevard, Port Washington, NY 11050
Tel : (516) 484 5353, Fax : (516) 484 5496
URL : http://www.bmgnet.com

Bogen Photo Corp.
565 East Crescent Ave., Ramsey, NJ 07446-0506
Tel : (201) 818 9500, Fax : (201) 818 9177
URL : http://www.bogenphoto.com

Cone Drive Operations, Inc.
240 E. 12th St., P.O. Box 272, Traverse City, MI 49685-0272
Tel : (616) 946 8410, Fax : (616) 963 8600

Crafco, Inc.
235 S. Hibbert, Mesa, Arizona 85210
Tel : (602) 655 8333, Fax : (602) 655 1712
URL : http://www.crafco.com

Cybo Robots, Inc.
2040 Production Dr., Indianapolis, IN 46241
Tel : (800) 883 0581, Fax : (317) 241 2727

Data Translation, Inc.
100 Locke Dr., Marlboro, MA 01752
Tel : (508) 481 3700, Fax : (508) 481 8620

Dayton Electric Mfg. Co.
5959 West Howard Street
Niles, IL 60714

Hamilton Castor & Mfg
1637 Dixie Hwy, Hamilton, OH 45011
Tel : (513) 863 3300, Fax : (513) 863 5508

Igus, Inc.
P.O. Box 14349, East Providence, RI 02914
Tel : (401) 438 2200, Fax : (401) 438 7270

Industrial Computer Source
6260 Sequence Dr., San Diego, CA 92121
Tel : (800) 619 2666, Fax : (619) 677 0615

Lovejoy, Inc.
2655 Wisconsin Ave., Downers Grove, IL 60515 4243
Tel : (888) 568 3569, Fax : (630) 852 2120

Pelco
300 W. Pontiac Way, Dept. T, Clovis, CA 93612 5699
Tel : (559) 292 1981

Pixell
360 Read Drive, Lafayette, CA 94549
Tel : (925) 283 5588, Fax : (925) 283 8210

SKB
931 Chevy Way, Medford, OR 97524
Tel : (800) 776 5173, Fax : (503) 772 9723

Spillar Custom Hitches
9204 United, Austin, TX 78759
Tel : (512) 837 7142

Texaco Lubricants Co.
1111 Bagby St., Houston, TX 77002
Tel : (800) 782 7852

Tripplite
1111 W. 35th St., Chicago, IL 60609
Tel : (773) 869 1000, Fax : (773) 869 1329

Winsmith
172 Eaton St., Springville, NY 14141
Tel : (716) 592 9310, Fax : (716) 592 9546

APPENDIX C. TIME TRIAL RESULTS

Medium Crack Density Trial
(5 feet of crack per section)

Longitudinal Cracks Times (sec)

Section	Moving Time	Draw/Snap Time	Sealing Time			Sealing Speed (m/min)
1	8.60	4.53	21.53			4.25
2	6.59	4.16	22.44			4.07
3	6.13	3.50	21.47			4.26
4	5.94	6.04	21.62			4.23
5	5.91	2.94	20.78			4.40
6	7.00	2.97	21.19			4.32
7	6.78	3.38	21.03			4.35
8	6.13	2.62	20.53			4.45
9	6.60	5.60	20.91			4.37
10	5.81	3.12	21.03			4.35
11	6.88	2.82	20.97			4.36
12	5.41	2.76	21.75			4.20
13	7.53	3.63	21.62			4.23
14	6.91	3.03	21.97			4.16
15	6.50	3.31	22.10			4.14
16	8.72	3.19	13.69			6.68
17	5.56	9.15	22.22			4.12
18	6.12	3.34	21.78			4.20
19	6.34	3.06	22.16	**Time (min)**		4.13
20	15.97	3.50	21.50	10.37		4.25
Averages:	7.07	3.83	21.11		**Max**	6.68

Transverse Cracks Times (sec)

1	6.72	4.81	20.19			4.53
2	8.10	3.44	22.54			4.06
3	7.66	4.84	23.01			3.97
4	7.28	3.34	20.84			4.39
5	6.50	4.50	23.38			3.91
6	8.22	2.82	24.25			3.77
7	9.56	3.44	22.19			4.12
8	7.47	2.88	19.29			4.74
9	7.31	3.58	21.38			4.28
10	7.57	2.75	20.03			4.57
11	6.88	6.50	24.53			3.73
12	6.10	2.97	22.06			4.15
13	6.75	3.19	24.85			3.68
14	10.13	2.75	22.60			4.05
15	9.40	2.81	19.46			4.70
16	7.75	3.07	18.47			4.95
17	6.78	3.35	21.97			4.16
18	11.38	3.19	26.62			3.44
19	13.50	3.79	23.96	**Time (min)**		3.82
20	8.50	3.10	18.69	11.40		4.89
Averages:	8.18	3.56	22.02		**Max**	4.95

Branched Cracks Times (sec)

1	8.35	2.66	21.93			4.17
2	6.38	4.11	22.00			4.16
3	8.68	3.28	18.94			4.83
4	6.30	4.28	19.22			4.76
5	6.00	6.59	21.16			4.32
6	6.20	3.78	22.65			4.04
7	7.56	4.08	20.28			4.51
8	6.21	2.40	21.13			4.33
9	6.50	6.56	22.13			4.13
10	6.10	4.77	22.03			4.15
11	7.00	3.43	20.02			4.57
12	7.53	5.41	24.53			3.73
13	6.10	6.53	24.44			3.74
14	5.20	3.75	25.15			3.64
15	14.10	5.22	17.41			5.25
16	7.60	4.56	23.25			3.93
17	5.80	6.75	23.78			3.85
18	5.60	3.72	23.88			3.83
19	5.40	5.91	20.56	**Time (min)**		4.45
20		5.56	25.25	11.17		3.62
Averages:	6.98	4.67	21.99		**Max**	5.25
				Total (min)		
				32.94		

High Crack Density Trial
(10 feet of crack per section)

Longitudinal Cracks Times (sec)

Section	Moving Time	Draw/Snap Time	Sealing Time		Sealing Speed (m/min)
1	9.20	5.03	19.90		9.19
2	9.00	5.75	21.97		8.32
3	10.00	10.28	21.50		8.51
4	8.00	4.88	28.28		6.47
5	10.00	6.12	21.28		8.59
6	7.00	4.68	21.54		8.49
7	8.00	5.25	20.93		8.74
8	8.90	9.90	21.03		8.70
9	8.00	4.81	20.91		8.75
10	9.00	5.63	25.84		7.08
11	6.70	4.00	21.19		8.63
12	6.20	13.19	29.38		6.22
13	8.59	5.41	20.34		8.99
14	6.19	5.06	26.41		6.92
15	9.00	6.19	20.13		9.08
16	7.97	5.44	25.98		7.04
17	10.20	5.19	44.03		4.15
18	7.40	6.03	63.50		2.88
19	6.00	5.53	29.10	**Time (min)**	6.28
20	9.60	6.90	28.40	14.02	6.44
Averages:	8.25	6.26	26.58	**Max**	9.19

Transverse Cracks Times (sec)

1	4.91	5.57	30.06		6.08
2	5.12	6.72	22.09		8.28
3	7.06	5.69	20.19		9.06
4	5.72	5.50	26.41		6.92
5	6.22	4.57	33.94		5.39
6	11.00	6.59	28.97		6.31
7	6.06	5.69	29.78		6.14
8	23.75	3.72	29.37		6.23
9	6.97	3.87	30.41		6.01
10	4.50	4.72	21.84		8.37
11	4.41	4.19	33.13		5.52
12	6.81	4.75	33.78		5.41
13	5.72	4.41	32.72		5.59
14	5.12	4.22	33.59		5.44
15	5.25	4.59	26.00		7.03
16	7.50	4.22	22.53		8.12
17	6.00	2.16	20.85		8.77
18	6.62	5.97	24.06		7.60
19	6.84	4.22	27.68	**Time (min)**	6.61
20	6.90	4.07	14.29	12.14	12.80
Averages:	7.12	4.77	27.08	**Max**	12.80

Branched Cracks Times (sec)

1	8.25	8.65	21.78		8.40
2	5.56	19.38	25.53		7.16
3	6.46	6.56	24.14	Missing data.	7.58
4	5.00	12.37	35.69		5.12
5	6.55	9.12	21.85		8.37
6	6.44	5.96	21.06		8.68
7	6.72	6.10	20.90		8.75
8	8.94	6.00	23.79		7.69
9	6.09	8.97	19.56		9.35
10	9.00	7.59	27.75		6.59
11	5.00	7.34	20.41		8.96
12	6.97	7.16	28.81		6.35
13	4.44	7.25	24.50		7.46
14	7.88	6.09	29.97		6.10
15	6.75	8.06	23.63		7.74
16	5.69	8.53	21.72		8.42
17	6.22	7.37	26.41		6.92
18	4.50	6.69	21.72		8.42
19	9.50	7.25	19.79	**Time (min)**	9.24
20		5.91	23.82	13.00	7.68
Averages:	6.63	8.12	24.14	**Max**	9.35
				Total (min)	
				39.16	

Severe Crack Density Trial
(15 feet of crack per section)

Longitudinal Cracks Times (sec)

Section	Moving Time	Draw/Snap Time	Sealing Time			Sealing Speed (m/min)
1	7.81	9.12	36.56			7.50
2	7.93	9.32	36.00			7.62
3	6.59	9.44	35.53			7.72
4	6.63	9.72	35.47			7.73
5	7.57	8.25	39.28			6.98
6	9.98	17.12	37.36			7.34
7	10.00	7.97	39.59			6.93
8	8.00	6.69	34.85			7.87
9	8.10	8.18	35.35			7.76
10	8.80	8.18	35.15			7.80
11	8.20	7.96	34.62			7.92
12	7.60	7.50	34.82			7.88
13	7.00	6.75	34.82			7.88
14	6.50	10.07	33.99			8.07
15	7.20	4.56	34.03			8.06
16	8.19	5.90	32.78			8.37
17	4.19	6.60	42.50			6.45
18	7.53	5.60	32.56			8.43
19	10.00	5.34	36.72	**Time (min)**		7.47
20	10.00	5.09	32.83	16.55		8.36
Averages:	7.89	7.97	35.74		**Max**	8.43

Transverse Cracks Times (sec)

Section	Moving Time	Draw/Snap Time	Sealing Time			Sealing Speed (m/min)
1	8.00	5.63	30.00			9.14
2	8.82	5.97	28.63			9.58
3	10.70	6.31	29.96			9.16
4	8.80	6.31	28.09			9.77
5	8.15	7.84	27.93			9.82
6	6.62	7.72	30.22			9.08
7	7.65	7.07	35.13			7.81
8	5.90	7.19	36.12			7.59
9	7.90	7.28	30.97			8.86
10	6.00	5.53	32.22			8.51
11	9.10	6.00	28.78			9.53
12	10.00	9.22	31.12			8.81
13	6.75	7.20	31.25			8.78
14	7.91	6.94	29.22			9.39
15	9.50	6.66	28.34			9.68
16	6.40	4.99	28.40			9.66
17	6.78	6.28	27.53			9.96
18	5.50	5.78	30.09			9.12
19	6.11	4.97	26.22	**Time (min)**		10.46
20	7.00	4.29	38.09	15.90		7.20
Averages:	7.68	6.46	30.42		**Max**	10.46

Branched Cracks Times (sec)

Section	Moving Time	Draw/Snap Time	Sealing Time			Sealing Speed (m/min)
1	7.66	6.34	31.64			8.67
2	6.90	8.12	24.96			10.99
3	6.20	9.23	25.75			10.65
4	6.06	11.06	29.88			9.18
5	5.90	6.93	31.06			8.83
6	6.20	5.97	31.75			8.64
7	7.00	7.00	32.40			8.47
8	5.90	10.37	44.25			6.20
9	7.00	9.63	38.25			7.17
10	6.90	6.28	43.00			6.38
11	7.00	10.38	30.35			9.04
12	7.50	8.13	37.10			7.39
13	6.00	6.97	42.38			6.47
14	5.00	7.53	42.91			6.39
15	6.60	8.60	33.44			8.20
16	5.50	9.37	29.50			9.30
17	6.60	7.87	36.69			7.48
18	6.00	9.78	31.96			8.58
19	8.00	10.22	32.89	**Time (min)**		8.34
20		8.44	36.06	17.10		7.61
Averages:	6.52	8.41	34.31		**Max**	10.99

Total (min)
49.55

PRODUCTIVITY CALCULATIONS (BASED ON THE REAL DATA)

Productivity (miles per 8 hour workday)

Crack Density			
Medium	**High**	**Severe**	**Average**
0.83	0.70	0.55	0.67

Linear Feet of Cracks per Hour (ft)

Crack Density			
Medium	**High**	**Severe**	**Average**
546	460	363	444

Total Time (min)

Crack Density			
Medium	**High**	**Severe**	**Average**
32.94	39.16	49.55	40.55

Sealing Time per Linear Foot of Crack (sec)

Crack Density			
Medium	**High**	**Severe**	**Average**
4.34	2.59	2.23	3.06

Turret Speed During Crack Sealing (m/min)

Crack Density	Min Speed	Max Speed	Average Speed
Medium	4.95	6.68	4.21
High	9.19	12.8	7.05
Severe	8.43	10.99	8.19
Average	7.52	10.16	6.49

Total Time per Linear Foot of Crack (sec)

	Crack Density			
Crack Type	**Medium**	**High**	**Severe**	**Average**
Longitudinal	6.22	8.41	9.93	8.19
Transverse	6.84	7.28	9.54	7.89
Branched	6.70	7.80	10.26	8.25
Average	6.59	7.83	9.91	8.11

Average Moving Time Between Sections (sec): **<u>7.37</u>**

Avg. Draw/Snap Time / Linear Foot of Crack (sec): **<u>0.59</u>**

The maximum speed at which the turret travels over a crack while sealing was measured as (m/min): **<u>26.0</u>**

THEORETICAL CALCULATIONS (BASED ON 26 M/MIN TURRET SPEED)

Productivity (miles per 8 hour workday)

Crack Density			
Medium	**High**	**Severe**	**Average**
1.43	1.20	0.95	1.16

Linear Feet of Cracks per Hour (ft)

Crack Density			
Medium	**High**	**Severe**	**Average**
942	793	626	765

Total Time (min)

Crack Density			
Medium	**High**	**Severe**	**Average**
19.11	22.71	28.74	23.52

Total Time per Linear Foot of Crack (sec)

	Crack Density			
Crack Type	**Medium**	**High**	**Severe**	**Average**
Longitudinal	3.61	4.88	5.76	4.75
Transverse	3.97	4.22	5.53	4.58
Branched	3.89	4.52	5.95	4.79
Average	3.82	4.54	5.75	4.70

APPENDIX D.

TxDOT REQUEST FOR PROPOSAL

Texas Department of Transportation

DEWITT C. GREER STATE HIGHWAY BLDG. • 125 E. 11TH STREET • AUSTIN, TEXAS 78701-2483 • (512) 463-8585

July 23, 1999

REQUEST FOR PROPOSAL (RFP)

RFP No. Q 44 1999 059156 000

Proposal Closing Date: 3:00 p.m., August 12, 1999

Mail proposal to:

Attn: Purchasing Central Files
Texas Department of Transportation
General Services Division - Purchasing
125 E. 11th Street
Austin, TX 78701-2483

Courier Service to:

Attn: Purchasing Central Files
Texas Department of Transportation
General Service Division - Purchasing
200 East Riverside Drive
Austin, TX 78704

Hand deliver to:

Attn: Purchasing Central Files
Texas Department of Transportation
General Services Division - Purchasing
150 E. Riverside Dr; No. Tower, 3rd Flr
Austin, TX 78704

INCLUDE RFP NUMBER, CLOSING DATE AND TIME ON RETURN ENVELOPE

Pursuant to the Provisions of Chapter 2156, Subtitle D, Title 10, Texas Government Code and Rules adopted by the General Services Commission, proposals will be received at this office until the date and time established for receipt, then opened, with only the names of the proposers who presented offers for the goods or services described in the attached specifications being made public. **Prices will not be divulged at time of opening.** Prices and other proposal details will only be divulged after the contract award, if one is made.

Agency Invoice Address:

Texas Department of Transportation
Finance Division, Voucher Processing
125 E. 11th Street
Austin, Texas 78701-2483

Contact the following Purchaser Regarding all Inquires for this RFP:

Glenn Hagler, CPPO
Fax: 512-416-2153
E-mail: ghagler@mailgw.dot.state.tx.us

All inquiries will result in written responses with copies sent to all applicants who received copies of the RFP.

All proposals shall become the property of the Texas Department of Transportation (TxDOT).

All proposals shall be completed as required by the instructions in this RFP. **One signed original and five copies shall be returned.**

FAILURE TO SIGN THE "EXECUTION OF PROPOSAL" WILL RESULT IN REJECTION OF THE PROPOSAL.

An Equal Opportunity Employer

REQUEST FOR PROPOSAL

AUTOMATED PAVEMENT CRACK SEALER (APCS)
SYSTEM, TRUCK MOUNTED

RFP No. Q 44 1999 059156 000

TABLE OF CONTENTS

TEXAS DEPARTMENT OF TRANSPORTATION
GENERAL SERVICES DIVISION

REQUEST FOR PROPOSAL
GENERAL TERMS AND CONDITIONS

ITEMS BELOW APPLY TO AND BECOME A PART OF THE PROPOSAL. ANY EXCEPTIONS SHALL BE SUBMITTED IN WRITING.

1. **PROPOSAL REQUIREMENTS:**

1.1. Proposers shall comply with all rules, regulations and statutes relating to purchasing in the State of Texas in addition to the requirements of this form.

1.2. Proposers shall quote price for item(s) or service(s) requested. Unit prices shall govern in the event of extension errors.

1.3. Proposals shall be delivered to TxDOT on or before the hour and date specified in the Request for Proposal (RFP).

1.4. Late proposals will not be considered under any circumstances.

1.5. Any proposal may be withdrawn in writing prior to the date and time set for receipt of proposals. Any proposal not so withdrawn shall constitute an irrevocable offer for a period of 90 days from RFP closing date. "Discount from list" offers are not acceptable unless requested. Cash discounts offered will be taken if earned.

1.6. Quote prices F.O.B. destination. Otherwise, show exact delivery cost and terms.

1.7. Proposal shall include Payee Identification Number (PIN), full firm name and address of offeror. Additionally, firm name shall appear on each continuation page of proposal. Failure to manually sign proposal will disqualify it. The person signing the proposal should show title or authority to bind his/her firm in contract. The PIN is the taxpayer number assigned and used by the Comptroller of Public Accounts of Texas. Enter this number in the spaces provided on the Execution of Order. If the PIN is not known, complete the following:

1.7.1. Federal Employer's Identification Number: ______________________________, <u>or</u>

1.7.2. Sole owner shall enter Social Security Number: ______________________________

1.8. Purchases made for State use are exempt from the State Sales tax and Federal Excise tax. Do not include tax in proposal. Excise Tax Exemption Certificates are available upon request.

1.9. Consistent and continued tie proposals may cause rejection of proposals and/or investigation for antitrust violations.

1.10. The telephone number for fax submission of offers is (512) 416-3482. This is the only number that will be used for the receipt of proposals. TxDOT will not be responsible for failure of electronic equipment or operator error. Late, illegible, incomplete, or otherwise non-responsive proposals will not be considered.

2. **CONDITIONS:**

2.1. Catalogs, brand names or manufacturer's references are descriptive only, and indicate type and quality desired. Proposals for brands of like nature and quality will be considered unless otherwise stated. If proposing other than referenced brand or trade name offer should show manufacturer and description of product. If other than brand(s) specified is offered, illustrations and complete description of product offered are requested to be part of the proposal. Failure to take exception to specifications or reference data will require offeror to furnish specified brand names, numbers, etc.

2.2. Unless otherwise specified, items offered shall be new and unused.

2.3. All electrical items shall meet all applicable OSHA standards and regulations, and bear the appropriate listing from UL, FMRC or NEMA.

2.4. Samples, when requested, shall be furnished free of expense to the State. If not destroyed in examination, they will be returned to the offeror, upon request, at offeror's expense. Each sample should be marked with offeror's name and address, and RFP number. Do not enclose in or attach proposal to sample.

2.5. TxDOT will not be bound by any oral statement or representation, contrary to the written specifications of the RFP. All addenda to and interpretations of this solicitation shall be in writing. Any addenda or interpretation that is not in writing will not legally bind TxDOT.

2.6. Manufacturer's standard warranty shall apply unless otherwise stated in the RFP.

3. **DELIVERY:**

3.1. Show number of days required to place material in TxDOT's designated location under normal conditions. Failure to state delivery time obligates offeror to delivery in 14 calendar days. Unrealistic delivery promises may cause offer to be disregarded.

3.2. If delay is foreseen, offeror shall give written notice to TxDOT. Offeror shall keep TxDOT advised at all times of status of order. Default in promised delivery (without accepted reasons) or failure to meet specifications authorizes TxDOT to purchase supplies elsewhere and charge full increase, if any, in cost and handling to defaulting offeror.

3.3. No substitutions permitted without written approval of TxDOT.

3.4. Delivery shall be made during normal working hours only, unless prior approval has been obtained from TxDOT.

TEXAS DEPARTMENT OF TRANSPORTATION
GENERAL SERVICES DIVISION

PREPARED BY: Glenn Hagler, CPPO
PHONE NO: (512) 416-2082
FAX NO: (512) 416-2153
E-MAIL: ghagler@mailgw.dot.state.tx.us
EOS CLASS CODE: 014020

SPECIFICATION NO.
TxDOT 755-30-68
DATED: JULY, 1999

REQUEST FOR PROPOSAL

AUTOMATED PAVEMENT CRACK SEALER (APCS)
SYSTEM, TRUCK MOUNTED

PUBLICATION

This specification is a product of the Texas Department of Transportation (TxDOT). It is the practice of TxDOT to support other entities by making this specification available through the National Institute of Governmental Purchasing (NIGP). This specification may not be sold for profit or monetary gain. If this specification is altered in any way, the header, and any and all references to TxDOT must be removed. TxDOT does not assume any liability when this specification is used in the procurement process by any other entity.

PART I
GENERAL CLAUSES AND CONDITIONS

1. The unit shall be completely assembled and adjusted, and all equipment including standard and supplemental equipment shall be installed and the unit made ready for continuous operation.

2. All parts not specifically mentioned which are necessary for the unit to be complete and ready for operation or which are normally furnished as standard equipment, shall be furnished by the vendor. All parts shall conform in strength, quality and workmanship to the accepted standards of the industry.

3. The unit provided shall meet or exceed all Federal and State of Texas safety, health, lighting and noise regulations and standards in effect and applicable to equipment furnished at the time of manufacture.

4. All electrical items must meet all applicable OSHA standards and regulations, and bear the appropriate listing from UL FMRC or NEMA.

5. It is the intent of TxDOT to purchase goods, equipment and services having the least adverse environmental impact, within the constraints of statutory purchasing requirements, departmental need, availability, and sound economical considerations. Suggested changes and environmental enhancements for possible inclusion in future revisions of this specification are encouraged.

6. TxDOT encourages all manufacturers to comply voluntarily with the Society of Automotive Engineers (SAE) Recommended Practice for marking of plastic parts per the current SAE J1344. All plastic components furnished to this specification should have an imprinted SAE symbol identifying the resin composition of the component so that the item can be recycled after its useful life. Manufacturers are encouraged to use recycled plastics and materials in the manufacture of their products in order to conserve natural resources, energy and landfill space. Bidders should note that future specification revisions may require mandatory compliance with the SAE plastic coding system.

7. TxDOT is committed to procuring quality goods and equipment. We encourage manufacturers to adopt the International Organization for Standardization (ISO) 9001-9003 standards, technically equivalent to the American National Standard Institute/American Society for Quality Control (ANSI/ASQC Q91-93 1987) and obtain certification. Adopting and implementing these standards is considered beneficial to the manufacturer, TxDOT, and the environment. It is TxDOT's position that the total quality management concepts contained in these standards can result in reduced production costs, higher quality products and more efficient use of energy and natural resources. Manufacturers should note that future revisions to this specification may require ISO certification.

9. BALANCE AND CLEARANCES: The weight shall be distributed as equally as possible over the axles and tires under all conditions of loading. Under no circumstances shall axle and tire manufacturer's ratings be exceeded.

10. DIMENSIONS: The principal dimensions of the crack sealing system proposed and all exterior attachments shall be displayed on a conceptual drawing(s) which shall be part of the review process in determining the successful proposal. Proposers shall submit with their proposal a full size conceptual drawing. Failure to submit drawing(s) will be cause for RFP rejection. The overall height, length and width of the vehicle shall be the smallest dimensions consistent with the rated payload for its class and operational performance requirements of the vehicle. Although payload and operational performance are of primary importance, cost-effectiveness and local functional consideration, existing roads, bridge and tunnel clearances, may dictate one or more specific dimensional requirements.

11. MANIPULATOR SYSTEM: The manipulator system shall:

11.1. Have a workspace having a length of between five and six and one-half feet (1.5 m to 2.0 m) and a width of between 11-1/2 to 13 feet (3.5 m to 4.0 m). "Workspace" is defined as area accessible by the tools without moving the equipment.

11.2. Not extend beyond the workspace more than one foot (0.3 m).

11.3. Have the capability of being utilized lengthwise or widthwise.

11.4. Be shielded from adverse weather conditions for regular operations and transport.

11.5. Be capable of night operation and shall be equipped with artificial lighting.

11.6. Withstand, without damage, transport speeds up to 70 MPH (113 km/h).

11.7. Be equipped with a motorized turret capable of rotating 360 degrees designed to clean, seal and effectively squeegee in one pass, each length of continuous cracking.

12. SEALANT SYSTEM

12.1. The applicator wand shall be one inch (25 mm) from the pavement surface on a flat surface.

12.2. The applicator wand central axis shall not deviate from the crack spines while traversing and sealing them by more than plus or minus 0.2 inches (5 mm), assuming the command line is drawn along the spines.

12.3. The minimum widths for longitudinal and transverse cracks that are to be sealed are 1/16 inch (2 mm).

12.4. The sealant system shall have a squeegee to force the sealant into the crack for a flat pavement surface.

12.5. The system shall have the capacity to convert to the conventional manual practice of sealing for spot area beyond the workspace, such as shoulders.

12.6. The finished squeegeed band of sealant shall not be greater than one and one-half inches (38 mm) in width and be above the pavement surface more than 1/8 inch (3 mm).

12.7. There shall be a rate control of sealant dispensed for different crack widths and depths.

13. CAMERA SYSTEM

13.1. Cracks of 1/16 inch (2 mm) width or greater shall be visible via the video monitoring system.

13.2. The pavement work area of the crack sealing shall have homogenous lighting for crack image production and identification.

14. SCANNING SYSTEM: The system shall accurately depict the image of the pavement surface and display the scanned image on a flat panel display installed in the cab easily accessible to driver/operator and crew member. The image shall be displayed in a manner that can be accurately interpreted by the operator.

15. COMPRESSED AIR SYSTEM: The system shall perform the following as a minimum:

15.1. Clean the pavement cracks prior to sealing the cracks.

21. VENDOR RESPONSIBILITIES

21.1. Design an APCS that shall perform sealant operations at the specified production rate. A full size (D) conceptual drawing(s) detailing principal dimensions of the system proposed and all exterior components shall be delivered with this proposal. Failure to submit drawing(s) will disqualify the proposal. The vendor shall:

21.1.1. Identify key personnel (project team) assigned to the project, their role, and the estimated time each shall dedicate to the project.

21.1.2. Provide a project manager with demonstrated experience in similar projects with authority to make decisions for the company. The project manager shall be a point of contact for TxDOT's representatives. The project manager's responsibilities shall include, but not be limited to the following:

21.1.2.1. Work closely with TxDOT on design issues, coordinating any changes in design, production schedule or delivery.

21.1.2.2. Attend bi-monthly meetings in Austin, Texas, as deemed necessary by TxDOT, for the duration of contract.

21.1.2.3. Provide monthly reports, both written and verbal, on cost/production schedule.

21.1.2.4. Be responsible for organizing and coordinating with TxDOT on the engineering conferences referenced in Part II, Para. 21.1.2.5.

21.1.2.5. Agree to allow an engineering conference, progress and final inspections at the factory. Two representatives of TxDOT shall be in attendance. TxDOT will be responsible for representatives' expenses.

21.1.2.5.1. Two-day conference at the factory prior to construction of the unit. During this conference, details of construction, material, and proposed blueprints shall be discussed with the vendor and factory engineers. Final approval on construction details shall be made, subsequent to this conference by TxDOT.

21.1.2.5.2. One-day progress inspection trip to the factory while unit is under construction.

21.1.2.5.3. One-day final inspection trip to factory prior to delivery. This inspection shall not be interpreted to represent acceptance of the unit. The unit will be accepted only after it has met all testing and inspection requirements, and received by TxDOT.

21.1.3. Provide competent technical representative(s) who is knowledgeable about the equipment to provide on-going training during the warranty period and assist with any problems arising with operation of the equipment.

21.1.4. The representative shall accompany the equipment for the first four demonstrations, at minimum, which will include trips to other states. The locations of the demonstrations will be determined at a later date.

21.1.5. Be responsive to requests from TxDOT regarding equipment operational problems during the warranty period. Every effort shall be made by the vendor to promptly remedy any problem.

21.1.6. Provide warranty repairs and the performance of service and maintain an inventory of high-usage parts and a quick source for low-usage parts.

Paid for by the vendor

22. DELIVERABLES

22.1. Provide an illustrated parts book, operator's manual and service manual which shall be delivered with unit. These shall include, at minimum, all appropriate manuals for the APCS, hydraulic system, controls, and electrical system. It is requested, but not required, that the manuals be printed on recycled paper.

22.2. Complete wiring, plumbing and hydraulic schematics shall be delivered with unit. Wiring and schematics shall be color-coded. All schematics shall be clear, legible and indicate the location of each component. Hydraulic schematics shall include the diameter and length of each hose and the manufacturer and part number of each fitting.

3.2.6. Company experience with similar projects.

3.2.7. List of key personnel (Project Team) dedicated to the project and their role (Project Team Chart).

3.2.8. Project Team's experience with similar projects.

3.2.9. Relevant comparable projects completed.

3.3. Project Plan: Shall include a conceptual design methodology and feasibility with conceptual drawing(s), quality, durability and maintainability of the design, operating procedure of the design, warranty of equipment and components, and support and service.

3.4. Request for Proposal General Terms and Conditions.

3.5. Year 2000 Performance Warranty.

3.6. Execution of Proposal.

3.7. Proposer Information - Non Resident/Hub Status.

3.8. Good Faith Effort Program.

3.9. All addenda, if applicable.

4. IMPORTANT DATES: The listed dates are TxDOT's targeted schedule and are critical to the success of this RFP.

4.1.	Pre-Proposal Conference	July 29, 1999
4.2.	Proposal Submission Date	August 12, 1999
4.3.	Oral Presentations	August 19, 1999
4.4.	Vendor Selections and Negotiations	August 24, 1999
4.5.	Notice of Award	August ~~30~~ 26, 1999

5. ACCEPTANCE OF PROPOSAL: TxDOT reserves the right to accept or reject any or all proposals, or to waive any minor technicalities. Failure to comply with the requirements of this RFP will eliminate proposer from further consideration. This RFP may be canceled and any or all proposals may be rejected in whole or in part when it is in the best interest of TxDOT.

6. GUIDELINES FOR PROPOSAL EVALUATION: Evaluation of proposals will be performed by TxDOT. TxDOT, at its option, may initiate discussions with vendors who submit proposals determined to have the qualifications to be selected for award. However, proposals may be evaluated and accepted without discussion. TxDOT reserves the right to conduct discussions with responsible proposers who submit acceptable or potentially acceptable proposals. If such discussions are held, TxDOT may establish a common date for the submission of Best and Final Offers (BAFO).

7. DEMONSTRATION: TxDOT reserves the right to require a proposer to demonstrate proposers' capabilities as outlined in the proposal. After the initial evaluation of the proposals and before award, TxDOT reserves the option to inspect the proposers' facilities and require demonstrations of the proposers' capabilities to meet the requirements outlined in this RFP.

8. AWARD SELECTION: The proposer selected for the award will be chosen on the basis of the proposal deemed to provide the best value and greatest value for TxDOT.

9. CONTRACTUAL OBLIGATIONS: The selected proposer will be considered as prime contractor and shall assume the total responsibility for the APCS. Contents of the selected proposal shall be considered as contractual obligations. Failure to meet obligations may result in the cancellation of the contract.

10. EXCEPTIONS

NOTE: Additional points will be given for two or more years experience with asphaltic material and the design/production of related equipment.

2.2.1. Company's experience with similar projects - design/production of equipment.

2.2.1.1. Experience and qualifications of key personnel.

2.2.1.2. Experience with asphalt material and equipment.

2.3. Financial Stability:

2.3.1. Organization Chart - staffing levels, technical expertise of employees.

2.3.2. Corporate background - Proven industry presence - stability of products in the market.

2.3.3. Corporate net worth.

2.3.4. Financial asset review.

3. PURCHASE ORDER AWARD: TxDOT will award a purchase order, based on merit, to the responsible proposer whose proposal, at the sole discretion of TxDOT, is the best value or the most advantageous and in the best interest of TxDOT.

3.1. Should unforeseen costs be incurred during the design and construction of the APCS, the vendor may request a change order increasing the amount of the purchase order by up to 10 percent of the awarded price.

3.2. The total amount of the purchase order shall not exceed $200,000.00.

Year 2000 Performance Warranty

For purposes of this warranty, the following definitions shall apply:

I. "Accurately" shall be defined to include:

a) calculations correctly performed using four digit year processing;

b) functionality on-line, batch, including but not limited to, entry, inquiry, maintenance and updates support four digit year processing;

c) interfaces and reports must support four digit year processing;

d) successful translation into year 2000 with valid date (e.g. CC/YY/MM/DD)without human intervention. Additional representations for week, hour, minute and second, if required, complies with the international standard ISO 8601:1988, "Data elements and interchange formats - Information exchange Representation of dates and time." When ordinal dates are used, the ISO standard format CCYYDDD is used;

e) processing with four digit year after transition to any date beyond the year 2000 without human intervention;

f) correct results in forward and backward date calculations spanning century boundaries; correct forward and backward date calculations spanning century boundaries, including conversion of previous years stored, recorded or entered as two digits.

2. "Date integrity" shall mean all manipulations of time-related data (dates, duration, days of week, etc.) will produce desired results for all valid date values within the application domain.

3. "Explicit century" shall mean date elements in interfaces and data storage permit specifying century to eliminate date ambiguity.

4. "Extraordinary actions" shall be defined to mean any action outside the normal documented processing steps identified in the product's reference documentation.

5. "General integrity" shall mean no value for current date will cause interruptions in desired operation - especially from the 20th to 21st centuries.

6. "Implicit century" shall mean for any data element without century, the correct century is unambiguous for all manipulations involving that element.

7. "Product" or "products" shall be defined to include, but is not limited to, any supplied or supported hardware, software, firmware and/or micro code.

8. "Valid date" shall be defined as a date containing a four digit year, a two digit month and a two digit day., or the ISO 8601:1988, Data elements - Information Exchange - Representation of dates and times". When ordinal dates are used, ISO standard format of CCYYDDD is used.

The vendor warrants that product(s) delivered and installed under this contract shall be able to accurately process valid date data when used in accordance with the product documentation provided by the vendor and require no extraordinary actions on the part of the Owner or its personnel. Products under this contract possess general integrity, date integrity, explicit and implicit century capabilities. If the contract requires that specific products must perform as a system in accordance with the foregoing warranty, then the warranty shall apply to those listed products as a system. The duration of this warranty and the remedies available the Owner for breach of this warranty shall be as defined in, and subject to, the terms and conditions of the vendor's standard commercial warranty or warranties contained in this contract; provided, that notwithstanding any provision to the contrary in such commercial warranty or warranties, the remedies available to the Owner under this warranty shall include repair or replacement of any supplied product whose non-compliance is discovered and made known to the contractor in writing within 90 days after final acceptance, as that term is defined elsewhere in the contract. Nothing in this warranty shall be considered to limit any rights or remedies the Owner may otherwise have under this contract with respect to defects other than Year 2000 performance.
Texas Department of Transportation

Dated: May 19, 1997

____
Vendor Name

____
Authorized Signature

____
Date

DATED: JULY, 1999

PRE-PROPOSAL CONFERENCE

RFP No. Q 44 1999 059156 000

A Pre-proposal Conference is scheduled for:

THURSDAY, JULY 29, 1999 AT 2:00 P.M.

Prospective participants in this procurement are invited to attend the conference, which will be held at:

TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT), CONFERENCE ROOM 3B.1, BUILDING 150, 150 EAST RIVERSIDE DRIVE, AUSTIN, TEXAS (from IH-35, West on Riverside, approximately one mile). Building is located behind the "Corner Store" Convenience Store and Sonic Drive-In.

Check-in with Security Guard located in the East Entrance Area between the Office Towers to receive a Visitor Pass.

Other administrative instructions:

TxDOT will conduct a pre-proposal conference for all interested participants to familiarize them with the requested equipment and to give all potential proposers an opportunity to seek answers to any questions, which they may have concerning this RFP. All changes as a result of the pre-proposal conference will be made by TxDOT in the form of an addendum to the RFP. No oral changes will be considered. Proposers should have a representative from their firm attend this meeting. Representatives shall be required to sign a register as the representative of the named firm.

EXECUTION OF PROPOSAL
RFP No. Q44 1999 059156 000

DATE: ______________________

In compliance with this RFP, and subject to all the conditions herein, the undersigned offers and agrees to furnish any or all commodities or services at the prices quoted.

By signature hereon, the proposer hereby certifies that he/she is not currently delinquent in the payment of any franchise taxes owed the State of Texas under Chapter 171, Tax Code.

By executing this offer, proposer affirms that he/she has not given, offered to give, nor intends to give at anytime hereafter, any economic opportunity, future employment, gift, loan gratuity, special discount, trip, favor, or service to a public servant in connection with the submitted offer. Failure to sign the offer, or signing it with a false statement, shall void the submitted offer or any resulting contracts, and the proposer shall be removed from all bid lists.

By the signature hereon affixed, the proposer hereby certifies that neither the proposer or the firm, corporation, partnership, or institution represented by the proposer or anyone acting for such firm, corporation, or institution has violated the antitrust laws of this State, codified in Section 15.01, et seq., Texas Business and Commerce Code, or the Federal antitrust laws, nor communicated directly or indirectly the offer made to any competitor or any other person engaged in such line of business. By signing this proposal, proposer certifies that if a Texas address is shown as the address of the proposer, proposer qualifies as a Texas Resident Bidder as defined in Rule 1 TAC 113.8.

This offer consists of pages number one (1) through ______________________.

PAYEE IDENTIFICATION NUMBER (PIN): ______________________

PROPOSER (COMPANY): ______________________

SIGNATURE (INK): ______________________

NAME (TYPED/PRINTED) ______________________

TITLE: ______________________

STREET: ______________________

CITY/STATE/ZIP: ______________________

TELEPHONE NO.: ______________________

Check below if preference claimed under Rule 1 T.A.C. 113.8

(_____) 1. Texas produced supplies, materials or equipment
(_____) 2. Texas agriculture products
(_____) 3. U.S.A. produced supplies, materials or equipment
(_____) 4. Historically Underutilized Business certified by GSC
(_____) 5. Products of persons with mental or physical disabilities
(_____) 6. Products made of recycled materials
(_____) 7. Energy efficient products
(_____) 8. Rubberized asphalt paving material
(_____) 9. Recycled motor oil and lubricants

DELIVERY IN __________DAYS

CASH DISCOUNT _____% ______DAYS

VENDOR NAME______________________________ Revised: 2/99

PROPOSER INFORMATION

The following information is required for reporting purposes. ***PLEASE RETURN THIS PAGE WITH YOUR OFFER.***

NON-RESIDENT

Are you a *non-resident?
__________Yes __________No

Do you propose to subcontract $25,000 or more of this work to a non-resident firm? __________Yes __________No

If Yes, provide subcontractor's name and address:
____
____
____

*A non-resident is a firm or individual which does not maintain a permanently staffed full-time office in the state of Texas.

HISTORICALLY UNDERUTILIZED BUSINESS

Are you a *Historically Underutilized Business (HUB)?
__________Yes __________No

Are you certified as a HUB through the General Services Commission?
__________Yes __________No

*A historically underutilized business is defined as a sole proprietorship, partnership, corporation, or joint venture, formed for profit, in which at least 51 percent of the equity is owned by one or more women, Black Americans, Hispanic Americans, Asian Pacific Americans, or native Americans, and who actively participate in the control, operation, and management of the business.

DATED: JULY, 1999

MINIMUM REQUIREMENTS

RFP No. Q 44 1999 059156 000
(For Information Purposes Only)

Company Name: ______________________ **Evaluator:** ______________________

PROPOSAL SUBMITTAL REQUIREMENTS	MEETS MINIMUM REQUIREMENTS		NOTES
Minimum Requirements/Submittal	**Yes**	**No**	
1. Conceptual Drawings (Part II, Para. 21.1)			
2. Cover Letter, one page (Part III, Para. 3.1).			
3. Company Data (Part III, Para. 3.2).			
4. Project Plan (Part III, Para. 3.3).			
5. General Terms and Conditions.			
6. Year 2000 Performance Warranty.			
7. Execution of Proposal.			
8. Proposer Information - Non Resident/Hub Status.			
9. Good Faith Effort Program.			
10. All Addenda, if applicable.			

ADDITIONAL NOTES:

DATED: JULY, 1999

Evaluation of Proposal
RFP No. Q 44 1999 059156 000

FOR INFORMATION PURPOSES ONLY

Company Name: ______________________ **Evaluator Name:** ______________________

Award will be made based on the factors below weighted as shown:

EVALUATION CRITERIA:

1. Part I - Evaluation of information provided with the proposal which will comprise a total of 60 percent of the overall evaluation score.
2. Part II - Proposal price will be scored from lowest to highest with the lowest score receiving the maximum number of points. Price will comprise 40 percent of the overall evaluation score.

PROPOSAL RESPONSE AND QUALIFICATION CRITERIA	POINTS	SCORE
Project Plan: Design methodology and feasibility. Quality, durability, and maintainability of design. Ease of operation. Delivery, warranty, and support.	Maximum Allowable Number of Points: **90**	
Experience/Expertise: Demonstrated Applicable Experience: Proven industry presence, stability of similar products in market, owner/user references.	Maximum Allowable Number of Points: **30**	
Financial Stability	Maximum Allowable Number of Points: **15**	
		TOTAL:

Texas Department of Transportation
Form 1997
(Rev. 8/98)
(Electronic version GSD-EPC Word 7.0)

Good Faith Effort Program (GFEP) for Other Services

State Agencies are required to make a good faith effort to assist Historically Underutilized Businesses (HUBs) in receiving contract awards issued by the State, see Tex. Gov't. Code Ann. Title 10, Subtitle D, Chapter 2161 (formerly Tex. Rev. Civ. Stat. Ann. Art. 601b). The goal of this program is to promote fair and competitive business opportunities for all businesses contracting with the State of Texas. The following documents must be completed and returned by bidders in order for the bid to be considered for award:

(1) Good Faith Effort Program (GFEP) Other Services Form - This form must be returned with the bid or within **seven working days** after the bid opening date.
(2) The bidder providing subcontracting opportunities shall submit to the Texas Department of Transportation (TxDOT) a copy of the written notice of solicitation advertising the subcontracting opportunities (see GFEP Other Services Form, criteria number two). This written notice of solicitation shall be submitted with the bid or within **14 working days** following notification of selection by TxDOT, but prior to award of a contract.

If all or any portion of the contract will be subcontracted, as indicated on the GFEP Other Services Form, the bidder must submit supporting documentation with the forms listed below within **14 working days** following notification of selection by TxDOT, but prior to award of a contract:

(1) Determination of Good Faith Effort (DGFE).
(2) The Historically Underutilized Business Solicitation Form (HUB-SF).
(3) Historically Underutilized Business Letter of Intent (HUB-LOI).

If an award is made, the contractor will provide the following documents to the contracting agency on a **quarterly** basis:

(1) Non-Historically Underutilized Business Progress Assessment Report (NON-HUB-PAR) - documentation of work subcontracted with HUBs;

--OR--

(2) Historically Underutilized Business Progress Assessment Report (HUB-PAR-A) - documentation of work subcontracted with Non-HUBs.

All forms must be submitted to TxDOT within the specified time frames. Failure to do so will cause disqualification of the bid from consideration for award or revocation of any contract awarded because of noncompliance.

NOTE: A random reference list of Texas certified HUBs has been attached to assist bidders in achieving the program goal. A complete list of all GSC certified HUBs may be electronically accessed through the Internet. The GSC information server is available through the Internet based World-Wide-Web. Although there are alternatives to connect to this data, the preferred method is through the Internet using a Web Browser (like Netscape, Mosaic, etc.). Using a Web Browser, please connect to **http://www.gsc.state.tx.us** (this is the home page for GSC).

HISTORICALLY UNDERUTILIZED BUSINESSES
SOLICITATION FORM (HUB-SF)

Bidder: ______________________ Vendor Identification Number: ______________
Address: ______________________
Phone: ______________ Contract Number: ______________ Contract Name: ______________
Specific Subcontract Solicited: ______________________
Contractor's Estimate of Approximate Dollar Value of Subcontract Advertised: ______________
Date of Solicitation Letter: ______________________

*List each HUB to which a written notice of solicitation letter was sent and attach a copy of each written notice of solicitation letter. If additional space is needed, please attach a separate sheet.

1. Name of HUB Subcontractor/Supplier: ______________________
   Address: ______________________
   Phone: ______________ Owner: ______________
   If GSC certified, enter Vendor Identification Number: __________ If not GSC certified, please complete the following information:
   ☐ Black American ☐ Male ☐ Female ☐ Native American ☐ Male ☐ Female ☐ Women
   ☐ Hispanic American ☐ Male ☐ Female ☐ Asian Pacific Americans ☐ Male ☐ Female

2. Name of HUB Subcontractor/Supplier: ______________________
   Address: ______________________
   Phone: ______________ Owner: ______________
   If GSC certified, enter Vendor Identification Number: __________ If not GSC certified, please complete the following information:
   ☐ Black American ☐ Male ☐ Female ☐ Native American ☐ Male ☐ Female ☐ Women
   ☐ Hispanic American ☐ Male ☐ Female ☐ Asian Pacific Americans ☐ Male ☐ Female

3. Name of HUB Subcontractor/Supplier: ______________________
   Address: ______________________
   Phone: ______________ Owner: ______________
   If GSC certified, enter Vendor Identification Number: __________ If not GSC certified, please complete the following information:
   ☐ Black American ☐ Male ☐ Female ☐ Native American ☐ Male ☐ Female ☐ Women
   ☐ Hispanic American ☐ Male ☐ Female ☐ Asian Pacific Americans ☐ Male ☐ Female

4. Name of HUB Subcontractor/Supplier: ______________________
   Address: ______________________
   Phone: ______________ Owner: ______________
   If GSC certified, enter Vendor Identification Number: __________ If not GSC certified, please complete the following information:
   ☐ Black American ☐ Male ☐ Female ☐ Native American ☐ Male ☐ Female ☐ Women
   ☐ Hispanic American ☐ Male ☐ Female ☐ Asian Pacific Americans ☐ Male ☐ Female

5. Name of HUB Subcontractor/Supplier: ______________________
   Address: ______________________
   Phone: ______________ Owner: ______________
   If GSC certified, enter Vendor Identification Number: __________ If not GSC certified, please complete the following information:
   ☐ Black American ☐ Male ☐ Female ☐ Native American ☐ Male ☐ Female ☐ Women
   ☐ Hispanic American ☐ Male ☐ Female ☐ Asian Pacific Americans ☐ Male ☐ Female

Signature: ______________________ Title: ______________
Address: ______________________ Phone: ______________

This form must be signed by an authorized representative of the Bidder. This form is due within 14 working days following the notification of selection, but prior to the award of this contract.

Return to: Texas Department of Transportation
General Services Division - Services Section
125 E. 11th Street, Austin, TX 78701-2483

HISTORICALLY UNDERUTILIZED BUSINESSES
LETTER OF INTENT (HUB-LOI)

PLEASE SUBMIT A SEPARATE FORM FOR EACH HUB SUBCONTRACTOR/SUPPLIER
For use by bidder to identify HUB Subcontractors and Suppliers

Bidder: ______________________ Vendor Identification Number: ______________

Address: ____

Telephone: __________ Contract Number: __________ Contract Amount: $ __________

Description of commodities/specifications: ______________________________

Time period covered: ______________________________________

Dollar amount/Percentage of contract with HUB subcontractor/supplier: $__________ __________%

Name of HUB Subcontractor/Supplier: ______________________________

Address: ____

Telephone: __________ Proposed Contract Amount: ______________________

Description of materials performed under agreement with HUB for amount indicated above:

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This form is due within 14 working days following notification of selection, but prior to the award of the contract.

______________________ ______________________
Signature of Bidder Title

____
Date

Return to: Texas Department of Transportation
General Services Division - Services Section
125 E. 11th Street, Austin, TX 78701-2483

Form 1997
(Rev. 8/98)
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NON-HISTORICALLY UNDERUTILIZED BUSINESS
PROGRESS ASSESSMENT REPORT (NON-HUB-PAR)
DOCUMENTATION OF WORK SUBCONTRACTED WITH NON-HUBs

Effective Date of Contract: ________ Contract Number: __________ Object Code (agency use): ____________

NON-HUB Contractor Name: ____

NON-HUB Contractor Vendor Identification Number (VID Number): ____________________

Total Contract Amount Paid this Period to NON-HUB Contractor: ____________________

Document HUB Subcontractor Information below:

NON-HUB Subcontractor/Supplier Name	Total $ Amount Paid This Period to NON-HUB Subcontractor	Total Contract $ Amount Paid to Date to NON-HUB Subcontractor	Percent of Contract $ Amount Subcontracted to NON-HUB Subcontractor
TOTAL			

Form to be reported quarterly according to the dates below. Please check the box for the quarter being reported:

Signature: ____________________________

Title: ____________________________

Date: ____________________________

Quarter	Months included	Deadline	Check Quarter
First	(Sept., Oct., Nov.)	Dec. 5th	☐
Second	(Dec., Jan., Feb.)	March 5th	☐
Third	(March, April, May)	June 5th	☐
Fourth	(June, July, Aug.)	Sept. 5th	☐

Return to: Texas Department of Transportation
Construction Division, Business Opportunities Section
125 E. 11th Street, Austin, TX 78701-2483