Thin Maintenance Surfaces

Phase One Report

CTRE Management Project 97-14

April 1999

Center for Transportation Research and Education

Iowa State University

Iowa Department of Transportation

CTRE's mission is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability, while improving the learning environment of students, faculty, and staff in transportation-related fields.

THIN MAINTENANCE SURFACES

PHASE ONE REPORT

Principal Investigator
Charles K. Jahren
Assistant Professor of Civil and Construction Engineering
Iowa State University

Co-Principal Investigator
Kenneth L. Bergeson
Professor of Civil and Construction Engineering
Iowa State University

Graduate Assistants
Ahmed Al-hammadi
Serhan Celik
Gabriel Lau
Civil and Construction Engineering
Iowa State University

Preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its research management agreement with the Center for Transportation Research and Education, CTRE Management Project 97-14.

Center for Transportation Research and Education
Iowa State University
Iowa State University Research Park
2625 North Loop Drive, Suite 2100
Ames, IA 50010-8615
Telephone: 515-294-8103
Fax: 515-294-0467
http://www.ctre.iastate.edu/

April 1999

Table of Contents

List of Tables

Page

List of Figures

ABSTRACT

The first phase of a two-phase research project was conducted to develop guidelines for Iowa transportation officials on the use of thin maintenance surfaces (TMS) for asphaltic concrete and bituminous roads. Thin maintenance surfaces are seal coats (chip seals), slurry seals, and micro-surfacing. Interim guidelines were developed to provide guidance on which roads are good candidates for TMS, when TMS should be placed, and what type of thin maintenance surface should be selected. The guidelines were developed specifically for Iowa aggregates, weather, traffic conditions, road user expectations, and transportation official expectations.

The project commenced with a literature review and a survey to determine current practice in the use of TMS in Iowa. Then three sets of test sections were constructed, two in 1997 near Cedar Rapids, Iowa, and one in 1998 near Ankeny, Iowa. The 1997 test sections included seal coat, double seal coat, seal coat with fog seal, cape seal, slurry seal, micro-surfacing, and thin lift overlay. Limestone aggregate and CRS-2P binder were used for the seal coat. These test sections were only partially successful because they were placed late in the construction season by a construction crew that had limited experience in seal coat application. The 1998 test sections included seal coat, double seal coat, micro-surfacing, micro-surfacing with seal coat interlayer, and ultra-thin lift overlays. Both quartzite and local limestone and both CRS-2P and HFRS-2P (high float) binder were used in the chip seals. A design method was used for the chip seals that reduces material requirements by 25 to 33 percent compared to current practice. Although the test sections appear to be successful at the time of the report, performance information was not yet available for the 1998 test sections.

In addition to interim guidelines, this report presents recommendations for phase-two research. It is recommended that test section monitoring continue and that further investigations be conducted regarding thin maintenance surface aggregate, additional test sections placed, and a design method adopted for seal coats.

INTRODUCTION

The use of thin maintenance surfaces (TMS) can be a cost-effective approach for maintaining the quality of pavement. These surfaces are usually applied to flexible pavements. They include seal coats, slurry seals, and micro-surfacing.

Seal Coats are constructed by spraying binder on the road (usually emulsified asphalt) and then spreading aggregate before the binder sets. The aggregate is rolled into the binder to ensure that it remains in place. The aggregate may be rock chips, pea gravel, or sand. A seal coat made with rock chip aggregate is sometimes called a chip seal, while a seal coat made with sand is sometimes called a sand seal. Double seal coats are constructed by successively placing two layers of aggregate.

Slurry Seal is produced by mixing the aggregate and binder in a mobile mixing machine. The binder is usually asphalt emulsion, and the aggregate varies in size and type, depending on the application. Portland cement, hydrated lime, or aluminum sulfate is often added to aid in setting the slurry. The slurry is applied with a spreader box that is pulled behind the mixing truck and distributes and finishes the slurry.

Micro-surfacing is similar to slurry seal technology. Polymer-modified binder and one-hundred percent crushed aggregate is used. Micro-surfacing cures faster and may be applied in a thicker layer than slurry seal.

Fog seals, crack repairs, and hot mix overlays are maintenance treatments that may affect the use of TMS. In some cases they are used with TMS and sometimes they are used instead of TMS. It is necessary to understand these related techniques in order to understand TMS.

Fog Seals are light applications of diluted asphalt emulsion. Usually aggregate is not applied, except that a small amount of sand can be placed immediately after the emulsion is applied in order to increase friction. Fog seals can be used to seal small cracks, retard raveling, and delineate shoulders of high volume roads. They should be used only on roads with adequate friction.

Crack Treatments involve crack sealing and crack filling. A variety of materials and techniques are used to stop or reduce the infiltration of moisture into the subgrade.

Thin Lift Overlays are usually constructed using hot mix asphalt and range in thickness from 0.75 to 2.00 inches. A variety of mixes can be used including dense graded mixes, open graded mixes, and gap graded mixes. A properly designed dense graded mix is relatively stable (not subject to rutting) and requires a relatively low asphalt content. Open graded mixes have a higher void content that allows water to drain, thereby reducing spray. However, they tend to be unstable and are limited to a thin lift. In gap graded mixes, large aggregate particles bear directly on one another while small particles fill the voids. Proper design can produce a stable mix.

Studies have shown that transportation agencies can maintain a road network with better pavement condition at a lower cost by properly using TMS. In planning TMS programs, project selection, treatment selection, and timing are extremely important. Projects must be selected for maintenance when TMS are still effective. In most cases, the proper time to apply the TMS is before the need is apparent to the casual observer. This is because once pavements start to deteriorate, they deteriorate rapidly beyond the point where TMS is effective. Maintenance planners may be reluctant to order treatments for roads that appear to be structurally sound, when nearby roads appear to be in greater need of repair. However, when TMS applications are properly timed, road networks will show improvements in service life over the long term *(1).*

TMS do not increase the structural rating of the road and will fail quickly if applied to a road that is experiencing a structural failure. Cracks reflect quickly through slurry seals and micro-surfacing. Therefore, these treatments should be applied before cracks form or in conjunction with crack maintenance programs.

It is important to select the right maintenance treatment for each situation. Pavement condition, traffic volumes, road type (urban, rural, interstate, primary, secondary), materials availability, and local preference must be considered in making this decision. For maximum benefit, TMS must be applied before pavement distress is apparent. Research has shown that pavement deteriorates slowly when it is new and then deteriorates more rapidly after it reaches a certain age (Figure 1). If the pavement is allowed to deteriorate rapidly, it will soon be necessary to rebuild the pavement, an expensive proposition. Alternatively, a thin maintenance surface may be applied that will improve the pavement condition to the point where pavement performance deteriorates slowly. Several maintenance treatments may be applied periodically to maintain the pavement above the point of quick deterioration. For each dollar spent on maintenance before the age of rapid deterioration, four dollars can be saved in rebuilding costs *(1).* Preventive maintenance provides benefits in addition to cost savings: on the average road users enjoy better pavement conditions when compared to a strategy of allowing the pavement to deteriorate to the point that rebuilding is necessary.

In the past, many applications of TMS have been unsuccessful because they have been applied too late and failed rapidly. After such experiences, transportation personnel tend to hesitate to use TMS. Also, it is difficult to institute a program of preventive maintenance with properly timed treatments because the public often perceives that money is being wasted on good roads while other projects are being neglected. It would be desirable to develop an assessment procedure that would allow planners to accurately determine the optimum timing of TMS and to include this assessment procedure in an overall pavement management system. Also, it would be desirable to clearly explain the need for prompt treatment of pavements before distress is apparent.

For success, TMS projects must be carefully designed and executed. Aggregates must be very clean and have sufficient durability and skid resistance. In Iowa, many of the locally available aggregates have not proven satisfactory for many projects. This has resulted in the use of expensive imported aggregates. It would be desirable to identify sources of local aggregate that have the proper characteristics for use with TMS and to clearly define situations in which local aggregates provide satisfactory performance, such as low volume roads.

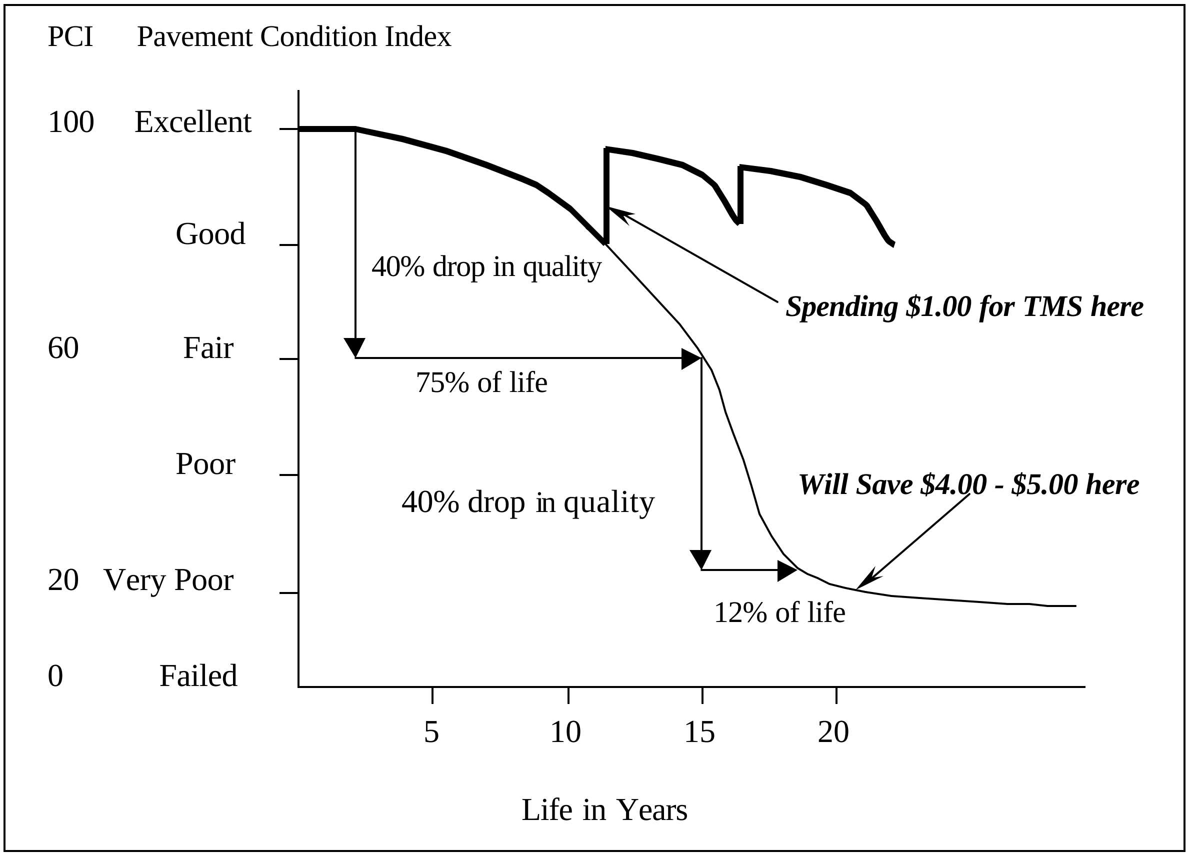


Figure 1. Typical Pavement Life Cycle (1)

The Iowa DOT is considering substantial increases in the use of TMS. First, however, it would be desirable to develop a system for planning TMS maintenance programs that are tailored to Iowa's climate, materials, and contracting practices.

PROBLEM STATEMENT

By properly using TMS as a preventive maintenance technique, agencies can cost efficiently maintain the surface condition of Iowa highways and streets at a high level. For this strategy to be successful, proper selection, timing, and application are critical. Previous international, national, and state research has provided a basic framework for implementing such maintenance programs in Iowa. However, it is necessary to customize this framework to address Iowa's specific needs with regard to aggregates, climate, construction practices, traffic, and fund management.

OBJECTIVE

The ultimate objective of this study is to develop recommendations, specifications, and construction procedures regarding which surface treatments to use at what time to maximize cost effectiveness and maintain acceptable pavement condition. This report focuses on the use of TMS as a preventive treatment, not as a method to extend the life of a pavement that is failing. Several alternative rehabilitation techniques are available for restoring such pavement. Discussion of these alternative rehabilitation techniques is beyond the scope of this report. A matrix will be developed that recommends particular TMS for particular traffic volumes, pavement conditions, and locally available materials. It will also specify requisite aggregate quality. The study will build on previously executed national studies and Iowa Department of Transportation (DOT) research. It will be specifically tailored to Iowa's needs. In addition the study will provide improved pavement assessment techniques that will provide objective measures for identifying TMS candidates.

This report describes the first phase of the study, which includes background research and construction and initial monitoring of two sets of research test sections. A set of interim guidelines has been developed based on the portion of the study executed so far. It is expected that the guidelines will be refined as more test sections are constructed and as monitoring continues on the current test sections.

METHODOLOGY

Several steps were required to execute the study to this point. The project commenced in May 1997 with a literature review to find previously developed guidelines for TMS. Researchers also found information on materials and mix designs for TMS, as well as assessment techniques for roads that are candidates for TMS treatments. The results of the literature review are discussed in connection with specific topics throughout this report.

A survey was also conducted to determine current uses of TMS by Iowa counties and municipalities. Questions were also asked regarding contracting strategy, future plans, and needs for information.

Plans were made for observing construction and assessing the performance of TMS research test sections. Before the start of this research project, Iowa DOT had contracted to construct a set of test sections in Linn County on US 151 northeast of Cedar Rapids and Benton County on US 30 just west of the intersection of US 218 (Figure 2). The test sections included several types of seal coats using local aggregates, micro-surfacing, slurry seal, cape seal (seal coat with slurry top), and a thin lift hot mix overlay.

Researchers conducted a pre-construction condition survey, observed construction, and conducted three post-construction condition surveys. Due to the contractor's schedule, construction of these test sections occurred late in the construction season (September and October 1997) when cold temperatures did not allow the emulsion to cure properly.

In addition many of the application rates varied considerably from the target rates. This compromised the research value of these test sections.

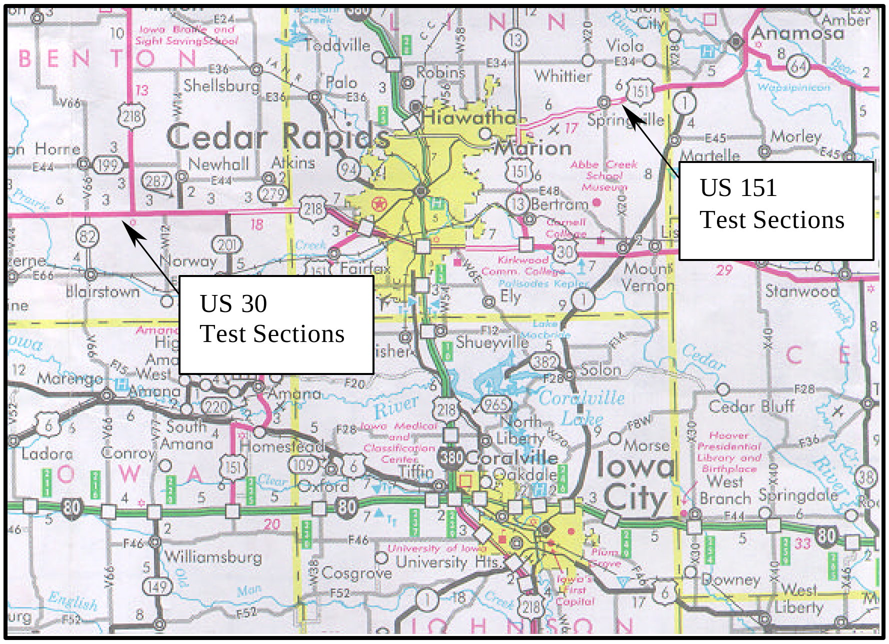


Figure 2. Map of Test Sections in Cedar Rapids Area

Plans were then made for constructing a set of test sections during the 1998 construction season between Huxley and Alleman on US 69 (Figure 3). These test sections were designed by the researchers in cooperation with the Iowa DOT and with Koch Materials Inc., which supplied emulsion and asphalt cement for the project. The sections included several types of seal coat using local and imported aggregate, micro-surfacing, micro-surfacing with a seal coat interlayer, a hot sand mix overlay, and a Nova Chip ultra thin hot mix seal. Minnesota DOT provided considerable assistance in designing the chip seal application rates. Researchers conducted a pre-construction condition survey, observed construction, and conducted a post-construction condition survey.

After reviewing the results of the literature review, the survey of the counties and municipalities, and test section construction, researchers developed a set of interim guidelines for selecting candidate roads and maintenance treatments. It is expected that these guidelines will be refined as more information becomes available regarding test section performance.

A steering committee was appointed to assist the researchers. Members included:

- John Selmer, P. E., Iowa DOT Maintenance Operations
- Francis Todey, P. E., Iowa DOT Maintenance Operations

- John Hagen, P. E., formerly Iowa DOT Bituminous Engineer, currently Ames Resident Construction Engineer
- Neal Guess, P. E., Newton City Engineer
- Randy Kraul, P. E., Carroll City Engineer
- Richard Scheik, P. E. and L. S., Koussuth County Engineer
- Dave Paulson, P. E., Carroll County Engineer
- William Dunshee, Fort Dodge Asphalt, Fort Dodge, Iowa
- Richard Burchett, Stabilt Construction Co., Harlan, Iowa
- Bill Ballou, Koch Materials, Inc., Salina, Kansas

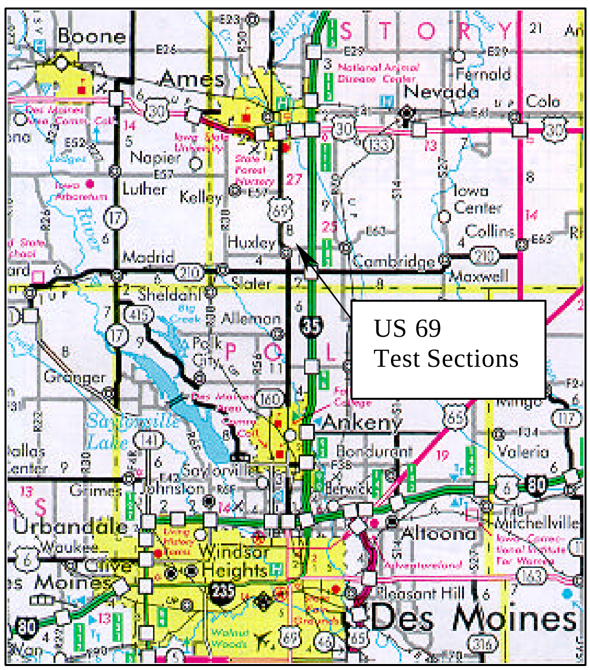


Figure 3. Map of Ames and Des Moines Area Test Sections

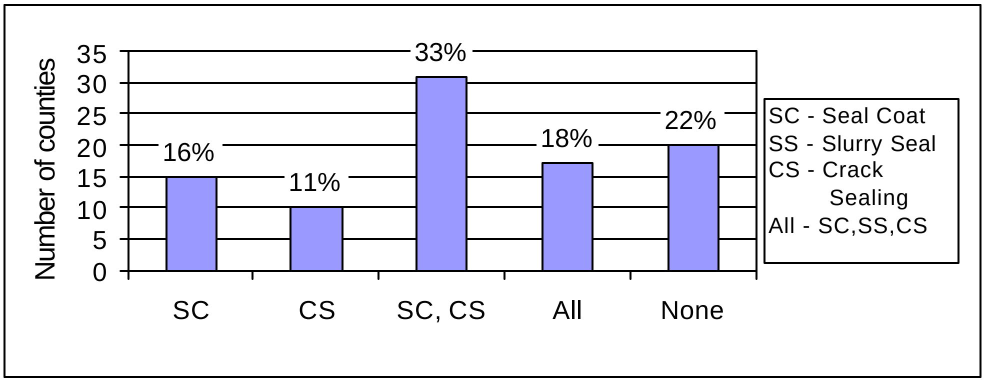
SURVEY OF COUNTIES, CITIES, AND TOWNS

A survey was developed to determine current practices on TMS and research needs for Iowa local transportation systems. A survey was sent to all 99 Iowa counties, all 93 cities with population over 5,000 (hereinafter referred to as cities) and a sample of 200 officials for towns with populations under 5,000 (hereinafter referred to as towns). There are 878 towns in Iowa. The return rates were 100 percent, 41 percent, and 23 percent respectively. Researchers obtained a 100 percent return rate from the counties by making telephone follow-up calls and in some cases tabulating the surveys during the phone conversation. Detailed results and analysis of the survey are provided by Al-Hammadi *(3)*; results are summarized below.

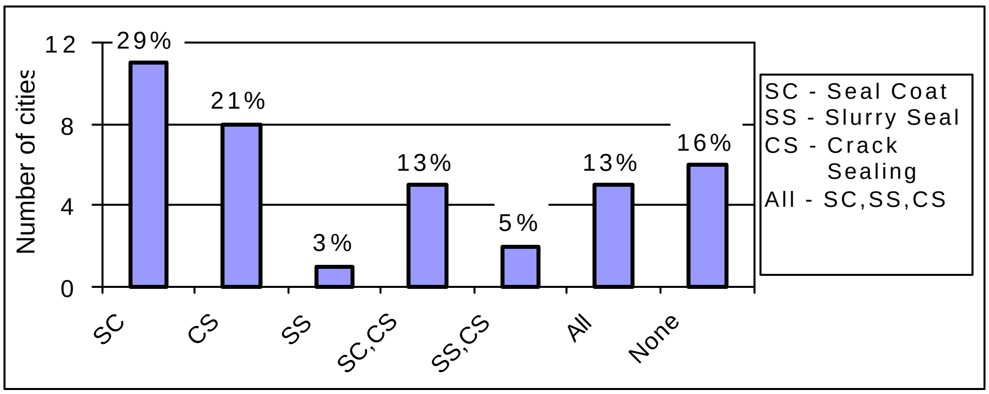
The survey asked respondents to check off the types of maintenance treatments that they use. The largest proportion of counties (33 percent) uses both chip seals and seal coats. Twenty-two percent perform no maintenance on flexible pavements (in some cases because most county roads are Portland cement concrete (PCC)), while 18 percent use all three treatments: chip sealing, crack sealing, slurry sealing (Figure 4). For cities and towns, the largest proportion of respondents performed chip sealing only. The second larger proportion reported that they only seal cracks (that is, they do not use other strategies aside from sealing cracks). Cities reported the use of several other combinations of treatments, including slurry seal, while activity in towns was limited to seal coating and crack sealing.

Twenty-four percent of the counties, 37 percent of the cities, and 56 percent of the towns reported performing maintenance somewhere in their entire system on a yearly basis (Figure 5). Counties were most likely to perform maintenance on an as-needed basis, followed by towns and then cities. Most jurisdictions expect little change in their maintenance program for the future. Treatments are primarily selected by repeating successful past practices.

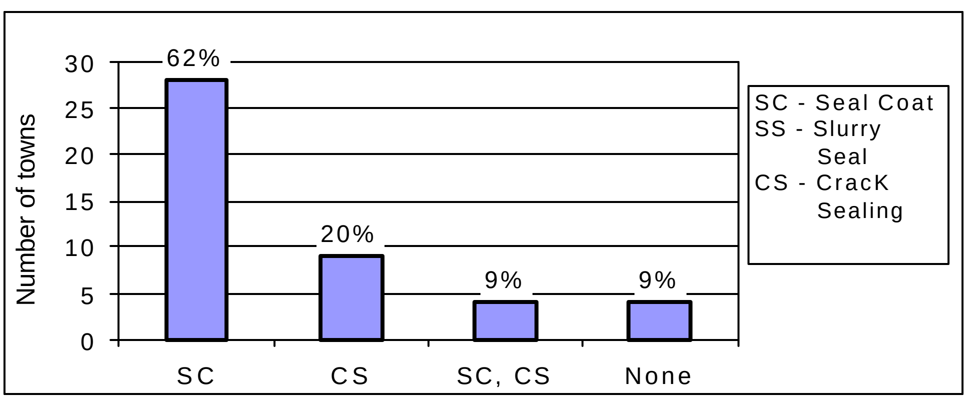
Respondents were asked to rate their needs for information on binder specifications, aggregate specifications, when to apply TMS, which surface to apply, and how to inspect construction (Table 1). There was a wide range of perceived needs for information, depending on the topic; the average amount of need was high to moderate in most cases. In general, towns saw a greater need for information than did cities, and cities saw a greater need for information than did counties.



(a)



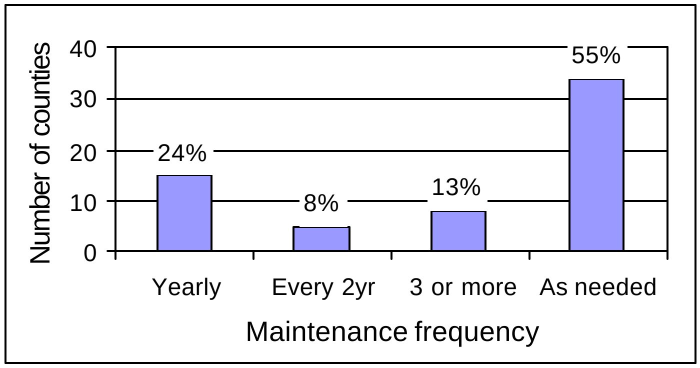
(b)



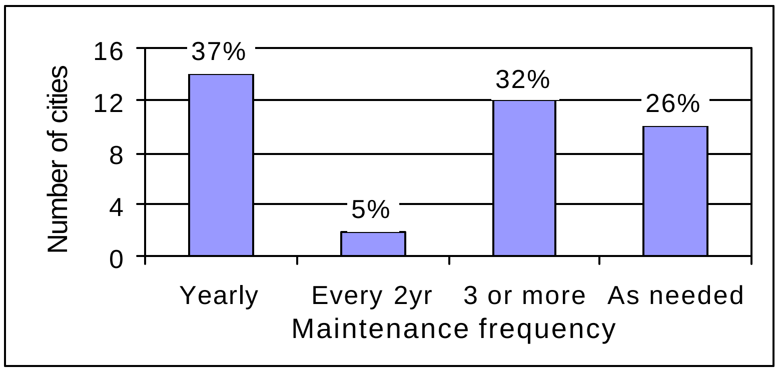
(c)

(a) Counties maintenance treatments (b) Cities maintenance treatments (c) Towns maintenance treatments

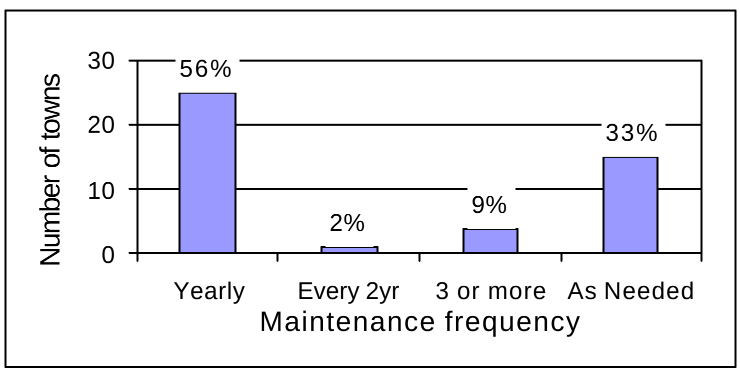
Figure 4. Maintenance Treatments *(3)*



(a)



(b)



(c)

(a) Iowa counties maintenance program (b) Iowa cities maintenance program
(c) Iowa towns maintenance program

Figure 5. Maintenance Program Frequency *(3)*

Table 1. Local Systems Research Needs *(3)*

	Percentage of Total Responses					
	None (0)	**Small (1)**	**Moderate (2)**	**High (3)**	**Extreme (4)**	**Average Response[1]**
Binder Specification						
County	6	25	33	32	4	2.0
City	11	11	33	26	19	2.3
Towns	9	3	21	52	15	2.6
Aggregate Specification						
County	14	24	31	27	4	1.8
City	8	23	46	8	15	2.0
Towns	9	11	17	46	17	2.5
When to apply TMS						
County	7	30	43	16	4	1.8
City	12	12	26	31	19	2.3
Towns	8	8	36	29	19	2.4
Which surface to apply						
County	4	24	43	25	4	2.0
City	7	7	30	37	19	2.5
Towns	8	6	25	39	22	2.6
How to inspect construction						
County	6	29	46	17	3	1.8
City	12	22	27	27	12	2.0
Towns	6	9	31	37	17	2.5

[1]Weighted average of response, where 0 = None, 1 = Small, 2 = Moderate, 3 = High, and 4 = Extreme

TEST SECTIONS

US 151 (Linn County) and US 30 (Benton County) Test Sections

The Linn and Benton county test sections were selected to provide a contrast between a road that was initially in poor condition and one that was initially in good condition: US 151 was in poor condition while US 30 was in good condition. The pavement condition indexes reported herein are calculated according to the method outlined in *(6)* for the U.S. Army Corps of Engineers PAVER System.

The US 151 test sections were located between Springville and the junction of IA 1 from milepost 45.06 to 49.38, northeast of Cedar Rapids (Figure 6). This road was originally constructed in 1928 as a 20-foot wide PCC pavement, 7 inches thick. It was widened to 24 feet and received a 1.5-inch ACC overlay in 1953 and again in 1965. In 1987 it received a 2-inch overlay. In 1997 it was in poor condition with severe cracks reflected from the PCC pavement below. The joint between the original pavement and the two-foot widening strip exhibited alligator cracks in several places. The surface was rough and raveling fine aggregate. ACC was beginning to spall out from the cracks. The Pavement Condition Index (PCI) (USA-COE) ranged from 27 to 43, which corresponds to a poor condition (US Army Corps of Engineers). According to Stephens *(4)* the PCI falls in the range of a pavement that should be reconstructed.

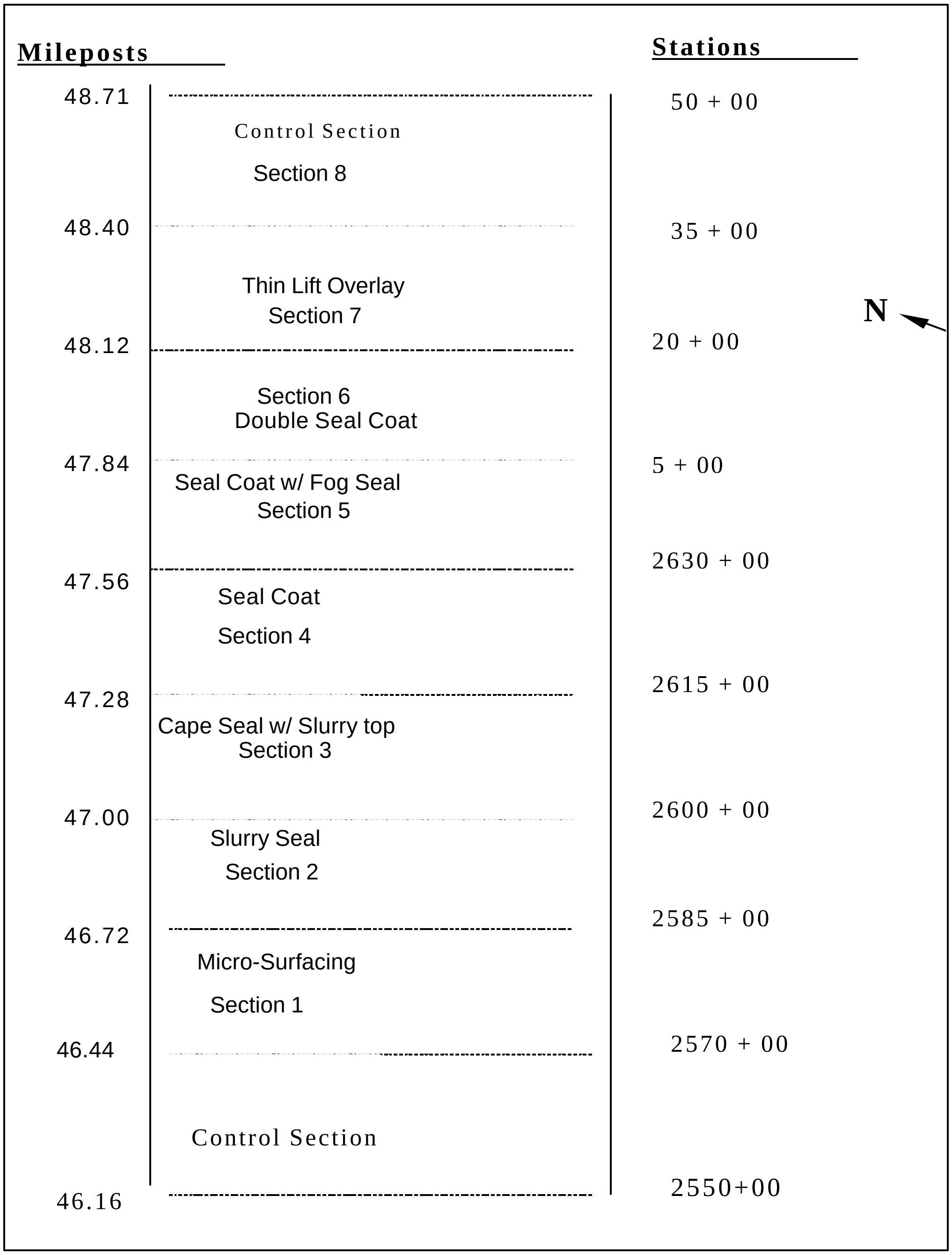


Figure 6. US 151 Test Sections

The US 30 test sections were located between the junction of US 218 north and the junction of IA 82 south from milepost 229.10 to 231.00, west of Cedar Rapids (Figure 7).

Figure 7. US 30 Test Sections

This road was originally constructed in 1949 as a 24-feet wide PCC pavement, 6.5 inches thick. It received a 3-inch ACC overlay in 1965, and 3-inch ACC overlays in 1977 and 1990. In 1997 it was in good condition with light to moderate cracks reflected from the PCC pavement below, some of which had been routed and sealed. The surface was smooth with little indication of raveling and no bleeding. The PCI (USA-COE) ranged from 65 to 83, which corresponds to a good condition. According to Stephens *(4)* the PCI falls in the range that should receive preventive maintenance.

Each site had the following test sections:

- Thin lift overlay (1.5-inch thick) Type A surface course with ½-inch aggregate with no special friction requirements, 50 blow Marshall design.
- Seal coat (½-inch cover aggregate from Wendling South Cedar Rapids quarry, CRS-2P binder)
- Seal coat with fog seal (½-inch cover aggregate from Wendling South Cedar Rapids quarry, CRS-2P binder)
- Double seal coat (aggregate: ½-inch bottom, 3/8-inch top, cover aggregate from Wendling South Cedar Rapids quarry, CRS-2P Binder)
- Cape seal (½-inch chip seal bottom, slurry seal top)
- Slurry seal (CSS-1H Binder, Type III Bowser/Springville Bed 7 aggregate)
- Micro-surfacing (quick setting CSS-1H Polymer Modified Binder, Type III Sioux Falls quartzite aggregate)
- Control section

Each test section was 1,500 feet long.

The construction contract for the test sections was included in micro-surfacing projects MP-151-6(701)45--76-57 and MP-30-6(700)229--76-06 which were awarded to Monarch Oil Company of Omaha, Nebraska. Because of its backlog of other projects, machine breakdowns, and weather delays, Monarch was not able to construct the test sections until September and October 1997 rather than July or August as originally planned.

Construction of the thin lift overlay was constructed on August 7, 1997 for US 151 and August 13, 1997 for US 30. The construction process was uneventful.

The dates of construction and material application rates for the other test sections are shown in Table 2 for US 151 and in Table 3 for US 30. Several difficulties were experienced during the construction of the TMS test sections. The application rates for the seal coats varied considerably from the targets. On US 151, the binder application rate for the seal coats was low due to a calculation error. The aggregate quickly raveled from this test section, leaving the binder exposed. On the double seal coat section, the binder application rate for the second layer of the double seal coat was high. This likely caused the wheel tracks to flush.

On US 151, the slurry seal for the cape seal and the slurry seal sections were initially placed on cold and rainy days. In some cases, it was not possible to allow sufficient cure time before returning traffic to the slurry surface. This situation caused the slurry to ravel out of the wheel paths. The contractor reconstructed the slurry surface in these areas. Because the slurry surface did not ravel along the centerline, a ridge developed in this area. This ridge remained after the slurry was reconstructed.

The micro-surfacing test section on US 151 was difficult to construct because the road surface was uneven. The screed scraped the original road at high places and left deep pools of material in low places. In these pools, the course aggregate sank to the bottom while the fines and binder migrated to the top giving the area a flushed appearance. After construction, the micro-surfacing quickly raveled from the high spots where the micro-surfacing application was thin.

In June 1998, micro-surfacing was applied to cover all of the test sections on US 151, except for the double seal coat, the thin lift overlay, and the control sections. This was because all of these sections were experiencing so much raveling that they were deemed to have failed. It is expected that this area can serve as a test section for micro-surfacing with a seal coat interlayer where it has covered the seal coat test sections. It can also serve as a test section for the use of two courses of micro-surfacing on the micro-surfacing test sections. Researchers plan to monitor these areas during future research projects.

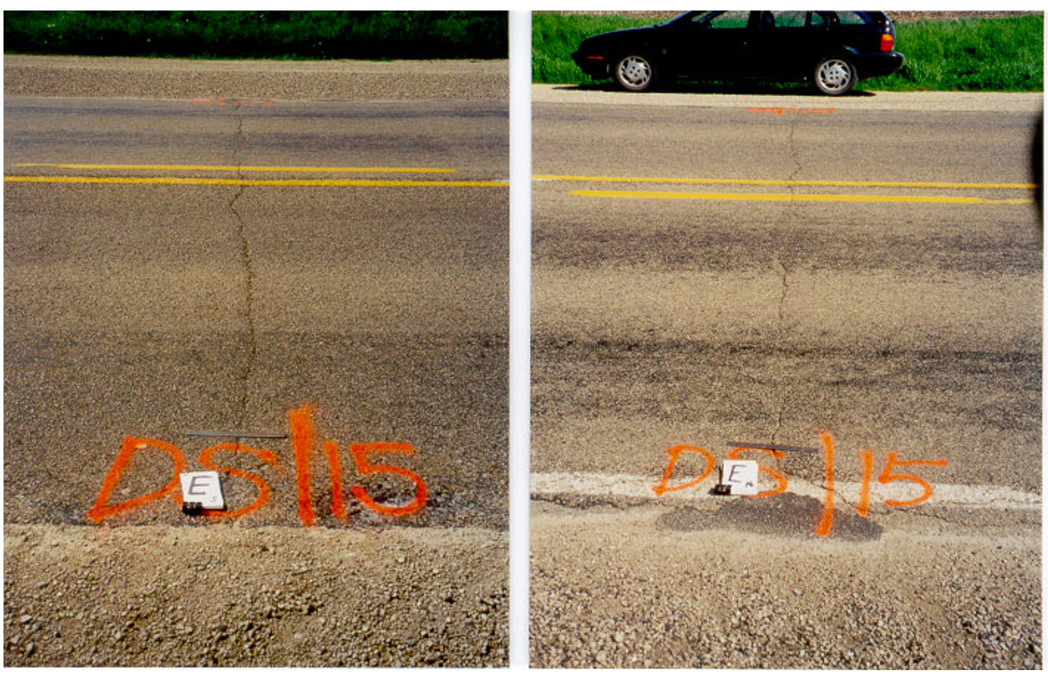
The double seal coat provided a relatively smooth, quiet surface in the spring of 1998. Few cracks reflected through and the ones that did were sealed with binder under traffic (Figure 8). The wheel paths were somewhat flushed. The 3/8-inch chips on the top course of the double seal coat provided a desirable surface, while the ½-inch chips on the single seal coat provided a rough, noisy surface. Of the seal coat surfaces, researchers and Iowa DOT officials preferred the double seal coat. For this reason, this surface was not covered with micro-surfacing when the others were. Over the summer of 1998, the wheel path became increasingly flushed and by August exhibited friction numbers in the teens and 20s. The decision was made to mill off the double chip seal for safety reasons.

In general, micro-surfacing was found to have significant advantages over slurry seal for high volume roads and late season construction because of its shorter cure time.

On many fall days, it might be necessary to wait until mid or late morning to begin construction in order to have an air temperature that meets specifications. All traffic control must be removed one-half hour before sunset, and the surface should be completely cured before traffic control is removed. Since sunset is earlier in the fall, and the cure time for slurry in cooler weather is up to three or four hours, the remaining work window becomes quite short. Micro-surfacing can cure well enough to return traffic in a little more than an hour. On short fall days this significantly lengthens the work window.

The quicker curing reduces the need for traffic control, which is also a considerable advantage.

(a) Pre-construction survey of US 151



(b) Post-construction survey of US 151

Figure 8. Pre- and Post-Construction Surveys of US 151

[blank]

Table 2. Application Rates for US 151 Seal Coat Test Section *(5)*

Treatments	Date	Location Stations (ft.)		Length (ft)	Width (ft)	Lane	Time		Aggr. Size	Rate lb/SY	Planned lb/SY	Emulsion	Temp F	Rate gals/sy	Planned gals/sy
Double Seal Coat 1/2"	9-26-97	20+00	5+00	1858	12	NB	1:45	2:15	1/2"	*38.8*	30	CRS-2P	158	0.33	0.35
Seal Coat w/ Fog Seal		5+00	2640+57											*0.33*	0.40
Seal Coat w/ Fog Seal & Seal Coat	9-26-97	2640+57	2619+32	2125	12	NB	3:35	4:05	1/2"	*26.60*	30	CRS-2P	158	*0.26*	0.40
Double Seal Coat 1/2"	9-27-97	20+00	5+00	2275	12	SB	11:30	12:00	1/2"	29.7	30	CRS-2P	*138*	*0.31*	0.35
Seal Coat w/ Fog Seal		5+00	2636+40											*0.31*	0.40
Seal Coat w/ Fog Seal & Seal Coat	9-27-97	2636+40	2618+60	1780	12	SB	12:21	12:45	1/2"	30.5	30	CRS-2P	*138*	0.41	0.40
Seal Coat & Cape Seal - Seal Coat	9-27-97	2618+60	2600+00	1860	12	SB	3:00	3:27	1/2"	30.2	30	CRS-2P	*138*	*0.43*	0.40
Seal Coat & Cape Seal - Seal Coat	9-27-97	2619+32	2600+00	1932	12	NB	4:15	4:41	1/2"	*27.00*	30	CRS-2P	*138*	0.42	0.40
Double Seal Coat 3/8"	9-27-97	20+00	5+00	1500	12	SB	2:05	2:22	3/8"	24.75	25	CRS-2P	*138*	*0.39*	0.30
Double Seal Coat 3/8"	9-27-97	20+00	5+00	1500	12	NB	5:00	5:15	3/8"	24.49	25	CRS-2P	*138*	*0.37*	0.30
Fog Seal for Seal Coat	9-29-97	2630+00	5+00	1500	12	LT							150	*0.17*	0.12
Fog Seal for Seal Coat	9-29-97	2630+00	5+00	1500	12	RT							150	*0.15*	0.12
Dust Control for Seal Coat	9-29-97	2615+00	2630+00	1500	12	RT							150	0.10	0.10
Dust Control for Seal Coat	9-29-97	5+00	20+00	1500	12	RT							150	0.10	0.10
Dust Control for Seal Coat	9-29-97	20+00	5+00	1500	12	LT							150	*0.12*	0.10
Dust Control for Seal Coat	9-29-97	2630+00	2615+00	1500	12	LT							150	*0.12*	0.10

Table 3. Application Rates for US 30 Seal Coat Test Section *(5)*

Treatments	Date	Location Stations (ft.)		Length (ft)	Width (ft)	Lane	Time		Aggr. Size	Rate lb/SY	Planned lb/SY	Emulsion	Temp F	Rate gals/sy	Planned gals/sy
Cape Seal - Seal Coat & Seal Coat	10-2-97	570+00	589+75	1975	12	WB	11:30	12:30	1/2"	*39.7*	30	CRS-2P	160	*0.43*	0.40
Seal Coat & Seal Coat w/ Fog Seal	10-2-97	589+75	611+75	2200	12	WB	1:45	2:13	1/2"	*39.5*	30	CRS-2P	160	0.42	0.40
Seal Coat w/ Fog Seal	10-2-97	611+75	615+00	1825	12	WB	3:15	3:45	1/2"	30.6	30	CRS-2P	160	0.40	0.40
Double Seal Coat 1/2"		615+00	630+00											*0.40*	0.35
Double Seal Coat 1/2"	10-3-97	630+00	615+00	1980	12	EB	10:38	11:15	1/2"	*39.4*	30	CRS-2P	150	*0.43*	0.40
Seal Coat w/ Fog Seal		615+00	610+20											*0.43*	0.35
Seal Coat w/ Fog Seal & Seal Coat	10-3-97	610+20	592+10	1810	12	EB	12:09	12:35	1/2"	*34.8*	30	CRS-2P	150	*0.36*	0.40
Seal Coat & Cape Seal - Seal Coat	10-3-97	592+10	570+00	2210	12	EB	1:45	2:05	1/2"	*33.0*	30	CRS-2P	150	*0.43*	0.40
Double Seal Coat 3/8"	10-3-97	630+00	615+00	1500	12	EB	2:35	2:50	3/8"	24.1	25	CRS-2P	150	*0.37*	0.30
Double Seal Coat 3/8"	10-3-97	630+00	615+00	1500	12	WB	4:40	5:00	3/8"	24.1	25	CRS-2P	150	*0.37*	0.30
Fog Seal for Seal Coat	10-4-97	600+00	615+00	1500	12	EB							160	*0.20*	0.12
Fog Seal for Seal Coat	10-4-97	600+00	615+00	1500	12	WB							160	*0.22*	0.12
Dust Control for Seal Coat	10-4-97	585+00	600+00	1500	12	WB							150	*0.12*	0.10
Dust Control for Seal Coat	10-4-97	615+00	630+00	1500	12	WB							150	*0.12*	0.10
Dust Control for Seal Coat	10-4-97	585+00	600+00	1500	12	EB							150	*0.13*	0.10
Dust Control for Seal Coat	10-4-97	615+00	630+00	1500	12	EB							150	*0.13*	0.10

On the US 30 seal coat sections, the aggregate application rates were high. Considerable excess aggregate was piled between the wheel tracks the morning after construction. The road was extremely dusty under traffic and during brooming. It was apparent that the limestone chips were being broken down under traffic. In some cases the excess aggregate served to loosen the aggregate that was bound to the road surface by wedging it out of place under traffic.

The slurry seal application rate was also less than planned for US 30. This was in part because slurry application started on the cape seal section where the application rate is supposed to be low so the top of the seal coat aggregate would not be completely submerged. Therefore, the construction crew adjusted the screed of the laydown machine so the application rate would be low. When the machine entered the slurry seal section, no adjustments were made, so the application rate remained low. Shortly after it was applied, cold weather arrived and the material raveled completely away. The cold weather arrived after the contractor surfaced the eastbound lanes with slurry seal but before the contractor surfaced the westbound lanes with slurry seal. Therefore, when the contractor shut down for the winter, the westbound lane of the cape seal and slurry seal sections were not surfaced with slurry seal. The contractor returned in May 1998 and surfaced the eastbound lane of the cape seal section only with slurry seal. The slurry seal section was not placed in the westbound lane because research determined that it is unlikely that slurry seal would be used often on high volume roads because longer cure time causes difficulties with traffic control and work scheduling.

Micro-surfacing was also applied to US 30 during the same time period; it suffered some raveling, but not as much as the slurry seal. Like the slurry seal and for similar reasons, it was only applied to the eastbound lane in the fall of 1997. In May 1998, the westbound lane was micro-surfaced. At the same time, another layer of micro-surfacing was placed on the eastbound lane to repair the raveling.

The test sections have been monitored to track the following:

- Pavement Condition Index (PCI)
- skid resistance (friction numbers)
- roughness

In addition pictures were taken of major cracks at 500-foot intervals so researchers could specifically compare the performance of surface treatments on cracked surfaces.

Pavement Condition Index

The PCI was calculated as described by Shahin and Walther *(6)*. This evaluation technique requires an in-depth survey of the pavement surface. Surface distresses are recorded and classified by severity level. This scale is determined by guidelines included in Shahin and Walther *(6)*. Then numerical deductions are assigned for each severity and type of distress. The types of distresses considered are shown in Table 4. These deductions are used to calculate a PCI, which can range between zero and 100, with higher numbers indicating pavement that is in better condition.

Table 4. Pavement Distress Types and Causes of Deterioration *(7)*

Load	Climate / Durability	Moisture / Drainage	Other Factors
Alligator cracking	Bleeding	Alligator cracking	Corrugation
Corrugation	Block cracking	Depression	Bleeding
Depression	Joint reflection cracking	Potholes	Bumps and sags
Edge cracking	Longitudinal and transverse cracking	Swell	Lane / Shoulder drop-off
Polished Aggregate	Patching and utility cuts		
Potholes	Swell		
Rutting	Weathering and raveling		
Slippage cracking			

For the pre-construction survey, researchers videotaped the test sections and then played the videotape back to assess pavement condition. Researchers planned to use rut depth measurements supplied by the Iowa DOT Office of Materials. The measurements are taken from a road rater that is pulled over the road at high speed and measures rut depths using lasers. Although these measurements have proven satisfactory as input for network level assessment, they proved to be unreliable for use on this project. Machine-measured rut depths did not check with manually measured rut depths at locations where spot checks were made in July 1997 (pre-construction survey) and October 1997 (first post-construction survey). Therefore measurements for the May 1998 post-construction survey were taken manually with a four-foot straightedge. Also, researchers found that it was more efficient to record distresses directly in the field, rather than to identify them from videotape. After the pre-construction survey, distresses were recorded directly in the field.

Comparisons of PCI results are provided in Table 5 for US 151 and Table 6 for US 30. Since the rut depth measurements were unreliable, the July and October 1997 results are shown with the assumption that the deduction for rut depth is zero. The May 1998 data are shown with and without the rut depth deductions. Readers can compare the May 1998 data without rut depth directly with the July and October 1997 data to see changes in the PCI. The May 1998 with rut depth information gives the actual PCI.

Before the test sections were constructed on US 151, the PCI ranged from 27 to 43 (not counting deductions for rutting). Control Section One was not established until after the test sections were constructed. Therefore, its pre-construction PCI was not found. After construction on October 26, the PCIs for the test sections ranged from 79 to 93. The thin lift overlay had the best PCI while the double seal coat and micro-surfacing were almost tied for second. The cape seal had the lowest score because the slurry surface was raveling. By May 15, 1998, the slurry seal had suffered severe raveling and had a PCI of 19. The micro-surfacing and cape seal test sections also suffered raveling and had a PCIs of 49 and 46 respectively when rutting is considered. Some raveling was also observed on the chip seal test section. The thin lift overlay performed the best with a PCI of 87, while Control Section One fared the worst with a PCI of 16.

Table 5. PCI Values for US 151 Test Sections *(5)*

Treatment	7/28/97	10/26/97	5/15/98 w/o rut	5/15/98 w/ rut
CTRL 1		29	24	16
Micro-surfacing	27	84	55	49
Slurry Seal	28		19	19
Cape Seal	29	65	56	46
Seal Coat	38	79	76	67
Seal Coat/Fog Seal	31	82	81	70
Double Seal Coat	43	85	85	68
Thin Lift Overlay	29	93	87	87
CTRL 2	37	33	35	28

Table 6. PCI Values for US 30 Test Sections *(5)*

Treatment	7/22/97	10/26/97	5/10/98 w/o rut	5/10/98 w/ rut
CTRL 1	68	68	63	63
Slurry Seal		Failed	Failed	Failed
Cape Seal	55	80	80	66
Seal Coat	70	87	83	74
Seal Coat/Fog Seal	75	93	89	68
Double Seal Coat	80	92	90	74
Thin Lift Overlay	77	93	89	89
Micro-surfacing	79	94	66	66
CTRL 2	83	83	82	72

Researchers reviewed construction weather records in an attempt to find the cause of the raveling. The micro-surfacing, slurry seal, and cape seal test sections were placed during a cold rainy period. Temperatures dropped below freezing on some of the nights immediately following construction. It is likely that these low temperatures caused the micro-surfacing and slurry seal to ravel. For the micro-surfacing, raveling was especially noticeable on high spots where the surfacing was especially thin. For the seal coat, the binder application rate was low due to a calculation error; apparently there was not enough binder to hold the limestone chips. Researchers also observed that the binder temperature was lower than that specified and that the roller tires were under-inflated. Both of these deficiencies are likely to lead to raveling.

Because of the test sections' poor performance, in June 1998 the researchers and Iowa DOT made the decision to cover all of the test sections with micro-surfacing, except for the double seal coat, the thin lift overlay, and the control sections. The double seal coat provided a relatively smooth quiet ride, so it was retained for further evaluation. On May 15, 1998, the wheel tracks were slightly flushed and the binder had flowed enough to seal cracks. By August, friction numbers had fallen to between 10 and 20. The double seal coat was milled off to restore friction.

The pre-construction PCI values for US 30 ranged from 55 to 83. After construction the test section PCIs ranged from 80 to 94 with micro-surfacing having the highest index and thin lift overlay, seal coat with fog seal, and double seal coat close behind. The seal coats were placed during a period of unusually warm fall weather after the crew had gained experience with the technique on US 151. Therefore the performance was better. As with US 151, the double seal coat provided the smoothest and quietest ride of the seal coats. It also flushed in the wheel tracks, providing friction numbers in the range of 10 to 20 in August 1998. Using their own forces, Iowa DOT covered the double seal coat with slurry seal in order to restore friction.

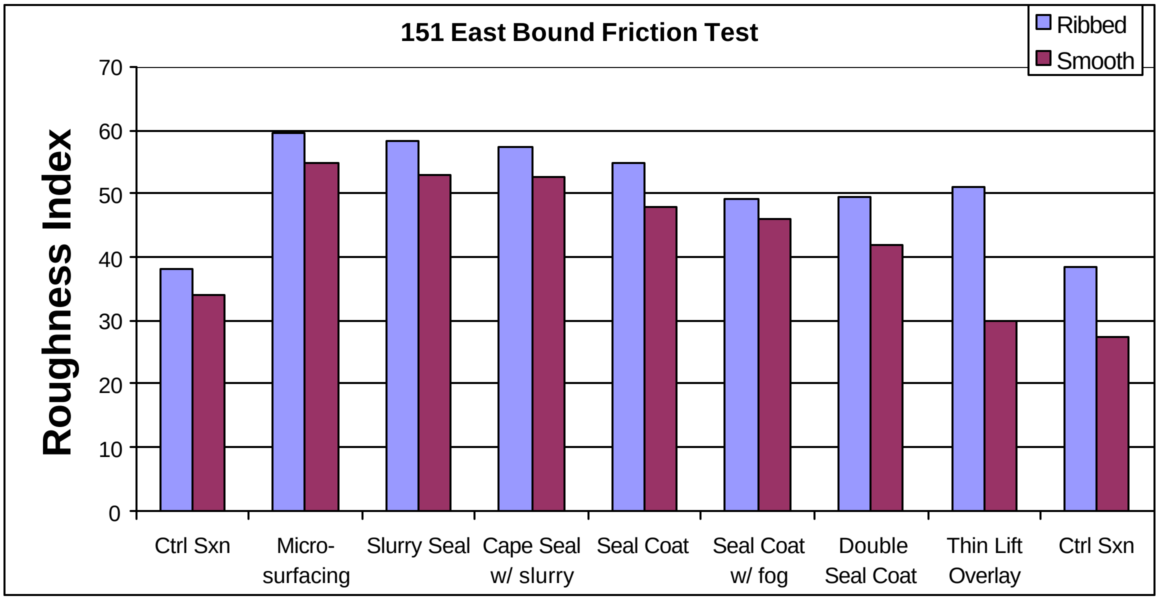
The slurry seal, cape seal, and micro-surfacing test sections were constructed immediately before the construction season closed due to cold weather. The slurry seal completely failed due to raveling, and the micro-surfacing experienced some raveling. In the fall of 1997, slurry seal and micro-surfacing were placed on the eastbound lanes only before adverse weather stopped construction. During June 1998, slurry seal was placed on the westbound lane of the cape seal section only. Micro-surfacing was placed on both the eastbound and westbound lanes of the micro-surfacing test sections.

Skid Resistance

Skid tests were conducted by the Iowa DOT according to ASTM standards E501 and E524. Before construction, the tests were conducted with a ribbed tire to assess the microtexture. After construction, the tests were performed with both ribbed and smooth tires to assess both microtexture and macrotexture. As macrotexture produces friction at high speeds, the smooth skid test is important for high-speed traffic.

The results of the skid tests for US 151 showed that the original friction numbers ranged from 28 to 37. All of the test sections improved these friction numbers (Figure 9).

The highest friction numbers were for the southwest bound cape seal (59.0 ribbed, 52.5 smooth) and northeast bound micro-surfacing (59.5 ribbed, 55.0 smooth). The slurry seal also had high friction numbers (55.0 to 58.5 ribbed, 51.5 to 53.0 smooth) immediately after construction. The seal coat had one friction value at 55.0 for the ribbed tire. The rest of the values were below 50.0. Also, the seal coat had higher friction values than the seal coat with fog seal and the double seal coat. Lower friction was expected for the double seal coat, which has smaller surface aggregate. For seal coat with fog seal, the lower friction may have been caused by the fog seal. The thin lift overlay had a high friction number for ribbed tire but a low number for the smooth tire test. This would be expected because thin lift overlays have less macrotexture than other treatments.



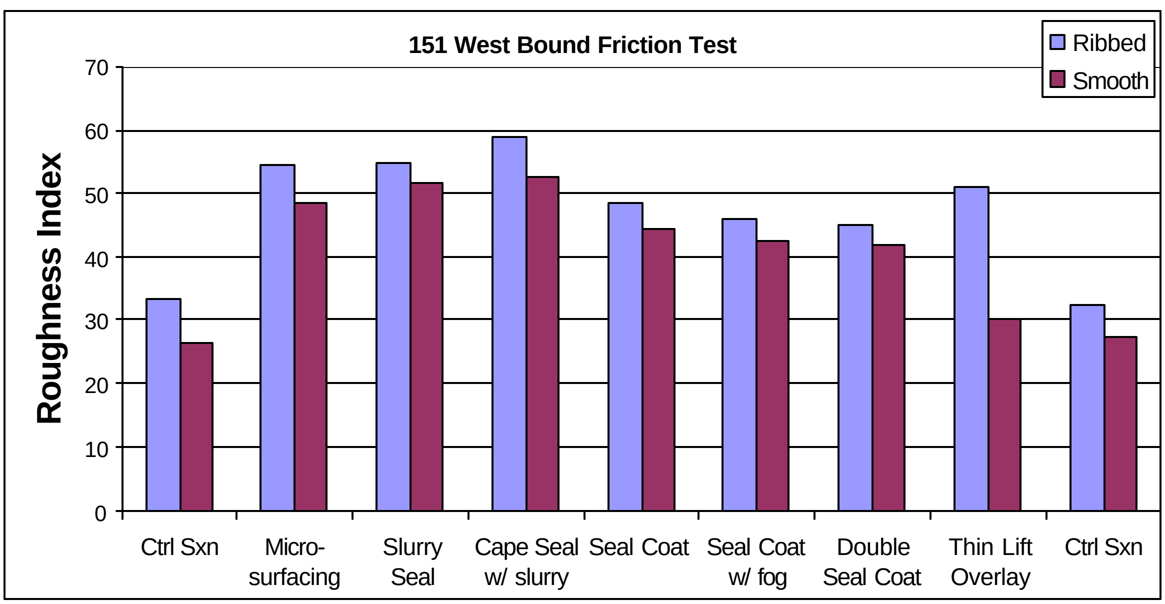
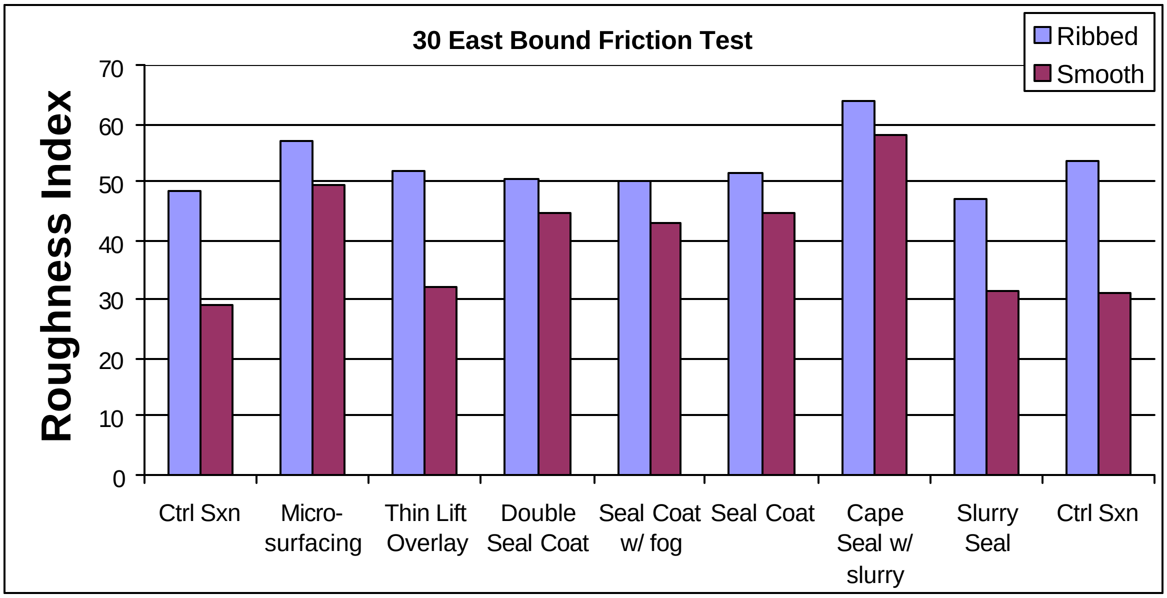


Figure 9. Comparison of Friction Numbers for US 151 Test Sections *(5)*

US 30 had higher friction numbers when compared to US 151. On US 30, the cape seal again had the highest friction number for the westbound lane, and thin lift overlay had the highest friction number for the eastbound lane (Figure 10).



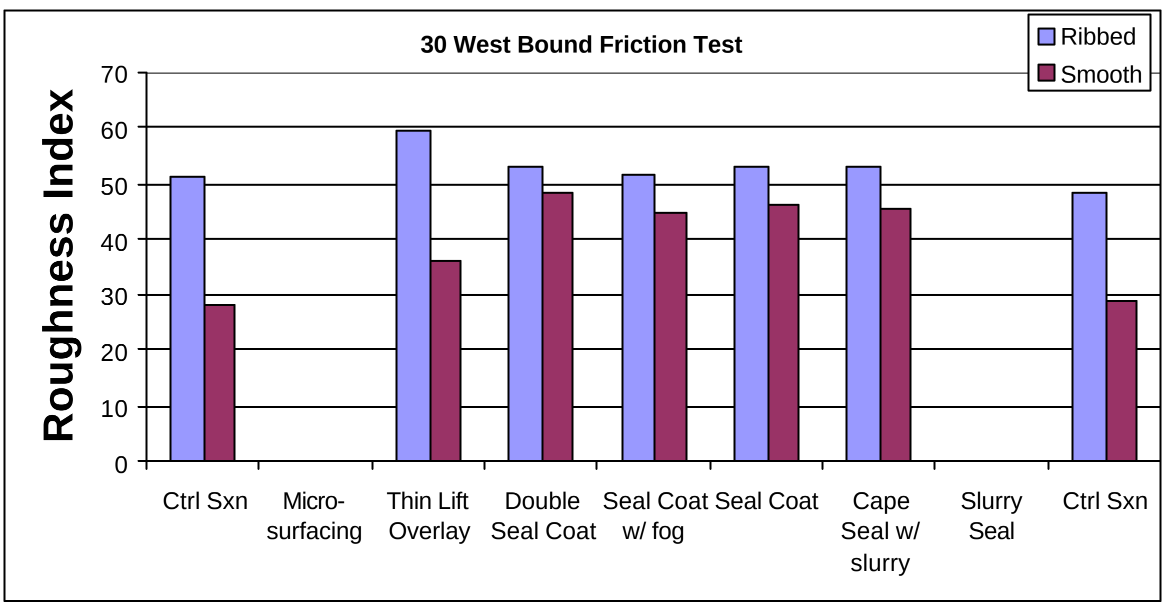


Figure 10. Comparison of Friction Numbers for US 30 Test Sections *(5)*

For the westbound lane, recall that the slurry sections and micro-surfacing sections were not constructed in the fall of 1997 due to weather problems. The slurry section had lower friction numbers since it had started to ravel at the time of the test. This is especially evident in the smooth tire friction number; it had the same value as the control sections. Although only a small amount of slurry seal covered the seal coat on the cape seal section, the friction number was over 60. The cape seal section in the westbound lane that was not covered with slurry seal had the same range of values as the other seal coats. For US 30, the friction numbers for seal coats seemed more consistent with values around and above 50. The micro-surfacing had higher friction numbers when compared to chip seals (results similar to those of US 151). Thin lift overlay ribbed tire friction numbers were higher, and smooth tire friction numbers were lower (results similar to those of US 151).

It can be concluded that TMS improved friction numbers when constructed properly. Although 3/8-inch aggregate was used, both slurry seal and micro-surfacing exhibited higher friction numbers than those of ½-inch seal coats. Properly constructed cape seal, with slurry seal filling the voids among the seal coat chips, resulted in higher friction numbers. Thin lift overlay was the only treatment that did not improve the smooth tire test friction number.

Roughness

A roughness index (RI) was used to assess roughness. Data were recorded by a South Dakota Type Profiler according to ASTM standards E950 and E1170. The results were averaged over the length of the test sections. The test equipment was adjusted to detect roughness with wavelengths up to 300 feet. Wavelengths over 100 feet on highways have little effect on vehicle ride, whereas for airport runway wavelengths, 400 feet might be significant *(8)*. The International Roughness Index (IRI) is sensitive to wavelengths between 4.2 feet and 75 feet as given by Shahin *(8)*. Therefore the RI used in the study cannot be compared to the IRI. However the RI used in the study can be used to compare roughness among test sections.

The control sections on US 151 were rougher than those of US 30 (2.5 to 3.7 vs. 1.2 to 1.4, Figures 11 and 12). The test sections on US 151 were also rougher than those on US 30 (1.8 to 2.6 vs. 1.1 to 1.6). All of the treatments improved the roughness values for US 151.

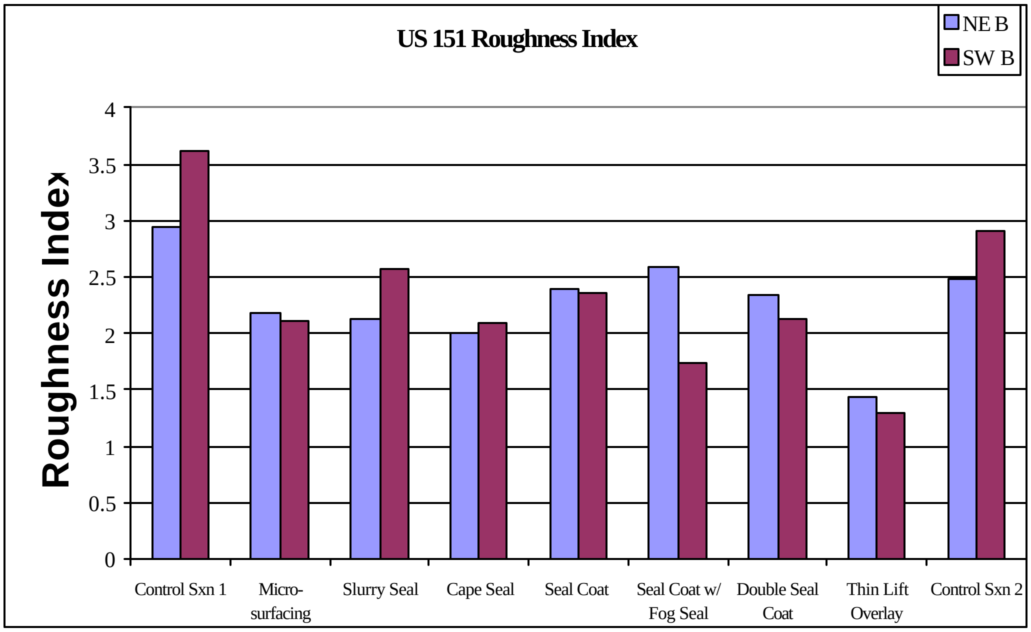


Figure 11. Comparison of Average Roughness Values for US 151 *(5)*

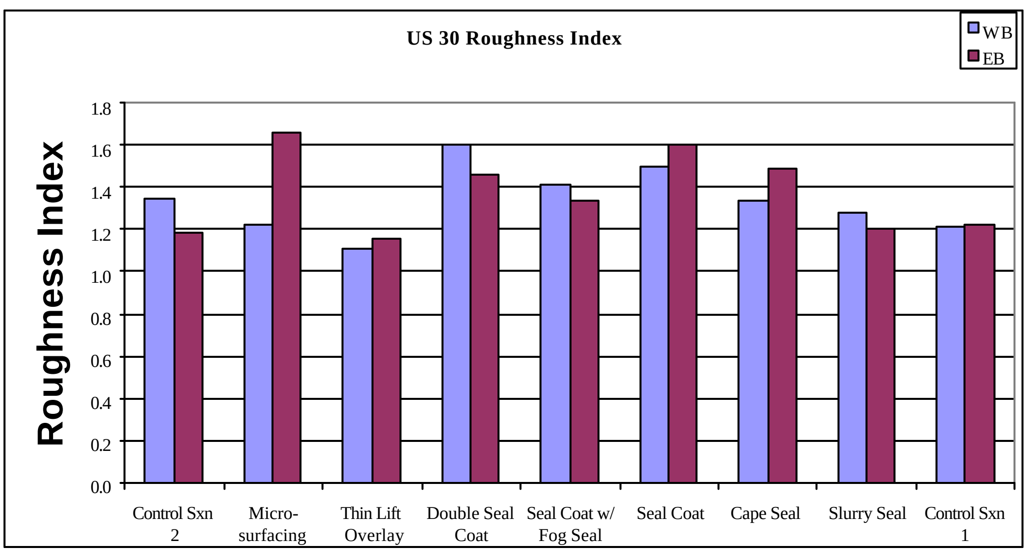


Figure 12. Comparison of Average Roughness Values for US 30 *(5)*

Summary – 1997 Test Sections

The results for the 1997 test sections show the importance of proper timing and attention to detail. It is likely that less raveling would have occurred on slurry seal and micro-surfacing test sections if they had been constructed earlier in the construction season. The slurry seal required a longer curing time; this was undesirable because it was necessary to maintain traffic control on these high volume roads for extended periods of time and to quit early to provide cure time before traffic control was removed at sunset. The quality of the seal coats would have improved with more control over the application rates. In general, the specified application rates resulted in too much aggregate. As a result the road was dusty and the loose aggregate wedged some of the bound aggregate off the road. The surfaces of the ½-inch seal coats were rough and noisy, while the surface of the 3/8-inch aggregate on the double seal coat was smooth and quiet. For high volume roads with smooth hot mix asphalt surfaces, the smoother surface provided by the 3/8-inch aggregate appears to be more acceptable. The micro-surfacing provides a satisfactory surface if it can be placed under good weather conditions so it does not ravel. All of the surface treatments increased the friction in the short term. The thin lift overlay provided the best riding surface; however, cracks reflected through after one winter.

1998 Test Sections

The 1998 test sections were selected to compare the surfaces that had greater success in the 1997 test sections. The test sections were constructed as a part of an existing micro-surfacing maintenance contract on US 69 between Ankeny and Huxley (Figure 13). US 69 is a PCC pavement constructed in 1948 and overlaid with hot mix asphalt (HMA) in 1956 and 1967. In 1990 it was milled and inlaid with two inches of HMA. The cracks have been routed and sealed. The surface was smooth and slightly flushed in places. Compared to many roads, this road was in good shape. However, other researchers have reported greater success and economy with TMS when they are applied seven to 10 years after a hot mix overlay (for example, *1*). The research group wanted to check that finding with the specific weather conditions and materials that are used in Iowa. In addition, it appeared that more cracks are beginning to reflect through. It was desirable to determine if application of TMS would retard propagation of these cracks.

The test sections were constructed under an extra work order negotiated between the Iowa DOT and the contractor Sta-Bilt of Harlan, Iowa. They included micro-surfacing, seal coats, and thin lift overlays. The micro-surfacing test section was a portion of the road constructed under the original contract. The seal coats provided a comparison between single and double seal coats, quartzite and local limestone aggregate, and CRS-2P and polymer-modified high float emulsion (HFRS-2P). The thin lift overlays were a hot sand mix and NovaChip®, a proprietary ultra-thin hot mix seal marketed by Koch Materials Corporation. A control section was also provided.

Prior to construction the road was surveyed to determine the PCI. The pre-construction PCI ranged from 59 to 85. Pictures were also taken of two cracks per test sections so researchers could monitor the performance of the various treatments over cracks.

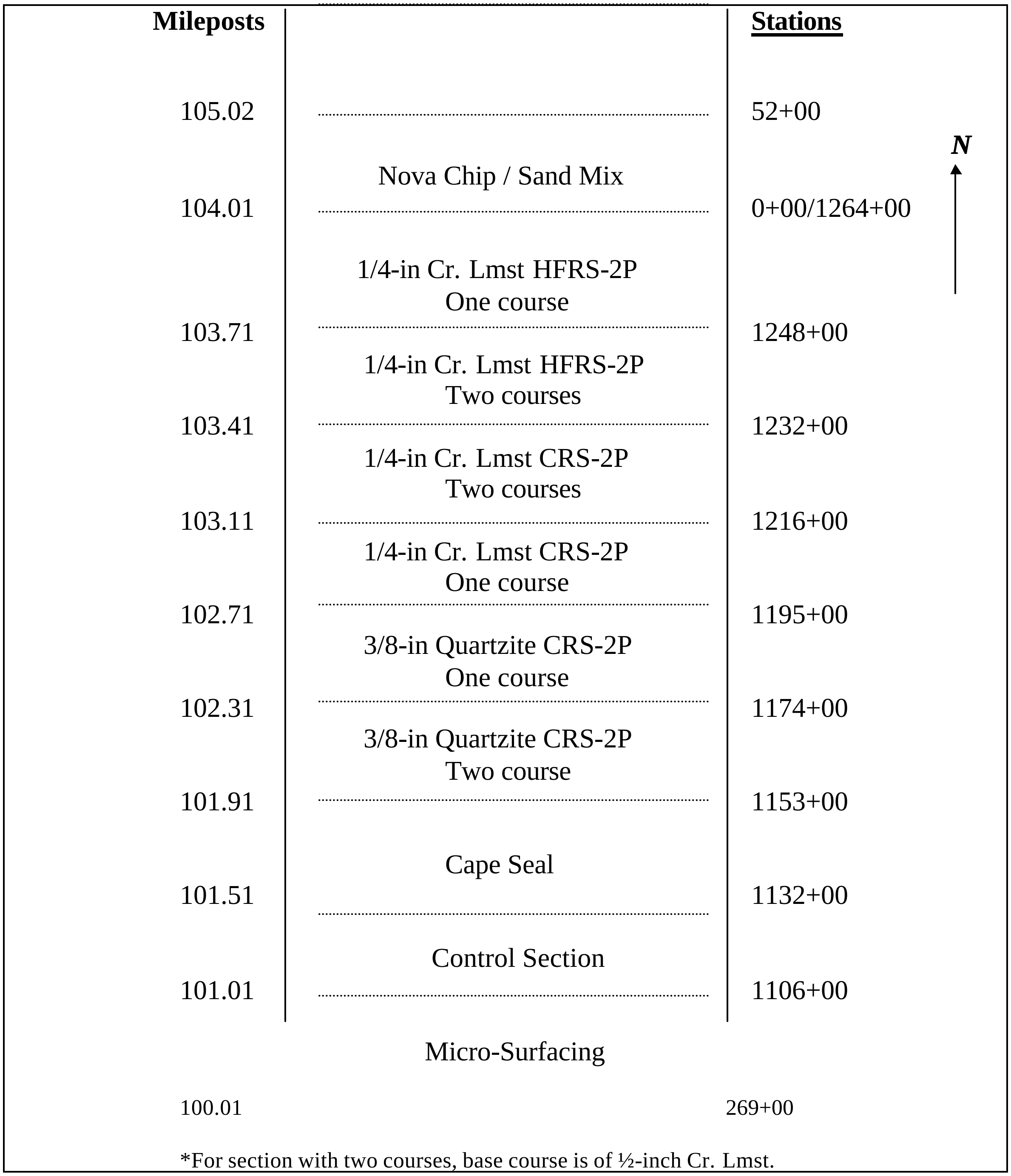


Figure 13. US 69 Test Sections

The micro-surfacing was constructed with Type III quartzite aggregate supplied by L.G. Everest, Inc., Sioux Falls, South Dakota, and Rolumac® binder supplied by Koch Materials, Inc. Quartzite has been used for micro-surfacing aggregate in Iowa because it works well with the micro-surfacing binder and because mixes that use quartzite have good friction characteristics. Micro-surfacing uses a highly reactive binder to provide a quick-setting surface. When highly reactive binders are used, the aggregate cannot contain “hot” materials such as clay or the mix will start to set while it is still in the mixing unit. Typically quartzite contains few hot materials and reacts predictably with the binder. Quartzite is durable and crushes into sharp angular particles that provide high skid resistance when they contact tires. Type III refers to the aggregate gradation which has a top size of 3/8 inch and a bottom size of #200. The International Slurry Seal Association recommends this gradation for high volume roads. Type I and Type II have top sizes of 1/8- and ¼-inch respectively. They are recommended for crack penetration and lower volume roads.

The aggregate gradation was on the course side of the allowable band. When the micro-surfacing was placed on the smooth surface of US 69, the aggregate slid along the road surface and would not go under the spreader box squeegees. The result was a low application rate, sometimes as low at 10 lb/yd^2. The contractor replaced 3/8-inch squeegees with ¼-inch squeegees; this increased the application rate. In areas where the application rate was lass than 15 lb/yd^2, the contractor provided another lift. One section of the micro-surfacing was intended for placement over an interlayer of ½-inch nominal limestone seal coat. Due to difficulties in scheduling material deliveries and crews, the micro-surfacing was not placed over the seal coat during the 1998 construction season. It is expected that it will be placed in 1999.

The surface courses of all seal coat test sections were ¼-inch or 3/8-inch nominal aggregate. Three types of surface aggregate were used: ¼-inch nominal chips from the Martin Marietta Ames Mine, 3/8 × #8 quartzite, and 3/8 × #4 quartzite. The 3/8 × #4 aggregate is a single size aggregate that was produced for use on South Dakota interstate highways, while the 3/8 × #8 was standard seal coat aggregate. The quartzite was purchased from L.G. Everest, Inc., Sioux Falls, South Dakota. The base courses for the double seal coats were ½-inch nominal aggregate supplied by the Martin Marietta Ames Mine. Quartzite aggregate was selected for testing because of its reputation for durability and good friction characteristics. Test sections of 3/8 × #8 and 3/8 × #4 were both included because they will provide a performance comparison between standard (graded) seal coat aggregate and single size seal coat aggregate. The advantage of single size aggregate is that it is theoretically possible to adjust the binder application rate so that most of the particles are 70 percent embedded in binder. This firmly binds the particles to the substrate without submerging the particles, which may lead to flushing. Researchers also investigated the possibility of using crushed gravel chips; however, this was found to be unfeasible because of the high demand for the material and the large amount of waste that is produced when gravel is crushed to make seal coat chips. This possibility could be revisited when the demand for material is lower.

Aggregate from the Eagle City Bed of the Ames Martin Marietta was chosen because it has extremely favorable LA Abrasion ratings for a limestone aggregate (25 to 27 percent). Since the source is also close to the project, it was economical. For double seal coats, ½-inch chips were selected because that is the current standard for Iowa DOT. For the surface course, ¼-inch chips were selected because they were graded so they would fit into the voids of the ½-inch chips. The current Iowa DOT standard for surface course is 3/8-inch chips. While the 3/8-inch chips that were available from Martin Marietta would have met the Iowa DOT specification, they were judged to be too close to the size of the ½-inch chips.

Double seal coats were specified so the double seal coats could be compared to single seal coats. Double seal coats provide a thicker surface and allow the application of more binder. The extra binder will enhance the sealing capability of the treatment. The smaller chips nest in the voids of the larger chips and provide a smoother surface. The double seal coat with ½-inch limestone base and 3/8-inch quartzite top was specified to investigate whether or not it would be possible to provide the economy of a limestone base and the durability and high friction of a quartzite surface.

The CRS-2P (cationic rapid set polymer modified) and HFRS-2P (high float rapid set polymer modified) binders were supplied by Koch Materials, Inc. CRS-2P is the current standard for Iowa DOT seal coats. It is generally recommended for high volume roads. Polymer modification increases early chip retention, reduces flushing in warm weather, and increases elasticity in cold weather. High float emulsions are made with a special family of emulsifying agents that leaves a gel structure behind in the asphalt residue. This reduces temperature susceptibility (bleeding at high temperatures and brittleness at low temperatures) and increases the coating thickness. In addition, many high float formulations include a distillate that aids in coating dusty aggregate. Rapid setting high float emulsions set somewhat slower than rapid setting cationic emulsions. This provides a longer time for the liquid to penetrate any layers of dust that might be present. By specifying both types of emulsion, researchers will be able to compare the performance of both types of emulsion.

The original target application rates for the seal coat aggregate and binder were designed with the assistance of Minnesota DOT using a modified version of the McLEOD design method. Before construction, the chip spreader was calibrated across its entire width with the assistance of Minnesota DOT personnel. For the first 200 feet of each test section, the application was the original target rate. This was adjusted after visual inspection by Minnesota DOT personnel and ISU researchers.

The thin lift overlay sections served as demonstration sections for products that had not been previously constructed in Iowa: hot sand mix with polymer modified binder and NovaChip®. The hot sand mix aggregate was 80 percent quartzite manufactured sand and 20 percent local mason sand. A polymer-modified binder was used to increase high temperature stability and reduce low temperature cracking. The hot sand mix was placed using traditional hot mix asphalt paving methods. NovaChip® is an ultra thin hot mix seal that was originally developed in France and is now supplied in the United States under license by Koch Materials, Incorporated. NovaChip® is placed with a special paver that places a heavy emulsion tack just ahead of the screed. The hot mix drives the water out of the emulsion as it is screeded and the emulsion rises in the hot mix voids to two thirds the height of the overlay. This provides a tenacious bond between the thin hot mix layer and the substrate. The aggregate was a blend of local limestone and imported quartzite. The maximum aggregate size was ½ inch and the overlay thickness was ¾ inch. The aggregate is gap graded to provide an open surface. The mix is rolled to orient the chips.

Compaction rolling is not required because the chips are relatively large for the thickness of the overlay. Due to considerations for scheduling the hot mix plant, the thin lift overlay test section was paved on one lane with the hot sand mix and in the other lane with NovaChip®.

The application rates for the 1998 test sections are provided in Figure 14. For comparison, Iowa DOT specifications call for 0.40 gal/yd^2 of binder and 30 lb/yd^2 of aggregate when ½-inch aggregate is used. When 3/8-inch aggregate is used, the binder application rate is 0.30 gal/yd^2 and the aggregate application rate is 25 lb/yd^2 (specified for second course of two-course seal coats).

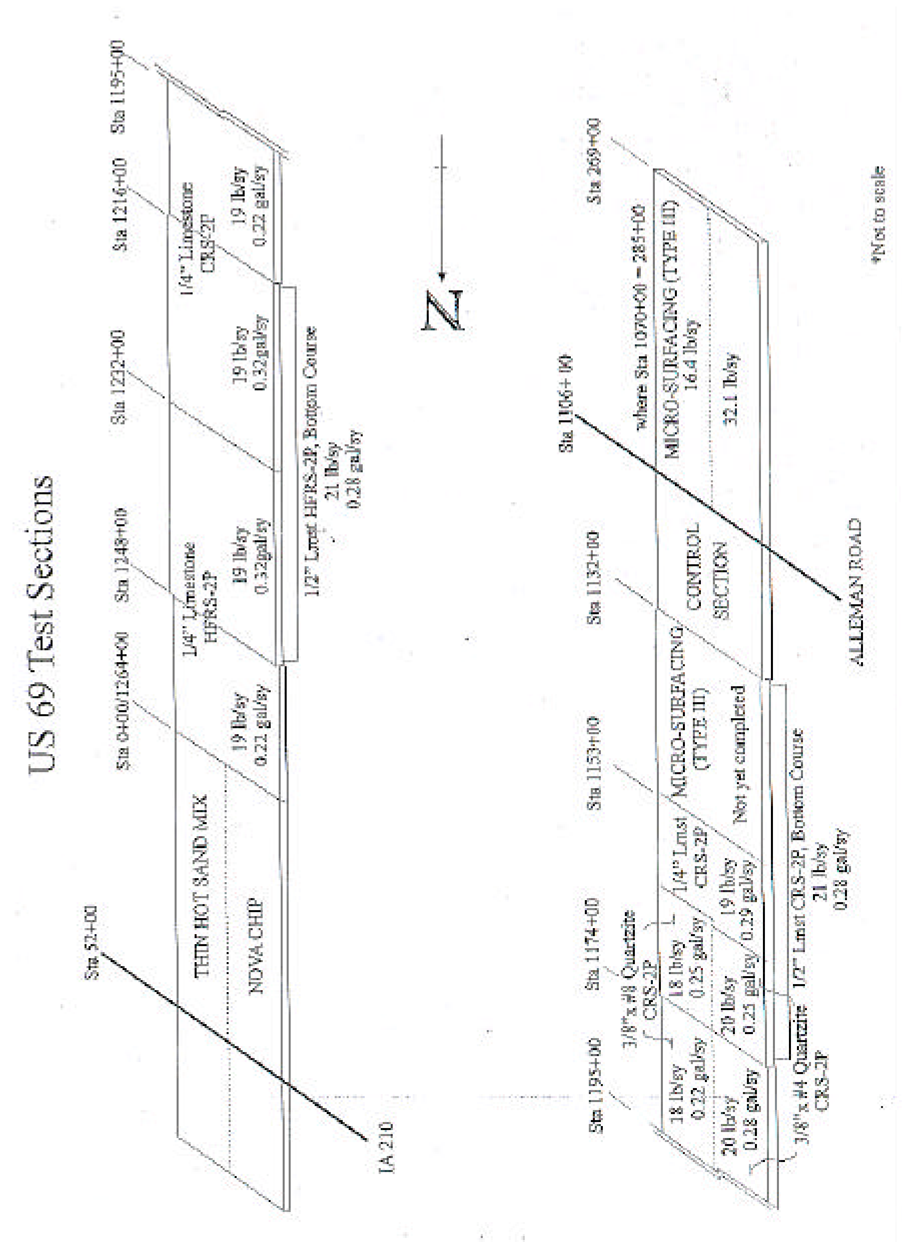


Figure 14. Materials Application Rates for US 69

MONITORING

Researchers plan to monitor the test sections for seven years after construction. Performance surveys will be conducted and the PCI will be calculated in the spring and fall for the first two years of the pavement test section life. Pictures will also be taken of certain cracks (two to three per test section) at the time of each performance survey. Surveys will be conducted each spring for the subsequent five years. Friction and roughness tests will be conducted by the Iowa DOT as part of the statewide regular testing program. Maintenance personnel will monitor the condition of the test sections and control sections and take actions that are necessary to maintain the roads in safe condition.

GUIDELINES FOR TMS

After reviewing the literature and the results of the 1997 test sections, a set of preliminary guidelines was developed to assist transportation officials with TMS timing and selection. It is expected that these guidelines will be refined as additional performance information is obtained from the test sections.

Three-Step Decision Procedure

A three-step decision procedure is recommended (see flowchart, Figure 15).

Step 1 - *Collect information on candidate roads for thin maintenance surfaces*. A performance survey should be conducted to assess the amount and type of distress that the road is suffering. The survey could be a detailed distress survey to provide input for PCI calculations. If a pavement management system is in place, the PCI has been calculated and tracked for a number of years. Thus additional helpful information regarding the rate of deterioration is available. At least a visual assessment should be made and rut depths should be noted. The traffic count should also be obtained and areas that must withstand many turning and stopping movements should be noted.

Step 2 - *Identify feasible treatments.* Using Table 7, identify feasible treatments. Table 8 provides additional guidance for selecting treatments for roads where rutting is the primary distress.

Step 3 - *Consider other factors before making a final selection.* Table 9 provides a list of other factors that should be considered before making a final selection.

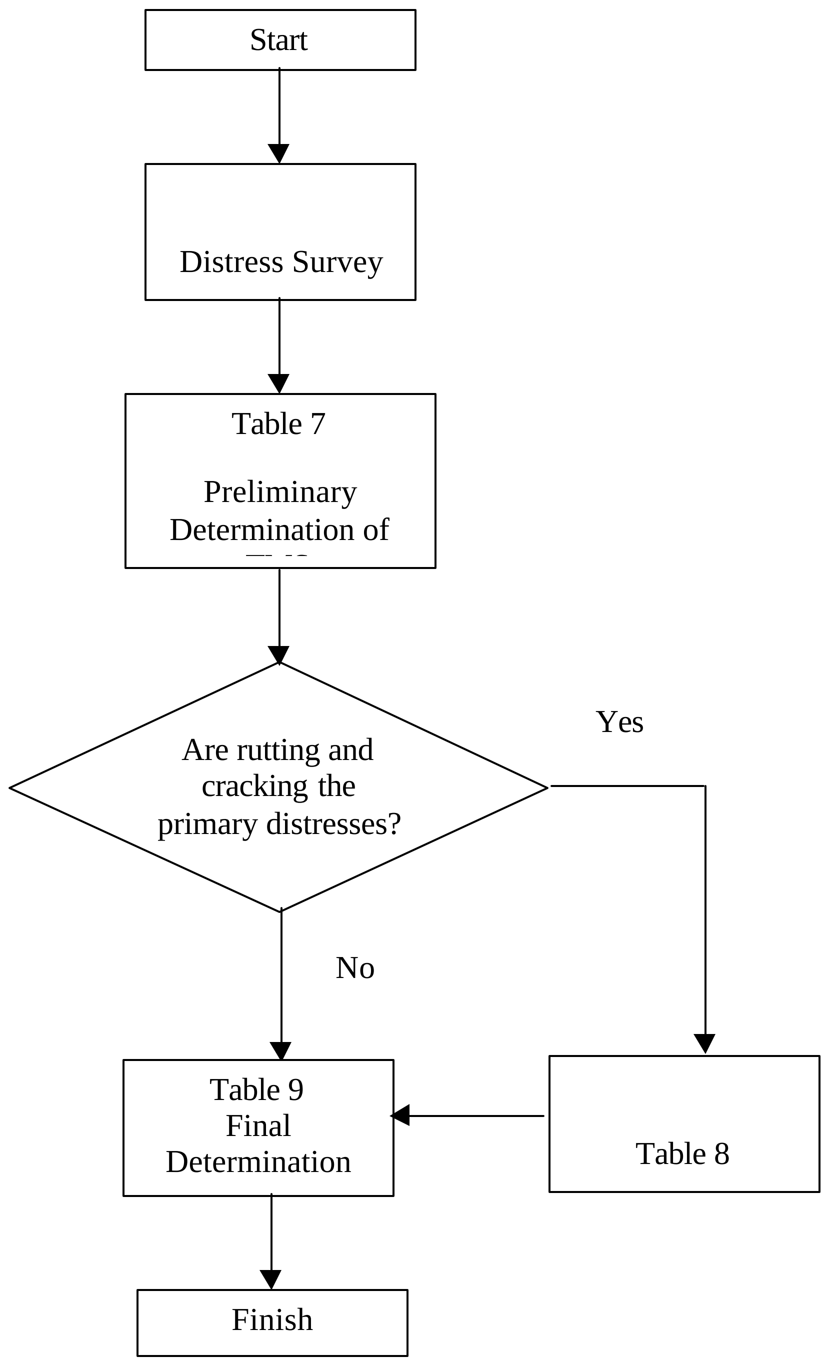


Figure 15. TMS Selection Flowchart

Table 7. Recommended Maintenance Strategies for Various Distress Types and Usage *(3)*

	Seal Coat	Slurry Seal	Micro-Surfacing
1. Traffic			
ADT < 2000	R	R	R
2000 > ADT < 5000	M[1]	M[1]	R
ADT > 5000	NR	NR	R
1. Bleeding	R	R	R
2. Rutting	NR	R	R
3. Raveling	R	R	R
4. Cracking			
Few tight cracks	R	R	R
Extensive cracking	R	NR	NR
5. Improving friction	Yes	Yes	Yes[2]
6. Snow plow damage	Most susceptible	Moderately susceptible	Least susceptible

R = Recommended
NR = Not Recommended
M = Marginal
[1]There is a greater likelihood of success when used in lower speed traffic
[2]Micro-surfacing reportedly retains high friction for a longer period of time

Table 8. Selection Process for Medium and High Traffic Based on Rutting and Cracking *(5)*

	Rut Depth			
Treatment	**Less than ¼-in**	**¼ to ½ in.**	**½ to 1 in.**	**Greater than 1 in.**
Micro-Surfacing[1]	One course	Scratch course and final surface	Rut box and final surface	Multiple placements with rut box
Slurry Seal[2]	One course	One course	Micro-surfacing Scratch course and final surface	See note 3

[1] As recommended by International Slurry Seal Association
[2] Current practice in Iowa
[3] Sometimes successful (anecdotal evidence)

Table 9. Factors That Affect Maintenance Planners' Decisions *(3)*

	Seal Coat (SC)	Slurry Seal (SS)	Micro-Surfacing (MS)
Past Practices	Most officials prefer not to change successful past practice unless there is definite reason for a change. These reasons could be positive or negative changes in funding, neighbor complaints, user complaints, or an opportunity to use better product.		
Funding and Cost	Least expensive option → less funding is required.	More expensive than SC and less expensive than MS.	Most expensive option → more funding is required.
Durability	Dependent of aggregate type, binder type, and application technique.	Less durable than micro-surfacing.	More durable than slurry seal.
Turning and Stopping Traffic	Can be flushed by turning and stopping traffic.	Can hold turning and stopping traffic.	Best wear in turning and stopping traffic.
Dust During Construction	Considerable dust possible.[1]	Little dust possible.	
Curing Time[2]	Road can be opened after rolling is completed and speed should be limited to about 20mph for 2 hours.	Road can be opened after 2 hours in warm weather, and 6-12 hours in cold weather.	Road can be opened after 1 hour.
Noise and Surface Texture	Fairly noisy surface, open surface texture, and many loose rocks immediately after construction.	Less noise, and dense surface texture (close to hot mix surface).	
Availability of Contractors	13 contractors in Iowa.	3 contractors in Iowa.	2 contractors in Iowa.
Use of local Aggregates	Maximum flexibility - Can use somewhat dusty aggregates with cutback binder. - Can use emulsion or cutbacks. - Rock chips, pea gravel, and sand may be used.	Less flexibility.	Least flexible. The binder is highly reactive (break time is affected by clay content).

[1] Dust is mitigated by using washed, hard, or precoated aggregate.
[2] U.S. Department of Transportation, Federal Highway Administration.

(blank)

Table 7 makes recommendations for the use of seal coats, slurry seal, and micro-surfacing. It is based on the results of literature reviews, interviews with Iowa transportation officials, review of survey results, and experience with test sections. A detailed explanation of the entries of Table 7 is given below.

Traffic—Seal coat and slurry seals are usually recommended for lower traffic volumes while micro-surfacing is usually recommended for higher traffic volumes. What constitutes low volume and what constitutes high volume is a matter of judgement and may depend on the expectations of transportation officials and highway users. Current Iowa DOT policy is to use seal coats for traffic volumes up to 2,000 vehicles per day (VPD). Researchers and transportation officials are working to improve seal coats so they can be used for higher traffic volumes by controlling the gradation and shape of aggregates, executing designs to determine application rates, and using polymer modified binders. Thus, in the near future it may be possible to extend seal coat usage in roads with higher traffic volumes. Since it seems likely that the traffic volume for seal coat application will likely increase in the future, it is recommended that the cutoff be set at 2,000 VPD or higher. Therefore, it is recommended that the current 2,000 VPD cutoff be retained.

Although 1,000 to 2,000 VPD seems like low volume traffic on state highways, it is a relatively high volume for county roads. Therefore, expectations may be different for a local jurisdiction. In such cases a lower cutoff (possibly 1,000 VPD) may be more appropriate to match the expectations of road users and transportation officials.

For TMS, the break between medium volume and high volume traffic was set at 5,000 VPD. This is the same as one used by Hicks (*2*) for a series of decision trees for thin maintenance surface selection. Because of expectations for durability, high friction, short construction time, and reduction of fly rock, only micro-surfacing is recommended for these roads.

Slurry seal is not recommended for high volume roads because a longer time is required before traffic can be placed on the newly constructed surface. A Strategic Highway Research Program study *(9)* included slurry seal on comparative test sections located on highways throughout the United States and Canada. Fewer than half of the slurry seal sections outperformed the control sections. The authors have found considerable anecdotal evidence that slurry seal is effective on low volume roads in Iowa. Therefore, it is recommended for low volume roads.

Both seal coat and slurry seal are shown as marginal for medium volume roads (between 2,000 and 5,000 VPD). As discussed previously, it appears that it is possible to extend seal coat use for medium volume traffic when application rates are designed, premium materials are used, and quality control is carefully maintained. Researchers assigned slurry seal to the marginal category for medium volume roads because there was not enough evidence available to select a more definite dividing line. Seal coat and slurry seal are likely to be more effective on medium volume roads with low traffic speeds because such roads suffer lower impact loads.

Bleeding—All types of surface treatments are effective in addressing light to moderate bleeding or flushing. For seal coats, success is increased if the amount of binder is reduced slightly when covering areas that are bleeding. Often it is not possible to correct heavy bleeding with surface treatments because the excess binder seeps through the surface treatment.

Rutting—Micro-surfacing is the most effective surface treatment for correcting rutting problems. The heavily polymer modified binder is stiff enough to maintain stability, even when layers as thick as one inch are placed to fill ruts. Deep ruts require multiple passes and special equipment as outlined in Table 8. Slurry seal can be used to fill ruts up to ½-inch deep on low volume roads. Seal coat applications follow the profile of the original road; therefore, chip seals cannot address rutting.

Raveling—Raveling is a surface defect; therefore thin surface treatments are extremely effective in correcting this problem. Surface treatments are especially effective in correcting raveling due to end load segregation.

Cracking—Working cracks reflect through slurry seal and micro-surfacing quickly because both mixes are relatively stiff and brittle when compared to hot mix or chip seal. However both treatments reduce the width of the cracks. Since micro-surfacing is stiff and tough, the cracks on treated pavements widen more slowly than those treated with slurry seal. Seal coats are more flexible when compared to slurry seal and micro-surfacing. Therefore seal coats are more effective in sealing cracks. Double seal coats are especially effective because this technique allows the placement of two layers of binder.

Low Friction—All surface treatments can be effective for increasing friction if properly applied. In cases where friction is important, extra care should be taken during seal coat application to ensure that bleeding will not result. If non-polishing aggregate is used, the increase in friction can last for as long as the surface treatment remains on the surface of the pavement. Since micro-surfacing aggregate is usually non-polishing, it tends to maintain high friction throughout its life.

Snow Plow Damage—Thin surface treatments are often susceptible to snow plow damage as the plow blade removes aggregates from the road surface. This is especially true for rutted pavements where the plow blade rides hard on the high surfaces. Taking steps to fill ruts will minimize plow damage (see Table 8). Operators can place more down pressure on underbody plow blades, so they are likely to cause greater damage.

Micro-surfacing has a hard dense surface that is most effective in resisting plow damage. Seal coats tend to have a more open surface and aggregate particles may not be securely bound; therefore they are most susceptible to plow damage. Slurry seals generally perform better than chip seals, but not as well as micro-surfacing, in resisting plow damage. Researchers received anecdotal evidence that durable surface treatment aggregate is associated with accelerated plow blade wear.

Table 8 provides further guidance in selecting strategies for rut filling with micro-surfacing or slurry seal. It should be noted that rut filling will serve as only a temporary remedy for ruts that are caused by instability of the ACC or subgrade. Information about micro-surfacing is based on that provided by the International Slurry Seal Association. Information about slurry seal represents current practices in Iowa. It should be noted that proper mix design and proper application technique are especially important when slurry seal is used to fill ruts.

Table 9 lists other factors that should be considered when selecting seal coats, slurry seals, and micro-surfacing. This table was developed after reviewing the literature, conducting interviews of Iowa transportation officials, and examining survey results. If previous investigation shows that more than one treatment is feasible, this table could be used to determine the preferred method. A detailed explanation of the entries for Table 9 is given below.

Past Practices—Most transportation officials prefer to continue successful past practices for as long as possible. Changes may possibly affect the staff, politicians, contractors, road users, and property owners; therefore, it is desirable to communicate with all these groups before, during, and after the change. When a change is made, there is a risk that the change may not be successful. However, there are good reasons for considering changes. These include the need to live within funding limits and opportunities to serve the public better with a better product. When the likely benefits of the change exceed the risk and effort, conditions are favorable for making the change.

Funding and Cost—Seal coats are usually the least expensive surface treatment; therefore, they are attractive to jurisdictions that have limited funding. Requirements for premium materials cause micro-surfacing to be the most expensive option. The cost of slurry seal is between micro-surfacing and seal coat; in some cases it is only slightly more expensive than seal coats.

Durability—Often the more expensive treatments are more durable. Therefore, the life cycle costs of the more durable treatments may be advantageous, even though they have higher first cost. Micro-surfacing is more durable then slurry seal. Seal coat durability depends on the choice of materials and the application technique. Harder aggregates and polymerized binders often result in greater durability and cost.

Turning and Stopping Traffic—Turning and stopping traffic can cause seal coats to flush as tires work the aggregate around in the binder and push it into the substrate. Slurry seal and micro-surfacing tend to be stiffer and therefore less likely to flush.

Dust and Fly Rocks—Seal coat construction tends to be dusty and produce fly rock. Using hard washed aggregate, controlling the aggregate application rate, and sweeping promptly can mitigate dust. Controlling the aggregate application rate and sweeping promptly reduces fly rock. Since slurry seal and micro-surfacing are placed after the emulsion and aggregate have been mixed, the construction process is almost free of dust and fly rock.

Curing Time—Micro-surfacing can be returned to traffic after one hour of curing on warm days, while slurry seal requires two hours in warm weather and six to 12 hours in cold weather. For seal coats, traffic can be returned to the road at low speed after rolling. Curing time is usually two hours, but this varies with climactic conditions.

Surface Texture and Noise—Chip seals have an open surface texture that can be noisy and rough. In residential areas, property owners often prefer a dense surface so children can more easily use bicycles, roller blades, and skateboards. Micro-surfacing and slurry seal provide a more dense, quiet surface, although it is not as dense and quiet as hot mix asphalt.

Availability of Contractor—When several contractors are available to perform work, competition increases and costs are reduced. Also scheduling is easier. In the summer of 1998, there were 13 contractors in Iowa who construct chip seals and seal coats, three who do slurry seal work, and two who perform micro-surfacing. In addition, two out-of-state contractors performed micro-surfacing work.

Use of Local Aggregates—Chip seals and seal coats offer the most flexibility with regard to aggregate usage. Although emulsion binders require the use of clean, washed aggregate, dusty aggregate can be used when cutback binder is used. High float emulsion binders are more forgiving with regard to coating dusty aggregate than cationic emulsions. Pea gravel and sand can be used as cover aggregate on low volume roads. For micro-surfacing, there is little flexibility with regard to aggregate selection. The micro-surfacing binder is highly reactive and will bind quickly and set if clay is present. Therefore, the aggregate may have little clay. High durability is also desired for micro-surfacing aggregate. Locally produced aggregate often does not have these attributes; therefore, it is often necessary to import aggregate. Slurry seal binder is less reactive and, since it is usually used for lower volume roads, durability is less important for slurry seal aggregate when compared to micro-surfacing aggregate. With regard to aggregate selection, slurry seal has more flexibility than micro-surfacing and less than seal coats.

Timing

Properly timing the construction of TMS is extremely important. If the treatment is applied too soon, funds are being expended on roads that do not require treatment. If the treatment is applied too late, the road may have deteriorated to the point that TMS are ineffective.

Of the 1997 test sections, it is likely that TMS were applied too late to be effective on US 151. This road had been overlaid in 1965 and then 22 years later in 1987. Deterioration of the 1987 overlay may have been accelerated because it was applied over pavement that was exposed for 22 years. So far, the results on US 30 are more promising. It was overlaid in 1965, 1977, and 1990. A longer period of observation will be required to determine the service life of these treatments. However, preliminary guidelines may be developed based on the results of literature reviews, interviews with transportation officials, and field observations.

Most experts suggest that TMS be first applied to a road seven to 10 years after it is first constructed. The expected life of the treatment is five to 10 years. Geoffroy *(10)* surveyed 60 state, provincial, and local transportation agencies and reported the results shown in Table 10. During interviews and field observations, researchers have obtained anecdotal evidence that confirms the findings shown in Table 10. Transportation officials who have successful thin maintenance surface programs for hot mix asphalt pavements usually time the first surface treatment when fine aggregate begins to ravel from the road surface; in most cases this is seven to 12 years after the pavement was initially constructed. Roads that consist of several layers of seal coat may require maintenance more often because less pavement structure is available to support loads.

Table 10. TMS Service Life *(10)*

Treatment	Pavement age at time of first application (yr.)	Frequency of application (yr.)	Observed increase in pavement life (yr.)
Crack Filling	5 to 6	2 to 4	2 to 4
Single Seal Coat	7 to 8	5 to 6	5 to 6
Multiple Seal Coat	7 to 8	5 to 6	5 to 6
Slurry Seal	5 to 10	5 to 6	5 to 6
Micro-surfacing	9 to 10	5 to 6	5 to 6
Thin lift overlay	9 to 10	9 to 10	7 to 8

Cost

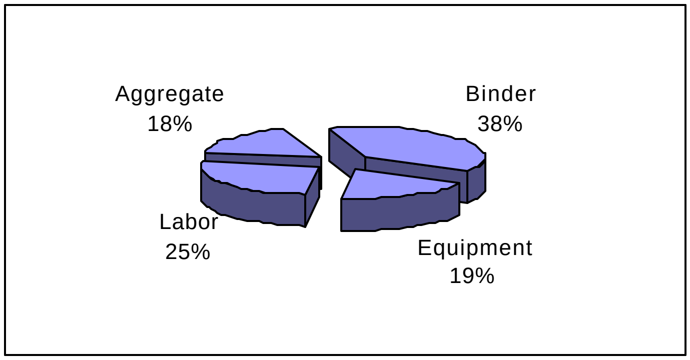
Construction costs for maintenance treatments are given in Table 11. These costs are averages from Iowa DOT Office of Maintenance Operations and include mobilization and traffic control. Overlay costs include the cost of adding shoulder aggregate. Costs range from $ 0.11 per yd^2 for fog seal to $ 3.91 per yd^2 for 2-inch ACC overlays. The average costs for surface treatments are less than half the average costs for two inches of ACC overlay.

Table 11. Average Costs of Maintenance Surfaces Reported by Iowa DOT Office of Maintenance Operations [1, 2]

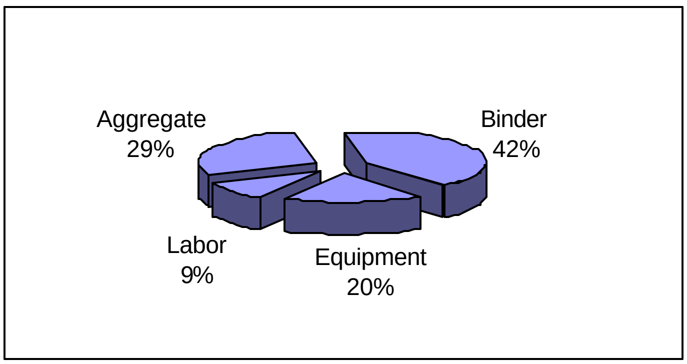
	1996 Cost per square yard	1997 Cost per square yard	Comparison to seal coat costs
Micro-surfacing	$1.29	$1.48	1.82
Fog Seal	$0.11	$0.11	0.13
Seal Coat	$0.71	$0.81	1.00
Slurry Seal	$0.92	$0.92	1.14
ACC 1 inch	$2.27[3]	$2.50[3]	3.09[3]
ACC 2 inch	$3.55[3]	$3.91[3]	4.82[3]

[1] Includes the cost of traffic control and mobilization.
[2] Local system costs may be lower.
[3] Includes the cost of adding shoulder aggregate.

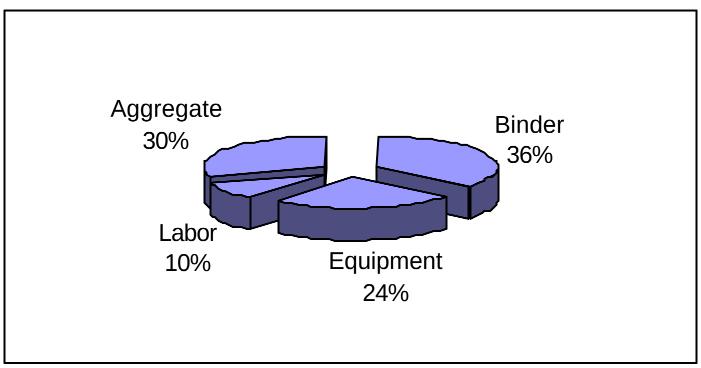
Al-Hammadi *(3)* calculated the proportion of cost that is associated with binder, aggregate, labor, and equipment for seal coats, slurry seals, and micro-surfacing (Figure 16).



(a)



(b)



(c)

(a) Slurry Seal cost breakdown (using local aggregates) (b) Seal Coat cost breakdown (using local aggregates) (c) Micro-Surfacing cost breakdown (using imported aggregates)

Figure 16. TMS Cost Proportion *(3)*

Al-Hammadi used crew sizes and equipment fleets that are typical of construction projects in Iowa. Labor rates were based on Davis Bacon minimum wage rates plus a 30 percent labor burden. Hourly equipment rates, production rates, and material costs were estimated after interviewing contractors and suppliers. In each case, binder accounted for the highest percentage of costs, ranging from 36 to 42 percent. Aggregate had the next highest percentages for seal coat (29 percent) and micro-surfacing (30 percent), while labor was the next highest percentage for slurry seal (25 percent). Equipment comprised a larger proportion of cost for micro-surfacing and seal coat and the smallest proportion of cost for slurry seal. Since the majority of costs are materials, efforts to reduce materials usage will reduce the costs of TMS. Reduced materials usage will also reduce equipment and labor costs because much of the equipment and labor costs are related to the amount of material used. Using seal coat designs is one possible approach to reducing materials usage and costs.

PHASE II RESEARCH

The first phase of research resulted in interim guidelines for the use of TMS in Iowa based on a literature review, a survey of local system transportation officials, investigation of other states that have thin maintenance surface programs, a study of local and imported aggregates, and observations of test sections for one year. It was also expected that recommendations would be developed for future test sections. Because of the limited value of the 1997 test sections, the research plan was modified and an additional set of test sections have been planned, executed, and monitored; this second set of test sections was not contemplated under the original research plan.

Preliminary observations of performance of the 1998 test sections indicate that considerable cost savings could be obtained by designing seal coats. The seal coat designs consider road and material properties and usually recommend lighter application rates of binder and aggregate. The reduction in aggregate is promising because it could result in reductions of fly rock and dust. The test sections also include ultra-thin overlays that may increase friction, reduce headlight glare, reduce water spray, and reduce pavement thickness buildup.

It would be desirable to extend this research project to continue monitoring existing test sections, recommend future test sections, develop seal coat design protocols, and provide technology transfer. Specific needs are outlined below.

Continue Test Section Monitoring—The current test sections should be monitored in the spring and fall for the first two years and yearly thereafter. Seven years was selected for monitoring because that is the generally expected life for TMS according to the literature. Although some of the 1997 test sections have been covered with micro-surfacing, the remaining sections may provide valuable information regarding the longevity of surface treatments on high volume roads. Also, the seal coat sections that have been covered with micro-surfacing will serve as test sections of micro-surfacing with a seal coat interlayer.

Select and Implement Seal Coat Design Process—A process should be developed to design seal coats based on road conditions and aggregate properties. Such a process could potentially reduce material usage by one quarter to one third, with a similar reduction in cost. In order to do this, a laboratory protocol must be developed and personnel must be trained. Lab personnel will be required to analyze the aggregate and develop the design application rates. Inspection personnel must be trained to supervise chip spreader calibration and make adjustments to application rates in the field. It is likely that a few people will need to act as specialists on a statewide basis, possibly consulting for local jurisdictions. Minnesota has a protocol that is being successfully implemented; it may be possible to develop similar procedures in Iowa or work cooperatively with Minnesota to expand the concept.

One of the first steps in starting such an arrangement would be to pilot test seal coat designs on several projects in Iowa and monitor the performance of the designed seal coats. A variety of state, county, and municipal projects could be selected.

Micro-Surfacing Aggregate—It would be desirable to develop a micro-surfacing mix that could utilize local limestone aggregate. This would reduce transportation costs, simplify logistics required to start a project, and ease scheduling concerns. An interim goal might be to use local aggregates for scratch courses and rut filling and imported aggregates for the surface course.

It would also be desirable to consider the possibility of using finer aggregate for micro-surfacing to reduce road noise and plow damage. Type II aggregate (¼-inch top size) would produce a denser surface than the currently specified Type III aggregate (3/8-inch top size); this dense surface may produce the advantages that are sought. The larger aggregate is specified in order to increase friction and durability. Test sections would allow transportation officials to compare the two surfaces and researchers to quantify performance.

Seal Coat Aggregate—It would be desirable to identify local aggregate that provides favorable friction characteristics. Researchers in Texas reported that certain friable limestone and dolomite aggregates developed a rough surface as they degraded, thus providing favorable friction characteristics. Such aggregates may exist in Iowa and may be suitable for low volume roads. Preliminary observations on the 1998 test sections show considerable plow damage for the quartzite seal coats. An effort should be made to make changes to improve the performance of these seal coats when they are plowed.

Thin Lift Overlays—An investigation should be conducted to identify the best uses for the thin lift overlays tested in the 1998 test sections: the hot sand mix and NovaChip®. Early observations show that the hot sand mix provides a dense surface, high friction, and good workability during construction with regard to providing feathered edges and transitions; however, it has limited resistance to crack reflection. NovaChip® provides greater resistance to crack reflection and the open surface reduces headlight glare and spray; however, it is difficult to provide feathered edges and transitions. Both provide fast construction (thin lift requires less material to be delivered, thus fewer delays waiting for materials and changing trucks) and minimal changes in surface grade (will not fill curbs and requires fewer utility cover adjustments). Other states have had more experience with these products, and it would be desirable to benefit from their experience. After initial experience with this product, the authors recommend testing NovaChip® on urban arterials. The product has several advantages that would be helpful on urban arterials:

- The non-glare surface would be beneficial on rainy nights.
- High friction would be beneficial in an area with much stopping, starting and turning.
- Thinness would be an advantage in area with curbs and utilities.
- Fast construction would be an advantage in areas of high traffic volume.

Hot sand mix would be advantageous in areas that require many transitions, feathered edges, and high friction but have a small number of cracks.

Effect of Crack Sealing—During performance observations, researchers have noticed that crack reflection is more severe for TMS that cover routed and sealed cracks than for other cracks on certain test sections. It would be desirable to investigate the effect of crack sealing in greater detail.

Future Test Sections—It would be desirable to provide test sections to test the following:

- Designed seal coats
- Micro-surfacing with local aggregates or finer aggregates
- Seal coats with high friction local aggregate
- Quartzite seal coats designed to minimize plow damage
- Thin lift overlays
- Effect of crack sealing

Refine Guidelines—The guidelines will be refined after the further research. In particular, it may be possible to develop quantitatively based guidelines for each type of distress that is commonly corrected by TMS. This would be setting cutoff limits for the PCI deduct values for each type of distress. Guidelines are currently available that suggest when maintenance and rehabilitation should be performed by considering the PCI for the pavement. The curve shown in Figure 17 is an example. Although this provides effective general guidance for roads that suffer a typical combination of distresses, it could be misleading for roads that suffer from one specific distress. For example, a road that has one-inch ruts and no other distresses would have a PCI of 45, which would put it in the category for deferring action or rehabilitating according to Figure 17. Actually, this distress could be addressed by micro-surfacing if the ruts are not caused by instability of the ACC or subgrade. Micro-surfacing is considered a routine maintenance or a preventive maintenance strategy. Therefore, if the low PCI is due primarily from deductions for rutting, the road is a candidate for TMS. Roads that have PCI values below 50 are candidates for TMS, especially if the distress is primarily due to rutting or raveling—distresses that TMS can most effectively address.

Technology Transfer—A technology transfer effort is required to provide transportation officials with the tools they need to make decisions regarding TMS. This is especially true for towns with populations under 5,000 people. A state-of-the-art review of TMS was written and could be published. Also details of the survey of local jurisdictions are similarly available. It would be desirable to develop shorter summaries that could be read quickly and that would explain critical aspects of thin maintenance surface design, selection, and construction. Brochures and publications are available from other organizations and government agencies that could be passed on to transportation officials in Iowa. It would be desirable to provide workshops and presentations on thin maintenance surface selection, design, and construction for transportation officials throughout the state.

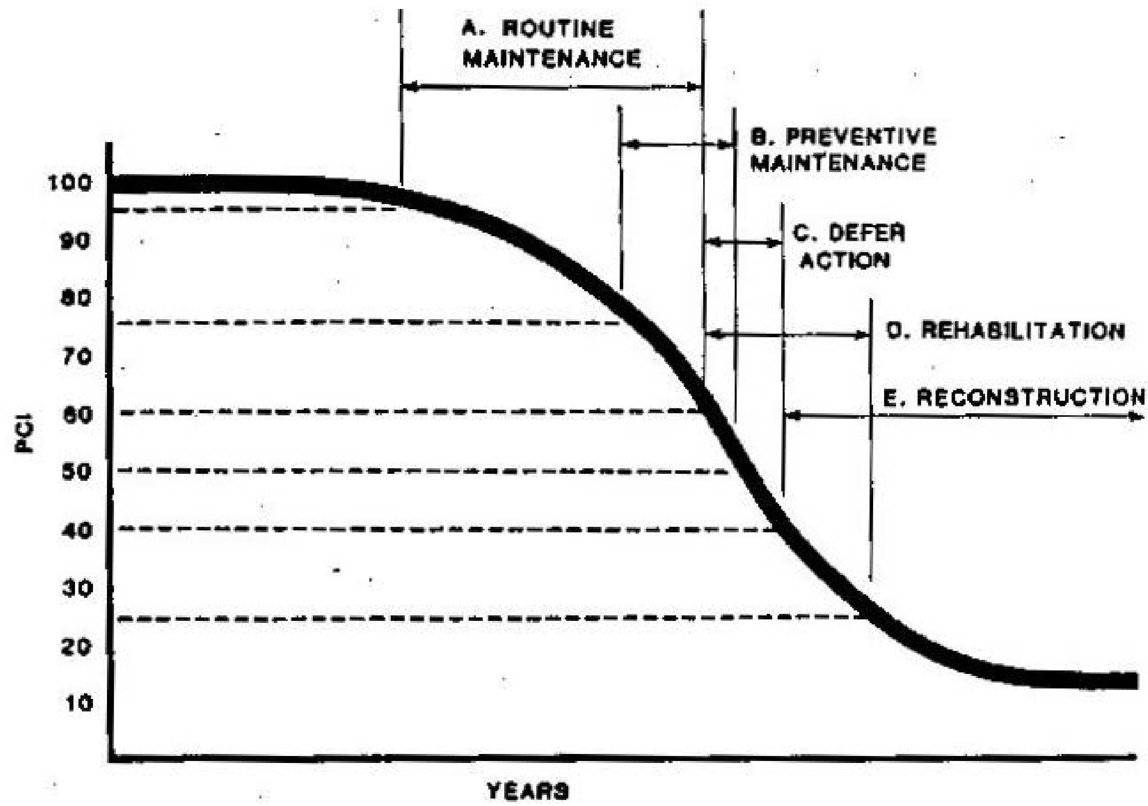


Figure 17. Maintenance Strategies and Timing *(4)*

CONCLUSIONS

Thin maintenance surfaces are an important part of a preventive maintenance program for pavements. A well conceived preventive maintenance program is cost effective and maintains the pavement in good condition by arresting deterioration before the pavement fails and rehabilitation is necessary. This extends the life of the pavement and lengthens the time between rehabilitation cycles. The application of TMS is inexpensive when compared to rehabilitation.

A less desirable alternative to preventive maintenance is to withhold maintenance until corrective action such as patching is required. After patching is required, the pavement often deteriorates quickly so that rehabilitation is necessary. At this point, TMS are sometimes applied in attempt to extend the life of the pavement. Although such action may defer failure for a short time, the long-term results are often disappointing. Ultimately, more expensive rehabilitation options are required.

Preventive maintenance programs are most successful when pavements are monitored and transportation official practice the three Rs:

Placing the

- *right **treatment***

on the

- *right **road***

at the

- *right **time**.*

Dedication is required to follow the three Rs. A reliable source of funding is required so that maintenance projects can be started in a timely manner. Transportation officials must constantly assess the condition of their network so they know which roads are the best candidates for TMS. A pavement management system is especially helpful because officials can track the deterioration of pavements over a number of years. In this way transportation official can select the *right road* at the *right time.* The guidelines set forth in this report will help transportation officials select the *right treatment*. Proper application of TMS is critical to their success. Therefore, it is necessary to assure the quality of materials and check mix designs and application rates during construction. After the maintenance treatments have been applied for a particular season, the monitoring process must continue so roads can be selected for preventive maintenance in future seasons.

Transportation officials face several challenges as they develop preventive maintenance programs that include TMS. Many stakeholders assume that the best strategy is to rehabilitate the worst roads first. After rehabilitation projects have been funded, in many cases funds may not be available for preventive maintenance projects. As maintenance projects are deferred, roads that could have been saved with less expensive preventive maintenance treatments deteriorate to the point that they must also be rehabilitated. Such problems may be addressed by setting aside a reasonable amount of funding each year for maintenance projects.

When transportation officials institute a preventive maintenance program that includes the use of TMS, employees, road users, and the public are often skeptical. To a casual observer, it appears that perfectly good roads are receiving treatments while roads needing rehabilitation are ignored. To be successful as preventive maintenance treatments, TMS must be applied to pavements that are in relatively good condition. This may be when fine aggregate starts to ravel from the surface or at the onset of small, non-working cracks. Then TMS must be applied every five to 10 years. People who are uninformed about the low cost and expected life of such treatments may wonder why they must be replaced so often. The transportation authority will have to invest in preventive maintenance for several years before they can reap the benefits of longer rehabilitation cycles.

The public may have poor perceptions of TMS for several reasons. The ride and texture of thin maintenance surface usually does not match the ride and texture of a rehabilitated road. Ride and texture can be especially disappointing with slurry seal and micro-surfacing because the surface looks like a hot mix overlay to a casual observer. Seal coat construction is somewhat dusty and results in some fly rock and some splattered binder, even when the treatment is properly designed and constructed. With poor design and construction, the problem is worse. Although most treatments increase friction, most also have a more open surface that increases road noise. The public's perception of TMS also suffers when TMS are applied to roads that are in poor condition so they fail quickly. People are likely to blame the maintenance treatment instead of the choice of road.

Considerable effort will be required to overcome these challenges. It will be necessary for transportation officials to better understand the role of TMS in a preventive maintenance program. They must know how to assess the condition of their network and select the proper treatments at the proper time for their roads. Then they must communicate with their employees and the public to explain the benefits of using TMS and guide their expectations regarding characteristics of finished TMS.

Specific conclusions follow:

- When properly selected, timed, and constructed, TMS can economically maintain the condition and extend the life of pavement surfaces.

- When improperly selected, timed, and constructed, TMS can degrade pavement surfaces.

- Good construction technique and attention to details are critical to the success of TMS.

- Warm weather is required for several days after application to properly cure emulsion products.
- If TMS are applied to roads that are in poor condition (such as the 1997 US 151 test sections), they are likely to have a limited life. Thin overlays or two lifts of micro-surfacing are most likely the best candidates in such situations.
- Roads should be first considered for TMS seven to 12 years after construction (when fine aggregate first starts to ravel).
- According to the literature, the expected life of a thin maintenance surface is between five and 10 years.
- With regard to road noise, nominal 3/8-inch cover aggregate is better than ½-inch cover aggregate for seal coats of roads that are in good condition before treatment. However, durability may be negatively affected.
- By designing seal coats, materials usage can be reduced by 25 to 35 percent.
- The majority of costs for TMS are material costs; a portion of labor and equipment costs is related to material costs.

RECOMMENDATIONS

The following recommendations are made:

- Iowa should continue its use of TMS as part of its maintenance program.
- Transportation officials should begin to use the guidelines given herein to plan their maintenance programs.
- When possible, transportation officials should conduct detailed distress surveys as part of the planning process.
- Researchers should continue to monitor test sections and refine the guidelines based on the results of the observations.
- Iowa DOT should continue to construct test sections on an annual basis in various geographic locations.

REFERENCES

1. Zaniewski, J. P. and M. S. Mamlouk. *Preventative Maintenance Effectiveness - Preventative Maintenance Treatments*. FHWA-SA-96-027. Federal Highway Administration, Washington, D. C., February 1996.

2. Hicks, R. G., Dunn, K., and Moultrop, J. T. (1996). "Framework for selecting effective preventive maintenance treatments for flexible pavements." Transportation Research Board 76th Annual Meeting, Washington, D.C.

3. Al-Hammadi, Ahmed Mohammed Ahmed. (1998). "Thesis Report: Thin Maintenance Surface Guidelines for Local Roads." Iowa State University, Ames.

4. Stephens, L. B. (1985). *Road Surface Management for Local Governments: Course Workbook*, Report DOT-1-85-37, FHWA, Washington D.C.

5. Celiks, Serhan. (1998). "Thesis Report: Short Term Performance Evaluation of Thin Maintenance Surfaces in the State of Iowa." Iowa State University, Ames.

6. Shahin, M.Y. and Walther, J.A. (1990). *Pavement Maintenance Management for Roads and Streets Using the PAVER System*. Technical Report No. M-90/05, U.S. Army Construction Engineering Laboratory, July.

7. Johnson, C. (1986). *Pavement (Maintenance) Management Systems.* American Public Works Association (APWA), Chicago, Illinois.

8. Shanin, M.Y. (1994). *Pavement Management for Airports, Roads, and Parking Lots.* Chapman & Hall, N.Y.

9. Raza, H. (1994). *Summary Report – 1993 Field Evaluations of SPS-3 and SPS-4 Test Sites.* Report No. FHWA-SA-94-078, Wshington, D.C.

10. Geoffroy, D. N. (1994). *Cost Effective Preventive Maintenance*, NCHRP Project 20-5, Transportation Research Board, Washington, D.C.