Holding Strategies for Low-Volume State Routes – Phase II

Final Report
November 2020

ASPHALT MATERIALS & PAVEMENTS PROGRAM



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16. Abstract

Low-volume rural roads are generally low funding priorities compared to the roads that are part of the National Highway System (NHS). Therefore, low-volume rural roads tend to deteriorate to a point where traditional pavement preservation and maintenance techniques no longer have the desired effect or sufficient funding is not available.

As a potential solution, the Iowa Department of Transportation (DOT) constructed 10 test sections with various base and surface treatments on a 13 mi low-volume asphalt road segment in northeast Iowa in 2013, which were studied as part of the first phase of this research project. The aim of the project was to develop holding strategies beyond pavement preservation as a solution to low-volume roads that are in poor condition when there are not resources available for a complete rehabilitation. Due to the success of this first phase, a second phase was proposed in 2018.

This second phase study focused on surface treatments and was intended to treat highly distressed composite pavements that have asphalt overlays on portland cement concrete (PCC) pavements. Eight test sections were constructed on US 65, between Hubbard and Zearing in Iowa. The holding strategies evaluated were a combination of cold in-place recycling with various surface mixes, 1 in. profile milling with various surface courses, 2.5 in. profile milling with interlayer and surface course, and double coats of microsurfacing with and without additional spot grinding.

Based on the evaluation of the test sections and follow-up surveys, recommendations are given regarding the selection of the most advantageous strategy for the conditions of the studied pavement.

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HOLDING STRATEGIES FOR LOW-VOLUME STATE ROUTES – PHASE II

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EXECUTIVE SUMMARY

The Iowa Department of Transportation (DOT) constructed 10 test sections on a 13 mi low-volume asphalt road segment in 2013, which were studied as part of the first phase of this research project. The aim of the project was to develop holding strategies for low-volume pavements where preservation would no longer be effective and where rehabilitation would be the appropriate treatment; however, adequate funding is not available. Due to the success of the first phase, a second phase was undertaken in 2018.

The second phase project studied similar strategies but was intended to treat highly distressed composite pavements that have asphalt overlays on portland cement concrete (PCC) pavements. The holding strategies evaluated in this second phase project were a combination of cold in-place recycling with various surface mixes, 1 in. profile milling with various surface courses, 2.5 in. profile milling with interlayer and surface course, and double coats of microsurfacing with and without additional spot grinding. These strategies were identified by the technical advisory committee (TAC) and the Iowa DOT.

The construction and one-year performance of the test sections are documented herein. In addition, the results from the six-year monitoring of the IA 93 test sections (from the first phase of the project) are presented. The performance of the test sections for both phases was evaluated based on pavement condition surveys and laboratory material tests.

The pavement condition surveys of the one-year post-construction sections studied as part of the second phase of this project indicated that longitudinal cracking, rutting, and transverse cracking in the existing pavement have been successfully corrected by the holding strategy treatments with the exception of the microsurfacing sections, which only saw marginal improvement in longitudinal cracking. The total cracking seen in the non-microsurfacing sections after one year initially appears to be related to the thickness of the treatment. The recycling technologies were the most effective treatments to prevent reflective cracking. The thin interlayer with ultra-thin asphalt overlay technologies showed excellent performance with a small amount of bottom-up cracking occurring.

INTRODUCTION

Each year, the Iowa Department of Transportation (DOT) devotes a substantial portion of its budget to road maintenance. Due to its limited resources, the Iowa DOT approach to road maintenance is to invest in pavements in which preventative maintenance can extend the life of a pavement further, and the result has been improved average pavement condition at the network level for less investment. However, this strategy has led to challenges for low-volume traffic roads, where conditions are more critical due to their lower funding priorities. The Iowa DOT faces the challenge of developing holding strategies beyond pavement preservation to maintain low-volume roads that are in poor condition when resources are rarely available for a complete rehabilitation.

In 2013, the Iowa DOT constructed 10 test sections on a 13 mi low-volume asphalt road segment, which were studied as the first phase of this research project. The first phase of the project aimed to develop holding strategies beyond pavement preservation as a solution to low-volume roads that are in poor condition when resources are not available for a complete rehabilitation. The effort of the first phase focused on developing detailed approaches for five components of holding strategies: project recognition, treatment selection, design and construction, maintenance, and late-life reactive maintenance.

Holding strategies were previously presented by Yu et al. (2015) as a management principle that aims to delay major rehabilitation or road reconstruction through the application of more intensive treatments than preventive maintenance treatments, with lower costs and potentially shorter service lives when compared to rehabilitation or reconstruction techniques. Holding strategies are recommended for roads in need of major rehabilitation or reconstruction in which adequate funding is not available.

Given the success of the first holding strategies project, a second phase was undertaken in 2018. This second phase of the project studied similar strategies but was intended to treat highly distressed composite pavements that have asphalt overlays on portland cement concrete (PCC) pavements.

The main objectives of this second phase, as in the first phase, were to identify treatment strategies to maintain low-volume highways near the end of their life cycle to a satisfactory level and delay larger rehabilitation and reconstruction costs. For this purpose, the Iowa DOT selected US 65 between Hubbard and Zearing in Iowa as the test roadway in 2018. The road was originally constructed in 1930 as a two-lane asphalt on old PCC and was resurfaced in 1997. The pavement had annual average daily traffic (AADT) of 1,620 vehicles with 271 trucks in Story County, and 1,560 vehicles with 302 trucks in Hardin County. The existing pavement had various surface distresses. Eight test sections were constructed using various treatments proposed for holding strategies. The treatments included cold in-place recycling (CIR) with hot-mixed asphalt (HMA) resurfacing, double course microsurfacing, milling, and high-performance overlays. Table 1 summarizes the treatments applied to the test sections on US 65.

Table 1. US 65 holding strategy treatment section lengths

Section number	Surface preparation	Surface treatment	Section length (centerline miles)	Reference location (Constructed)	Reference location (Plan set)
7 South	Grinding	Double course microsurfacing	2.3	Both lanes 547+02 to 666+76.92	(BOP) 123.36 to 125.62
1	4.0 in. CIR	2 in. HMA surface mix	0.7	Both lanes 666+67.92 to 685+90.80 and 0+00 to 18+28.12	125.62 to 126.32
2	4.0 in. CIR	1.5 in. HMA surface mix	0.7	NB lane 18+28.12 to 58+59.59 SB lane 18+28.12 to 55+40.00	126.32 to 127.02
3	4.0 in. CIR	1 in. high-performance thin lift overlay	0.7	NB lane 58+59.59 to 94+91.17 SB lane 55+40.00 to 94+91.17	127.02 to 127.76
4	1.0 in. milling	1 in. high-performance thin lift overlay	1.0	NB lane 94+91.17 to 148+64.87 SB lane 94+91.17 to 148+25.41	127.76 to 128.76
5	1.0 in. milling	1 in. high ultra-thin lift overlay	1.0	NB lane 148+64.87 to 201+01.50 SB lane 148+25.41 to 201+01.50	128.76 to 129.76
6	2.5 in. milling	1 in. interlayer + 1.5 in. HMA surface mix	0.7	Both lanes201+01.5 to 238+97.45	129.76 to 130.46
7 North	None	Double course microsurfacing	2.1	Both lanes 238+97.45 to 353+30.00	130.46 to 132.66 (EOP)

CIR = cold in-place recycling, NB = northbound, SB = southbound, BOP = beginning of project, and EOP = end of project

LITERATURE REVIEW

The literature review for this phase builds on the previous literature review that was conducted for the first phase of the project and searching for similar treatments. It was previously found that individual treatments were successfully used and widely accepted. However, treatment combinations and their application to severely deteriorated roads are few.

Thin and Ultra-Thin Asphalt Overlays

Asphalt mixtures that are placed over existing pavement structures as a preventive maintenance treatment to extend the pavement's service life are called thin and ultra-thin overlays. These treatments aim to protect the pavement structure and restore skid resistance (Hajj et al. 2018).

Thin Asphalt Overlays

Thin asphalt overlays are generally asphalt surface courses with a layer thickness less than 1.5 in. (Newcomb 2009). The California DOT (Caltrans) defines the layer thickness of thin asphalt overlays as less than 1.25 in. (Caltrans 2013). Thin overlays, as a pavement preservation technique, are mainly suitable for correcting pavement distresses at the pavement surface such as raveling, longitudinal cracking that is not in the wheel path, and transverse cracking. A thin overlay should not be used to correct widespread structural distresses such as alligator or longitudinal cracking in the wheel path that originates deep in the pavement (Newcomb 2009). A review of the performance of thin overlays by Newcomb (2009) indicated that the life expectancy of thin asphalt overlays ranges from 5 to 16 years with a lower life-cycle cost than other preventive maintenance treatments. Chou et al. (2008) concluded that thin overlays on composite pavements were less cost-effective than thin overlays in flexible pavements, probably because of greater deterioration prior to the overlay placement.

The performance of this preservation technique depends on traffic, climate, surface preparation, the initial pavement condition, and construction quality control, among other factors. Noise reduction, decrease in international roughness index (IRI), and improvement in the pavement surface condition rating are some of the reported immediate benefits of the application of thin overlays. In terms of overall performance improvement and longevity, an American Association of State Highway and Transportation Officials (AASHTO) survey (Gulden et al. 1999) reported overlay techniques as the most frequently cited treatments used by transportation agencies.

Ultra-Thin Asphalt Overlays

Ultra-thin overlays are usually defined as a surface course with a layer thickness less than 0.5 in., not yet in use as a conventional application (Hajj et al. 2018). This technique is generally used to extend the pavement service life, protect the pavement structure, and restore pavement smoothness. Ultra-thin overlays, like thin overlays, as a pavement preservation technique are mainly suitable for correcting pavement distresses originated at the pavement surface. Their use is not recommended for correcting widespread structural distresses. Their life of expectancy is five to nine years, depending primarily on the pavement's initial condition and surface preparation. The AASHTO survey (Gulden et al. 1999) reported 14 out of 41 agencies use ultra-thin overlays as a pavement preventive maintenance treatment.

Mill and Overlay

The AASHTO survey (Gulden et al. 1999) reported 38 out of 41 agencies use the combination of mill and overlay as pavement preventive maintenance treatments. Milling is the cutting process of removing part of the surface of a paved area. Milling is very effective for thin and ultra-thin overlays because of the importance of surface preparation in these two techniques. Milling is useful for maintaining the current grade and creating a rough surface texture that strengthens the bond between the existing pavement and the overlay (Hajj et al. 2018).

In-Place Recycling

In-place recycling techniques are typically used to rehabilitate degraded asphalt pavement. Hot in-place recycling (HIR), CIR, and full-depth reclamation (FDR) are some of the most commonly used in-place recycling methods. These methods are generally considered environmentally friendly and low-cost alternatives when compared to the conventional overlay reconstruction process. After a recycling process, old pavement materials are used in place. Hence, cost, energy, and resources are optimized by eliminating the production of new materials, hauling, handling, and storage.

Hot In-Place Recycling

HIR is the process of repairing a distressed asphalt pavement surface using heat. The process consists of softening the existing surface with heat, scarifying the surface of the pavement to be mixed with a recycling agent, adding virgin asphalt or aggregates, and replacing it on the pavement without removing the recycled material from the site. The working temperature generally ranges from 110°C to 150°C (Button et al. 1994). This technique is recommended for pavements with sound structural integrity. Severely patched, rutted, or chipped surfaces will not likely be managed by this recycling process. The treatment depth ranges from ¾ to 1 in. without exceeding 2 in., and the existing asphalt binder air void needs to be high enough to accommodate the required amount of rejuvenator. The type of surface treatment used in the pavement to be treated is a major factor in the efficiency of the HIR technique. If the removal of great depths of distressed pavement is needed, HIR may not be applicable. The AASHTO survey (Gulden et al. 1999) reported 14 out of 41 agencies use hot in-place bituminous recycling as a pavement preventive maintenance treatment.

Cold In-Place Recycling

CIR is a pavement rehabilitation technique in which reclaimed asphalt pavement (RAP) is mixed with water and recycling agents without using heat. Emulsified asphalt cement and emulsified recycling agents are the recycling additives most commonly used. A cold recycling train consists of cold-milling machines, crushers, screeners, pugmills, and pavers to produce a recycled asphalt concrete layer. This technique is generally combined with partial-depth or full-depth reclamation (Salomon and Newcomb 2000). CIR is useful in treating distresses and failures such as raveling, potholes, bleeding, shoving, fatigue, edge, block cracking, skid resistance, rutting, and corrugation. It can also improve the ride quality caused by bumps, swells, sags, and depressions; enhancement of an existing brittle-aged pavement; and it can provide improved rutting resistance in the pavement life. CIR applications are limited to pavements with adequate underlying soil structures.

CIR can be applied as a base preparation treatment before overlaying. The literature indicates that for more than 40 years, several state agencies using CIR apply surfacing to the recycled pavement. The expected life of the surface layer depends on surface layer type (HMA overlay, rubber or conventional chip seal, microsurfacing, among others [Wood et al. 1988]). The Arizona DOT has used CIR in conjunction with both HMA overlays and double applications of seal treatments. Other DOTs such as Nevada, Pennsylvania, and Ontario have reported a CIR life expectancy of more than 10 years and up to more than 20 years, and a cost savings of between about 45% and 75%. Ninety-five percent of the responding agencies apply a surfacing to the recycled pavement. The AASHTO survey (Gulden et al. 1999) reported 21 out of 41 agencies use CIR, and only 1 agency out of 41 uses full-depth cold recycling. Adequate curing time is essential for the strength gain of the CIR layer. The working environment must be favorable to ensure the construction success. Therefore, some state agencies specify weather restrictions for CIR applications. Usually, temperatures above 15°C (59°F) and dry weather conditions are desirable.

Asphalt Surface Treatments

Asphalt surface treatments (ASTs) are generally a thin asphalt layer, less than 1 in. (25 mm), formed by the application of emulsified asphalt (alone or plus aggregates) to protect or restore an existing roadway surface. Among these treatments are seal coat ASTs, double-layer ASTs, and high-float ASTs. Treatment selection is based on the initial pavement condition, and the average daily traffic (ADT) among other factors. Surface treatment extension of the pavement service life is short, and it is very dependent upon traffic and adequate construction process. The use of the technique is justifiable when traffic is heavy, and the foundation soils are poor, or in projects with frequent maintenance of long stretches of roadways, because of the low life-cycle cost analysis compared with other pavement preservation/maintenance techniques (McHattie 2001).

Seal Coat AST

Seal coats are placed on existing, clean asphalt surfaces to enhance and protect the surface. The existing pavement surface must be in good condition in terms of smoothness, grade, and crown. The seal coat seals and rejuvenates the existing pavement, improving the old surface including skid resistance. The construction process follows the application of oil in a single layer, the addition of coarse, single-sized, crushed aggregate material, and crushed cover aggregate material application. The curing time is crucial to ensure the success of the technique. The expected service life from AST ranges between two and six years depending on the condition of the road before the AST placement.

High-Float AST

The high float is a single layer high-float emulsified asphalt, combined with a single layer of well-graded crushed aggregate. The technique can be used to protect unpaved roads with heavy traffic. The high float is performed in a single step process. Hence, it does not require additional periods of additional brooming, traffic control, or the construction personnel's time, which results in a lower initial cost compared to similar AST techniques.

Double-Layer AST

The double layer is very similar to that of the high-float technique. It can be applied to protect unpaved roads with heavy traffic, and it yields similar service life extensions. This technique consists of a layer of oil and then coarse, crushed, single-sized aggregate material, where the layer is rolled and then the oil is allowed to cure for a few days. The second step is the removal of loose material by brooming and then another application of a layer of oil and aggregates, which is again broomed after several additional days of curing. A double-layer treatment is placed on a smooth base course surface.

A summary of the life extension for the various treatments, as presented by presented Yu et al. (2015), is shown in Table 2.

Table 2. Expected life extension in years

Treatment	Geoffroy 1996	Hicks et al. 2000	Maher et al. 2005	Huang et al. 2009	Wu et al. 2010	Galehouse et al. 2003
Crack sealing		2–5		up to 3	0–4	up to 3
Thin asphalt overlay		2–12		9–12	3–23	5–10
Chip seal	4–7	3–7	3–5	3–5	3–8	3–6
Double chip seal			4–8			4–7
Microsurfacing	4–7	3–9	5–8	7–9	3–8	3–5
Slurry seal	1–6	3–7	3–8	3–8	4–7	
Fog seal		2–7	1–3		4–5	
Otta seal			4–8	4–8		
Double Otta seal			8–15			
CIR			6–20		4–17	
HIR			6–15		3–8	
FDR			7–20		10–20	

Source: Based on Yu et al. 2015

As indicated by Yu et al. (2015), there is limited information on the performance of pavement maintenance techniques when combined and applied to roads in poor condition with the exception of the first phase of this project.

OBJECTIVE AND METHODOLOGY

The main objective of this study is to assist the Iowa DOT and local agencies in developing strategies for maintaining lower-volume highways that are near the end of their service life to a satisfactory level in order to delay the larger expense of rehabilitating or reconstructing them. This report summarizes the one-year performance observation of the treatment sections on US 65 and includes the ongoing monitoring of the IA 93 test sections.

Pre-Design Investigation

A pre-design investigation was conducted to ensure that the test sections for holding strategies were appropriate for the local circumstances. The investigation consisted of a review of the available information from the Iowa DOT's Pavement Management Information System (PMIS) and its Test Sections by Milepost book (2016). The IRI for each wheel path, longitudinal and transverse cracking, alligator cracking, and rutting were documented. Coring was conducted to assess current pavement and base section characteristics.

Pavement Condition Survey

A summary of the cracking data from the PMIS (2014) for the Story County and Hardin County sections is presented in Table 3.

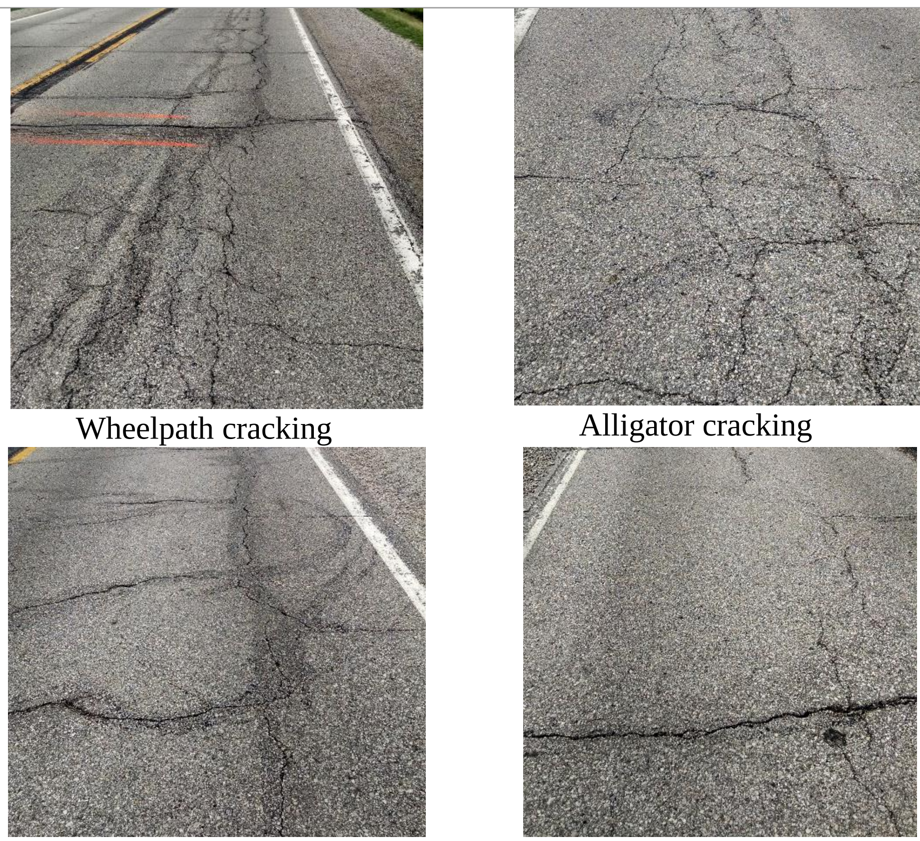
Table 3. Cracking data from the PMIS

		Severity			Combined
	Cracking data	**High**	**Medium**	**Low**	**index**
Story County	Transverse		2	511	
	Longitudinal		18	3,833	3,860
	Longitudinal wheel path		17	4,836	4,860
	Alligator		26	1,857	39
Hardin County	Transverse	2	55	901	
	Longitudinal	19	303	5,069	5,562
	Longitudinal wheel path	6	190	4,010	4,338
	Alligator		44	2,107	66

Pavement condition surveys were performed according to the Federal Highway Administration (FHWA) pavement distress identification manual (Miller and Bellinger 2014). The severity level of the cracks was determined using a caliper. Figure 1 shows a deflectometer equipped with a 4 ft straight edge and a vertical ruler used to measure the rutting in the wheel paths.

Figure 1. Deflectometer for measuring rutting

Cracking, fatigue cracking, raveling, and rutting were evaluated. The majority of the evaluation used was visual inspection as presented in Figure 2.



Wheelpath cracking

Alligator cracking

Longitudinal cracking

Transverse cracking

Figure 2. Surface distresses from pre-construction visual inspection

Each survey test section was 500 ft long. The study included at least one 500 ft test section for each treatment. Sections with more than 2 miles (i.e., sections 7 North and 7 South) included three 500 ft test sections. The location of the survey sections depended on the terrain and geometry of the road. The results from the pre-construction survey for transverse and longitudinal cracking and rutting are shown in Figures 3 through 5.

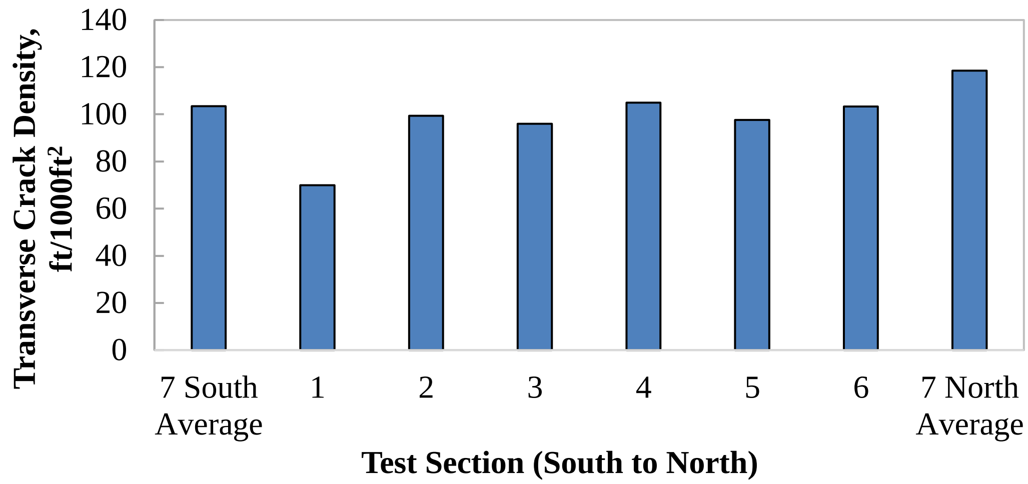


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Figure 3. Pre-construction transverse cracking density per test section

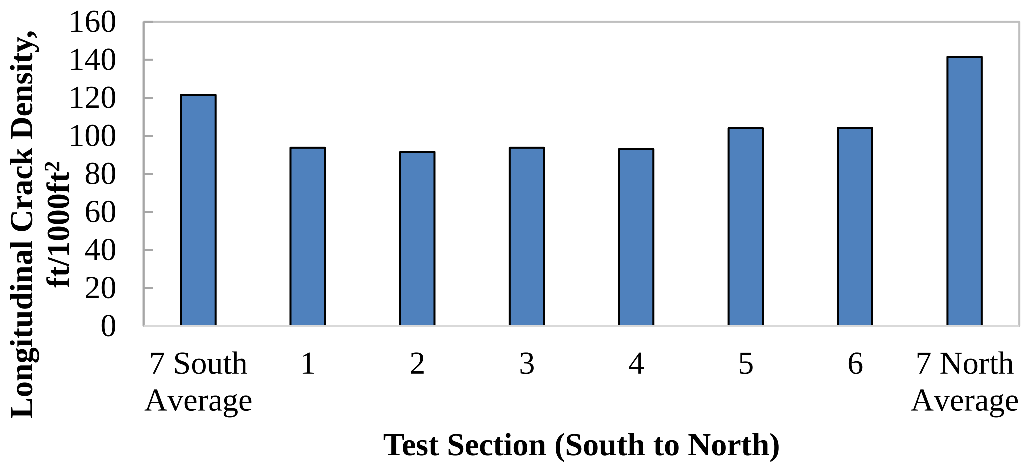

Figure 4. Pre-construction longitudinal cracking density per test section

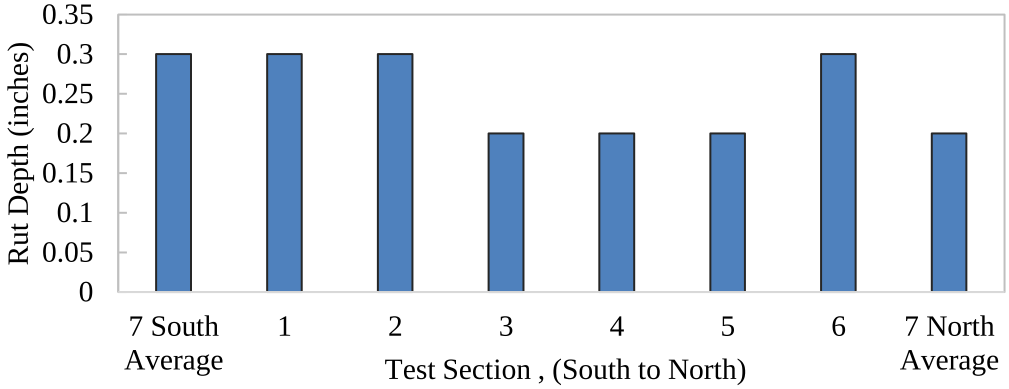

Figure 5. Average rut depth per test section

A higher crack density (longitudinal and transverse) and rutting was found in all sections, making this stretch of pavement an ideal candidate for various treatments.

Surface Characterization

The surface characterization was assessed from an analysis of the existing information from the PMIS in 2014. The average pavement condition index (PCI) was reported to be 53, which falls between very poor to poor condition. The IRI ranged between 114 in./mi in Story County and 106 in./mi in Hardin County. These surface characteristics influence road functional performance, such as friction, noise generation, tire wear, and fuel economy, which is related to passengers' safety, level of comfort, and user costs.

TEST SECTION CONSTRUCTION

The test sections were constructed in accordance with the contract documents.

Test Section Information

The test sections were constructed on US 65 between Hubbard and Zearing in Iowa from milepost 123.36 to 132.66 (Figure 6 and Figure 7).

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Figure 6. Project location in Iowa

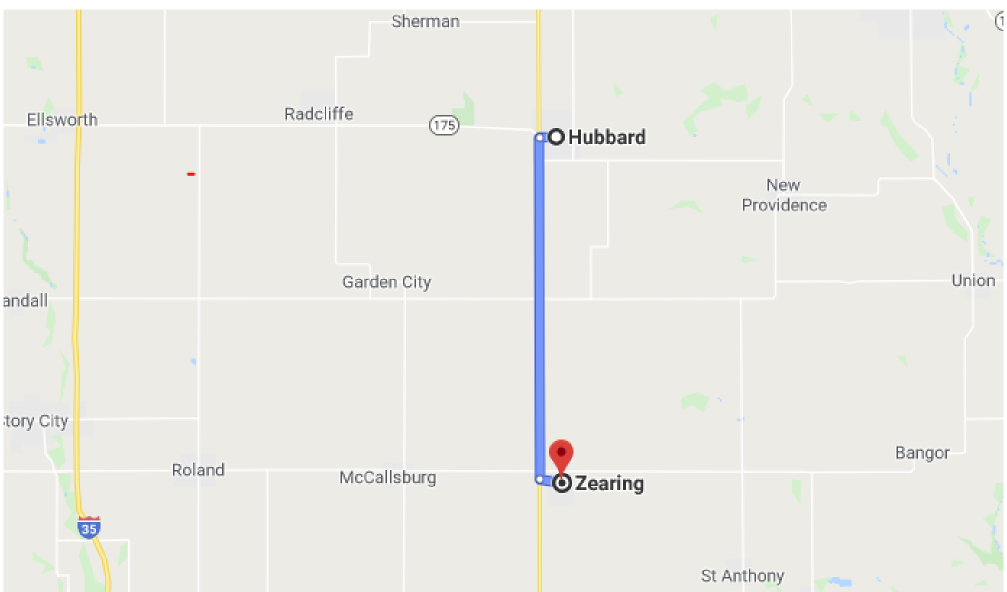

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Figure 7. Project location on US 65

US 65 is a state highway in the southern and midwestern US. US 65 connects Clayton, Louisiana, intersecting several interstates, to I-35 in Albert Lea, Minnesota. US 65 enters Iowa at Lineville, it runs concurrently for 1 mi with I-80, and it leaves the state north of Northwood. The primary industry in this region is agriculture.

For US 65 near the test sections, the AADT was 1,620 vehicles with 17% trucks in Story County in 2014 and was 1,560 vehicles with 19% trucks in Hardin County in 2014. The design equivalent single axle loads (ESALs) are 46,930 and 51,880 for Story and Hardin counties, respectively. The road is subjected to heavy, oversized farm traffic during harvest seasons. The road was first built in 1930. Resurfacing maintenance was performed in 1997. The lane width is 24 ft with 6 ft of shoulder.

The original pavement structure consisted of a 10-7-10 PCC pavement constructed in 1930. The Story County portion was resurfaced in 1952, 1957, 1972, 1978, and 1997, and the Hardin County portion was resurfaced in 1957,1978, and 1987. The most recent surface maintenance in 1997 was resurfacing and milling, with an addition of recycled asphalt materials and 2 in. recycled asphalt surfacing. Investigation of the pre-construction cores indicated considerable variability among the thicknesses of the existing HMA along the test sections. The results from the HMA core thicknesses for each test section are presented in Table 4.

Table 4. HMA core thicknesses from pre-construction pavement structure on US 65

Section number	HMA core thickness (in.)
7 North	7.75
1	12.38
2	10.25
3	9.74
4	15.88
5	7.00
6	8.00
7 South	10.25

A general sketch of the structure of the existing pavement is presented in Figure 8.

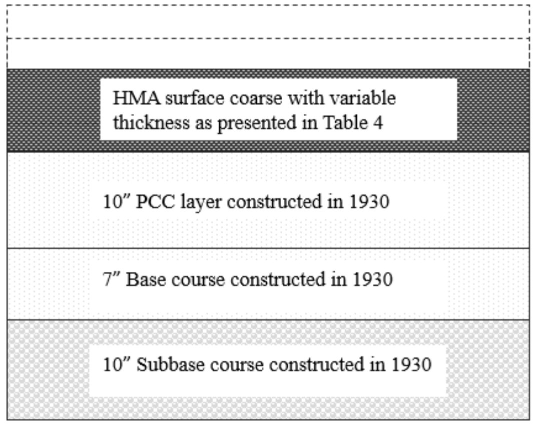

Figure 8. Structure of existing pavement

Pre-construction field coring yielded cores for all eight test sections. The field core samples showed high pavement thickness variation. Multiple distress types were observed including bleeding, potholes, raveling, surface cracking, and edge cracking. The Iowa DOT records indicated the roadway rutting index was 47 and 51 for Story and Hardin counties, respectively. The project applied various holding strategy treatments to the eight test sections as previously presented in Table 1.

Materials

HMA Concrete

For each test section that required in-place recycling or milling, the binder content was determined, ranging from 5.2% to 5.6%, and the section aggregate properties for the appropriate depth are specified and presented in Tables 5 through 10.

Table 5. Test section #1 aggregate properties

Sieve size (US)	Sieve size (mm)	% retained on each sieve	% passing cumulative
1 in.	25	0.0%	100.0%
3/4 in.	19	0.0%	100.0%
1/2 in.	12.5	6.3%	93.7%
3/8 in.	9.5	4.1%	89.6%
#4	4.75	20.0%	69.6%
#8	2.36	20.0%	49.6%
#16	1.18	12.9%	36.7%
#30	0.6	11.8%	24.9%
#50	0.3	11.5%	13.4%
#100	0.15	5.9%	7.5%
#200	0.075	1.9%	5.7%
Pan	0	0.2%	5.6%*

*Percent finer than No. 200 by AASHTO T 11-05 with the addition of dry sieve <No. 200. Percent binder content determined by asphalt extraction (AASHTO T 319), 5.38%.

Table 6. Test section #2 aggregate properties

Sieve size (US)	Sieve size (mm)	% retained on each sieve	% passing cumulative
1 in.	25	0.0%	100.0%
¾ in.	19	1.5%	98.5%
½ in.	12.5	9.8%	88.7%
3/8 in.	9.5	7.6%	81.1%
#4	4.75	20.5%	60.6%
#8	2.36	16.6%	45.5%
#16	1.18	10.5%	35.0%
#30	0.6	9.8%	25.2%
#50	0.3	10.0%	15.2%
#100	0.15	5.4%	9.7%
#200	0.075	2.3%	7.5%
Pan	0	0.3%	5.9%*

*Percent finer than No. 200 by AASHTO T 11-05 with the addition of dry sieve <No. 200. Percent binder content determined by asphalt extraction (AASHTO T 319), 5.65%.

Table 7. Test section #3 aggregate properties

Sieve size (US)	Sieve size (mm)	% retained on each sieve	% passing cumulative
1 in.	25	0.0%	100.0%
¾ in.	19	1.7%	98.3%
½ in.	12.5	8.7%	89.6%
3/8 in.	9.5	6.1%	83.5%
#4	4.75	19.9%	63.6%
#8	2.36	17.5%	46.1%
#16	1.18	11.4%	34.7%
#30	0.6	10.3%	24.4%
#50	0.3	10.4%	14.0%
#100	0.15	5.5%	8.5%
#200	0.075	2.2%	6.3%
Pan	0	0.4%	5.7%*

*Percent finer than No. 200 by AASHTO T11-05 with the addition of dry <No. 200. Percent binder content determined by asphalt extraction (AASHTO T 319), 5.65%.

Table 8. Test section #4 aggregate properties and binder content

Top milled aggregate properties and binder content	Percent
Percent binder content determined by asphalt extraction (AASHTO T 319)	5.4%
Percent finer than 75µm (No. 200) sieve (AASHTO T 11-05)	5.8%

Table 9. Test section #5 aggregate properties and binder content

Top milled aggregate properties and binder content	Percent
Percent binder content determined by asphalt extraction (AASHTO T 319)	4.9%
Percent finer than 75µm (No. 200) sieve (AASHTO T 11-05)	5.7%

Table 10. Test section #6 aggregate properties and binder content

Top milled aggregate properties and binder content	Percent
Percent binder content determined by asphalt extraction (AASHTO T 319)	5.9%
Percent finer than 75µm (No. 200) sieve (AASHTO T 11-05)	5.7%

CIR Material

The cold in-place recycled material consisted of 4 in. of pulverized existing asphalt pavement mixed with foamed asphalt binder at an average application rate of 0.0011 tons/yd^2/in.

Construction and Quality Control/Assurance Procedures

Scarification

The existing pavement was milled with a profiler to the design depth and profile. The milling was extended uniformly across the shoulder where needed. The milled pavement materials were transported by a discharge conveyor to a truck in front of the profiler. Water was sprayed on the milling drum in order to control dust and cool down the drum. A water tank truck was accompanied by the profiler to provide a continuous source of water.

Cold In-Place

Cold in-place recycling operations were conducted by a CIR train including a milling machine, a crushing and screening unit, a pug mill, and an oil tank trailer (Figure 9).

Figure 9. CIR operations: train, left, and pavement placement, right

The milling machine milled the existing pavement to 4 in. depth and the RAP was conveyed to the crushing and screening unit. This unit further crushed large chucks of RAP into smaller particles that met the specification requirements for RAP gradation. The processed RAP was then conveyed to the pug mill, where it was blended with foamed asphalt. The asphalt binder was supplied by the oil tank trailer that was attached behind the pug mill. The blended mixture was placed in a windrow for the paver. Iowa specifications require the density of the CIR layer to be 94% or above the laboratory density.

After speaking with Heartland, the researchers found that they had pulled cores on the sections that required density, but were not able to obtain a record of the voids.

Microsurfacing

This project required two full-width lifts of emulsified asphalt and microsurfacing aggregate. The total microsurfacing for north and southbound US 65 was 4.4 mi long. The microsurfacing met the current specifications for polymer-modified microsurfacing placed as a two-course treatment, as stated in the project documents. The first course was placed 24 ft wide as a scratch course and placed with a spreader box using a metal or stiff rubber strike-off. The first course cured under traffic for a minimum of 24 hours before the application of the second course. The second course was placed 24 ft wide and was estimated at 18 lb/yd^2.

The contractor protected all bridge decks and their associated expansion joints from the emulsion and any damage. In addition to expansion joints within the bridge deck, typically, there are additional full-width, transverse, and expansion joints located within the first 70 ft of roadway on both ends of bridge decks that were protected from being damaged.

HMA Paving

HMA materials for surface, interlayer, and leveling and strengthening courses were placed following Iowa DOT specifications (Figure 10).

Figure 10. Microsurfacing and paving operations

Quantity and Cost

The total cost for the construction of the treatment sections was $794,990.86. Table 11 summarizes the cost and material quantity for each bid item.

Table 11. Construction costs and material quantities

Bid item	Quantity	Unit	Price	Total	Sections
Granular base	434.9	ton	$27.85	$12,111.97	All
Cleaning of base	4.8	mi	$150.00	$720.00	1–6
Pavement scarification	40,536	yd^2	$0.92	$37,293.12	7S
HMA interlayer rock	561.1	ton	$48.31	$27,106.74	6
HMA thin lift rock	1,376.9	ton	$47.50	$65,402.75	3 and 4
HMA ultra-thin rock	794.7	ton	$46.67	$37,088.65	5
HMA surface rock	2,745.2	ton	$43.10	$118,318.12	1, 2, 6
Surface binder	164.7	ton	$477.00	$78,561.90	1, 2, 6
80% recovery binder	108.5	ton	$570.00	$61,845.00	5 and 6
90% recovery binder	110.2	ton	$586.00	$64,577.20	3 and 4
Cold in-place	29,536	yd^2	$2.16	$63,797.76	1, 2, 3
Foamed asphalt	130.0	ton	$440.00	$57,200.00	1, 2, 3
L-4 microsurfacing agg	1,176.5	ton	$30.00	$35,295.00	7N and 7S
Prep microsurfacing	4.4	mi	$9,000.00	$39,600.00	7N and 7S
Emulsion	32,567	gal	$2.95	$96,072.65	7N and 7S
Total				**$794,990.86**	

A comparison between the costs for the various test sections is shown in Figure 11.

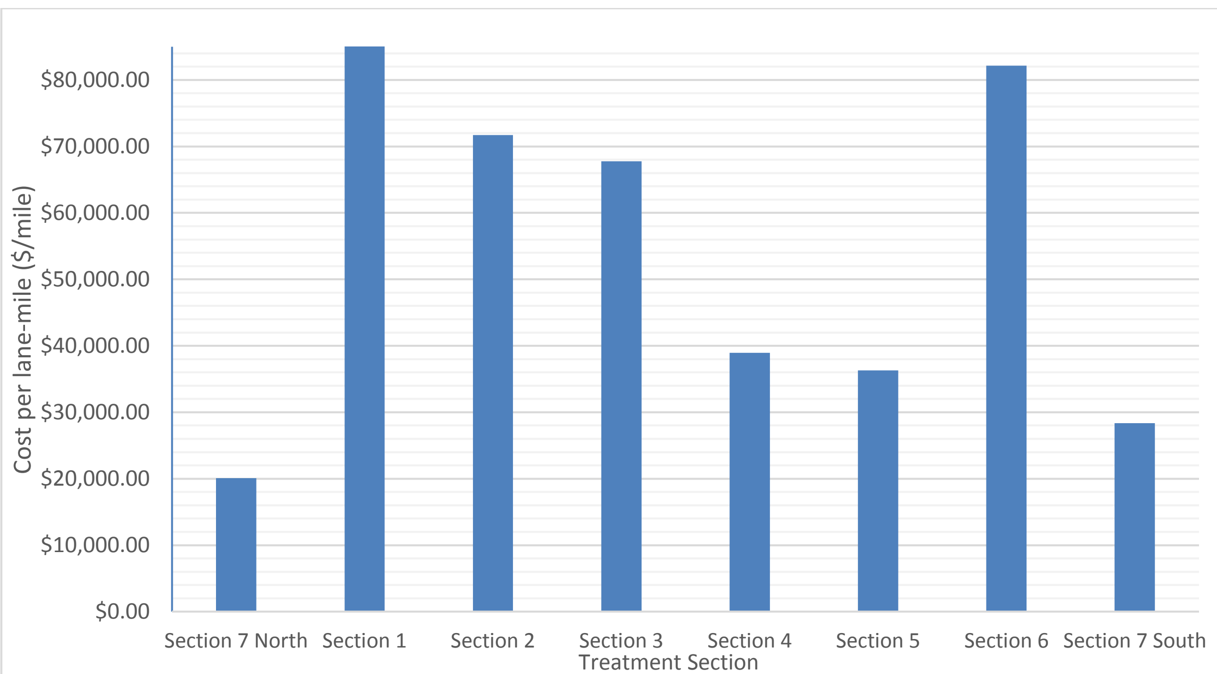

Figure 11. Comparison costs per test sections, dollars per lane-mile

The cost per lane-mile was most related to the HMA thickness of the constructed pavement. The treatment thicknesses ranged from 1 in. in the ultra-thin overlay section to 6 in. of CIR and HMA surface in Section 1.

TEST RESULTS

Test Section Performance

Pavement condition surveys were conducted before and after the construction. A comparison of the pavement conditions from before and after the construction is presented in Figures 12 and 13 for transverse and longitudinal cracking. The rut depth from the post-construction surveys for each section was 0 in. so were excluded from the following comparisons.

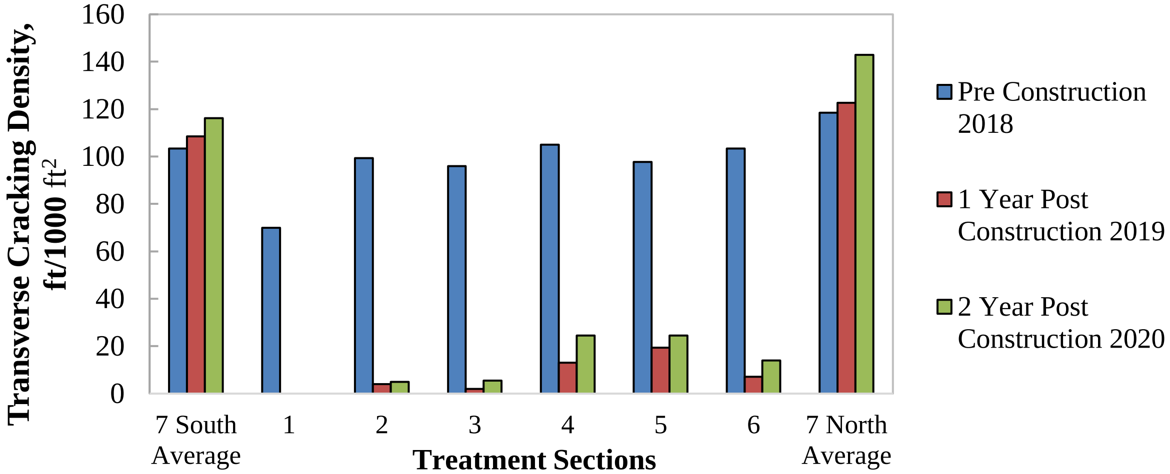

Figure 12. Transverse cracking densities for each treatment section

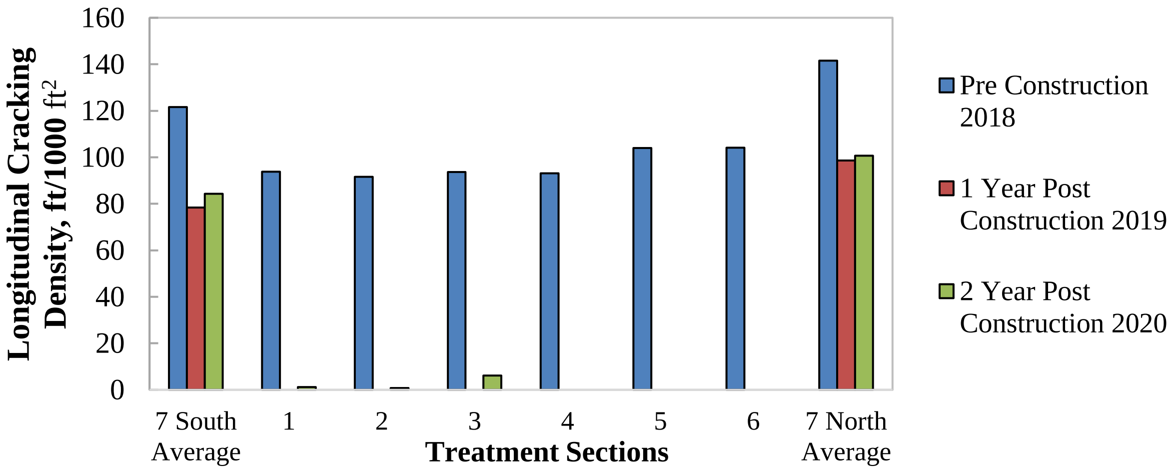

Figure 13. Longitudinal cracking densities for each test section

From Figures 12 and 13, it is apparent that the microsurfacing had little effect on the transverse cracking mitigation while reducing some of the longitudinal cracks present. Sections 1 through 6 showed major improvement in both longitudinal and transverse cracking. Additional pavement condition surveys over the life span of these treatments are required to evaluate the long-term cracking performance of these treatments over the holding period. The rule of thumb with regard to crack progression is 1 inch per year, which would imply a significant increase in the reflective cracking of these treatments in the 3- to 5-year post-construction time frame based on their thickness. The estimated holding life of these treatments can be extrapolated, but accurate holding lives will take several more years of crack propagation to determine accurately.

ASTM D7313 disk-shaped compact tension (DCT) testing (shown in Figure 14) was done to compare the fracture energy of field cores pre- and post-construction (Table 12).

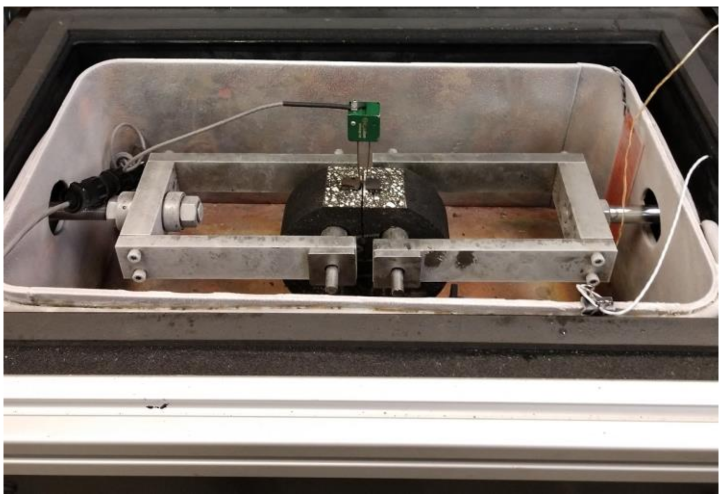

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Figure 14. DCT testing apparatusTable 12. DCT fracture energy results

Section number	Treatment	Pre-construction DCT (J/m^2)	Post-construction DCT (J/m^2)	Improvement in DCT results
1	4 in. CIR with 2 in. HMA surface mix	245	404	165%
2	4 in. CIR with 1.5 in. HMA surface mix	243	387	159%
3	4 in. CIR with 1 in. high performance (PG58-34E with 90% recovery)	210	748	356%
4	1 in. mill with 1 in. high performance (PG58-34E with 90% recovery)	218	408	187%
5	1 in. mill with 1 in. ultra-thin overlay HMA (PG58-34E with 80% recovery)	217	486	224%
6	2.5 in. mill with 1 in. interlayer and 1.5 in. HMA surface mix	157	382	243%
7N	Double course microsurfacing	193	291	151%
7S	Double course microsurfacing with grinding	238	291	122%

Due to the fabrication standards of DCT specimens, only to a depth of 2 in. (~50 mm) from the pavement surface was tested. All pre-construction sections tested within a range of 157 J/m^2 to 245 J/m^2. Post-construction Sections 3, 4, and 5 performed the best, likely due to the high elastic recovery in the overlays.

Sections 3, 4, 5, and 6 contained highly elastic modified binders and were tested using the AASHTO T 321 four-point bending test to evaluate their fatigue performance (Figure 15).

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Figure 15. Four-point bending test apparatus

Sections 3 and 4 contained thin lifts, Section 5 was constructed with an ultra-thin lift, and Section 6 was an interlayer. The performance of the mixes is displayed in Figure 16.

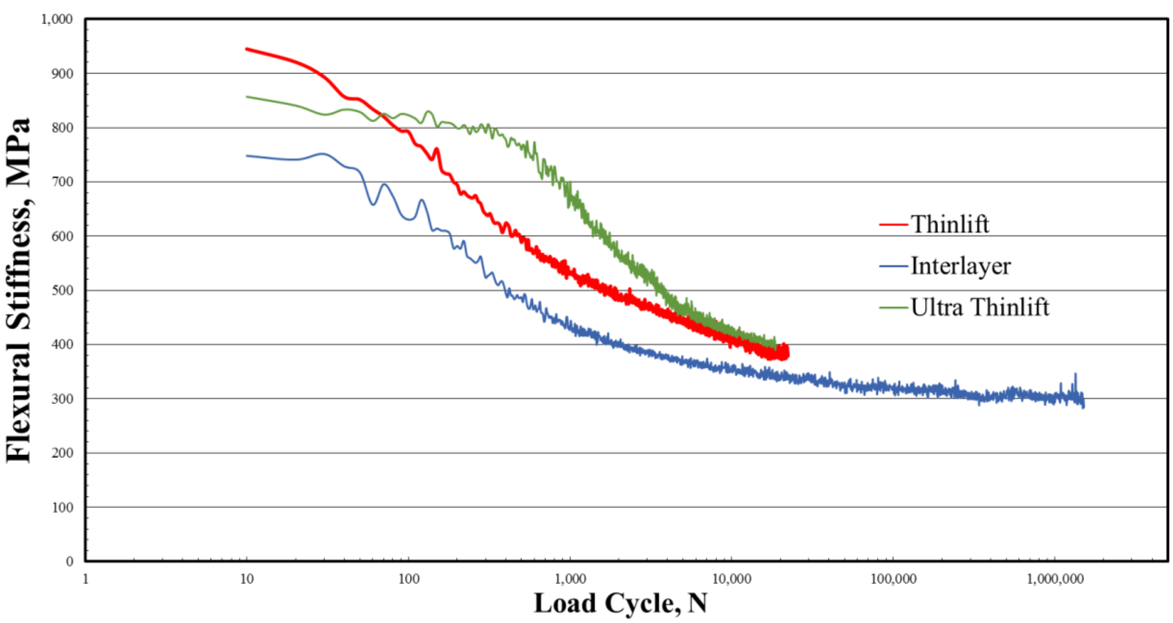

Figure 16. Four-point bending fatigue testing results

The interlayer reached 50% of its initial stiffness, which is designated as the failure point for interlayers by the Iowa DOT, at 1,508,170 cycles. The ultra-thin lift and the thin lift reached failure at 22,350 and 75,220 load cycles, respectively.

COST ANALYSIS

A cost analysis was conducted to evaluate the cost-effectiveness of the various holding strategy treatments applied to the US 65 test sections. Comparing life-cycles costs among the many different layer treatments with widely varying life cycles on top of a pavement in poor condition was impractical. The method proposed is a multi-year post-construction pavement survey evaluation that will track the combined cracking density and compare it to the initial investment by treatment during a 10-year holding period. A 10-year holding period was selected based on one-half of the average new pavement design life. The results are summarized in Table 13.

Table 13. Expected treatment performance for holding strategies on US 65

Section number	Treatment method	Investment per centerline mile, 2018	Cracking density increase per year ($ft/1000ft^2$/ year)	Extrapolated holding life (years)	Estimated % of pre-construction cracking density after 10 years
1	4 in. CIR with 2 in. HMA surface	$171,587	1.2	20+	7.1%
2	4 in. CIR with 1.5 in. HMA surface	$143,462	1.8	20+	11.7%
3	4 in. CIR with 1 in. high performance	$135,543	9.7	19.5	52.0%
4	1 in. mill with 1 in. high performance	$77,925	11.5	16.1	64.6%
5	1 in. mill with 1 in. HMA ultra-thin	$72,570	5.2	20+	35.2%
6	2.5 in. mill with 1 in. interlayer with 1.5 in. HMA surface	$164,325	6.8	20+	36.4%
7N	Double course microsurfacing	$40,173	13.7	2.8	173.5%
7S	Double course microsurfacing spot milling to remove roughness	$56,674	22.2	1.8	125.7%

The initial investment of each treatment is calculated based on bid documents materials costs. The rate of cracking density increase is based on annual post-construction pavement surveys over two years and is expected to increase over time. The estimated holding life is based on the extrapolation of the years required for the treated section to reach pre-construction cracking density based on the rate of cracking density increase. All treatments with the exception of the microsurfacing treatments have an estimated holding life of 10 or more years.

Over the next several years, additional pavement surveys will be completed, similar to Phase I of the project. These ongoing cracking surveys will more accurately define the longevity, performance, and life-cycle cost of each treatment over time. Table 13 shows an estimate of the total cracking density expected after a 10-year period for each treatment. As additional data are acquired, these individual treatment cracking curves will be better defined. These cost-to-cracking curves, for a specified treatment, may aid agencies in selecting an appropriate holding strategy until funding for rehabilitation is available.

Six Years Post-Construction Results for Phase I

A six-year post-construction pavement survey was conducted to determine the progression of cracking on IA 93, between Sumner and Fayette, where the first phase test sections were constructed. The pavement condition survey schedule is shown in Table 14.

Table 14. Pavement condition survey schedule

Survey	Time frame
Pre-construction survey	July 2013
Project construction	August and September 2013
1st post-construction survey	September 2013
2nd post-construction survey	April 2014
3rd post-construction survey	November 2014
4th post-construction survey	April 2015
5th post-construction survey	December 2018
6th post-construction survey	October 2019

Table 15 shows the test section treatments. Because Section 10 had a different geometry, traffic speed, and pavement structure, it was not compared with the other sections with regard to cracking over the investigation period.

Table 15. IA 93 holding strategy section treatments

Section number	Base treatment	Surface treatment
1	1 in. scarification	1.5 in. HMA overlay
2	1 in. scarification	1.5 in. HMA overlay and single-chip seal
3	1 in. scarification, and 1 in. interlayer course	0.75 in. ultra-thin HMA overlay
4	8 in. FDR	1.5 in. HMA overlay
5	8 in. FDR	Double chip seal
6	2.5 in. CIR	Double chip seal
7	2.5 in. CIR	1.5 in. HMA overlay
8	None	2 in. HMA overlay
9	1 in. leveling and strengthening course	Single chip seal

As of October 2019, more than 80% of all cracking had been sealed in accordance with the maintenance schedule. However, these sealed cracks were included in the cracking density as they represent pavement deterioration. Rutting data was measured but considered negligible for all sections.

From six years of pavement survey conditions, Figure 17 and Figure 18 were developed showing the trends for both transverse and longitudinal cracking density.

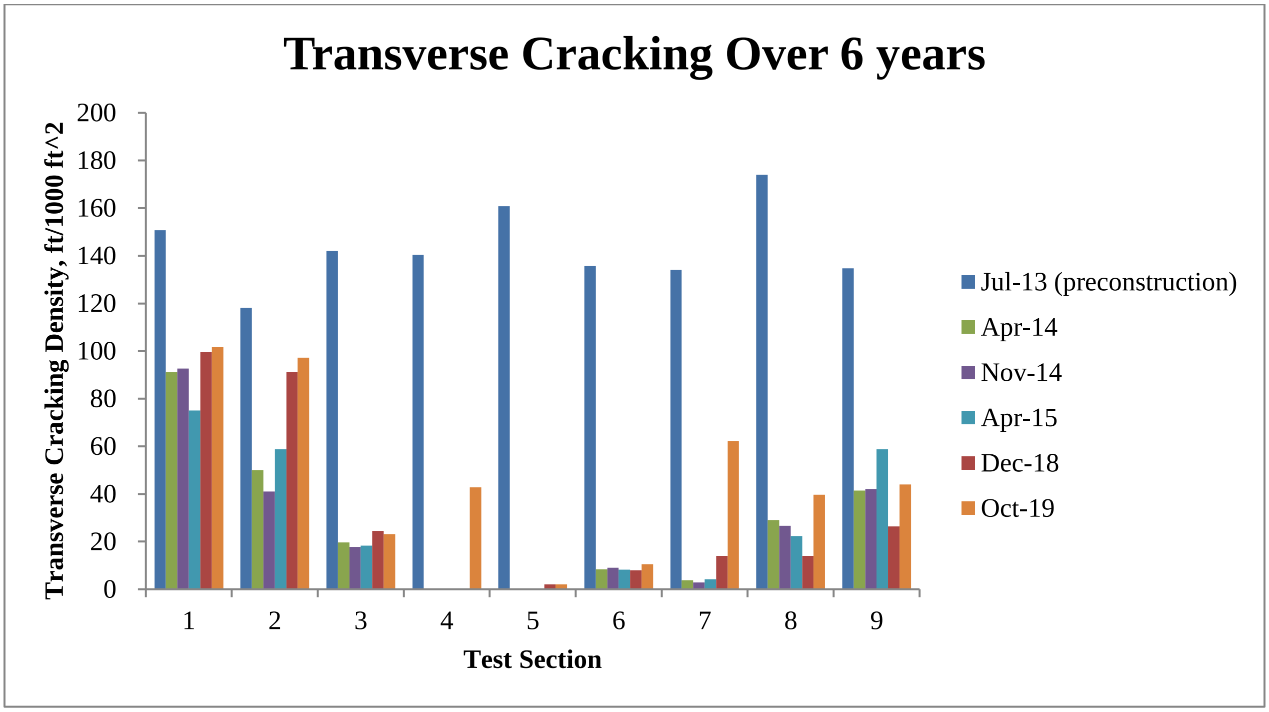

Figure 17. Transverse cracking density for Phase I test sections

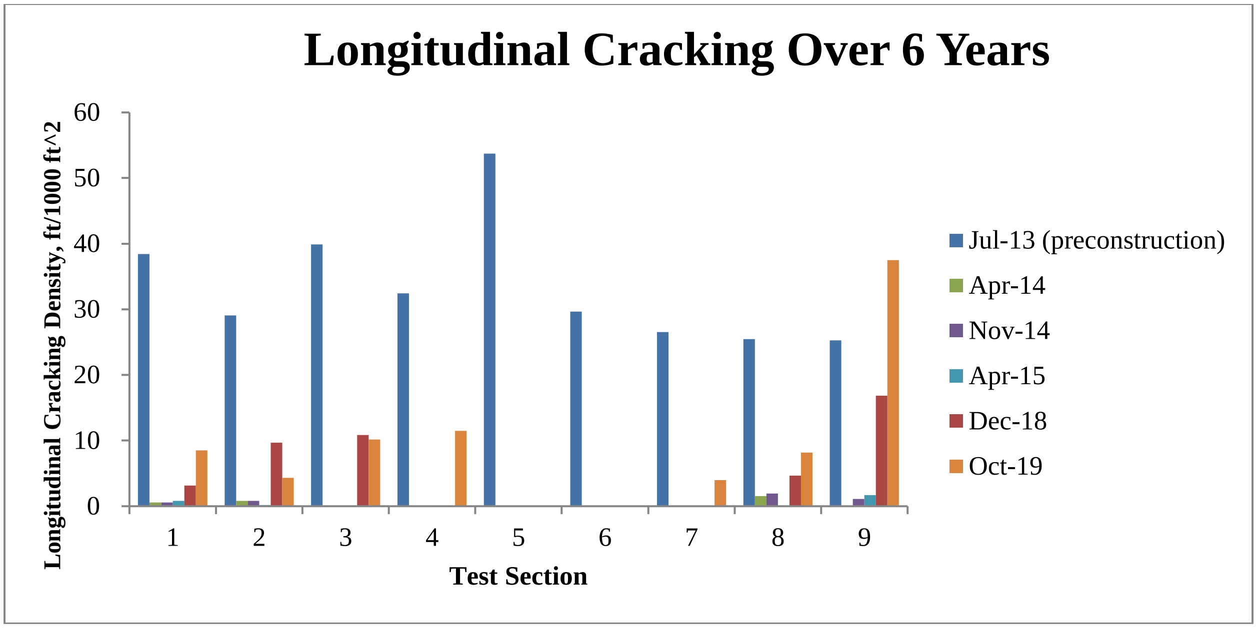

Figure 18. Longitudinal cracking density for Phase I test sections

The findings support the 2015 report's conclusion that the recycling technologies, including CIR and FDR, seemed to be the most effective treatments for mitigating reflective cracking.

The CIR and FDR sections also showed the lowest amount of transverse and longitudinal cracking after five years, with a reduction of more than 92% in transverse cracking and more than 97% in longitudinal cracking compared to the pre-construction survey. The CIR and FDR sections also had among the lowest equivalent annual costs.

CONCLUSIONS AND RECOMMENDATIONS

This report documents the construction and two-year performance of the treatment sections on US 65. The treatment sections were constructed by the Iowa DOT to develop holding strategies that postpone major rehabilitation or reconstruction for deteriorated low-volume asphalt pavements by utilizing treatments with relatively lower installation costs and reasonable life-cycle cost-effectiveness.

Eight holding strategy treatments using various combinations of thin asphalt overlays, recycling technologies, and microsurfacing were constructed. The performance of each treatment section was evaluated by pavement condition surveys. Additional pavement condition surveys will be conducted annually to build out a model capable of tracking the investment for the life span of the individual treatments.

Based on the findings from Phase I and the initial assessments from Phase II, the following conclusions and recommendations can be drawn.

Phase I

- Reflective transverse cracking is the primary early-age distress type for the holding strategy treatments involved in this study.
- The effectiveness of the methods to prevent reflective cracking, from the most effective to the least effective, are: CIR or FDR, high-quality asphalt material or thick asphalt lift thickness, an additional chip seal layer, and 1 in. milling.
- The functionality of the chip seal is comparable to that of the asphalt surface from a safety perspective. However, chip seals have higher macro-texture than asphalt surfaces, which can lead to increased noise level and tire wear.
- Chip seal applied on an FDR layer is susceptible to snow plowing and traffic damage, and it may require frequent maintenance activities and increased maintenance costs.
- Chip seal applied on milled pavement surface on an urban street, which has a low speed limit and frequent deceleration and acceleration traffic, can be effective in correcting cracking but is vulnerable to snow plowing.
- CIR or FDR with thin asphalt overlay and CIR with double chip seal provide a comparable service life to new asphalt pavement with lower construction and life-cycle costs. These treatments can be used as a lower-cost alternative to traditional rehabilitation treatments.
- FDR with a double chip seal and interlayer with ultra-thin asphalt overlay are recommended to use as holding strategies to postpone major rehabilitation or reconstruction.

- An asphalt overlay of less than 2 in. without aggressive base preparation treatment can result in considerably higher life-cycle costs than the traditional rehabilitation method. This method is not recommended as a holding strategy.

Phase II

- Treatment thickness was related to lower two-year cracking as well as low annual cracking density increases

- Double microsurfacing had no effect on transverse cracking and, the test sections are expected to return to their pre-construction cracking densities at two to three years post-construction.

- All surface treatments applied corrected the longitudinal cracking to a higher degree than the transverse cracking.

- Based on the 2-year post-construction cracking surveys and a 10-year holding period, an economic ranking of the various treatments was determined, as shown in Table 16.

Table 16. Ranking of holding strategies for US 65

Rank	Section number	Section treatment	Cracking density increase per year (ft/1,000 ft^2/year)	Investment per centerline mile over 10-year holding period
1	5	1 in. mill with 1 in. HMA ultra-thin overlay (PG58-34E with 80% recovery)	5.2	$7,257
2	4	1 in. mill with 1 in. high performance (PG58-34E with 90% recovery)	11.5	$7,793
3	3	4 in. CIR with 1 in. high performance (PG58-34E with 90% recovery)	9.7	$13,554
4	2	4 in. CIR with 1.5 in. HMA surface mix	1.8	$14,346
5	6	2.5 in. mill with 1 in. interlayer and 1.5 in. HMA surface mix	6.8	$16,433
6	1	4 in. CIR with 2 in. HMA surface mix	1.2	$17,159
7	7N	Double course microsurfacing without grinding	13.7	Will not hold
8	7S	Double course microsurfacing with grinding	22.2	Will not hold

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