SD97-06-F

PB99-132870

SD Department of Transportation
Office of Research

Process Evaluation of Spray Injection Method for Asphalt Surface Repair

Study SD97-06
Final Report

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

Prepared by
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December, 1998

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ACKNOWLEDGEMENTS

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. SD97-06-F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Process Evaluation of Spray Injection Method for Asphalt Surface Repair		5. Report Date December 18, 1998 6. Performing Organization Code
7. Author(s) Richard A. Reid		8. Performing Organization Report No.
9. Performing Organization Name and Address South Dakota State University Department of Civil Engineering Box 2219, CEH 106 Brookings, SD 57007		10. Work Unit No. 11. Contract or Grant No. 402051
12. Sponsoring Agency Name and Address South Dakota Department of Transportation Office of Research 700 East Broadway Avenue Pierre, SD 57501-2586		13. Type of Report and Period Covered Final; July 1997 to December 1998 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

One method of reducing manpower without cutting production in highway maintenance is to use the spray injection method for asphalt surface repair. Although the benefits of using this method have been well documented by previous research such as the Strategic Highway Research Program Report H-353 *Innovative Materials Development and Testing*, there are some major unsolved problems unique to its use in South Dakota. Specifically, the emulsions necessary for spray injection operation must be maintained at or near room temperature and most have a relatively short shelf life. Emulsions are generally purchased in substantial volumes to keep the shipping costs to a minimum. During the spring and summer months, this poses no problem but in the winter and early spring, when a substantial portion of repair should be done, handling and storage of emulsions is a problem. Another area of interest is the potential for cooperative scheduling and sharing of equipment and materials allowing the greater productivity of spray injection technology. The objective of this research was to determine if spray injection repair assets within the State of South Dakota could be kept in service during all or part of the winter months. This would be done through an evaluation of the spray injection method equipment, material storage and handling requirements, training programs, equipment maintenance requirements, equipment productivity and scheduling, safety and cost analysis.

The work included interviews with over twenty organizations involved with the spray injection method for asphalt surface repair. This included spray injection equipment manufacturers, asphalt producers, state and federal highway maintenance organizations, commercial contractors, and storage tank manufacturers. From the information collected from these interviews and a review of previous research in this area, recommendations for proper year round material supply and storage requirements, equipment scheduling methods, opportunities for interagency cooperation, training requirements, acquisition and operation costs, and cost/benefit analysis data were developed or documented.

17. Keyword Spray injection, Pothole Repair		18. Distribution Statement No restrictions. This document is available to the public from the sponsoring agency.	
19. Security Classification (of this report) Unclassified	Security Classification (of this page) Unclassified	21. No. of Pages 33	22. Price

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CHAPTER 1

EXECUTIVE SUMMARY

Background

In the early 1990's, the Strategic Highway Research Program (SHRP) sponsored research investigating innovative methods for pothole repair in asphalt pavement. The results of this research, published in 1993 (SHRP, 1993), concluded that the spray injection method of asphalt surface repair was a viable method for repairing potholes in asphalt pavements and that it was desirable for use in adverse weather conditions. Additionally, it was concluded that this method improves the safety of highway workers and the traveling public. The binder material used in the spray injection repair method is emulsified asphalt, which is a mixture of asphalt and water. Because the binder material is water-based, it is susceptible to freezing at low temperatures, which may limit the use of this repair method in cold weather climates.

Purpose

The purpose of this research was to determine if the spray injection repair assets within the State of South Dakota could be kept in service during all or part of the winter months. Additionally, this study would investigate the usage rates of the equipment in the state and if coordination within the various highway maintenance organizations would result in increased equipment usage.

Approach

In order to determine how to increase the number of months per year that spray injection repair equipment could be used, each individual component of the spray injection process was to be investigated. Specifically, this consisted of examining the manufacturing process used to construct spray injection repair equipment, meeting with

an asphalt emulsion producer, interviewing users of the various pieces of spray injection repair equipment, observing how the materials used in the equipment was supplied and stored, and obtaining information on system costs and maintenance requirements. While conducting the investigation, specific attention was placed on how cold temperatures effected each component of the process and how the various organizations involved adapted to those effects.

Significant Findings

The following are the most significant findings from this investigation:

1. Truck mounted spray injection repair machines can be successfully used throughout the year in South Dakota.
2. Trailer mounted spray injection repair machines may be used in cold weather, however worker exposure to the cold, safety issues, and inability to keep the aggregate warm prevents users from using the equipment in the winter.
3. The cost of obtaining a heated storage tank for asphalt emulsions with the capacity to support one truck mounted machine during the winter months is approximately $6,000.00
4. Specialized storage for aggregates may be recommended, but is not required.
5. The life cycle cost of spray injection repairs, on a cost per cubic foot basis (installed), is the most economical method for pothole repair.
6. Potholes repaired by the spray injection method have a reported life of 21 months.
7. Spray injection repair equipment can be successfully shared between SDDOT regional offices and their respective area offices.
8. Maintenance requirements of spray injection repair systems do not appear to be any greater than other standard highway maintenance equipment.
9. Initial training by the manufacturer or other experienced user requires two days.
10. Truck mounted systems used in South Dakota are typically operated by a single operator. Flaggers or follower vehicles are used on state highways.
11. Truck mounted systems may be used at night.

Conclusions

The spray injection method for pothole repair provides significant advantages in the South Dakota climate. These advantages include year round operation, higher quality of repair, longer lasting repairs, more production with fewer personnel, and the lowest life cycle cost of any repair method. Disadvantages are the specialized storage requirements for asphalt emulsion and the initial capital investment for the equipment.

Winter repair of potholes is a difficult operation because it is currently done by hand. Workers are exposed to the cold and they require additional measures to ensure their safety while working. The methods currently used may only provide a repair that lasts as little as two months, requiring workers to continue repairing the same hole multiple times in a year. This reduces productivity and leaves a negative perception with the public.

Alternatively, when spray injection systems are used for these repairs, patch life increases up to 21 months. In truck mounted systems, these repairs can be placed with a crew of one. Because this person performs the work from inside a heated cab, that worker can repair more potholes in a given day, protected from both the elements and traffic hazards. The longer lasting patches placed by these machines allow maintenance organizations to work on more repairs, which would increase road user satisfaction. Finally, the timely repair of pavement distresses would serve to increase the life of a pavement by slowing pavement deterioration.

Recommendations

Recommendation One:

If the SDDOT continues to only use trailer mounted spray injection equipment, then obtaining specialized storage for winter operations may not be feasible.

Worker exposure to winter weather limits the number of days trailer mounted systems may be used. Also, trailer mounted systems do not have on board aggregate storage. Aggregate is fed from the towing vehicle, which does not have the capability of keeping the aggregate warm. If the aggregate gets cold, then the mixing of cold aggregate and hot emulsion does not allow for proper set of the materials. However, the main reason trailer mounted systems are not used in the winter months is due to worker exposure to the cold and operator safety considerations.

Recommendation Two:

The SDDOT should consider using truck mounted systems and developing heated emulsion storage if they desire to use spray injection repair methods throughout the year.

Experience from the city of Sioux Falls and numerous cold climate states has shown that truck mounted systems can operate successfully throughout the year in winter climates. These same organizations have shown that, for a rather moderate investment, heated emulsion storage can be constructed.

Recommendation Three:

The use of alternative oils should be demonstrated by the manufacturers and not left to the users.

The use of oils other than CRS-2 has been tried by many organizations. In some cases, one organization would report limited success with an alternative oil. However, conversations with other uses report no success with the same material. Until an asphalt producer or another user can show better evidence that their alternative oil will work, it appears that users should continue to use CRS-2.

Recommendation Four:

To perform spray injection repairs throughout the year, equipment could be obtained and coordinated by each regional office.

One potential method to do this would be for regional offices to obtain truck mounted systems and heated emulsion storage at a cost of approximately $120,000.00 These trucks could be dispatched from the regional office to the area offices as needed. If additional emulsion is needed, users from the area offices could travel to the regional office to obtain additional emulsion as needed. This emulsion could be transported in distributor trucks and stored inside in a heated garage or maintenance area. Each area office would need to have at least one qualified operator trained on the use of the machine.

CHAPTER 2

PROBLEM DESCRIPTION

Problem Statement

One of the most challenging problems facing the maintenance department of any highway agency is the repair of potholes and wide cracks in the pavement structure. Eliminating these pavement distresses is critical to the survival of the pavement. Without timely maintenance, water intrusion into the base course and continued traffic can destroy a pavement in a short period of time.

Recently, the development of the spray injection method for asphalt surface repair, also known as spray patching, has resulted in a mechanized repair process for localized pavement distresses. The spray injection method now provides a self-contained system that can transport asphalt and aggregate to the repair location, mix the materials, and perform distress repair with only one equipment operator. Although the mechanical aspects of the transportation, mixing and delivery have been addressed by the spray injection method, the logistical requirements necessary to optimize the productivity of this equipment for an individual user or a network of users has not been addressed by the equipment manufacturers or through a research study. The State Department of Transportation has identified two problems unique to users in South Dakota. The first problem is how to provide greater usage of this equipment in the winter months when the asphalt emulsions used in the process must be stored at approximately room temperature and applied at higher temperatures. This problem is also affected by the limitation that emulsified asphalt is purchased in large volumes to minimize shipping costs. This problem has resulted in idling of the spray injection equipment in the winter months and resorting to less efficient manual repair methods.

The second problem area is that if multiple agencies within the state operate their own spray patch injection systems, they will also have to develop the necessary logistical support to keep these systems operational. For example, each user may set up their own storage area for aggregate and emulsified asphalt. This may result in a redundancy

within the state, which could be more efficiently addressed through a series of centrally located storage areas for multiple users.

Additionally, spray patch equipment is typically operated in areas with the greatest number of roads and traffic usage. Currently, Sioux Falls, Rapid City, Aberdeen and the Mitchell area have enough repair work to justify owning spray injection equipment even though it may only be used for part of the year. Rural areas, which have less repair work and therefore cannot justify the capital expense, are relying on manual patching methods. Cooperation between the various highway agencies within the state, coupled with increasing the number of months the equipment could be used, would result in more repair work being done with the same number of spray injection machines, with a commensurate reduction in the number of man-hours required because fewer manual patches would be placed.

The research proposed herein is focused on three issues: lowering the unit cost ($/cu. Ft.) of spray patching, expanding the use of spray patching technology, and making the existing spray patch assets within the state accessible to more users. This will require identifying and developing cost effective methods for the proper storage of the materials used with spray injection asphalt repair. This will be accomplished by identifying regional users of spray injection asphalt repair systems and investigating, documenting, and analyzing the successful and unsuccessful approaches used by these organizations. Also, this research will recommend methods for coordination of spray injection equipment, storage facilities and materials within the state to eliminate redundancy and provide maximum efficiency. This will be accomplished by evaluating the assets that exist within the state related to the operation of spray injection equipment, repair needs in the state, and developing scheduling and management methodologies to fully exploit the resources within this state related to the use of spray injection equipment. Additionally, cost/benefit analysis of the various approaches must be developed to quantify the economy of each approach.

Background Summary

Distresses in asphalt pavements may be caused by improper design or deficiencies in construction, materials, and maintenance. To the engineer, pavement distresses provide insight as to the cause of the deterioration of the pavement. The timely repair of these distresses is necessary to slow the rate of pavement deterioration. To the roadway user, the cause of the distress is of little concern. What driver's demand is a serviceable road that will safely and efficiently transport them to their destination and provide a smooth ride at adequate speed. Their view of the highway engineers and maintenance personnel is often based on how our highway system meets these demands.

The repair of pavements with distresses that cover large areas may be performed relatively quickly and efficiently through the use of overlays and seal coats. These methods can take advantage of heavy equipment and mechanized processes resulting in lower unit costs. Localized distresses, such as potholes, have to be repaired individually. Three common methods used for pothole repair are: 1) throw and roll, 2) semi-permanent, and 3) spray injection. Research by the Strategic Highway Research Program (SHRP) (Wilson and Romine, 1993) provided an objective evaluation of these different pothole repair methods to determine which are the most effective under actual traffic and climatic conditions.

The most prevalent method of pothole patching is the "throw-and-roll" or "dump and run" method. This method consists of placing the repair material into a pothole with no preparation of the pothole (i.e. removal of water and debris), compacting the patch using a number of passes with a truck tire, ensuring the patch had a slight crown, and then moving on to the next distress location.

A second method is the semi-permanent repair or "do-it-right" method. This is a partial-depth repair that starts by removing all water and debris from the pothole using compressed air or a broom. The sides of the pothole are cut vertical such that sound pavement exists on all sides and patching material is then placed into the hole. The material is then compacted with a vibratory plate compactor before moving onto the next hole.

The spray injection method consists of a self contained, truck or trailer mounted system that uses air to blow the water and debris out of the hole and sprays the bottom of the hole with a binder material to serve as a tack coat. At this time the asphalt and aggregate are sprayed into the hole simultaneously until the repair elevation is slightly higher than the surrounding pavement. The top of the patch is then covered with a thin coat of aggregate to prevent tracking by vehicle traffic before moving on to the next distress location.

An economic analysis comparing the five-year cost of the three repair methods is presented in the SHRP report. The throw and roll, semi permanent, and spray injection methods had unit costs of $44.38, $42.08, and $10.54 per cubic yard of placed repair material. The estimated repair life of the throw and roll repair was 3 months, 12 months for the semi-permanent, and 21 months for the spray injection repair. Also, both the throw and roll and spray injection methods could place four tons of repair material per day, while the semi-permanent repair could only place 1.5 tons of material per day. Material, equipment, and labor costs as well as repair life were included in this evaluation.

Based on the cost data presented by the SHRP, the spray injection repair method clearly provides an economic advantage over the other methods. However, in South Dakota these economic advantages cannot be fully exploited because of the problems associated with the freezing of stored emulsified asphalt in the winter, forcing highway maintenance agencies to resort to the clearly less cost effective throw and roll repair method. Also, rural users are forced to use less cost effective repair methods because they do not have access to this repair equipment.

CHAPTER 3

OBJECTIVES

Defined Objectives

The primary objective of this research proposal is to determine if the existing spray injection repair assets within the state can be kept in service during all or part of the winter months and to determine if coordination between the various highway maintenance organizations would result in increased usage of the equipment. To meet this overall objective the following sub-objectives have been identified:

1. Outline methods for coordinating the use of spray injection asphalt repair equipment, storage facilities, and materials within the department and local government maintenance forces. This will be accomplished by identifying organizations within the state that have any of the assets required to support the spray injection method of asphalt surface repair. Once sources have been identified, the quantities of materials needed by receiving organizations will be estimated and the feasibility of transferring the assets from one organization to the other will be determined. Coordination methodologies will consider quantities of materials available in storage, quantities needed by the users, costs of transporting and handling materials, scheduling requirements, and the transfer of funds or in kind services between organizations.

2. Identify cost effective methods for year round storage and handling of materials used with spray injection asphalt repair. This will be accomplished by first determining what minimum level of facilities are necessary for providing effective storage and handling. Current users of this technology and material suppliers will be interviewed to determine what innovative methods have proven effective in meeting storage requirements. An assessment of the success of these storage methods will also performed. This information will be used to determine where material storage and handling facilities exist within the state, or if any existing facilities can be modified to

meet system requirements. If existing facilities are not available or modification is not feasible, then effective methods of storage and handling may require one organization providing storage and allowing other organizations access to that material rather then building redundant storage facilities throughout the state.

Accomplishments

The objectives of this research were met through the completion of the research tasks listed in Chapter Four and the findings are detailed in Chapter Five. Because the existing spray injection repair equipment owned by the state is not suited for cold weather operations, it was determined that these assets could not be kept in service during the winter months. Year round storage requirements and usage quantities were established, a method to coordinate equipment use is proposed, equipment productivity was determined, cost-benefit data was established and training requirements summarized. Based on these accomplishments, recommendations are made as to how the South Dakota Department of Transportation could develop and implement a year round spray injection repair capability.

CHAPTER 4

TASK DESCRIPTION

Research Plan

The work plan for carrying out the research objectives is detailed below. The plan takes the form following the tasks in the Request for Proposal and briefly details the methods for performing each of the tasks. The information obtained in the accomplishment of these tasks is discussed in greater detail in Chapter 5.

Task 1

Meet with the technical panel to review project scope and work plan.

A meeting between the principal investigator and technical panel took place on July 10, 1997 in Pierre. The technical panel provided input as to potential sources of information relevant to the topic within the state. These included various state Department of Transportation offices, as well as city and county highway maintenance organizations. The technical panel also provided input as to the prioritization of the tasks. It was realized that the number of budgeted work hours would allow for some tasks to be investigated more thoroughly than others. It was concluded that the primary focus was to learn and document how organizations both in and out of state were conducting spray injection repairs, with special attention paid to cold weather operations, training, material handling and storage, and scheduling of equipment. Additionally, site visits to some maintenance organizations, spray injection equipment manufacturers, and asphalt emulsion producers were also a priority. Because of the amount of information produced in the 1993 SHRP report relative to the costs and benefits of the spray injection repair process and the time required to develop benefit/cost data, this task was determined to be a lower priority. With respect to training, this report would document how both the equipment vendors and users currently conducted training, however this project would not develop new training materials.

In summary, it was realized that an important part of this project was to document how spray injection repair systems were being used for road maintenance. The technical panel realized that considerable experience was developing relative to the use of this equipment, yet little information was available in written form. Each new user of spray injection equipment was often required to "learn as they go" with this equipment which does not allow them to benefit from the experience of others. By documenting the experience of others, successful ideas, borne from experience, could be passed to new users. From this base of knowledge, a review of the SDDOT spray injection repair assets could be made and recommendations could be made for potential methods to increase their use in the winter. Also, this project should be open to identification of problems or issues not specifically addressed in this study to determine if there were other technical issues that should be investigated in the future.

Task 2

Continue a literature search to identify spray injection asphalt repair vendors, material sources, and material storage and handling requirements.

A literature review was conducted through the Transportation Research Record, Federal Highway Administration, The Engineering Index®, Transportation Research Information Services, and Science Citation Index.

Task 3

Conduct meetings with representatives of the manufacturers of spray injection asphalt repair equipment.

In September 1997 a site visit was made to Rosco Manufacturing Company in Madison, SD and Wildcat Manufacturing Company in Freeman, SD. At each site a tour of their manufacturing operation was conducted and meetings were held to discuss the spray injection method for pothole repair. Each company was able to provide lists of customers who were using their equipment for pothole repair. Additionally, copies of equipment training manuals and videos and related information were also obtained.

Task 4

Review existing spray injection repair processes used by DOT's and other maintenance units both in South Dakota and in adjacent states to assist in satisfying the research tasks.

After completion of tasks 1-3, over 20 personal visits and telephone calls were made to commercial companies and state, county, and city highway maintenance organizations using spray injection repair equipment as well as asphalt distributors. Conversations centered on obtaining the type of information listed above in the task statement. The information obtained from this task is the basis for the discussion in tasks 5-9.

A general list of questions asked to each user is as follows:

a. What spray injection equipment do you use?
b. Do you use it year round?
c. What do you like about it?
d. What problems do you have?
e. What aggregate do you have the most success with?
f. How do you store emulsion in the winter?
g. How do you dispatch your equipment?
    a. Response to emergencies
    b. Routine maintenance
    c. Part of a pavement management plan
h. How do you conduct training?
i. How much time is spent on equipment maintenance?
j. How many repairs can you complete per day?
k. What safety measures do you use?
l. How do you store your aggregate?
m. Do you do work for other organizations?

The organizations contacted during tasks 3 and 4 are listed as follows:

Wildcat Manufacturing, Freeman, SD
Roscoe Manufacturing, Madison, SD
Sheehan Mack Sales & Equipment, Inc., Sioux Falls, SD
Jebro, Incorporated, Sioux City, IA
Unique Paving Materials, Inc., Clevland, OH
City of Sioux Falls Street Department, SD
Pennington County Highway Department, SD
Union County Highway Department, SD
South Dakota Department of Transportation
- Rapid City Regional Office
- Yankton Area Office
- Mitchell Regional Office
- Headquarters, Pierre
- Aberdeen Regional Office

Kittitas County, WA
City of Billings, MT
Alaska DOT, Anchorage Area
Thielbars, Madison, SD
Patchworks, Inc., MI and Ontario, Canada
City of Marquette, MI
Minnesota DOT, St. Cloud Area
Huron Tank and Culvert, Huron, SD

Tasks 5 through 10 are listed below. Each one was accomplished based on the information obtained in tasks 2 through 4. When necessary, follow up calls were made to clarify questions or to obtain additional information.

Task 5

Recommend proper material supply and storage methods particularly noting winter operations.

Task 6

Identify scheduling management needs with respect to emergency use and general highway maintenance through interviews with state and local jurisdictions. The scheduling of equipment is based on three primary factors: 1) how much work a piece of equipment may accomplish in a given time period; 2) what volume of work needs to be accomplished; and, 3) material usage rates to maintain adequate quantities of raw materials on hand.

Task 7

Identify opportunities for interagency cooperation to enhance efficiency and productivity.

Task 8

Identify initial and ongoing training required, including a course outline, for specific spray injection systems

Task 9

Identify system acquisition and operations costs and provide maintenance requirements.

Task 10

Produce cost/benefit analysis of manual methods versus various machine methods considering signing, traffic control requirements and material storage. Include factors such as patch life, material costs and other pertinent costs. Discuss intangibles such as personnel safety and public perception.

Task 11

Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, and recommendations.

A draft report was submitted to the Technical Panel in October 1998 and a final report was submitted in December 1998.

Task 12

Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

A presentation to the Technical Panel was made on November 24, 1998.

CHAPTER 5

FINDINGS AND CONCLUSIONS

Introduction

Based on the research tasks and work plan, information was gathered and the findings are summarized in seven categories: Literature Review, Material Storage, Scheduling Management, Interagency Cooperation, Training, Acquisition/Operation Costs, and Cost-Benefit Analysis. The findings in each of these categories are summarized below.

Literature Review

In searching the various sources of literature little information specific to spray injection repair methods was found. The 1993 SHRP report remains the sole research report that provides a comprehensive presentation on the quality and relative costs of the various pothole repair methods. Other articles that were found were based on the 1993 SHRP report, with no new or additional information. A few magazine articles were also identified, however they were non-technical in nature and were written to provide a reader with limited background on the subject an introduction to the spray injection repair process. In most cases, the articles were co-written by the spray injection repair equipment manufacturers as a way to publicize their products. Additionally, one web page was located (http://www.r-n.com/) of a commercial company in Canada that does spray injection pothole repairs. Their web page describes the process and capabilities of their equipment and shows pictures of the spray injection repair equipment at work. Considerable information was identified related to the more traditional methods of pothole repair and the equipment and materials used in those methods.

Material Storage

Emulsified asphalt and aggregate are the only two material components necessary for the spray injection repair method. Proper storage of these materials is essential to the success of the patching operation, especially in cold weather.

Emulsified Asphalt

Because emulsified asphalt contains 30 to 45 percent water, they are sensitive to temperature extremes due to freezing or evaporation of the water. Exposure to temperature extremes will therefore cause significant degradation of the flow and setting properties of the asphalt. The cold weather effects on asphalt emulsions causes two problems. First, emulsified asphalt users must have heated storage for the emulsion. Since most do not, they do not buy emulsified asphalt in the winter months. The second problem is that due to the decreased demand and the requirement for heated storage at the distribution points, asphalt suppliers in the northern climates often do not manufacture asphalt emulsion in the winter (Jebro, 1997; Sioux Falls, 1997). Most local users reported that emulsion distributors in Iowa and Minnesota stop production of emulsion in the fall. The nearest year round source reported by users is Kansas City, MO. Even with these limitations, highway maintenance organizations that aggressively pursue spray injection repair methods have found ways to work within these limitations.

Organizations that store emulsified asphalt during the winter months have employed three different storage techniques. The first is to use outdoor heated storage tanks; second, indoor tanks; and third, indoor storage on vehicles with tanks.

In each case users reported storing the emulsion at a temperature in the range of 40 to 50 degrees Fahrenheit. Although agitation is recommended for emulsions in storage, most users did not use any mixing devices to agitate their emulsions. Three types of agitation were reported: 1) circulating pump, 2) convection heat and, 3) none. For circulating pump agitation, emulsion was simply pumped from the bottom of the tank and to the top of the tank. For the convection heat agitation, blanket heaters at the base of the tank warmed the emulsion which caused it to rise up, allowing the cooler emulsion to

sink to the bottom. This allowed the material in the tank to periodically "turn over" and reduce settlement. Finally, some users reported using no agitation in their tanks. These tanks were stored indoors and did not have a heating system within the tank. These were often users who used the tanks on distributor trucks for storage. Because these tanks stored smaller amounts (<1500 gallons) they were able to use up the emulsion before significant settlement occurred.

Users reported that if agitation methods were used in their tanks and the temperature was maintained in the 40 to 50 degree range, emulsified asphalt could be stored for approximately four months without any noticeable difference in patch quality. Users that stored their emulsion in tanks without agitation used the material in less than a month with no noticeable affect on patch quality.

Because the emulsified asphalt needs to be applied at approximately 125 to 165 degrees, the stored emulsion is pumped into the spray injection repair machine storage tank the night before use. During the night, the emulsion is heated using the on board heating system.

Aggregate

Among the spray injection equipment users, quartzite, granite, and limestone were the most common aggregate mineralogies. The chip size most frequently used was 3/8", followed by ¼" and then 5/16". In each case, angular, crusher run chips were preferred over rounded pea gravel. The angular chips were reported to lock together and hold a tighter patch. Although there were occasional reports of aggregates that were incompatible with emulsions or spray patches, those users reported that simply changing supply sources solved the problem. The problems universally reported by the users were the percentage of fines in the aggregate, moisture content, and for limestone aggregates, haul distance.

In each case, users reported that washed aggregates were necessary for use in spray patching. Manufacturers recommend using aggregate with less than 3 percent passing the number 200 sieve. The presence of fines tend to cause the emulsion to break faster because they possess greater surface area than an equal weight of coarse aggregate. Also, dirty aggregate or excessive fines may accelerate breaking and retard curing

(Roadpatcher, undated). This low tolerance for fines can present a problem for users who store their aggregate in unprotected outdoor storage for long periods of time in areas of high winds and/or dusty conditions. In many cases, after a period of time the stored aggregate had to be washed again prior to use in the spray injection repair equipment because it had accumulated excessive fines while in storage. This problem was only reported in Montana.

In terms of mineralogy, users of limestone aggregate were sensitive to the haul distance from their aggregate sources. Limestone aggregate tends to abrade during shipment and create fines. Excessive handling and shipping of limestone resulted in an aggregate that was very clean upon leaving the plant, but when delivered it had a higher percentage of fines. This problem was reported in Michigan where aggregates for the state DOT are purchased by one state contract in bulk and then shipped to all users. This aggregate was shipped across the Great Lakes, offloaded into stockpiles, loaded into trucks and shipped statewide.

A second problem with outdoor storage of aggregates is that they should not be used when cold. A cold aggregate when mixed with hot emulsion will cause the emulsion to cool too quickly and the emulsion will break. Although aggregates need not be heated like the emulsion, manufacturers do not specify an optimum aggregate temperature. Most users reported that in the winter months aggregates worked successfully if they had been warmed in a garage overnight. Finally, aggregates stored outside in freezing conditions tend to freeze into chunks. Aggregate that was frozen into chunks clogged the machine.

Some users reported having indoor storage for aggregates and that they were moved to a heated building prior to placement in the spray injection equipment. Other aggregate stockpiles were partially covered with tarps.

Finally, the moisture content of the aggregate also affects the operation of the machine. Aggregate that is totally dry creates too much dust and aggregate that is too wet clogs the machine. Wet aggregates will also slow the curing because they will not be able to absorb water from the emulsion, which speeds setting. No minimum or maximum water contents were ever specified by the users or the manufacturers.

Other Oils

Many users reported using different oils for use in their machines. The equipment manufacturer's (Rosco, 1995; Roadpatcher, undated) recommend using emulsions or asphalt cements, but recommend against using cutbacks. The most common emulsion used was a CRS-2 and very few problems were reported for that oil. A few users had used some high float oils (HFRS-2) which worked well in summer operations but always lead to bleeding of the patch. Another user reported using a medium set emulsion (MS-2) in the winter because the CRS-2 tack layer gets hard in the cold. However, this led to bleeding. The most common emulsion used by far was the CRS-2.

A user in Michigan is preparing to test a new (or modified) oil being developed by the Unique Paving Materials, which does have a distributor in Sioux Falls. Their corporate headquarters was willing to donate some of this material to a user who was willing to conduct field trials. It was described as a cutback with additives. The Michigan user has done one field test with limited success, however the problem was felt to be related to too many fines in the aggregate. Some spray injection equipment vendors recommend cutback asphalts should not be used in their machines. The development of a non-emulsified asphalt for use in spray injection repairs would simplify the winter storage requirements for the oil.

Scheduling Management

The amount of work done in a period of time can be reported a number of ways. Some users report the quantity of raw materials used in a time period and this was reported in some cases by volume and in others by weight. Other users report a number of patches installed in a day. All of these values will be reported to give a general feel for the productivity of the truck-mounted equipment.

In an eight-hour day, one commercial user reported using approximately 6 cubic yards of aggregate and 200 gallons of emulsion. One county highway maintenance supervisor was able to report productivity in patches per day. For patches less than 1 foot in diameter, they were able to typically fill 57 in a day and spray 300 feet of shoulder. For medium patches (1-3 ft. diameter), 90 could be filled in a day, and for large (>3 ft.

diameter) 110 could be filled in a day. Another user reported a machine could fill an estimated 120 patches per day. All of these values are based on relatively short travel distances between patches. As one might expect, these values would decrease rapidly if there were significant travel distance between patches.

Another user reported they could place 2 to 2 ½ tons of patch material per day, with more being placed if they were filling larger utility cuts instead of potholes. If most truck mounted machines carry 300 to 400 gallons of emulsion and 5 tons of aggregate, users report needing to refill the emulsion tank every third day when they are busy, and a minimum of once a week. This generally requires refilling the aggregate every day to day and a half.

For trailer mount machines, productivity may be +/- 50% of the truck-mounted system. This difference comes from where the patching work needs to be done. In a parking lot, a trailer mounted system may outperform a truck mounted system if the potholes are close together. The trailer-mounted system is more productive in confined spaces. The truck-mounted system has a more limited radius of operation and may have to spend more time repositioning itself to repair the potholes. Conversely, the truck-mounted systems are much more productive repairing individual potholes on streets.

These figures should provide a good basis for any user to estimate both the anticipated productivity of these machines and quantities of materials needed on hand to support their operation.

Finally, no user was able to report any quantity of work needing to be accomplished. For those who kept their machines in use year round, they simply reported they were never without any patching requirements. At the same time, they did not report any extensive backlog of work either. Most users reported they stopped running their spray injection repair equipment for reasons other then lack of potholes. Lack of emulsion, weather, lack of labor, and diversion to other tasks was the primary reasons organizations halted spray patch operations.

In terms of work scheduling, users did not report using their spray injection repair equipment in following a formal pavement management system. Rather, the work assigned was determined one of two ways. First, was based on direction from the street superintendent. This person, who spends considerable time driving the streets under his

or her jurisdiction, simply gives the operators assigned areas to work in on a daily or weekly basis. Time is also allowed for service calls to respond to public reports of potholes. This type of system was reported by a majority of the users.

The second method was where the equipment operators taken care of specific areas. These operators, through knowledge developed from years of experience in their local area, simply drove the streets making repairs as necessary. By keeping track of the streets they had treated, they rotated through all of the streets in their area in a continuous cycle. These operators also used the beginning of each day to respond to service calls submitted by local citizens. This will also vary during the year. During spring thaw, operators may spend all day just responding to service calls, while during the rest of the year they may spend an average of eight hours a week on service calls.

Finally, users of truck mounted machines were able to use their machines at night when high volume roads have reduced traffic or to meet maintenance backlogs.

Interagency Cooperation

Within the various SDDOT regional and area offices the opportunities for cooperation to enhance efficiency exist. However, when seeking opportunities for cooperation between state, city, or county maintenance organizations, the opportunities appear more limited.

The Aberdeen regional office provides one example of how the regions and areas can share equipment. The Aberdeen regional office maintains one trailer mounted spray injection repair machine, and this is shared between the area offices. Typically, each area requests the equipment and it is dispatched on a first come, first serve basis. Within each area is at least one trained operator for the equipment. If an area has an emergency and the equipment is being used by another area office, then the equipment may be taken from the area office using it and sent to the other area in response to the emergency. According to the Aberdeen office, this system has worked well for them to date.

The Rapid City Region maintains two trailer mount spray injection repair machines and to date they are used and operated solely by that office. Within the

Mitchell Region, one trailer-mounted device is maintained and operated by the Yankton area office.

None of the SDDOT machines are operated in the winter. This is due to the fact that they are trailer-mounted machines. Of all users interviewed, no users of trailer mount machines performed repair operations in the winter due to worker safety and exposure to the cold.

Most highway or street maintenance organizations are reluctant to lend or rent specialized equipment to other organizations. Past experience from other operators damaging equipment or the perception of damage leads to these feelings. Also, if a machine breaks down, there is often the difficult question of who pays for the repairs. The borrowing organization may say it would have broken no matter who was using it, while the lending organization says it broke due to the way the borrower was using it. When two dissimilar organizations (County vs. City, City vs. State, County vs. City, etc.) have these disputes, there is no one office that may serve as arbitrator. Different organizations may be more apt to lend non-specialized equipment such as loaders, dump trucks, graders, etc., since they are more common and there is the opportunity reciprocate on the borrowing/lending. The same may go for supplies. A city may be able to temporarily borrow some aggregate from another maintenance organization and simply replace what it used at a later date. However, if one city has heated storage for emulsion, and only enough to last the winter, it would be reluctant to provide it to another organization when it couldn't get resupplied until March or April.

In interviews with some state maintenance personnel out of state, they did not lend equipment to other offices; they simply billed the other office (state, county or municipality) an hourly rate for the equipment and operator. One rate for use of a truck-mounted system was $55.00 per hour for the equipment, operator, oil and rock. If they trusted the user with the equipment, it was rented without the operator for $35.00 per hour. This rate is quite low compared to what commercial business charge for pothole repair using spray injection machines. Typical rates from commercial businesses were $120.00 (low) to 180.00 per hour for the equipment, operator, and materials. This would increase by $25.00 an hour if a follower truck and operator were needed. These hourly commercial rates would drop by approximately $30.00 per hour if the user provided the

emulsion and aggregate. Rental agreements between organizations may help prevent the types of conflicts that may arise from simple verbal agreements.

For truck mounted machines, sharing between organizations is not an option because they are in use all the time. The machine simply isn't available for use. The only organizations that did not use their truck mounted systems full time were the ones that could not store emulsion in the winter. Only one organization with a truck-mounted unit did not use it full time and that was due to a lack of operators. Their labor was so short that after spring thaw ended every person worked at other tasks.

With regards to material storage, the main opportunity for sharing needs to be in the area of heated storage of emulsion. No organizations interviewed appeared to have any shortage of aggregate and they each had heated space to park a machine indoors prior to use to allow aggregates to warm. However, every user of truck mounted spray injection repair equipment who did not use it in the winter reported it was due to emulsion not being available. Again, no trailer mount users reported using their equipment in the winter.

The development of heated emulsion storage appears to be reasonable, especially when compared to the cost of the equipment it is supporting. One local tank company estimated conservatively that a 6,000 gallon heated and insulated tank, including pumps, would cost about $6,000.00. This tank would be approximately 7 feet in diameter and 18 feet long. The City of Sioux Falls reported adding a heat system to an existing tank for a cost of approximately $3,500.00. Based on the usage figures listed above, a 5,000 gallon heated tank should support one truck-mounted unit through the months when emulsion was not locally available.

Training

Each manufacturer provides its customers with owner's manuals for the equipment. The manuals provide parts lists, schematic diagrams of system components, troubleshooting guides, maintenance recommendations, aggregate and asphalt specifications, and operating instructions. Formal training aids such as videos, classroom training materials, etc. are not available.

Formal training of the equipment operators consists of factory representatives traveling to the customer's office and providing a few days of on site training with the operators. The training is not conducted in the classroom, but rather in the equipment itself. The trainees then learn more about the equipment through their subsequent use. When new operators are hired, the experienced operators train the new personnel. No formal ongoing training exists. If an operator needs to get a feel for how to repair alligator cracking vs. potholes, he or she may just take the equipment out to the maintenance yard parking lot, find some alligator cracks, and practice until a satisfactory repair is achieved.

From review of the manufacturer's literature, an operator could not learn how to successfully operate the equipment just by reading what was provided. That would be like learning to operate a motor vehicle for the first time by reading the owner's manual found in the glove compartment. The most effective and efficient way to provide initial training is having experienced operators climb into the cab with the trainee and train by doing. Most users reported training took 1 to 2 days.

Acquisition/Operation Costs

Most users were not able to report exact bid prices on the equipment they had purchased; rather they reported approximate prices. However, the initial acquisition costs were similar among the different users. A typical cost for a trailer-mounted machine was approximately $33,000 and a truck mounted machine approximately $110,000. However, a trailer-mounted machine requires a dump truck for towing and aggregate storage. The cost of such a vehicle will approximately equal that of the trailer mounted machine. These values are based on those organizations that had made recent equipment purchases without trade in.

With regard to maintenance, most users reported little maintenance problems with the newer machines. Older machines were reported to have a higher frequency of hose replacement and wear in the aggregate feeding system. Discussions with the users and the manufacturers suggest these problems have been reduced due to design changes on the new models. Most users reported maintenance in terms of days lost per month.

Most maintenance was routine in nature and performed by in house maintenance shops. Maintenance downtime was estimated by the users and the most typical responses are as follows: 2 days/month, 2 weeks/year, and the most common response "not much downtime." One user estimated they used their equipment 4 days a week on average, which allowed for both equipment maintenance and operator training, vacation, or assignment to other work.

Based on these responses, a properly maintained unit should require no more maintenance then any other piece of equipment. The only exception was reports of a trailer mount unit manufactured out of state. Two users of these particular machines were quite displeased with their maintenance requirements.

Cost-Benefit Analysis

The SHRP report clearly showed cost benefit analysis as a function of operating cost and patch life. In this project no attempt was made to establish costs, rather users were questioned as to any insights they had as to patch life and labor costs.

All users, especially those who operate truck mounted units, were extremely pleased with both the productivity of the machines and the quality of the patches. With regards to productivity, they reported placing patches in all weather conditions and at temperatures down to 10 below zero. This increased productivity because typical patching crews are not able to work outside for long periods of time in those temperatures. Secondly, were the reports of needing fewer people do to pothole repair.

For truck mounted units on rural or residential streets, one operator can work the machine without a need for flaggers, lane closings, or a follower truck. The largest crew reported for a truck-mounted unit was either 2 or 3 people for interstate repairs where arrow boards or lane closure was required. A user in Washington State reported his pothole repair crew went form 8 to 1 person with rarely a need for pilots or flaggers. In his estimation, the truck-mounted unit had a four-year payback period. Most reported using a three-person crew for pothole repair prior to spray injection, and using primarily a one person after obtaining a truck mounted system.

For trailer mounted systems, users reported using crews of 1 to 3 people. For work not in traffic areas (i.e. parking lots) a single person could safely operate the equipment. However, since the operator is exposed, most users had crews of 2 or 3 to allow for a follower vehicle and flaggers.

The SHRP report contains a detailed cost-effectiveness analysis based on cost of repair, life of patch, and user delay costs. These results are summarized in Table One.

Input	Throw & Roll A	Throw & Roll B	Semi-Permanent	Spray Injection	Throw & Roll C	Spray Injection – South Dakota
Crew Size	2	2	4	2	2	1
Wages/Day	300	300	1200	300	300	150
Traffic Control Cost/Day	280	280	280	280	280	0
Repair Life- Months	3	21	12	21	3	21
Cost $\$/ft^3$ – w/o delay	44.38	8.66	42.08	10.54	44.38	6.70
Cost $\$/ft^3$ – user delay	106.88	17.59	83.75	19.46	669.38	15.63

Table 1. Repair Method Cost-Effectiveness

One objective of this project was to examine if the SHRP cost study was valid for South Dakota. If one were to recalculate the analysis summarized above using local material cost figures, then the end result may not change much, because the material costs would change for each method. However, one striking difference is that the SHRP report assumes traffic control costs are the same for every repair method, and that the spray injection equipment uses two operators. In most areas, this is rarely the case. Most truck-mounted machines are being operated by one person with no traffic control devices. If, using the SHRP cost analysis methods, except reducing crew size by one and using no traffic control devices, the cost of repair drops by $3.84 per cubic foot of patch. The adjusted cost of spray patching using a truck mounted system with one operator and not additional traffic control measures is shown in the last column of Table One.

In reality, truck mounted operations do not always operate without traffic control and in some cases operators do not work alone. Depending upon the percentage of time a truck mounted machine is used by a lone operator, the actual cost will be no greater than that reported by SHRP, and no less than that shown in the final column of Table One.

CHAPTER 6

IMPLEMENTATION RECOMMENDATIONS

Introduction

The purpose of this report was to examine if existing spray injection repair assets within the state could be kept in service during all or part of the winter months. Additionally, recommendations as to what material storage requirements were needed to sustain winter operations were to be developed.

Recommendations

Recommendation One:

If the SDDOT continues to only use trailer mounted spray injection equipment, then obtaining specialized storage for winter operations may not be feasible.

Worker exposure to winter weather limits the number of days trailer mounted systems may be used. Also, trailer mounted systems do not have on board aggregate storage. Aggregate is fed from the towing vehicle, which does not have the capability of keeping the aggregate warm. If the aggregate gets cold, then the mixing of cold aggregate and hot emulsion does not allow for proper set of the materials. However, the main reason trailer mounted systems are not used in the winter months is due to worker exposure to the cold and operator safety considerations.

Recommendation Two:

The SDDOT should consider using truck mounted systems and developing heated emulsion storage if they desire to use spray injection repair methods throughout the year.

Experience from the city of Sioux Falls and numerous cold climate states has shown that truck mounted systems can operate successfully throughout the year in winter climates. These same organizations have shown that, for a rather moderate investment, heated emulsion storage can be constructed.

Recommendation Three:

The use of alternative oils should be demonstrated by the manufacturers and not left to the users.

The use of oils other than CRS-2 has been tried by many organizations. In some cases, one organization would report limited success with an alternative oil. However, conversations with other uses report no success with the same material. Until an asphalt producer or another user can show better evidence that their alternative oil will work, it appears that users should continue to use CRS-2.

Recommendation Four:

To perform spray injection repairs throughout the year, equipment could be obtained and coordinated by each regional office.

One potential method to do this would be for regional offices to obtain truck mounted systems and heated emulsion storage at a cost of approximately $120,000.00 These trucks could be dispatched from the regional office to the area offices as needed. If additional emulsion is needed, users from the area offices could travel to the regional office to obtain additional emulsion as needed. This emulsion could be transported in distributor trucks and stored inside in a heated garage or maintenance area. Each area office would need to have at least one qualified operator trained on the use of the machine.

REFERENCES

Answering El Nino's Challenge, Roads and Bridges, May 1998

Automated Pothole Patching – Better Patches for Less Money, Road Management and Engineering Journal, http://www.usroads.com/journals/rmj/rm970404.htm, April, 1997.

Blaha, J.R., *Workplan for Pothole Patcher Demonstration Program*, Northwestern University Infrastructure Technology Institute, Evanston, IL, May, 1993.

Garritt, J., *Welcome to the Year of the Pothole*, Detroit Free Press, February 19, 1997.

Jebro, Inc., Personal Interview with Kevin Carlson, July, 1997.

New Guidelines Help Highway Agencies Make the Most of Maintenance, Focus, Federal Highway Administration, McLean, VA, March, 1997.

Roadpatcher, Operations and Maintenance Manual, Wildcat Manufacturing, Freeman, SD, undated.

Rosco Manual Part No. 36640, RA-300 Patcher Operations, Maintenance, Service and Parts Manual, Rosco Manufacturing Company, Madison, SD, January, 1995.

Sioux Falls, Personal Interview with Darrel Jurrens, July, 1997.

Wilson, T.P., and Romine, A.R. *Innovative Materials Development and Testing Volume 2: Pothole Repair*, Strategic Highway Research Program, National Research Council, Washington, DC, 1993.