AN ANALYSIS OF THE COSTS AND IMPACTS OF THE AUTOMATION OF PAVEMENT CRACK SEALING

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INTRODUCTION

Recent developments in the automation and mechanization of pavement crack sealing show potential to have a significant influence on pavements over their life cycle. It is expected that these developments will not only reduce the costs of this routine maintenance activity but improve the quality of pavement crack sealing and hence the longevity of pavements to which crack sealing has been applied in a timely manner. Understanding the impacts of improved maintenance quality is also important for the economic analysis of the automated or mechanized system.

This paper describes the analysis undertaken to quantify the impacts of improved quality of crack sealing and the economic evaluation of automation, mechanization, and existing manual approaches. This involves an evaluation of the current practice with respect to crack sealing based on responses to surveys and the impacts of the quality of crack sealing.

An assessment of current practice is based on two surveys. The first survey, conducted in the Fall of 1990, involved 7 states of the United States and one Canadian Province. The data were analyzed to estimate the extent of crack sealing, the potential market for automated equipment and the anticipated savings in labor costs. No effort was made to include the effects of increased productivity or consistency in the operation. The survey clearly indicated great variability in current crack sealing practice. The second survey was conducted during the summer of 1991 and was a comprehensive survey of all 50 states including not only extents and expenditures but crew organization and utilization, and safety records. Results of the surveys are presented.

For the automated system the savings in terms of reduced labor costs, and reduced exposure of workers (improved safety) is assessed. A detailed cost estimate for automated equipment is developed. These estimates include equipment acquisition, operating and maintenance costs. The expected productivity and life of the equipment is also considered. The analysis indicates that nationally the mechanized and automated methods provide significant cost reductions.

1. BACKGROUND

Pavement maintenance represents a significant highway expenditure. It is important to forestall rehabilitation and reconstruction and maintain riding comfort. Despite the fact that it is a labor intensive, costly activity it has not been mechanized or automated. While significant research and development has been invested in improved and automated data acquisition, pavement evaluation and decision support, implementation or the actual maintenance activities themselves have received little attention. Recent assessments of the potential of this area for automation (Haas91, Skibniewski90) indicate that recent advances in other fields and current maintenance needs present several opportunities for automation in pavement maintenance. Furthermore, several development efforts are currently underway. This paper focuses on the efforts in automated pavement crack sealing at Carnegie Mellon University, Pittsburgh (Hendrickson91, Hendrickson91a). The analysis of the impacts also applies to the development efforts at the University of California, Davis (Velinsky91). Both efforts are support by SHRP (Strategic Highway Research Program) the former under the IDEA program and the latter under SHRP 107.

A field prototype of a robotic pavement crack sealer has been developed at Carnegie Mellon University. The system identifies pavement cracks using video imaging and verifies that the cracks actually have depth using a laser range sensor. The system then develops a map of the pavement cracks and can be extended to proceed automatically to clean and fill the cracks. The system is intended to reduce labor costs, improve worker safety due to reduced exposure to traffic and improve the quality of the crack sealing operation. A preliminary analysis of the costs and benefits of automated crack sealing indicated that the system is economically feasible (McNeil90). This analysis was based on a limited survey of current practice. To obtain better estimates of the costs and benefits of automation, a more comprehensive survey was administered to determine

- current crack sealing practice,
- the expected extent to which an automated system would be adopted, and
- the expected labor savings due to automation.

This paper describes and summarizes the survey responses and analysis of the economics of automation based on the survey responses.

2. DATA SOURCES

A two page survey was developed to obtain information on current crack sealing practice including materials, crew organization, costs and safety record. The limited survey used in 1990 served as a test for the range of responses and wording of the questions. The survey in 1991 was more comprehensive in terms of the questions asked and its distribution. The survey was mailed to the department of transportation or public works in the 50 states as well as several turnpike and toll authorities, cities and townships, countries and all Canadian provinces. Responses were received from 42 states representing an 84% response rate. Complete mailing lists and responses are included in (McNeil91). The data were entered into a spreadsheet to facilitate summarizing and analysis. Due to the small sample sizes for the cities, townships, counties and provinces this analysis focuses on responses from the states.

3. CURRENT PRACTICE FOR CRACK SEALING

The survey responses indicate tremendous variability in crack sealing practice from organization to organization in terms of both the extent of crack sealing and the methods used. The following subsections provide more detail on expenditures, method of accomplishment, crack preparation, crew size and organization, labor costs, materials, crack sealing periods, safety and expected usage of an automated system.

3.1 Expenditures

Survey respondents were asked for crack sealing expenditures and their total maintenance budget. The proportion of the maintenance budget used for crack sealing is used to indicate the importance of crack sealing for a state. Three states - Alaska, Louisiana, and Wisconsin reported that in general they did not do crackfilling. Others, such as Illinois, indicated that it varied from district to district. Figure 1 shows the variability in the importance of crack filling for the states responding to the survey. Of the 42 states responding, 26 states spend less that 1% of their maintenance budget on crack sealing, compared with 8 states that spend more than 6% of their maintenance budget.

The surveys indicated that an average percentage of maintenance budgets spent on crack filling is 2.8% with a high of 13.3% and a low of 0% for the agencies surveyed. Table 1 provides similar descriptive statistics for each agency type. An estimate of the percentage of budget spent on crack filling for each type of agency is also given in Table 1[1]. The former quantity provides an indication of importance of crack sealing in states where the latter can be used to estimate national expenditures as follows. Total expenditures for crack filling are computed by agency type by determining

1. the percentage of maintenance expenditures used for crack filling based on survey responses (Table 1), and
2. total maintenance expenditures by agency (Table 2).

Using this method, roughly $53 million per year is spent by states on crack filling. The survey responses indicated that in 1990 $48 million was spent on crack filling in 38 states which is comparable. The total value of expenditures in Table 2 is approximately $190 million representing national expenditures on crack sealing, but excluding expenditures by private organizations, the military and airports.

Table 1: Percentage of Budget Spent on Crackfilling Based on Survey Responses

Agency	Min	Max	Std Dev	Mean of % Expenditure	Estimated % Expenditure
States	0	6.00	1.45	1.22	0.69
Provinces	0	5.71	2.55	1.93	1.23
Cities	0.62	13.33	5.96	4.44	1.50
Counties	0	8.33	4.40	3.35	0.83
Turnpikes (1 observation)	0.18	0.18	0	0.18	0.18

Table 2: Maintenance Expenditures by Agency

Agency	Total O&M million $	Amt for Crack Filling million $
States	7,761	53.3
Municipalities	5,707	85.9
Counties & Townships	5,529	46.1
Toll Facilities	1,212	2.2
Total		187.5

Source: *Highway Statistics*, 1989

3.2 Method Of Accomplishment

Crack sealing may be undertaken by agency forces or by contractors or both. Figure 2 summarizes the method of accomplishment (contract, agency forces or both) for each of the states. The majority of states use their own labor forces to seal cracks.

3.3 Crack Preparation

States prepare cracks for sealing using a variety of procedures, either individually or in combination. The procedures include hot air lance, routing, sweeping, compressed air and sandblasting. The number of states using each procedure is shown in Figure 3. All states responding used compressed air to clean cracks but only 16 routed cracks prior to sealing.

3.4 Crew Size and Organization

The procedures used for crack sealing differ by state in terms of the activities involved in crack sealing. For example, some states rout cracks and some states use contract rather than direct labor forces. As a result crew size and organization varies. For the states using agency forces, crack filling appears to be an activity undertaken by multi-functional maintenance crews on an as required basis. The survey responses indicate that on average crews are involved in crack sealing almost 15% of the time. However, the reported crew utilization showed some inconsistencies. For example, it was not clear if reported utilization rates were over a whole year or just the season during which crack sealing was undertaken. Therefore, crew utilization was also calculated as follows:

$$\% \text{ Utilization} = \frac{\$ \text{ spent on crack sealing}}{\text{Sum(daily costs)} * \text{\#months} * 20 \text{ day/month} * \text{\# crews}}$$

Based on calculated values the expected utilization of a crew on crack sealing is 28%. The surveys also provided details of crew compositions. Crew compositions for representative states are shown in Table 3. The average crew size is seven with a maximum of 14 and a minimum of 3.

3.5 Labor Costs

Labor costs vary from $5.11/hr to $23.04/hr with an average of $13.26/hr for a laborer, not necessarily including overhead and profit. These values are significantly lower than Means (Means90) which gives $26.05/hr for a highway laborer including overhead and profit. Crack sealing is relatively labor intensive with labor costs representing over 61% of costs on a per lane mile basis.

3.6 Materials

A variety of materials are used including AC Cement, Asphalt Rubber, Polymerized Asphalt Rubber, Fiberized Asphalt, Emulsified Asphalt, and Asphalt Cutback. The number of states using each material is shown in Figure 4. Some states use different materials for different applications or in different areas so the total number of users exceeds the number of survey respondents.

3.7 Crack Sealing Periods

The months of the year in which states undertake crack sealing vary significantly depending on the location, the temperature and precipitation of the area and the deterioration of the pavement to be sealed. Figure 5 shows the number of states undertaking crack sealing in each month of the year. The most common times for crack sealing are Spring and Fall, but some agencies seal all year (or in all but the very cold months). On average states undertake crack sealing six months of the year. The surveys also indicated that approximately 70% of states use pavement condition to determine when crack sealing is required.

Table 3: Crew Composition for Crack filling (1990 $)

California Composition	Cost	Connecticut Composition	Cost
Traffic Control		Kettle Operator	$11.33/hr
Clean, Fill, Squeegee		Compressor Operator	$11.33/hr
Cover with Sand,	$15.00/hr	2 Truck Drivers	$10.97/hr
Sweep	each	4 Laborers	$10.63/hr
(6-10 members)		2 Flaggers	$10.63/hr
Illinois Composition	**Cost**	**Missouri Composition**	**Cost**
2 Flaggers	8 @	1 Supervisor	$9.82/hr
2 Laborers	$15.35/hr	2 Truck Operators	$8.74/hr
(compressed air)		3 Maintenance	each
2 Laborers		Workers	
(routers)			
1 Wand Operator			
1 Squeegee Operator			
1 Driver	$16.13/hr		
1 Supervisor	$16.42/hr		

3.8 Safety

All states reported that they close a lane to do crack sealing and most (33) states use flagmen. The number of states using various safety measures is shown in Figure 6. However, despite routine safety practices, a significant number of accidents involving maintenance workers were reported. For example, a total of 3681 reported injury accidents involved maintenance workers. Therefore, a slight reduction can have a significant impact.

3.9 Expected Usage of Automated System

The survey responses indicated that 35 of the 42 states would adopt the automated method if it was cost effective. That is, of the states sealing cracks, 90% would adopt the automated system.

4. ANALYSIS OF THE COSTS AND BENEFITS OF AUTOMATION

In order to analyze the costs and benefits of automation, estimates for the number of crack sealing units to be used, the expected costs and the expected savings need to be developed.

4.1 Estimate of the Market for Automated Crack Sealing Units

To develop an estimate of the number of crack sealing units likely to be used by states, the analysis focussed on crack sealing by agency forces. The 35 states indicating that they would use an automated crack sealing system represent 1800

Figure 1: % of Maintenance Budget Used for Crack Sealing

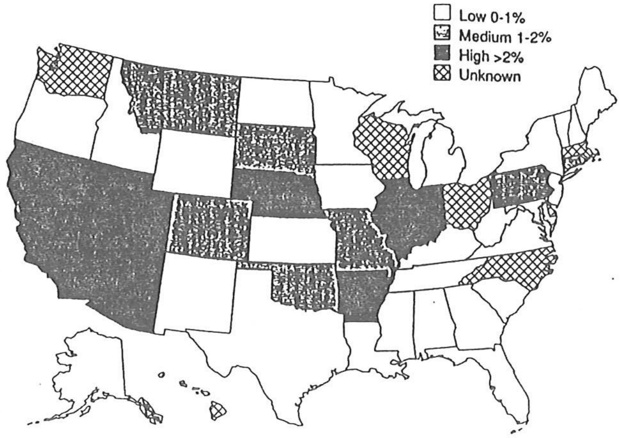
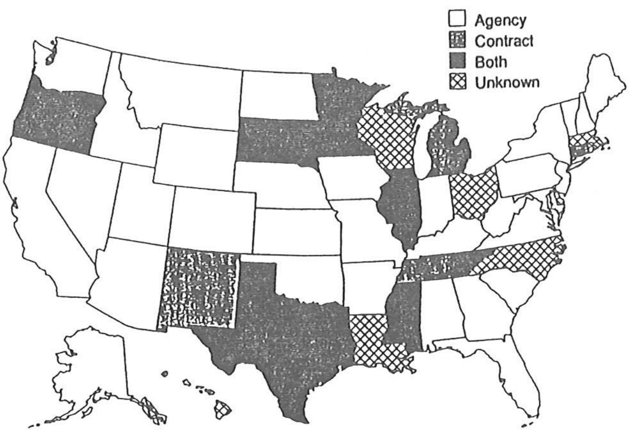


Figure 2: How Cracks are Sealed by State



Note: Some states use more than one method of crack preparation.

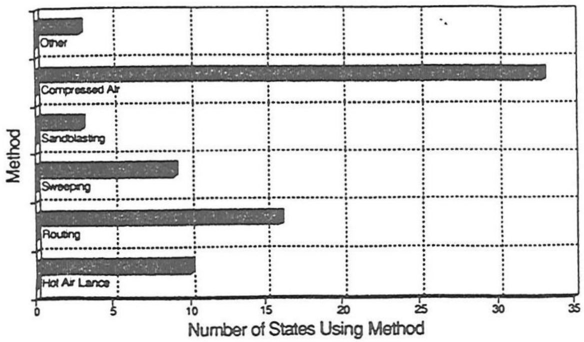


Figure 3: Number of States Using Crack Preparation Procedure

Note: Some states use more than one material to fill cracks.

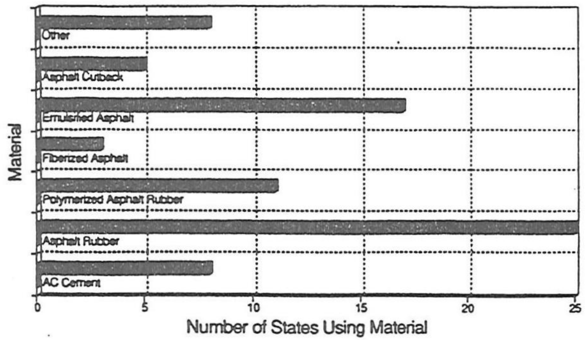


Figure 4: Number of States Using Material

Note: Some states utilize more than one safety measure.

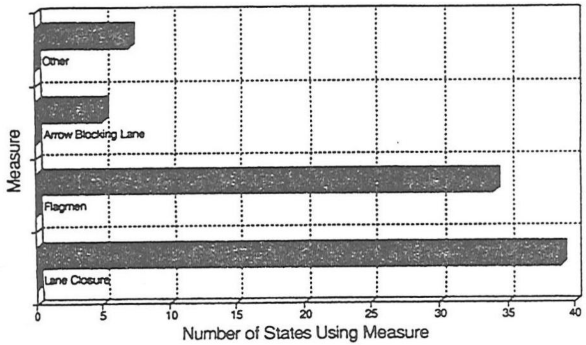


Figure 5: Number of States Crack Sealing in Each Month

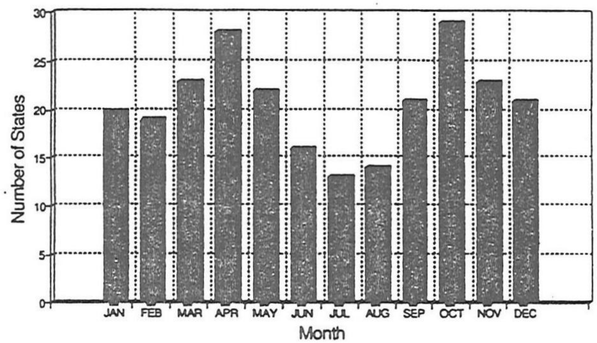


Figure 6: Number of States Using Various Safety Measures

crews. Based on the survey responses, a crew is involved in crack sealing 25% of the time on average. Therefore, it is assumed that a crack sealing system could be shared between 4 crews. Therefore, it is expected that 450 units (1800 crews/ 4 crews per unit) are required nationally by states intending to used automated crack sealing for work performed by agency forces.

4.2 Reduced Labor Costs Due to Automation

An important benefit of automation is the reduced labor costs. The data presented in Table 3 indicates that three (3) laborers could be eliminated from the process while still maintaining adequate supervision of the equipment. These three laborers would normally be involved in cleaning the crack, and using the filling wands. Using the automated system, a crew would then consist of a supervisor, a driver and two flagmen. The expected labor savings are estimated to be:

$$\frac{3\text{ Laborers}}{\text{Crew}} \times \$12/\text{hr} * 0.25 * 2000\text{ hrs/yr} * \frac{6\text{ Months}}{12\text{ Months}}$$

$$= \$9{,}000 \text{ per year per crew.}$$

This is based on the following assumptions:

- The crew uses the equipment 25% of the time for 6 months of the year.
- Average labor rate is $12/hr.
- Available work time is 2000 hours per year.

4.3 Life Cycle Costs for Automated System

Life cycle costs for the system include acquisition costs, and annual operating and maintenance costs (McNeil90). The system acquisition costs are estimated to be $100,000 per unit based on the breakdown of costs given in Table 4.

Table 4: Capital Cost Breakdown

Item	Cost $
Computing	10,000
Generator and UPS	8,000
Controllers and Motors	5,000
Camera and Boom	10,000
x-y table and trailer	10,000
Other	17,000
Engineering, Assembly and Manufacturing	40,000
Total Capital Cost	100,000

Annual maintenance and operating costs of $10,000 per unit per year are based on the following assumptions:

- Software maintenance - $2,500/year
- Energy expenditures - $2,500/year
- Set-up and dismantling costs - $500/year
- Transportation costs between job sites - $1,000/year
- Maintenance and repair - $3,500/year

The system life is assumed to be 6 years based on 6 months operation per year and regular maintenance.

5. NET BENEFITS DUE TO REDUCED LABOR

Using these cost estimates for the automated system and estimates for the labor savings, the difference in expenditures using the automated rather than the manual method can be developed. Using a discount rate of 5%, a system life of 6 years (with the equipment only being utilized for 6 months in any one year), and productivity rates comparable to existing procedures, the net present value of the additional cost (acquisition, maintenance and operating) of the automated system is $150,760[2]. When subtracted from the labor savings over the life of the system of $182,736[3] the net labor savings are $31,976 per unit over the life of the system or $6,300 per unit per year. Annual crackfilling expenditures by states were estimated to be $53.3 million per year and it is expected that 450 units will operate nationally. This gives a national saving of approximately $14.4 million over the 6 year life of the equipment or $2.84 million per year, or 5.3% of estimated expenditures by states for crack sealing.

6. OTHER BENEFITS OF AUTOMATION

6.1 Improved Safety

By substituting robotic systems for manual work in the field, the exposure of workers in unsafe roadway conditions is greatly reduced. With typical injury accident costs of $1,100 for medical cases and $21,100 for for restricted activity/lost work day cases (Hinze91)[4] and assuming a 1% reduction in reported injury accidents in each year represents a savings of $180,700 based on thirty (30) medical cost injury accident and seven (7) restricted activity/lost work day accident.

In addition to exposure to uncontrolled vehicular traffic, roadway workers applying crack filling material are exposed to volatile organics that can cause dermatoses and respiratory problems, and the equipment and traffic noise may lead to impaired hearing. Furthermore it appears that this procedure can be extended to joint sealing where workers routinely used sand blasting equipment for cleaning.

6.2 Improved Quality

While the automated system is not expected to increase crew productivity, the consistency of the crack filling operation can be improved. The improvement occurs in several phases of the operation such as accurate crack identification, uniform cleaning and potentially, delivery of material at a rate appropriate to the depth and width of the crack. Benefits will be derived from improved durability of the pavement due to proper sealing of the crack, including longer pavement life and reduced user costs due to delays for resealing pavement cracks or undertaking other maintenance activities.

To illustrate the potential benefits of improved consistency the following example is based on data from (Chong88). Consider a crack sealing operation that is to be undertaken 2 years after the pavement is rehabilitated. This extends the pavement life from 12 years to 16 years at which point rehabilitation is required. Assume that more consistent crack filling using the automated method extends the pavement life an additional year. If rehabilitation costs including user delay during rehabilitation are $40,000 per lane km, savings are achieved from the time value of money when the rehabilitation is deferred one year and from the additional year of life the pavement has gained. Over the pavement life this is equivalent to a savings of $145 per lane km[5]. Based on the survey response approximately 77,000 lane km of cracked road are sealed annually. Conservatively, assuming that only 50% of sealed cracks extend the life of the pavement by an additional year (or that the automated system is only used to seal 50% of the cracks) gives a saving of $5.6 m per year. This represents an additional savings of approximately 10% of the cost of crack sealing.

This analysis indicates that significant savings may be realized from improved consistency.

7. LIMITATIONS OF THIS ANALYSIS

As this analysis is based on survey responses, the limitations should be noted:

- The survey responses may not represent a random sample due to biases introduced by non-responses.
- Actual labor costs may be higher, as reported labor cost are significantly less than Means figures including overhead. Therefore, larger savings may be realized.
- Analysis focuses on crack sealing by state public works or department of transportation crews that work on crack sealing as just one of many maintenance operations. Additional crack sealing units and ultimately labor savings will be realized as contractors adopt automated crack sealing. Additional savings may also be realized if organizational changes occur and specialized crack sealing crews are used to ensure more effective utilization of the equipment.

Sensitivity analysis indicated that the net benefits of automation vary significantly with the values of the parameters and costs assumed (Deng, 1992). However, conservative cost and parameter estimates have been reported in this paper.

8. CONCLUSIONS

The analysis shows that automated crack sealing is economically feasible and desirable. Assuming the elimination of three laborers, the labor savings of $9,000 per year per crew represents 5.3% of annual crack sealing costs. The analysis is based on crack sealing by agency forces and assumes crack sealing is undertaken 6 months of the years and a crack sealing system (one piece of equipment) is shared between 4 crews. Automation of this process is expected to require about 450 crack filling units nationwide. Furthermore, the economic impacts of improved consistency may be significant.

Notes

[1]The average of the percentage expenditure is the mean of the ratios for each agency where the estimated percentage expenditure is the ratio of the mean expenditure on crack sealing divided by the mean maintenance budget (Cochran77).

[2]($100,000 + (P|A 5%, 6) * 10,000) where (P|A, 5%, 6) is the present value of an annual amount over a 6 year period at a 5% discount rate and is equal to 5.076.

[3](9,000 * 4 * (P|A, 5%, 6))

[4]Based on reported costs for 249 medical cases and 65 restricted activity/lost workday cases, including indirect costs as 118% and and 206% of direct costs respectively.

[5]Based on a savings of $((A|P,5\%,17)/(1.05)^{17}-(A|P,5\%,16)/(1.05)^{16})$ *40,000 where (A|P, i, n) is the annual equivalent over n years at interest rate i.

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