AUTOMATED POTHOLE PATCHER

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INTRODUCTION

Most state highway agencies use a labor intensive procedure for the repair of potholes in asphalt pavements. This creates several problems that are increasingly difficult to tolerate. For example, safety factors, frequent repair, and high maintenance cost are some of the concerns of the state highway agencies and the public.

Worker and traffic safety are difficult to maintain on our nation's highways, particularly during the repair seasons of winter and spring. The statistics of work zone related casualties indicate the importance that must be placed on research addressing safety issues. SHRP H-107B program takes the approach of improving safety for all concerned by automating the pothole repair process, removing workers from the road, and speeding up operations to reduce the traffic hazard.

Many equipment manufacturers and material producers are claiming to have developed products to reduce the need for intensive preparation of the pothole cavity and surrounding area. Some proprietary cold mix materials have demonstrated good performance in wet conditions with little post-compaction. Their widespread use has been hampered, however, by high material costs and a reluctance on the part of agencies to allow the "throw and go" technique.

Automation can make it cost effective to prepare a pothole using today's materials. A permanent pothole repair procedure used by many agencies involves cutting pavement, cleaning out debris, tack coating, filling, compacting, and sealing. Specialized equipment and trained laborers are required to effectively accomplish these tasks. However, this "do-it-right" repair procedure is labor intensive and with low cost hot-mix, the final cost of a pothole repair can exceed $100. These funds can be wasted when a lack of skilled workers or poor weather conditions can make it difficult to "do-it-right." This program is developing equipment that will demonstrate the economic potential of automating the pothole repair process. Rather than reinvent the shovel, the development strategy has been to use existing repair technology, and then computer-automating, selected components into a vehicle that will automate the pothole repair process. In one sense, automating the pothole patching process can be compared to a manufacturing process where raw materials, tools, and a process plan all combine to produce a product--the roadway patch. The missing link until now has been the creation of a pothole-patch process control system on wheels.

BIRL, the applied research laboratory of Northwestern University, has designed, fabricated, and will soon begin a field testing of a complete vehicle system for the repair of potholes in asphalt pavements.

OVERALL PRODUCT DESCRIPTION

Potholes come in all sizes and shapes. Defining them is difficult and little guidance is found in the literature. For this program, we use a pragmatic definition, "a pothole is in the eyes of the beholder," in this case the operator of the pothole repair truck. We would like the operator of our truck to be able to fix anything he or she considers to be a pothole. Potholes may have a base of asphalt, sand, rock, concrete, cobblestone, or whatever. They may be water-filled, mud-filled, or contain foreign objects like a muffler part or in some cities an occasional Volkswagen.

Usually, they are bowl-shaped, from 1 to 10 square feet in area, with a depth of 2 to 6 inches. They most often occur in the wheel paths of traffic or at the centerline or along edges where overlays have met. Surface water, drainage, and traffic loading are primary factors in the creation and growth of a pothole. The pothole may lie adjacent to concrete, thus making it difficult for pothole routing and shaping tools. They also may lie in areas that collect water, such as a depressed area at a bus stop or near a curb. Potholes may be closely spaced or they may lie at random intervals along a road. Each of these variations present different problems to the computer automation of the repair process. During this two year-long program, we have developed a system capable of handling most of these variations (except the Volkswagen).

At the start of this program in December 1990, SHRP provided a set of requirements and guidelines that we have implemented in our design. It was felt that the best solution would be a single vehicle capable of moving about on the highways under its own power with enough materials and capacity to handle a whole day of patching. It was desirable to make repairs over an entire lane width, with minimal shutdown of the adjacent lanes. It had to operate rapidly to realize economic goals and to make the system safer for the traveling public. The less time spent stopped for repair, the better. A minimum of crew was also desirable to improve safety. The state highway agencies were targeted as the end users, so operating and capital costs were to be kept as low as possible. We set a goal of

$250,000 for the first prototype equipment cost and we have met that. Breakdowns and equipment maintenance requirements were to be kept to a minimum. We recognize that a machine of this size, if kept in the shop for repair, is worse than useless. Wherever possible, our designers have sought simple and no-maintenance approaches for each component. The system had to be designed to address the application of different patch materials, not just a single selection finely tuned to the capabilities of the truck. Finally, it had to be highly automated to assure consistent patch quality with nearly permanent lifetimes, at minimal in-place costs. Permanent patches were considered to last the remaining life of the surrounding road, anticipated to be 3 to 5 years.

PRODUCT FEATURES AND DESIGN

We call the system the Automated Pavement Repair Vehicle (APRV). The vehicle is based on a truck chassis by Crane Carrier Company (CCC). The "Low Entry Tilt" (Model LET) is often used in the refuse industry where gross vehicle weights can run high, and turning radius is critical. The CCC has the best turning angle of the 4 trucks we examined. The truck has a turning radius of 22.7 feet for excellent maneuverability to reach potholes and pavement distresses wherever they are found.

The frame is structural steel ship channel of high modulus, heat treated and then straightened to eliminate racking and twisting problems. The 10 inch rails extend from the front bumper to the tailboard. Heavy duty electrical systems and air brake systems are specified for this application.

The CCC model features a prime mover of Cummins Diesel L10 260 horsepower with a front-mounted power-take-off (PTO) that drives the hydraulic system for pavement cutting. An Allison automatic transmission equipped with an eight-bolt PTO powers the blower. Slight adjustment of the engine speed from normal idle of 700 RPM to 1100 or 1500 RPM is all that was required to drive the blower and hydraulics efficiently.

An additional generator provides 12 kilowatts of electrical power for the computer systems, lighting, vision systems, and sensors. The vehicle chassis will handle a gross weight of 62,000 pounds, though we expect to operate at less than that with a full load. With a wheel base of 200 inches, body width of 8 feet, and height of 10 feet, the overall size has been designed to make it legal in every state.

Although the driver is the only required operator, we provided a crew cab for additional crew or observers on day-long repair excursions. The crew cab gives air-cushion ride for 3 or 4, in air conditioned comfort. We will mount the computers and displays in the crew cab in a shock-mounted cabinet for extra protection. Hard disk drives for the computer systems may be eliminated in favor of optical disk drives. The entire software for the computers could be contained on a single three and one-half inch, replaceable optical disk, thus making software upgrade a simple process. Keyboards are out, and mice are impractical, so a touch screen is the best interface for an operator. We are designing the system for use by a skilled individual, such as a gradeall operator--not a rocket scientist. A training program would not require more familiarity with computers than the local "Lotto," video game, or automated teller machines.

A physical model was constructed to 1/8 scale to resolve issues in component placement and overall body design. We felt this approach was an inexpensive alternative to computer modelling, since we could carry the model to vendors for their viewing when they made quotations for equipment. Some portions of the truck were made full-scale so the operator interface could be developed without having the truck chassis on hand. Everything has been laid out to make the system easy to maintain and productive in use. From the outset the design team has tried to eliminate knee-knockers and maintenance problems.

Each of the subsystems has been designed with 6 driving factors in mind. **Repair performance** includes patch lifetime and annualized cost per repair. The objective is a patch lasting 3 to 5 years and costing less than a permanent pothole repair by traditional means. **Low maintenance** is essential for commercial viability and highway acceptance. Field breakdowns must be minimal. Simple maintenance should be accomplished without disassembly. Part wear must be controlled and minimized. Automated self-cleaning is desirable. **Safety** to the crew and public is emphasized. Since most industrial accidents happen during equipment maintenance, lowering maintenance frequency actually improves safety. Safety interlocks prevent crew from exposing themselves to risks of operation. Since the single crew member never leaves the cab, there is great potential to reduce traffic related injuries when using this system. The APRV must be **easy to use**, particularly on cold and rainy days. The emphasis must be to make it easy to use and let the operator feel confident that he is controlling the system to help him do pavement repair. Autonomy must be balanced with suitable manual overrides. Controls must be intuitive and not require a light touch or a steady hand that will strain the nerves of the operator over the course of the day. **Cost of operation**

and maintenance must be low. Production model pricing also should reflect state budget restrictions, thus options to lease must be available. The sixth driving factor in the design is **versatility.** The design should accommodate all sizes and shapes of potholes and other pavement distresses that broadly fall into the definition. If the operator thinks he can repair it, he will find a way to try. The machine must allow for this without breaking down. Also, a strong plus is given to a system that can be used for multiple purposes besides pothole repair, such as crack sealing, utility cut patching, or shoulder reconstruction.

With respect to these design priorities, let us review the conceptual drawings. Gull-wing doors over the dual 13 foot aggregate hoppers permit a 12 foot wide loader to dump a bucket directly into each of the 4 cubic yard hoppers with minimal spillage. The covers will keep the weather off the aggregate during storage and improve the aerodynamics and safety of the system in transport. Heavy-duty edges prevent accidental damage from the loader. The dual emulsion tanks each have a capacity of 180 gallons. They are heated electrically (120 volts) and they may be kept warm with engine heat during operation. Ideal emulsion temperature should be between 120 to 160 degrees Fahrenheit. Heat prevents clogging and improves the flow of the emulsion. Side panels can be removed for easy cleaning. The tanks are not pressurized and seals are not a problem.

Many states have specified pothole repair procedures. Some agencies and institutes have studied these procedures over the years and made recommendations. The state's repair procedures vary, as well as the equipment and materials used to perform them. Thus, we had to determine a generic procedure that seemed to satisfy all the state's requirements and that could be flexibly utilized by individual states. The APRV will perform 2 generic procedures using equipment specially-developed for this program or adapted from commercial products.

The repair sequence could be performed as follows.

Step 1: The driver could locate a hole to be repaired using his eyes and a downward-pointing CCD camera looking through the windshield. With a cab-over-engine design on the truck, the operator will be able to see a point on the road 2 feet in front of the plane of the windshield. He will then point to the target hole on the touch screen of the display. A bumper-mounted light-bar can be used at night to sight the potholes.

Step 2: The driver could use joystick control to manipulate the bumper-mounted pavement cutter to clean and shape the edges of a pothole. Some states do not perform pothole cutting with some materials so this is an optional step.

The hydraulically-operated cutter uses a vertical-milling principle. The cutter head contains several carbide-tipped bits that can be easily replaced in the field. It is rotated at high speed to achieve the shear forces needed to cut asphalt pavement. Although maneuvered by joystick located in the cab in the prototype, it could be fully computer-automated. It can shape the edges of a 4 square foot pothole in a few minutes.

Step 3: The truck could then be driven forward about 25 feet in a creep-gear until the pothole is positioned under the repair box area at the rear of the truck. Exact alignment is not required and the computer vision system can provide assistance.

The rear of the truck has an overhanging area we call the repair box where most of the repair takes place. The repair box houses the repair equipment. Doors on the underside of the box unfold to pavement level to keep weather conditions away from the repair as it is made. They also confine the repair process and materials to the repair area. Thus, we can bring a warm summer day to the pothole, day or night, rain or shine. The payback analysis we have done shows the impact of keeping a machine operating two or three shifts, for 300 or more days of the year.

Step 4: A 3-dimensional vision system located inside the repair box could scan the 5 x 8 foot pavement area under the box to detect the depressed area of the pothole as well as cracks. Styrofoam models of potholes were created to test these concepts in the laboratory. Scanning the pothole by laser light allows it to be seen in detail, even in changing lighting conditions. This system will show the operator a 3-dimensional graphic display of the pothole surface, including accurate readings of the depths and overall dimensions. It also will send this data to a robot to perform the rest of the repair sequence.

Step 5: The robotic arm could extend from its retracted position to move a vacuum nozzle down into the cavity. High power vacuum sucks out water, mud, and cutter debris. Enough power should be available to suck up large asphalt chunks. The vacuum system has stages of filtration that empty into a waste hopper that is dumped from the passenger side once per day. The filtration should be economical yet very efficient to protect the blower intake from receiving damaging dust and water from the pothole vacuuming process. Maintenance of this component should be infrequent and involve simple and inexpensive filter replacement.

Step 6: The same robotic arm then could ignite and move a hot air lance across the pothole surface, to heat the surface and bonding edges of the cavity. The hot air lance is commonly used in highway applications for crack filling, because an intense blast of heated air is ideal for heating and drying pavement surfaces. The lance is a handheld torch powered by liquid propane gas and compressed air. We have constructed a safe electrical ignition and gas control system to operate the lance automatically. The system has no open flame, yet very high exit temperatures can be achieved. The temperature of the pavement will be closely monitored to assure that no overheating takes place. In our tests with the lance, we have brought 50 degree pavement up to 150 degrees with about 10 seconds of heat over a small pothole area. Larger areas will require back and forth movement of the lance to distribute the heat evenly. The truck usage of propane is estimated to be less than two RV-sized propane cylinders per week. Storage for four cylinders is provided.

Step 7: The next step would be the application of patch material. We feel that spray emulsion or spray injection has the best promise for complete automation and the creation of a consistent and permanent patch at minimal cost. The patch material cost is about $22 per ton. We have developed a spray patching system that matches our design goals and in our trials it has exceeded the performance of commercially available systems. The spray patch concept conveys rock aggregate in the size range of 1/4 to 1/2 inch into a high speed air stream. The rock moves down a tube or hose to a point within one or two feet of the pothole. Just before it exits a nozzle, it is sprayed with asphalt emulsion, thus making the patch material on the fly. As it strikes the cavity, the emulsion breaks, the patch begins to cure, and air voids are removed as the patch is built from the bottom up. Experiments with our spray patcher have demonstrated it shooting rock out of the nozzle at a speed of nearly 100 mph. The overall material discharge rate is about one cubic foot per minute and it is controllable. This will allow the automated filling of a thoroughly prepared pothole cavity with commonly available patch material.

Step 8: After the computer has controlled the filling of the pothole cavity, the robotic arm could vacuum away any over spray from the patching process, thus leaving the repair site clean. The doors of the work box will close and a green light will signal the driver to drive to the next pothole. Enough material and waste storage is on-board to allow all day operation without stopping. Liquid propane gas is easily refilled on a weekly or bi-monthly schedule depending on the season and the climate.

CONCLUSION

Referring to the original design goals, we are constructing and testing a vehicle for pothole repair in asphalt roads. It should have a repair cycle time of 5 to 10 minutes, yet require only a single driver/operator. It will function across a full lane width, up to 8 feet by 5 feet at a time, performing a generic permanent pothole repair procedure. We hope that a commercial system will be low maintenance and easy to use, costing in the area of $300,000 in limited production and lower-priced versions sure to follow in the marketplace. Based on all considered costs, we target the in-place patch cost to be less than $30 for a two square foot hole. It will be automated to improve safe, rapid repairs in day or night, most weather conditions, at most any repair site.

We anticipate the vehicle to be ready for field testing in the fall of 1992. States that can provide repair sites and materials are urged to contact us for more information. We are actively seeking commercializers for the truck and hope to see a production model available for purchase in 1993. Further information on this project is available by contacting me at BIRL, Northwestern University, 1801 Maple Avenue, Evanston, IL 60201-3135.