# Design Considerations for Automated Pavement Crack Sealing Machinery

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## Abstract

The purpose of this paper is to discuss the numerous considerations for designing automated machinery for the sealing of cracks in pavement. Operational requirements are presented and a generic system architecture for such machinery is discussed. Two distinct automated machines are proposed, one to seal only longitudinal cracks, and the other to seal general cracks in pavement. The functions of the component subsystems is also presented.

## Introduction

Worldwide, a tremendous amount of resources are expended annually maintaining highway pavement. In California alone, the state Department of Transportation (Caltrans) spends about $100 million per year maintaining approximately 33,000 lane-miles of flexible pavement (Asphalt Concrete - AC) and 13,000 lane-miles of rigid pavement (Portland Cement Concrete - PCC). A portion of these maintenance activities involve the sealing and filling of cracks (approximately $10 million per year). The purpose of crack sealing and filling is to prevent the intrusion of water and incompressibles into the crack, while crack filling is additionally used to hold broken pieces of pavement together. When properly performed, these operations can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitation.

The sealing and filling of cracks are tedious, labor-intensive functions. In California, a typical operation to seal transverse cracks in AC pavement involves a crew of eight individuals which can seal between one and two lane miles per day. The associated costs are approximately $1800 per mile with 66% attributed to labor, 22% to equipment and 12% to materials. Furthermore, the procedure is not standardized and there is a large distribution in the quality of the resultant seal. In addition, while crack sealing/filling, the work team is exposed to a great deal of danger from moving traffic in adjacent lanes.

The crack sealing/filling operation is an ideal candidate for the infusion of advanced technologies in order to automate the process. Automated crack sealing/filling machinery has the potential to:

- Minimize the exposure of workers to the dangers associated with working on a major highway.

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- Considerably increase the speed of the operation.
- Improve the quality and consistency of the resultant seal.

Increasing the speed of the operation will in turn reduce the accompanying traffic congestion since lane closure times will decrease. The combination of the increased speed and the higher quality seal will prove to be extremely cost effective and reduce the frequency of major highway rehabilitations.

In order to have the greatest impact, such machinery should satisfactorily perform the following functions automatically:

- Sense the occurrence and location of cracks in pavement.
- Adequately prepare the pavement surface for sealing/filling with the appropriate methods; for example, any operation that is deemed necessary such as removing entrapped moisture and debris, preheating the road to ensure maximum sealant adhesion, refacing of reservoirs, etc.
- Prepare the sealant/filler for application; i.e., heat and mix the material, etc.
- Dispense the sealant/filler.
- Form the sealer/filler into the desired configuration.
- Finish the sealer/filler.

Additionally, the machinery will have many other more detailed overall functional specifications related to safety, cost, reliability, etc.

## Operational Requirements

For purposes of brevity, we will now consider only sealing operations. The first fundamental questions related to sealing of pavement cracks are: which cracks should be sealed and when should they be sealed? These answers to these questions are quite difficult to generalize as they have been the subject of many studies, and thus an automated sealing machine need not be required to make such decisions. However, given information on the general location of cracks and joints to be sealed, such machinery should be able to locate cracks with sufficient accuracy for automated machine operation.

The various types of operations that this machinery should address includes:

- AC/PCC longitudinal crack sealing.
- PCC longitudinal joint sealing.
- PCC transverse joint resealing.
- PCC transverse crack sealing.
- AC transverse crack sealing.

Without getting into too many details of the required operations for each type of seal, one recognizes that the simplest of these operations is longitudinal sealing, and the most complex operation is AC transverse crack sealing. Machinery that is developed to address these two extreme operations (in terms of difficulty) could easily be modified to address any of the others.

## Machine System Concepts

Based on the operational requirements for sealing the different types of cracks, we envision two distinct automated machines; one to seal only longitudinal cracks, and the other to seal general cracks in pavement. While these machines would share many of the same component subsystems and components, the overall manner in which these machines will operate are quite different. The development of a machine to automatically seal or fill cracks of sometimes arbitrary geometry (transverse cracks) is quite challenging. The primary challenges arise from:

- The necessity for the sensing system to identify the presence of cracks in addition to locating their position.

- The number of degrees-of-freedom required to follow an arbitrary crack.
- The required unsteady operation of many of the components.

In contrast, a machine to perform the longitudinal operations has several different requirements including:

- Fewer required number of degrees-of-freedom to follow longitudinal joints and cracks.
- Considerably different sensing requirements (i.e., the presence of longitudinal cracks is known and the sensing system is thus required only to locate the position of the crack).
- The steady-state operation of many of the components.

Furthermore, the simpler longitudinal operations are expected to be performed at a much higher rate of speed.

**Machine Architecture**

The overall system architecture of the two automated sealing machines is identical and is depicted in Figure 1. This system architecture includes four primary systems, and in this figure, each system block includes a partial list of the types of components that may comprise it. The four primary systems are: Crack Sensing System, Applicator Assembly and Peripherals, Positioning System, and Integration and Control System. Of course, all of these systems would in turn be mounted or towed by a support vehicle. The Crack Sensing System will be primarily responsible for locating and describing roadway cracks and joints. The Applicator Assembly and Peripherals includes all the hardware necessary to mix, heat, dispense, shape and finish sealant/filler, and to prepare the pavement including reservoir creation. This system may be comprised of any number of dispensers, valves, cutting tools, heaters, air compressors, etc. The Positioning System will include the hardware necessary to move the applicator assembly end effectors in such a manner that they follow the required path. The Integration and Control System will coordinate the Crack Sensing, Applicator Assembly and Peripherals, and Positioning Systems. It will transform the information from the Sensing System into a desired path for the applicator assembly. The Integration and Control System will then control the motion of the applicator through the Positioning System as well as controlling the individual functions of the Applicator System. Additionally, the Integration and Control System will monitor all of the peripherals to ensure proper sealant/filler supply, sealant/filler temperature, heat supply, etc. More details of each of these systems follows.

<u>The Crack Sensing System</u>

The purpose of crack sensing is to determine the location of cracks and joints on the road in sufficient detail so that crack preparation, sealant/filler application, and shaping can be performed automatically. A wide range of sensing technologies have been investigated in order to select the most appropriate crack sensing system. The Crack Sensing System is comprised of two subsystems; a global machine vision based subsystem with a full lane width field of view, and a local laser range finder subsystem to verify the presence of cracks and joints.

The machine vision based subsystem uses a CCD (Charge Coupled Device) video camera for the sensor as in other recent roadway crack detection studies (Bomar, 1988; Haas & Hendrickson, 1989; Mahler, 1990). We have developed a histogram analysis based image processing algorithm in order to identify cracks in both AC and PCC pavements (Kirschke & Velinsky, 1991). This algorithm has been successful in locating unprepared, and relatively dirty, cracks as small as one-eighth inch in width in both of these types of pavement. However, the global machine vision subsystem cannot distinguish true cracks from apparent cracks which are actually shadows, wet



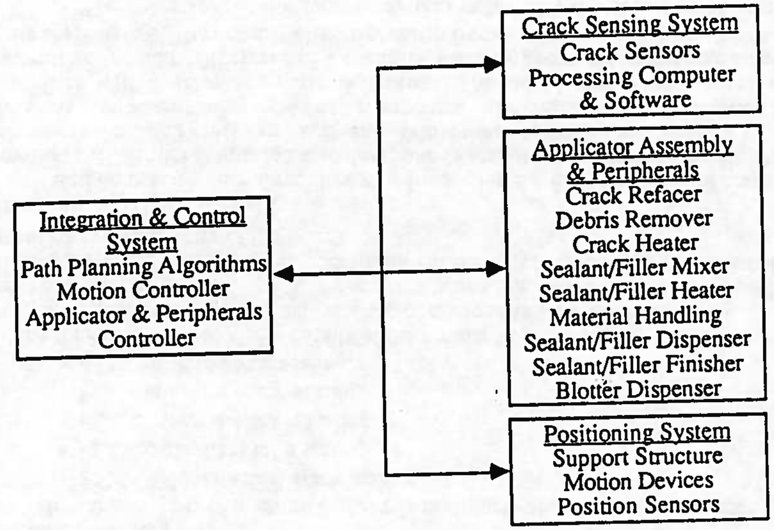


Figure 1. Component Systems of the Automated Crack Sealing Machine

areas, oil spots, or previously sealed cracks. As such, the local laser range subsystem is used to complement the vision system. Preliminary testing and algorithm development has clearly shown the feasibility of this type of sensor for overcoming the vision system's shortcoming. For the longitudinal machine, only the local subsystem will be necessary.

<u>Applicator Assembly and Peripherals System</u>

The key to sealed/filled crack/joint longevity is directly attributable to proper cavity preparation. Additionally, for most hot applied sealants/fillers, a uniform surface heating prior to application is desirable. While there are significant differences between the practices of the various states, for the widest possible applicability, an automated machine must also allow for pavement routing. The Applicator Assembly and Peripherals System prepares the crack/joint and applies and finishes the sealant.

Recent studies (e.g., Rossman, et al., 1988) have shown that the ideal method for crack preparation should include the use of a two phase hot air system. The primary phase of this system should include a source of high temperature and high velocity compressed air to remove entrapped aggregate/vegetation and moisture. The second phase of the heating system should be used to warm, to approximately 280°F (based on recent studies at Caltrans), the surrounding horizontal crack margins to ensure a highly adherent bond between the surface and the sealant material. Once the crack is cleaned, dried and heated, a suitable sealant can be applied. The desired patch configuration requires moderate penetration of sealant material into the vertical crack surface, and sealant penetration can be sharply increased as the temperature differential between the surface and the sealant material is minimized.

<u>Positioning System</u>

The various components of the crack sealing machine are physically connected through the positioning system. The Positioning System will consist of three primary components; the machine support structure, the applicator assembly motion devices, and the position sensors. The machine support structure is the framework that physically supports the crack sensing system, applicator assemblies and peripherals, applicator assembly motion devices, and position sensors. The support structure (frame) may be mounted on a wheel assembly which will support the frame during the crack/joint sealing/filling operation as well as during high speed road travel.

The applicator assembly motion devices consist of stepper motors, drives, translation and rotation positioning components, cables, and other equipment which are used for the purpose of positioning and actuating the applicator assemblies. Position sensors will be employed to determine the exact position of the support structure and applicator assemblies with respect to the road surface and to accurately position the applicator assemblies while adjusting for a variety of disturbances.

System Integration and Control

The Integration and Control System oversees the entire operation and coordinates the activities of the other subsystems. The information forwarded from the Crack Sensing System will be translated into a planned path for the Applicator and Peripherals System components (crack/joint preparation equipment, etc.). Thus, the Integration and Control System will include the necessary algorithms to plan a crack/joint sealing path. This path corresponds to the relative positioning of the Applicator System. If multiple applicators are employed, the Integration and Control System will need to first allocate cracks to the individual applicators and will do so in a manner to maximize speed and avoid interference. This system will keep account of the actual position of the total machine and its components by interacting with sensors on the Positioning System. It will additionally monitor the Applicator Assembly and Peripherals to ensure adequate volume and temperature of sealant/filler, air, etc. Following the planning of the appropriate path(s), the Integration and Control System will control the motion of the applicator(s) and the individual applicator functions.

## Conclusions

This paper has discussed numerous considerations for the design of automated machinery for the sealing of cracks in pavement. Such machinery is being developed under the joint UC-Davis/Caltrans project acknowledged below, and prototype machinery will be field tested late in 1992.

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# COMPARISON OF TRAFFIC SIGNAL SYSTEMS IN AUSTRALIA AND NORTH AMERICA

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Abstract

Dynamic coordinated traffic signal systems were developed in Australia in the 1970's, and are now installed in many countries. In contrast, strong interest in new generation control philosophy has only recently developed among North American practitioners. The results of applicable comparative studies to are reported.

## Introduction

The development of coordinated traffic signal systems in North America has had a rather mixed history. The first electric traffic signals appeared in Cleveland in 1914, and the first electrically connected coordinated signals appeared only three years later in Salt Lake City's "checkerboard" system (ITE, 1971). By 1928 New York City had some 3,000 traffic signals, but very few were under its "block" coordinated control. Denver introduced the computer age in 1952 with an analogue computer using six sampling detectors to select the most appropriate signal timing from a library of programs.

During the 1950's, and 1960's, many cities installed interconnected electromechanical systems, typically offering one to three coordination plans, which define the cycle length, phase splits and offset for each intersection. The first application of a digital computer for traffic signal control was in Toronto in 1963 (Camkin and Sims, 1974), following a pilot study in 1960. However, most developments since then have improved the equipment, more than the control logic.

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