Thin Maintenance Surfaces for Municipalities

Final Report
May 2007

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16. Abstract

As streets age, officials must deal with rehabilitating and reconstructing these pavements to maintain a safe and comfortable ride. In light of nationwide budget shortfalls, cost-effective methods of extending pavement service life must be developed or the overall condition of street systems will continue to fall. Thin maintenance surfaces (TMSs) are a set of cost-effective preventive maintenance surfacing techniques that can be used to extend the life of bituminous pavement—pavement built with hot mix asphalt, hot mix asphalt overlays of portland cement concrete pavements, built-up seal coat (chip seal), stabilized materials, or a combination of these.

While previous phases of TMS research have provided information about the uses of thin maintenance surfaces in rural settings, urban areas have different road maintenance challenges that should be considered separately. This research provides city street officials with suggestions for TMS techniques that street departments can easily test and include into their current programs. This research project facilitated the construction of TMS test sections in Cedar Rapids, Council Bluffs, and West Des Moines (all urban settings in Iowa). Test section sites and surfaces were selected to suit the needs of municipalities and were applied to roads with an array of various distresses and maintenance needs. Condition surveys of each test section were performed before construction, after construction, and after the first winter to record the amount and severity of existing distress and calculate the pavement condition index.

Because conditions of the test sections varied greatly, determining which surface was most successful by comparing case studies was not feasible. However, some general conclusions can be made from this research. TMSs are suitable preventive maintenance techniques for a municipal street department's program for preserving existing pavements. Careful attention should be paid to proper planning, quality control during construction, aggregate and binder selection, and aggregate embedment in order to support successful TMS application.

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THIN MAINTENANCE SURFACES FOR MUNICIPALITIES

Final Report
May 2007

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- Jeff Nash, PE, City of West Des Moines
- Jeff Krist, PE, City of Council Bluffs
- Denny Clift, City of Cedar Rapids
- Greg Parker, PE, Johnson County Engineer
- David Paulson, PE, Carroll County Engineer

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EXECUTIVE SUMMARY

When thin maintenance surfaces are properly applied, they can economically extend the life of a road, enhance appearances, and improve the road users' driving experience. Thin maintenance surfaces include fog seals, seal coats, slurry seals, and micro-surfacing. Thin hot mix overlays are closely related maintenance treatments. All these treatments waterproof and restore the pavement surface. Some can also fill ruts and depressions, but none significantly add to the structure of the pavement. Previous phases of this study investigated the use of thin maintenance surfaces on primary and secondary roads in rural areas of Iowa (Jahren et al. 1999 and 2003). This phase of the project focuses on the use of thin maintenance surfaces in municipalities.

The objectives of this report are as follows:

- Update previously conducted literature reviews on the topic.
- Demonstrate and compare the use of thin maintenance surfaces for municipalities in a series of test sections.
- Revise the treatment selection matrix based on the findings of this investigation.

A handbook for the use of thin maintenance surface treatments will be provided in a separate forthcoming document.

Test sections were constructed in five locations in three Iowa cities: Cedar Rapids, Council Bluffs, and West Des Moines.

Cedar Rapids—Two comparisons took place: (1) a demonstration of chipmat (geotechnical fabric–reinforced seal coat) over alligator cracked but stable pavement; included a comparison between areas with chipmat and areas without chipmat, and (2) a comparison of four seal coat cover aggregates using high-float emulsion binder HFE-90:

- 3/8-in.uncoated limestone chip single seal coat
- 3/8-in. pre-coated limestone chips single seal coat
- 3/8-in. precoated pearock single seal coat
- 1/2-in. uncoated limestone and 3/8-in. pre-coated limestone chip double seal coat

Council Bluffs—Demonstration of seal coating on an unbound stabilized road with 3/8-in. pearock and CRS 2P binder

West Des Moines—Comparison between Type III micro-surfacing with quartzite versus limestone aggregate

The test section locations and treatment types were selected in consultation with the municipal engineers in their respective locations and applied by in-house crews or by contract through the municipality. The test sections were rated for distresses before and after application of the treatments, according the method described by Shahin (1994), and summarized as a pavement condition index (PCI).

The following conclusions were drawn:

- Pre-coated limestone chips and high-float emulsion provided a robust treatment that performed well despite shortcomings in the construction process, has good public acceptance, and generates low amounts of fugitive dust.
- Chipmat is a promising maintenance treatment for low-volume roads with relatively stable alligator cracks.
- Type III limestone micro-surfacing aggregate appears to be a promising alternative to quartzite aggregate. The modified gradation used for this investigation produced micro-surfacing with a tighter surface that suffered less snowplow damage in comparison to the surface that was investigated (from 1999) in Jahren et al. (2003).
- The exterior noise produced by vehicles trafficking new micro-surfacing was higher in comparison to a smooth hot mix surface. However, the noise level was reduced as the micro-surfacing aged and the surface became smoother and tighter under traffic.
- Proper treatment selection, good construction techniques, and careful planning are necessary for good results in applying thin maintenance surfaces.

It is recommended that highway and road officials (1) consider selecting robust maintenance treatments in order to enhance chances for success, (2) maintain good quality control and schedule control in applying treatments, and (3) consider the use of limestone for micro-surfacing aggregate.

More testing is recommended for chip mat and limestone aggregate micro-surfacing.

INTRODUCTION

Rationale

Cities across America are continually facing budget cuts from decreased revenues.

> In the National League of Cities' latest annual survey of city finance directors, more than three in five respondents (63%) said their cities were less able to meet financial needs during 2004 than in the previous year. Looking ahead, 61 percent say they expect their cities to be less able to meet their 2005 needs, relative to the current fiscal year. (Pagano 2004)

As a result of decreased revenues, city officials are forced to cut budgets and streamline services provided. Major sectors requiring large amounts of city budgets are municipal public works departments. These departments are responsible for facilities such as streets, sewers, water works, electricity, cemeteries, and parks maintenance. Although a city cannot radically reduce public works funding for obvious reasons, funding may not be adequate to meet current needs or effectively increased to support growth.

To compound the problem of budget shortfalls, public works officials must also deal with aging public works systems—specifically, streets. As these streets age, street officials must deal with rehabilitating and reconstructing these pavements to maintain safety and a comfortable ride. The cost of maintenance, rehabilitation, and reconstruction of these streets is increasing. When budgets are fixed, the amount of work the public works department can perform each season is reduced. This lack of resources and attention causes other streets and facilities to degrade.

Cost-effective methods of extending pavement service life must be developed or the overall condition of street systems will continue to fall. By extending the life of a pavement, public officials are able to spread out the workload and decrease the amount of rehabilitation and reconstruction necessary to maintain the system in good condition.

However, in cities, many public officials who are responsible for streets are also responsible for cemeteries, sewer systems, and city mowing. These additional responsibilities reduce the amount of time that could be used to investigate and test different techniques to determine effective pavement maintenance strategies. Currently, many street officials have limited awareness of and experience with the wide variety of maintenance techniques that are available.

Some public works directors and street superintendents utilize preventive maintenance strategies to address the deterioration of their aging streets. The American Association of State and Highway Transportation Officials (AASHTO) defines preventive maintenance as "the planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity)" (1986). Many types of preventive maintenance techniques have been developed to maintain and extend the service life of a street. Each of these surfaces and techniques can effectively mitigate or prevent distresses such as cracking and raveling that shorten a pavement's service life. However, many of the techniques that work well with certain types of pavements and distresses are not necessarily effective on others.

Thin maintenance surfaces (TMSs) are a set of cost-effective preventive maintenance surfacing techniques that can be used to extend the life of bituminous pavement—pavement built with hot mix asphalt, hot mix asphalt overlays of portland cement concrete pavements, built-up seal coat (chip seal), stabilized materials, or a combination of these. These thin maintenance surfaces do not serve to increase the strength or structure of a road but, rather, to mitigate existing distresses and prevent future distresses that shorten a pavement's service life. TMSs include surfacing techniques such as seal coats, slurry seals, micro-surfacing, fog seals, and smooth seals. A municipality can both address the issues that cause early deterioration and simultaneously extend pavement life by using thin maintenance surfaces. When pavement life is extended, funding does not have to be invested in rehabilitation and rebuilding as often, allowing more funding to be invested in each cycle with better results.

Extensive research and numerous studies have been performed to improve and evaluate the effectiveness of these various TMSs. These studies include the Long Term Pavement Performance (LTPP) SPS-3 test sections conducted by the State Highway Research Program (SHRP), which constructed 81 test sites that used various thin maintenance surfaces (Galehouse et al. 2005, Hanna 1994), and the two previous phases of research performed at Iowa State University, which involved construction of test sections on four US highways (Jahren et al. 1999, Jahren et al. 2003). Many other states such as Alaska (McHattie and Elieff 2001), Colorado (Outcalt 2001), and Minnesota (Geib and Wood 2001) have conducted their own studies of TMSs. These studies and others have focused on developing new design techniques for each surface, determining what distresses are mitigated, determining ideal application times, defining best practices for construction (Gransberg and James 2005), developing decision matrices for determining which surface to apply (Hicks and Peshkin 2000), and analyzing life cycle costs of the maintenance techniques.

The previously referenced studies also encourage public officials to develop pavement management programs and overhaul existing programs to incorporate preventive maintenance and TMSs. However, many of these studies are lengthy and do not provide street and road officials with easy access to relevant material; if officials must struggle to learn about and test new techniques, the chances of adopting a new program are small. Additionally, although these studies may provide useful information, many public officials prefer to see the surface for themselves or discuss the effectiveness of these techniques with colleagues who have had actual experience. Furthermore, some elements of these programs need to be modified to meet the needs of smaller communities.

Research Objectives

Previous phases of TMS research have provided information about the uses of thin maintenance surfaces in rural settings and a decision matrix for selecting appropriate TMS strategies. Although this information is somewhat applicable to an urban setting, urban areas have different road maintenance challenges that should be considered separately. This research project will provide street officials with suggestions for thin maintenance surface techniques that street departments can easily test and include into their current programs.

This research project facilitated the construction of five test sections in three municipalities using TMSs in urban settings. Test section sites and surfaces were selected to suit the needs of municipalities and were applied to roads with an array of various distresses and maintenance needs. The test sections were constructed and the performance observed for a period of one year.

During construction of the test sections, successes, hindrances, and lessons learned were documented for inclusion in this report and other technology transfer activities.

Study Methodology

City street engineers who expressed interest in this project were asked to serve on the technical advisory committee and recommend streets in their respective cities to become candidate test sections. The following individuals comprised the advisory committee:

- Jeff Nash, PE, City of West Des Moines
- Jeff Krist, PE, City of Council Bluffs
- Denny Clift, City of Cedar Rapids
- Greg Parker, PE, Johnson County Engineer
- David Paulson, PE, Carroll County Engineer

The labor, equipment, and materials for test section construction were to be supplied by the sponsoring city. In each case, test section construction addressed a current maintenance need for each of the sponsoring cities. The criteria defined by the researchers for the test sections were as follows:

- Street needed to be located in an urban setting.
- Existing surface needed to be bituminous.
- Situation needed to be similar to situations that officials in other cities were experiencing.

Moreover, each city was asked to outline its current street maintenance program. This included brief descriptions of current maintenance practices and previous experiences with

TMSs. Researchers needed to become familiar with the needs of the city as well as the level of funding available for the test sections.

Each city provided three to six streets of varying ages, locations, traffic loads, and pavement conditions. The researchers toured the designated roads and made final selections. Consideration was given to the pavement type, types of distress present, density of the distresses, and the traffic volume. The researchers also wanted to test some pavements with higher traffic volumes, so efforts were made to include at least some streets with higher average daily traffic (ADT) densities. If the test section had distresses that indicated structural failure of the pavement, the pavement was considered for a stopgap procedure. A stopgap procedure is a procedure that is intended to extend the life of a pavement for a few years before a more expensive rehabilitation or reconstruction project can take place. Because TMSs are not effective at mitigating or preventing structural-related distresses, researchers recommended that base stabilization or full-depth patching be performed in problem areas before application of a new surface. The test sections selected were three in West Des Moines, two in Cedar Rapids, and one in Council Bluffs.

Discussions between the city engineers and researchers aided the process of selecting test sections. Researchers interviewed the city engineers, collecting further details on each test section in order to determine the goals for each effort. A number of TMSs were suggested for each pavement that was a likely candidate. The advantages and disadvantages of each surface were discussed for each street. These discussions involved several topics, ranging from construction limitations to material availability and funding concerns. In some cases, city engineers were uncertain whether the materials for certain TMSs could be acquired. These discussions required a number of weeks to complete in order to ensure that all concerns could be identified and uncertainties addressed.

After the final TMS selection for each test section, researchers finished investigating how the surface would be constructed, what materials were available, and which materials were the best to use. Past experiences and information gleaned from the literature were considered in making decisions. Material suppliers and contractors were contacted.

Condition surveys of each of the test sections were performed before construction, after construction, and after the first winter. These condition surveys recorded the amount and severity of existing distresses, and a pavement condition index was calculated. The condition survey procedure is described in the following section. Digital photo logs were taken of the test sections before, during, and after construction.

A description of the construction process for of each test section is included in subsequent sections.

Pavement Condition Survey Procedure

The survey type that was used to evaluate the condition of the test sections was the pavement condition index (PCI) developed by the U.S. Army Corps of Engineers (Shahin 1994). The PCI is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition (see Table 1). As Shahin states, "Calculation of the PCI is based on the results of a visual condition survey in which distress type, severity, and quantity are identified. The PCI was developed to provide an index of the pavement's structural integrity and surface operational condition" (1994). To identify the PCI of a test section, the section must be broken down into a series of sample sections. These sample sections may compose 25%–30% of the entire pavement area and are used to evaluate the average condition of the entire test section. The sample sections are all approximately the same size, equally spaced, and randomly selected. During the survey, the various visible distresses are measured by their length or area and rated by severity. The severity of each type of distress is defined in *Pavement Mangagement for Airports Roads, and Parking Lots* and is usually dependent on the size of distortions or the width of cracks (Shahin 1994). All of the distresses are recorded on a PCI survey form, and a separate form is used for each sample section. After the survey is completed, measures of the distresses serve as inputs in a series of formulas, the output of which is the condition index for each sample section. The average PCI for all of the sample sections is reported as the final PCI for the test section. This average ensures that relatively poor sample sections do not reflect the overall condition of the test section.

Table 1. PCI condition rating

PCI Range	Rating
100–86	Excellent
85–71	Very good
70–56	Good
55–41	Fair
40–26	Poor
25–11	Very poor
10–0	Failed

Unfortunately, thieves broke into the second author's vehicle and stole a number of items, including a folder that contained many of the pre-construction surveys. Because the surveys were stolen after the application of the new surfaces, the researchers performed surveys on streets with similar structure, history, and traffic. Estimates of the PCI values prior to construction were developed using photo logs and estimates of the density of the known distresses. Due to the loss of pre-construction data, only the performance of the surface will be analyzed.

THIN MAINTENANCE SURFACES

Thin maintenance surfaces are thin applications of an asphalt binder and aggregate that is applied to an existing bituminous pavement. These surfaces are not intended to add any structure but serve as a waterproof seal and a new wearing course. These surfaces can be used to extend the life of a pavement by preventing future distress or mitigating current distress.

There are three types of an asphalt binder that can be chosen for a TMS. The three options are a hot asphalt binder, an emulsion, and a cutback. A hot asphalt binder is merely an asphalt binder that has been heated to 300°F so that it has reached its melting point and has become liquid and sufficiently non-viscous to allow application by spraying. After the hot asphalt binder is applied and the temperature of the binder drops, it becomes viscous and hardens. An emulsion is a mixture of asphalt binder, water, and an emulsifier. An emulsion can be heated to 150 ºF to 185ºF (65 ºC to 85ºC) and can then be applied at ambient summertime temperatures (Iowa DOT 2006). After an emulsion is applied to a pavement, the water evaporates and leaves the asphalt binder (called residue) behind. A cutback is a mixture of an asphalt binder and a petroleum solvent, usually kerosene or fuel oil. When a cutback is applied to a pavement, the solvent evaporates, leaving the asphalt binder behind.

The aggregate that is selected for a TMS is typically that which is locally available. The common aggregates that are used in Iowa are limestone, quartzite, and pea rock. One of the main considerations when selecting the aggregate for a TMS is the aggregate gradation. Depending on the TMS, the proper aggregate gradations can vary greatly from a dense gradation (for slurry seal or micro-surfacing) to a single-size gradation (for certain seal coat or chip seal applications).

Seal Coat (Chip Seal)

A seal coat is an application of a bituminous binder followed by an application of single-sized aggregate chips. Although "seal coat" is the most common terminology for this procedure in Iowa, the same procedure is often called "chip seal" elsewhere. Seal coats can be used on bituminous surfaces (such as hot mix asphalt pavements) and for further maintenance and sealing of built-up seal coat. With proper operation, it may be used to provide a bound surface for unpaved roads such as gravel or crushed rock roads. Seal coats can be used as (1) a preventive maintenance treatment on hot mix asphalt, (2) another layer for a road surfaced with many layers of built-up seal coat, or (3) as a stopgap holding treatment to extend the life of a severely distressed pavement a short amount of time until rehabilitation or reconstruction can take place. However, if seal coat is used as a stopgap for severely distressed pavement, the amount of time it can be expected to extend the life of the pavement is considerably less than the amount of life extension that would result from using seal coat as a preventive maintenance treatment on lightly distressed pavement.

Seal coats are useful in waterproofing the surface and sealing existing cracks in the pavement. They also provide a new wearing course and add friction for traction. Some disadvantages of a seal coast include that it may have the appearance of a gravel road to some road users and neighboring property owners, and there is a possibility for dust and flyrock, both of which may be annoyances to vehicle and property owners. Also, seal coats add no structure to a pavement and cannot be used to fill in ruts.

Traffic can be allowed on a seal coat after the aggregate has been seated by a pneumatic tire roller. However the speed should be controlled (possibly by a pilot car) so that the top vehicle speed does not exceed 25 mph. Seal coats are also very cost effective with an average price of $0.80/yd^2 (based on anecdotal evidence from first author in 2005).

Variations on a typical seal coat include a double seal coat, cape seal, sandwich seal, and racked-in seal. A double seal coat is the double application of a single chip seal. The nominal aggregate dimension used for the first layer of the seal coat is typically one and a half to two times the dimension of the second layer of aggregate. A double seal coat provides more waterproofing and is more robust than a single seal coat. A cape seal is single seal coat followed by the application of a slurry seal. (Slurry seal will be discussed in more detail later). A sandwich seal is an application of aggregate, followed by the application of the binder, and topped off with another layer of smaller aggregate. A racked-in seal is a single seal coat followed by an application of sand to fill voids.

In Iowa, seal coats are typically used on low-volume roads (< 2000 vehicles per day) such as residential streets and lower volume secondary and primary roads. In other locations, particularly some western states, they are used on higher traffic roads as well.

Construction of a seal coat requires the following steps:

- Set up traffic control.
- Sweep the pavement, removing any debris such as sand, rocks, salt, or dirt.
- Spray the pavement with an emulsion, cutback, or hot asphalt binder with a distributor truck. Specified application rates are 0.35 to 0.35 gal/yd^2 (1.1 to 1.6 l/m^2) for 1/2-in. cover aggregate, and 0.25 to 0.35 gal/yd^2 (1.6 to 2.0 l/m^2) for 3/8-in. cover aggregate (Iowa DOT 2006). In previous research, application rates ranged from 0.22 to 0.32 gal/yd^2 after a material application rate design was executed (Jahren et al. 2003). This was less than the standard practice in Iowa.
- Spread a single layer of chips over the binder with a chip spreader. A specified application rate is 30 lb/yd^2 (16 kg/m^2) (Iowa DOT 2006). Reports from construction projects indicate that this spread rate results in extra aggregate that must be swept from the road and that 25 lb/yd^2 (14 kg/m^2) often provides better results. In previous research, application rates ranged from 19 to 22 lb/yd^2 after a material application rate design was executed (Jahren et al. 2003).
- Immediately seat the aggregate in the binder by following the chip spreader with a pneumatic tire roller. The roller should make several passes to adequately seat the

aggregate. If one roller cannot keep up with the operation, additional rollers should be added to the fleet.
- Allow the binder to cure and then sweep off any unbound aggregate.

Chipmat

Chipmat is a thin maintenance technique that is new to Iowa. It is a single seal coat placed over geotechnical fabric. The geotechnical fabric is used to bridge over existing cracks in order to mitigate the reflections of cracks to the new surface. The binder-soaked fabric also provides an extra layer of waterproofing and resists water entrance in the subbase, an already weakened area. A chipmat process using hot asphalt binder has been developed and successfully used in the hot arid regions of southern California (Davis 2003). However, hot asphalt is not commonly used in Iowa. Since emulsion is more commonly available in Iowa, the following construction process was developed specifically for use with emulsion as part of this research project:

- Set up traffic control.
- Sweep the pavement. Blow out the cracks with an air compressor.
- Apply the tack coat with the distributor truck.
- Roll the fabric over the binder.
- Spread sand over the fabric and any exposed binder. If the fabric will not be covered by the seal coat for a number of days, more sand should be used to protect the fabric from traffic.
- Seat the fabric in the binder using a pneumatic tire roller. Sweep the sand off of the fabric.
- Wait several days for the emulsion to cure completely and for water to evaporate from the tack coat that is holding the geotechnical fabric.
- Sweep sand from the geotechnical fabric.
- Place the standard seal coat.

When placed correctly on alligator cracks that do not pump under traffic, the chipmat is effective for limiting the extent to which these cracks reflect through to the new seal coat. One of the disadvantages of the chipmat is that if the agency ever desires to mill the road using a milling machine, the fabric can get tangled in the teeth of the milling drum. Specifications and a guide for the fabric have been developed by the Asphalt Interlayer Association (AIA) and can be downloaded at http://www.aia-us.org.

Slurry Seal

A slurry seal is a mixture of emulsion, well-graded aggregate, mineral filler (typically cement), and water. The ingredients are mixed before placement, and after application the mixture cures into a hard wearing surface. The slurry has a consistency of wet mud and can be easily shaped with hand tools.

The advantages of a slurry seal are that it provides water resistance, seals micro-cracks (small cracks that have not propagated through the entire pavement layer), and provides a new wearing surface with more friction and a black appearance similar to that of hot mix asphalt (HMA). Slurry seal also has sufficient stability to fill ruts. With careful mix design and application, anecdotal evidence indicates that slurry seal has been successfully use to fill ruts in Iowa up to one inch deep. Compared to seal coat, slurry seals have fewer problems with flyrock and dust and they cure to a darker color, which in many cases is more satisfactory to road users and neighboring property owners. One disadvantage of a slurry seal is that after it cures, it becomes brittle. Because the surface is brittle, when the underlying pavement moves, cracks are reflected very quickly. Another disadvantage of slurry seals is that the road must be closed for approximately 6 hours after application in order for the binder to properly cure. Once the binder has properly cured, traffic can be allowed on the surface without traffic control.

Slurry seals are also cost-effective solutions. The average price was \$0.90–\$1.10/yd^2 in Iowa in 2005, based on anecdotal evidence from the first author and interviews with city engineers. Construction of a slurry seal involves sweeping the surface, removing vegetation from cracks, and applying the slurry with a machine.

Micro-surfacing

Micro-surfacing is a slurry seal that uses 100% crushed aggregate and polymer-modified emulsion. Micro-surfacing is also very brittle like slurry seals; however, because of the added polymers, micro-surfacing is more robust and the cracks do not spall and widen as quickly as they do in slurry seals. Compared to slurry seal, micro-surfacing is more stable and therefore can be more effective at filling ruts in more extreme situations. Another advantage of micro-surfacing over slurry seal is that it can be trafficked within one hour of application. The main disadvantage of micro-surfacing compared to other TMS is the higher cost. Also, there is less working time, which makes this technique less forgiving if hand work is necessary.

The average price of micro-surfacing was approximately \$1.50/yd^2 in Iowa in 2005, based anecdotal evidence from the author. The micro-surfacing application process is similar to that of slurry seal.

Fog Seal

A fog seal is a light application of binder to a pavement, which serves to seal the surface, restore volatile components the surface binder, and slow or reverse the effects of oxidation (hardening of surface asphalt). Fog seals should only be used on pavements that are in good condition and serve only to prevent distresses such as oxidation and raveling. If necessary, a light coating of sand should be spread over the fog seal to provide sufficient friction. The binder used in fog seal can be asphalt emulsion, gilsonite, or a mixture of asphalt and other chemicals, known as rejuvenators, that are intended to improve the properties of the asphalt surface.

Some advantages of a fog seal are the low cost, ease of construction, and black appearance. Some disadvantages include the fact that a road with a new fog seal cannot be trafficked until the binder has cured, which can take up to 6–8 hours depending on weather conditions. Also, fog seals may have low friction numbers until the binder wears off from the surface of the aggregate that engages tires.

The average cost of a fog seal is \$0.18–\$0.80/yd^2. The cost increases if rejuvenators have been added to the emulsion. Rejuvenators help to soften oxidized asphalt on the surface of the pavement. Construction involves sweeping the surface, applying the diluted emulsion, and spreading the sand.

Thin HMA Overlays, Smooth Seal, and Other Thin Overlays

Thin HMA overlays are typically less than two inches thick and are applied in manner that is similar to that of a regular HMA overlay. HMA has the stability to fill ruts, dips, and depressions, and it provides a smooth, quiet surface. Although design assumptions are that thin overlays do not add structure to the pavement, in actuality they do add a marginal amount of structure and that can be helpful in extending the life of the pavement.

A smooth seal, a trade name coined by Heartland Asphalt of Mason City, IA, is a one- to two-inch HMA overlay on an existing seal coat road that is in good condition with little to no structural distress. A smooth seal should be applied over low-volume roads with small amounts of truck traffic. If regular truck traffic is present, the thickness of the overlay should be increased to two inches or more. Advantages of the smooth seal include a smooth black pavement, long life, and elimination of the need for seal coat at short intervals. Typically, for a pavement made from built-up seal coat, it is necessary to apply a new seal coat every one to three years to prevent water from reaching the subbase through newly formed cracks. However, if a smooth seal is applied, it is no longer necessary to apply seal coats unless the purpose is for preventive maintenance of the asphalt pavement. These maintenance seal coats can last from five to seven years. Smooth seals have performed very well with overlays, having a life of 12 years with little to no distress. This good performance can be attributed to the fact that the seal coat pavements that they covered provided excellent bases.

Cost of a smooth seal is dependent on the local cost for HMA. Before application of the smooth seal, any structural distress should be repaired with full-depth asphalt patches to prevent the distress from reflecting through on the overlay. The application of the smooth seal is the same as the application of any asphalt overlay.

Another thin overlay is NovaChip®, which is a proprietary process developed by Koch Pavement Solutions. NovaChip® is a thin lift overlay that uses a coarse-graded aggregate. The overlay is placed over a special membrane called NovaBond®. NovaBond®, an emulsion, which according to product literature, provides a superior bond between the existing pavement and the overlay and also provides a water-resistant membrane. Advantages of NovaChip® include (1) quick application because only one piece of equipment is necessary for application, and (2) good drainage and skid resistance due to the coarse-graded aggregate. Based on an interview with Koch Pavement Solutions in 2004, the average cost of NovaChip® is \$3.50/yd^2 (Matteson).

Decision Matrix for TMSs

The following decision matrix was developed by researchers at Iowa State University for use in selecting appropriate thin maintenance surfaces for pavements experiencing particular distresses (see Table 2). This matrix was developed using the experience gleaned from constructing various TMSs on seven test sections since 1997. Information obtained from the literature review and from previous and current phases of this project was considered in developing this matrix.

Table 2. Decision matrix

Factor		Thin maintenance surface				
		Fog seal	**Seal coat**	**Slurry seal**	**Micro-surfacing**	**HMA overlay 1-1/2 in. thick**
Traffic	AADT < 2,000	R	R	R	R	R
Traffic	2,000 < AADT < 5,000	R	M*	M*	R	R
Traffic	AADT > 5,000	R	NR†	NR	R	R
Bleeding		NR	R	R	R	R
Rutting		NR	NR	R	R	R
Raveling		R	R	R	R	R
Cracks	Few tight cracks	R	R	R	R	R
Cracks	Extensive cracking	NR	R	NR	NR	R
Cracks	Alligator cracking	NR	M‡	NR	NR	NR
Low friction		I§	I	I	I#	I#
Price (\$/yd^2)‖		\$0.10–\$0.80@	\$0.80	\$0.90	\$1.50	\$4.40

R = recommended, NR = not recommended, M = marginally recommended, I = may improve
*There is a greater likelihood of success when used in lower-speed traffic.
†Not used in Iowa, but other states have seen success.
‡On a low-volume road, a chipmat can be used with alligator cracking that is not pumping.
§Fog seal will reduce friction for the first few months until traffic wears binder off the tops of aggregate.
#Micro-surfacing reportedly retains high friction for a longer period of time.
‖Prices were obtained from Iowa DOT unit prices and interviews and anecdotal evidence from author in 2004 and 2005.
@Prices vary considerably, depending on fog seal material.

LITERATURE REVIEW

This section provides a summary review of literature written on thin maintenance surfaces since 2000. A complete version of this review is provided by Plymesser (2005). Previous literature was reviewed in reports for previous phases of this research (Jahren et al. 1999 and 2003). This review covers the following: seal coats, chipmats, fog seals, slurry seals, micro-surfacing, thin HMA overlays, and any studies that have tested these surfaces.

Seal Coating

A seal coat is an application of an asphalt binder onto a bituminous pavement, followed by a single layer of aggregate. In a report analyzing the effectiveness of seal coats in America, researchers found that states which regarded their seal coat programs as excellent used seal coats as a preventive maintenance measure. These states had set a cycle for applying the seal coat to a pavement at specific times and in specific intervals. These agencies use a five-year cycle and expect a six-year service life from the chip seal (Gransberg and James 2005).

The success of a seal coat is based largely on the timing of the application with respect to the life of the pavement or, in the words of AASHTO, “placing the right treatment, on the right road, at the right time” (1986). Research has quantitatively shown that when seal coats are used on pavements in good condition, the initial increase in pavement condition is small but the reduction in pavement deterioration is high (Labi and Sinha 2004). Likewise, if the initial increase in pavement condition is high, the reduction in pavement deterioration is low. For example, if a seal coat was placed on a new pavement with low-severity cracks, the initial increase in the pavement’s condition would be relatively low, but the life of the pavement would be extended because the surface and cracks would be sealed from water damage. However, if a seal coat was placed on a pavement in poor to fair condition, the initial increase in the pavement condition would be high because the existing distresses would be sealed and covered, but because the pavement has already been distressed, no value other than a waterproof membrane was added to the pavement. In that scenario, failure has already occurred and distress will reflect through to the new surface quickly.

Research and common experience has shown that the use of polymer-modified emulsions for chip sealing increases the effectiveness of the seal coat. Although the cost of a polymer-modified emulsion is greater, many agencies choose to use it because it retains chips better than regular binders—especially under heavy traffic. Polymer-modified binders also prevent bleeding and have more resilience against cracking and crack spalling. The international scan team found that each country visited vigorously promoted and used polymer-modified emulsions for seal coats, so the team strongly encouraged all agencies to adopt the use of polymer-modified emulsions (Beatty et al. 2002; Gransberg and James 2005).

When placing a seal coat, it is necessary to use rollers to embed the aggregate into the binder and assure chip retention. Rolling should be performed immediately after the chips have been placed on the binder. When placing a seal coat, the distributor truck governs the speed at which the seal coat is placed, because no other activities can take place until the binder has been applied. Sometimes it is necessary to provide more than one roller in order for the rollers to keep up with the distributor truck and chip spreader. Gransberg, Karaca, and Senadheera (2004) released a paper that provides information on determining the number of passes a roller must make on the seal coat to ensure that the entire seal is rolled. This paper also details how to select the number of rollers required, based many variables including the speed of the distributor truck, width of the seal coat, width of the rollers, and speed of the rollers (Gransberg, Karaca, and Senadheera 2004).

Chipmat

The method of seal coating over fabric, called chipmat, has proved to be effective for reducing the likelihood that existing alligator cracks will reflect through the new seal coat. This process is gaining popularity in southern California. In 1987, San Diego County constructed a number of test sections on a pavement in the desert. The county used seal coats with various binders over sealed cracks and over fabric. All of the surface treatments were effective at sealing the surface. However, the only treatment that eliminated reflective cracking was the chipmat. As of 2003, no cracks had reflected through the chipmats constructed in 1987. In 1999, the San Diego County performed a life cycle cost analysis of the three different treatment methods and found that, although the cost of placing the fabric increased the initial construction costs, the annual cost of the chipmat was far less than the other seal coats using rubberized emulsion or seal coats over sealed cracks (Davis 2003).

Based on 19 years of experience with the method, Brown (2003) describes successful construction methods for chipmat. The procedure is briefly summarized as follows:

1. Fill all cracks that are wider than 1/4 inch to prevent the fabric from having to span the cracks.
2. Spray tack coat binder at a rate of 0.30 to 0.40 gal/yd^2 for hot oil (AR4000 or AR8000) or 0.35 to 0.45 gal/yd^2 for emulsion.
3. Roll geotechnical fabric from a modified tractor. Brown recommends 4-oz/yd^2 non-woven needle-punched fabric.
4. Immediately roll the fabric with pneumatic rollers to immerse it in the binder.
5. If it is necessary to traffic the road between application of the fabric and application of the seal coat, apply a light coating of sand (2 to 4 lb/yd^2) to reduce tackiness.
6. Apply seal coat according to the usual good practice.

Like Davis (2003), Brown (2003) reported excellent results in mitigating crack reflection at a reasonable life cycle cost with this method.

Fog Seal

A fog seal is an application of binder onto the surface of an asphalt pavement. The purpose is to seal the surface and to mitigate oxidation.

After applying a fog seal to a pavement, it is common to spread a light application of blotting sand. Because the fog seal can temporarily reduce the friction of the pavement, the sand is used to restore texture and increase skid resistance. A brief study analyzing the effects of a fog seal product with the trade name GSB-88 has investigated the effect of a gilsonite sealer binder (GSB) fog seal on pavement friction numbers (Hall 2004). Gilsonite is a naturally occurring substance that is mined in Utah and has a high content of nitrogen and resin; it is reportedly effective as an asphalt rejuvenator. Under the study, three test sections were constructed and researchers monitored changes in friction for eight to ten months. The study found that after the fog seal was applied, friction values dropped by 12 to 27 points. This drop in friction number can be dangerous, as motorists are not able to stop as quickly because there is little skid resistance. However, after about five to nine months of traffic, the friction numbers were restored to their pre-construction numbers, because the seal had worn off of the top of the aggregate. The report also commented that the fog seal was effective at filling in the voids between the individual pieces of aggregate (Hall 2004).

A second phase of research on the fog seal is currently testing the ability of the fog seal to waterproof a surface. Again, one test section was constructed and monitored. Researchers were using a falling head permeameter to test the permeability of both the untreated and treated sections. Initial results show that the fog seal was effective at sealing the surface (Hall 2004).

Micro-surfacing

Micro-surfacing is a slurry seal that uses a polymer-modified emulsion and other additives that produce a chemical break. One main advantage of micro-surfacing is its ability to cure and be trafficked within one hour.

Because micro-surfacing is stable after curing, it can be effectively used as filler for ruts up to 1.5 inches deep. When deep ruts are filled, a special rut box is used that places the micro-surfacing slurry in one rut at a time. The rut box places the largest aggregate in the deepest part of the rut to provide the most stability. When micro-surfacing is used to fill ruts or other voids, it is recommended that multiple lifts be placed. The multiple lifts provide structure and also produce a smoother pavement surface with a more uniform appearance (McHattie and Elieff 2001).

From the perspective of Minnesota Department of Transportation (Mn/DOT), the primary benefits of micro-surfacing are the fast-paced construction and ability to handle traffic on the surface within one hour of placement (Geib and Wood 2001). This Mn/DOT report concluded that micro-surfacing is effective at filling ruts when a rut box or scratch course is used. When micro-surfacing is initially applied, the surface is noisier than a conventional asphalt pavement due to the stones in the surface that do not lay flat until after the surface is trafficked. The Mn/DOT performed a noise level study and found that there was very little increase (Geib and Wood 2001).

LTPP/SPS-3 Preventive Maintenance Study

In 1987, the Strategic Highway Research Program (SHRP) set up a project to study the cost effectiveness and optimum timing for application of preventive maintenance treatments. A number of test sections consisting of seal coats, slurry seals, thin HMA overlays, and crack seals were constructed throughout the country in different regions with different climates, and the test sections were constructed on pavements with various subbases. These test sections were monitored by Long Term Pavement Performance (LTPP) and designated as SPS-3. Many of the test sections had exceeded their design lives and were still in service in 2004.

The seal coat was the best performer on many of the test sections sites in Texas and is recommended as the best choice for high-traffic routes, based on the SPS-3 test sections, if rutting is not a concern (Chen, Lin, and Luo 2003). Seal coats were also very effective in reducing longitudinal, transverse, and fatigue cracking, and the seal coat sealed and protected the centerline joints. Thin HMA overlays had the lowest roughness and rutting values but were experiencing some structural distresses such as fatigue cracking and potholes. Sections that received the slurry seal are performing better than the control sections and the crack sealed sections, which shows that the slurry seal is effective at protecting and sealing the surface (Galehouse et al. 2005).

Of interesting note was the fact that the TMS in Michigan—the test sections which had the most severe climate—were performing very well. This is strong evidence that preventive maintenance techniques are suitable in all climates (Galehouse et al. 2005).

TEST SECTION DESCRIPTION AND CONSTRUCTION

This section of the report will describe the five test sections that were constructed by three Iowa cities: Cedar Rapids, Council Bluffs, and West Des Moines (see Figure 1).

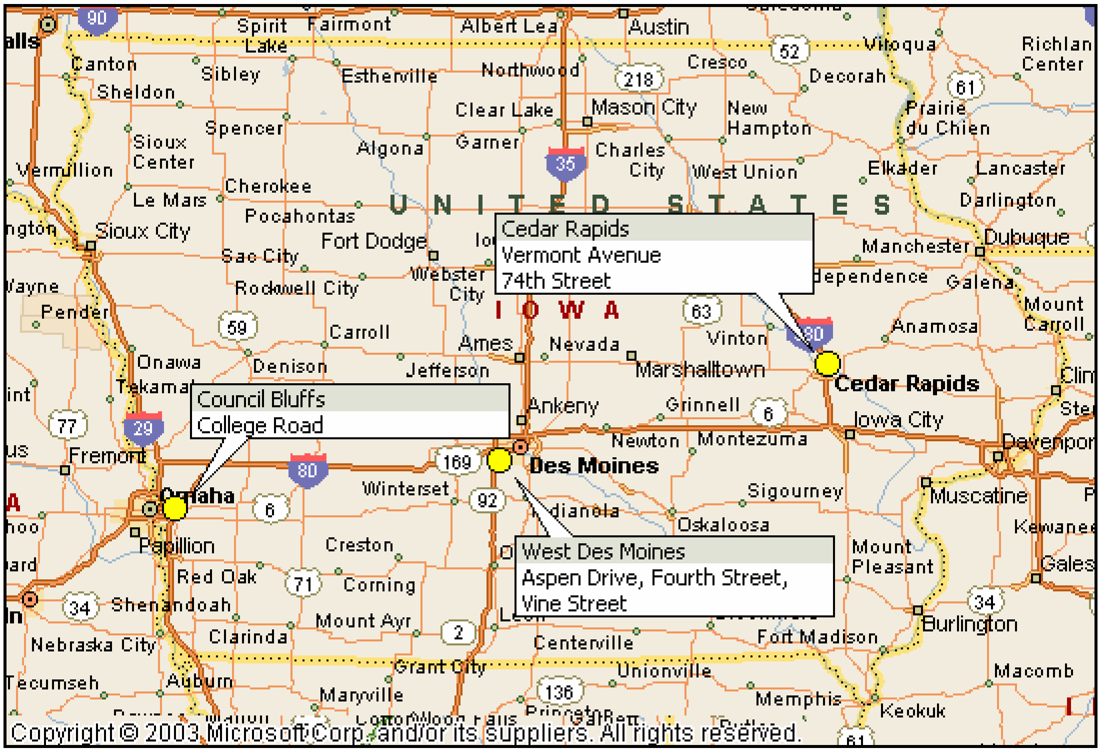

Figure 1. Municipal test section locations

Cedar Rapids Test Sections

Vermont Avenue

Vermont Avenue is a local residential street located on the south side of Cedar Rapids (see Figure 2 and Figure 3). Previous to construction, Vermont Avenue pavement was a seal coat over an HMA pavement. The seal coat was placed many years ago (actual date unknown), and pea rock was used as the cover aggregate. The major distress experienced by the pavement was low to medium alligator cracking (see Figure 4). The street foreman in charge of maintenance on Vermont Avenue said that the alligator cracking reflected through the pavement after the first few years of the seal coat construction. He also said that the alligator cracking had not propagated significantly since the initial alligator cracks formed, and at the time of construction of the test section, the cracks were dormant (i.e., the pavement did not pump under traffic). Other distresses included low-severity longitudinal and transverse (L&T) cracking and low-severity raveling. A high percentage of the alligator cracks and L&T

cracking had been sealed by the city in previous years, and the seals were in good condition. No patching or resealing was performed before the new surface was applied.

The test section is located in a subdivision and experiences only local residential traffic, with the exception of a city bus service. One of the main concerns with a new surface was the aesthetics. The city engineer was concerned with citizen complaints about dust problems and with the possible misperception that the road would appear to be a gravel road instead of an asphalt pavement.

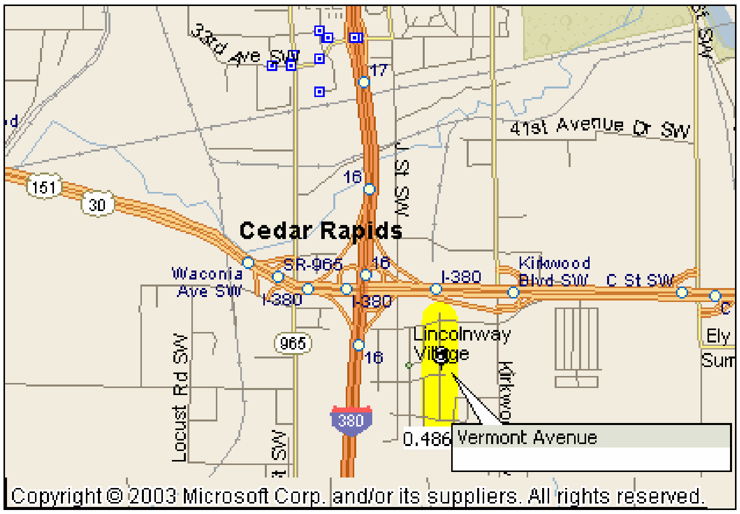

Figure 2. Vermont Avenue overview map

Figure 3. Vermont Avenue test section layout

Figure 4. Alligator cracking on Vermont Avenue

Vermont Avenue Construction

The decision was made to use the chipmat on Vermont Avenue, and an investigation was conducted to aid in fabric selection, binder application rate design, and construction procedure determination. Commonly, hot asphalt is used as the binder underneath the fabric. Emulsion was not recommended, because it can be difficult to provide proper curing conditions. Emulsion is approximately 33% water, and after the emulsion is applied to a surface, the water begins to evaporate, leaving the asphalt binder behind as residue. If another layer of emulsion and chips is placed over the fabric and tack coat layer, water from the emulsion might be trapped underneath the fabric and seal coat. This trapped water could weaken the bond between the fabric, the asphalt, and the road surface, which might cause the fabric to delaminate.

It was not feasible to use hot asphalt for the base underneath the fabric and then use emulsion for the seal coat, because the city owned only one distributor truck and it is difficult to quickly switch from hot asphalt binder to emulsion. Thus, in order to construct the chipmat, the tack coat for the fabric needed to be emulsion. To prevent the water released by the emulsion from getting trapped underneath the fabric and seal coat, it was decided to allow the fabric and tack coat to set and cure for a few days before final seal coat was applied. In the meantime, while the fabric was exposed to traffic, a layer of sand would be placed over it so that the fabric would not stick to tires. The sand also blotted the extra emulsion, thus preventing bleeding.

Since neither the seal coat foreman nor the researchers had experienced or observed the construction of a chipmat, a rough procedure was developed; it was assumed that the procedure would take the better part of a day. Once on site, the foreman and crew discussed the procedure and agreed on a final procedure to be followed. A small trial section was constructed in an alley before any fabric was laid on the actual test section. The procedure used was as follows:

- Sweep the pavement to remove any large debris.
- Use compressed air to blow any sand and debris out of the alligator cracks to be covered.
- Set the distributor's spray bar approximately 1–1.5 feet wider than the fabric. This ensures that the edges of the fabric are completely saturated, minimizing the chances that the edges might roll up.
- Apply the emulsion to the pavement. The length of the strip should be a few feet longer than the piece of fabric.
- Adjust the application rate based on the amount, width, and depth of alligator cracking. This is because some of the emulsion will seep into the cracks and will not be available to tack the fabric.
- Increase the application rate if the emulsion does not completely soak the fabric.
- Set the roll of fabric in the emulsion, being careful to align the roll with the strip of emulsion. Seat the end of the fabric in the emulsion. Roll the fabric out, carefully ensuring that the fabric is always parallel with the emulsion strip (see Figure 5).
- When finished rolling, cut the fabric seated in the emulsion away from the roll of extra fabric.

Figure 5. Placement of the fabric in the tack coat

- Repair any large wrinkles in the fabric. Make a cut down the middle of the wrinkle and overlap the fabric in the direction of traffic. If the wrinkle is large, cut away any excess fabric.
- Spread approximately 1/4 inch of sand on top of the fabric with a sand spreader truck. Make multiple passes if necessary.
- Make several passes over the fabric and sand using a pneumatic tire roller. If any fabric begins to pull up, do not attempt to reseat the fabric; just cut it away.
- Allow the emulsion and fabric to cure for a few days.
- Apply standard seal coat.

Because the test sections were small and the instrumentation was not operational on the distributor truck and the chip spreaders, application rates were not recorded. Given the small size of the test sections, accurate rate measurements would have been difficult to obtain using manual methods. In general, the application rates were in compliance with Brown's (2003) recommendations. Emulsion as shown in Figure 6 was used. The fabric that was used (Petromat® 4598) was in accordance with the following specifications:

- Tensile strength—either direction, 101 lb (0.450 kN) minimum; ASTM D-4632
- Elongation at break—either direction, 50% minimum; ASTM D-4632
- Mullen burst strength—180 psi (1370 kPa) minimum; ASTM D-3786
- Weight—4.1 oz/yd^2 (140 g/m^2) minimum; ASTM D-3776
- Asphalt retention by fabric—0.20 oz/yd^2 (0.90 l/m^2) residual minimum; ASTM D-6140
- UV Stability—70% at 150 hrs; ASTM D-4355

The seal coat crew worked very well together, and no problems were encountered throughout the chipmat application process. All the fabric was laid within 3 hours, which was much faster than anticipated. While the fabric was covered with sand, the foreman asked the city bus drivers to vary their driving pattern over the fabric so as to further seat the fabric. Three days after laying the chipmat, the same crew applied the seal coat using pre-coated limestone chips and the same emulsion that was used for the chipmat. No problems were encountered when applying the seal coat.

KOCH

MATERIAL SAFETY DATA SHEET

1 CHEMICAL PRODUCT & COMPANY IDENTIFICATION

TRADE NAME	**HFE-90**
CAS NUMBER	MIXTURE
MSDS NUMBER	7066
PRODUCT CODE	ND
SYNONYM(S)	HF
MANUFACTURER	Koch Materials Company P.O. Box 2338 Wichita, KS 67201

TELEPHONE NUMBERS - 24 HOUR EMERGENCY ASSISTANCE

Chemtrec: 800-424-9300

Security: 316-828-6777

TELEPHONE NUMBERS - GENERAL ASSISTANCE

8-5 (M-F, CST) 316-828-6777

8-5 (M-F, CST) MSDS Assistance 316-828-8486

For technical assistance regarding this product, contact your local Koch Materials Company representative.

2 COMPOSITION / INFORMATION ON INGREDIENTS

Ingredient Name	CAS Number	Concentration*	Exposure Limits / Health Hazards
PETROLEUM ASPHALT	8052-42-4	40 - 70 %	Asphalt Fumes: 5 mg/m3 8-Hour TWA (ACGIH)
PETROLEUM BITUMEN	PROPRIETARY	40 - 70 %	Asphalt Fumes: 5 mg/m3 8-Hour TWA (ACGIH)
WATER	7732-18-5	25 - 35 %	ND
PETROLEUM DISTILLATE	PROPRIETARY	0 - 25 %	ND
LUBE STOCK	PROPRIETARY	0 - 25 %	ND
HEAVY PETROLEUM DISTILLATE	PROPRIETARY	0 - 10 %	ND
EXTENDER OIL	PROPRIETARY	0 - 5 %	ND
EMULSIFIER	PROPRIETARY	< 4 %	ND
1,2,4-TRIMETHYLBENZENE	95-63-6	0 - 1.5 % **	25 ppm 8-Hour TWA (ACGIH)
ETHYLBENZENE	100-41-4	0 - 1 % **	100 ppm 8-Hour TWA (OSHA) 100 ppm 8-Hour TWA (ACGIH) 125 ppm 15-Min STEL (ACGIH)
ANTI-STRIP	PROPRIETARY	0 - 1 %	ND
HYDROGEN SULFIDE	7783-06-4	< 1 %	10 ppm 8-Hour TWA (ACGIH) 15 ppm 15-Min STEL (ACGIH)

ND = No Data NA = Not Applicable Printed On 9/3/98

Material Id 7066 Trade Name HFE-90 1 / 9

Figure 6. Cedar Rapids emulsion

74th Street

74th Street is a collector street located on the north side of Cedar Rapids (see Figure 7). It was an existing built-up seal coat road with 3/8-inch limestone cover aggregate. City employees were uncertain if the limestone chip was pre-coated or not. The primary distresses that the pavement experienced before construction were medium- to high-severity bleeding, low-severity alligator cracking, and potholes (see Figure 8). Most of the alligator cracking was on the east end of the project in a section approximately one block in length. Seal coats do not commonly have a large amount of L&T cracking, because a seal coat is much more flexible and resilient than an asphalt pavement.

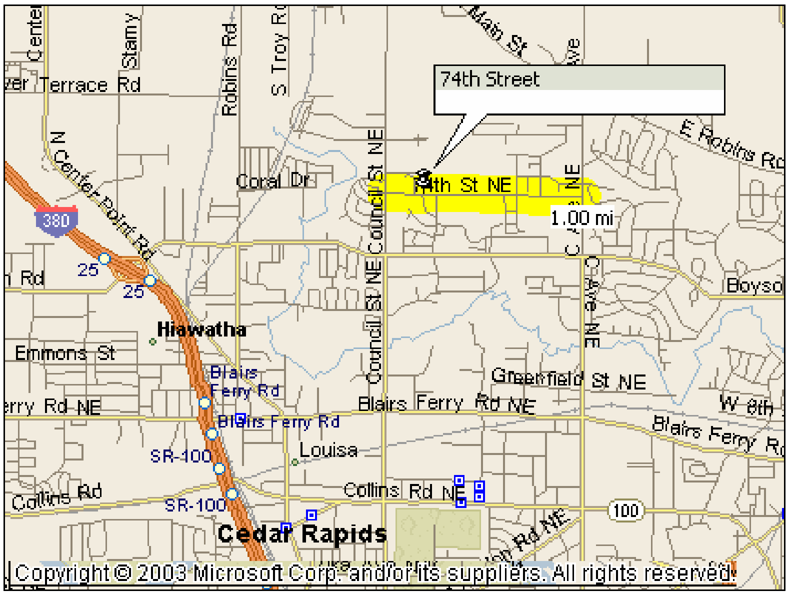

Figure 7. 74th Street overview map

74th Street Construction

Before construction of the seal coat, the city engineer decided to patch all alligator cracks and potholes with full-depth hot mix asphalt patches. The amount of patching increased the PCI value of the road because most of the structural distresses were removed. On the east end of the test section road, a small portion of the road had experienced considerable structural failure. Here the street maintenance crew stabilized the base with magnesium chloride. The procedure was as follows:

- Pulverize the road with a soil mixing machine.
- Use a motor grader to place the pulverized pavement material in a windrow.
- Soak the windrow with magnesium chloride.
- Re-grade the road.
- Compact with a pneumatic tire roller.

Figure 8. 74th Street (dark areas are bleeding)

The city of Cedar Rapids uses two different types of aggregates for their seal coating program. The first of the two is pre-coated limestone chip, which is used in residential areas or other locations where dust is highly undesirable. The other type of aggregate is pea rock, which is used mainly in rural areas on built-up seal coat roads because it creates a lot of dust and gives the appearance that the road has been converted to gravel. Also, while the pea rock easily ravels off of HMA streets that are more prevalent in urban areas, it remains bound onto built-up seal coat roads. Local officials speculated that the pea rock is better able to embed into the softer built-up seal coat than into the stiffer HMA. This embedment apparently helps to mitigate raveling. The 74th Street test section was approximately one mile long, and the researchers thought that this would be a good place to evaluate the effectiveness of seal coats that use various types of aggregate. This section was scheduled for rebuilding, so it was understood that possible poor results from the test sections would not have long-lasting consequences. Four test sections could be accommodated in the length of the road. Three different types of aggregate were used. The aggregate gradations for each type of aggregate are listed in Table 3, Table 4, and Table 5. The following is a description of each segment (see Figure 9):

- Segment I—Seal coat of 3/8-inch pre-coated limestone chip with high-float emulsion HFE-90 (see Figure 6)
- Segment II—Seal coat of 3/8-inch washed limestone chip with high-float emulsion HFE-90
- Segment III—Seal coat of 3/8-inch pea rock with high-float emulsion HFE-90
- Segment IV—Double seal coat of 1/2-inch washed limestone base chip and 3/8-inch pre-coated limestone cover chip with high-float emulsion HFE-90

Table 3. Limestone chip gradation (used for both pre-coated and washed chips)

Sieve Size	% Passing
1/2"	100
3/8"	100
#4	25
#8	1.5
#16	1.5
#50	1.5
#200	1.5
Material	3/8-inch limestone chips
Quarry	Wendling Quarries, INC
Location	Cedar Rapids, IA

Table 4. Gradation of 3/8-inch pea rock

Sieve Size	% Passing
1/2"	100
3/8"	99
#4	1.4
#8	0.7
#16	0.6
#30	0.5
#50	0.4
#100	0.4
#200	0.4
Material	3/8-inch pea gravel (0938)
Quarry	Martine Marietta Aggregates
Location	26119 – Linn County Sand

Table 5. Gradation of 1/2-inch limestone

Sieve Size	% Passing
3/4"	100
1/2"	100
3/8"	71
#4	7.7
#8	0.9
#16	0.6
#30	0.5
#200	0.4
Material	Porous backfill, 1/2-inch cover aggregate, and 1/2-inch washed chips
Quarry	Martine Marietta Aggregates
Location	196 – Cedar Rapids quarry beds 3–5

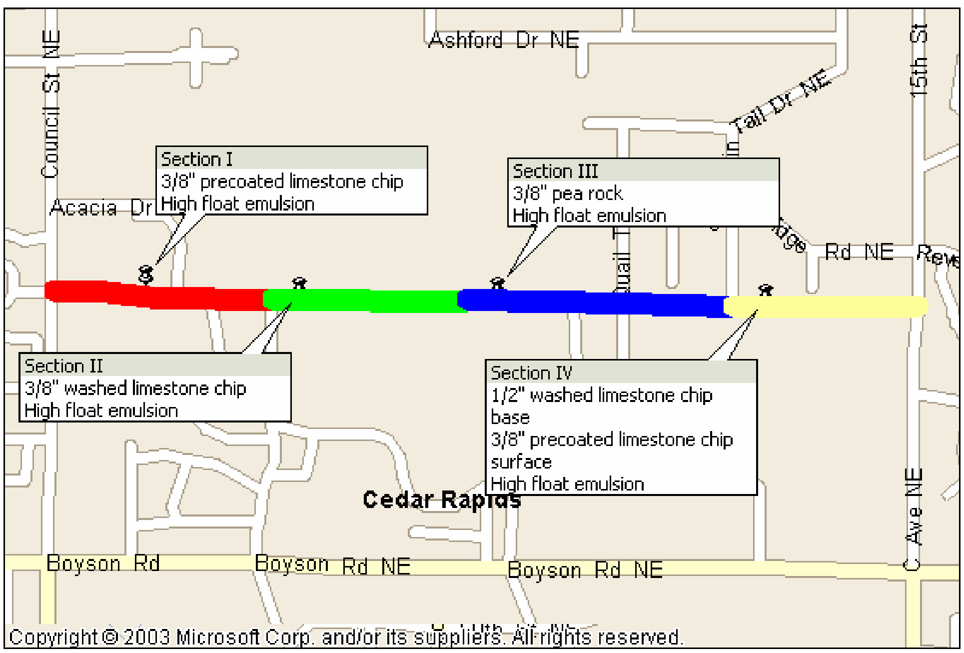

Figure 9. 74th Street test section layout

The researchers chose not to design the seal coat emulsion and aggregate application rates in order to observe how the seal coating crew performed the work and how they determined the application rates. The target application rates were 0.35 gal/yd^2 for HFE 90P emulsion and 20 lb/yd^2 for 3/8-in. pre-coated limestone chips. The seal coat crew members had considerable experience using this application rate and were confident that they could visually observe the results and adjust the equipment to an appropriate application rate without the help of instrumentation. The computer controls that adjusted the application on the chip spreader and distributor were not working properly over the summer, so the crew was using this method to adjust the application rates.

The following is the procedure for seal coat application in Cedar Rapids:

- Set up traffic control.
- Sweep the street with the power broom.
- Spray the approaches and radii with the distributor truck.
- Apply the emulsion to the rest of the road with the distributor truck.
- Allow the emulsion to form a skin (this can take two to three minutes).
- Apply chips with the chip spreader (see Figure 10).
- Break spreading routine as necessary to spread chips to radii and approaches.
- Follow chip spreader with a roller, making multiple passes on the freshly laid chips.
- Open the road to traffic.

For most seal coating operations, the chip spreader is expected to follow the distributor more closely than in Cedar Rapids procedure followed. This is especially true when fast-setting cationic emulsion is being used. However, in Cedar Rapids, high-float emulsion is used and under this circumstance, City of Cedar Rapids crews have found that they obtain better results with some waiting time between the application of the emulsion and the aggregate. The high-float emulsion tends to have a slower set in comparison to the cationic emulsion and is less viscous after it is sprayed onto the pavement. If aggregate is placed in this surface too soon, it tends to roll in the emulsion as it is dropped from the spreader. The result is that the top surface is coated with emulsion. When rollers and other equipment pass over the newly placed seal coat, the emulsion on the top surface of the aggregate is picked up by wheels and tracked across the surface. By contrast, cationic emulsion tends to set faster, so when aggregate is dropped from the chip spreader, it sticks to the pavement surface and does not roll, leaving the top side of the aggregate free of emulsion.

Being able to allow more time between the application of the emulsion and application of aggregate is desirable in a congested urban setting, because sometimes it is impossible to maneuver equipment so that the chip spreader can follow immediately behind the distributor. This is especially true in culs-de-sac and other short streets that do not have outlets. Crews reported to researchers that they had successfully applied pre-coated aggregate to high-float emulsion more than an hour after the emulsion had been placed.

Figure 10. Seal coat construction on 74th Street

The construction of the 74th Street test section was accomplished over a two-day period. On the first day, the crew started construction during a one-hour time period at the end of their work day by applying the seal coat to the first 1,000 feet of the test section, starting from the west end of the project and working east. Construction was completed the following day. The crew experienced some challenges in the initial organization for this project. One of the supervisors was called away at the beginning of the project. Also, the project was located at the edge of city, 8.6 miles from the equipment yard. Therefore, the roller and some of the aggregate trucks did not arrive promptly. In addition, the washed limestone aggregate and the pre-coated pea rock were not the usual materials used by this crew, so a break in routine was required to pick up these materials. In some cases, aggregate spreading was delayed by as much as 60 minutes after the emulsion was applied. For the sections constructed on the second day, rolling was delayed by as much as three hours after the emulsion was applied. For the section that was constructed on the first day, rolling was delayed until the following day. As the project progressed, coordination improved and the construction procedure closely matched recommended practice for seal coat construction. The construction procedure is summarized in Table 6.

Table 6. Construction summary for Cedar Rapids 74th Street test section

Section	Aggregate Spreading	Rolling	Comment
Pre-coated 3/8-inch limestone chips on first 1,000 feet	20 to 30 minutes after emulsion application; extra aggregate dumped on road	Following day	Performed during late afternoon of the first day
Pre-coated 3/8-inch limestone chips for balance of test section	30 to 60 minutes after emulsion application	Two to three hours after emulsion application	Performed at the beginning of the second day
Washed 3/8-inch limestone chips	30 to 60 minutes after emulsion application	One to two hours after emulsion application	The limestone chips were dusty
Pre-coated 3/8-inch pea rock	Chip spreader followed distributor truck	Less than one hour after emulsion application	The pre-coated pea rock was very dirty because it had been previously used
Double seal coat with 1/2-inch washed limestone first course; 3/8-inch pre-coated limestone second course	Chip spreader followed distributor truck	Roller followed chip spreader	Procedure was followed for both courses; construction followed closest to recommended best practices on this section

Council Bluffs Test Section

College Road

College Road is a collector street located near Iowa Western Community College in the northeast corner of Council Bluffs (see Figure 11). The pavement section was 2 inches (50.8 mm) of built-up seal coat with pea rock cover aggregate, underlain by 6 to 12 inches of asphalt-stabilized base. The shoulder width is approximately two feet and, although the ditches do not appear to be well drained, they are deep (approximately ten feet); it is unlikely that the drainage condition affects the subbase. The test section is located on the curved section of the road where the speed limit is reduced to 25 mph because of the tightness of the curve (see Figure 12). The traffic before construction was approximately 1,800 vehicles per day. The PCI of College Road before construction was estimated at 30–50 (poor). Some of the more severe distresses included alligator cracking, potholes, bleeding, and rutting. The alligator cracking and potholes were located in the outer wheel paths in the lane on the outside of the curve (see Figure 13). Most of the rutting was also located in the outer wheel paths of both lanes. It was apparent that the pavement was suffering a structural failure. Since TMSs are not usually recommended for pavements with structural failures, the researchers (in cooperation with the City of Council Bluffs) undertook efforts to improve the structural condition of the road.

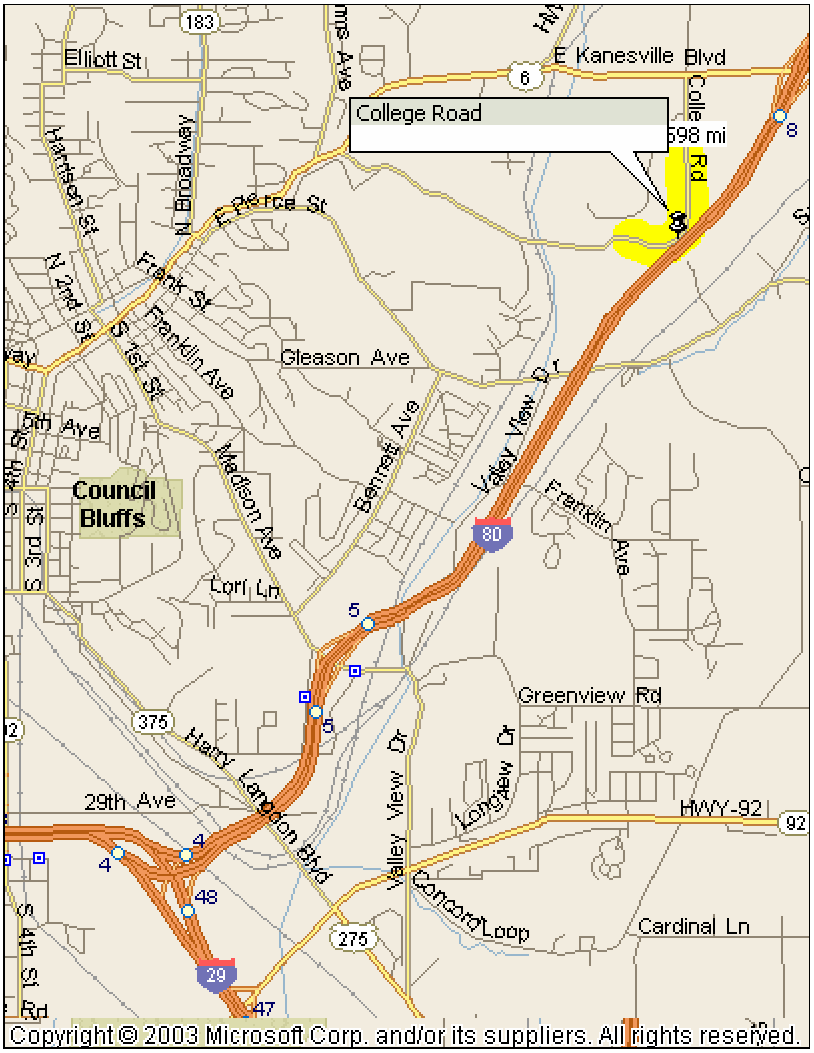

Figure 11. College Road overview map

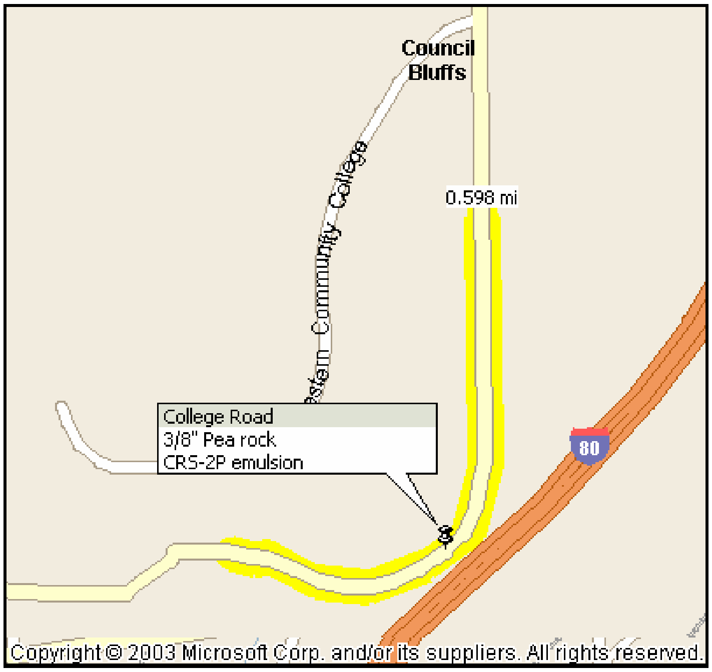

Figure 12. College Road map

Figure 13. College Road alligator cracking, potholes, and bleeding

College Road Construction

In order to asses the pavement's structure, dynamic cone penetrometer (DCP) tests were conducted prior to construction to assess the stability of the subbase. The DCP testing procedure used, ASTM D 6951-03, requires measurements of the penetration of a steel rod with a cone tip into subbase (ASTM International 2003). The road is driven using a hammer of prescribed height and drop. Readings are taken of the depth of penetration per blow. The results of the testing are found in Appendix A. The penetration rate was then correlated to the California bearing ratio. The tests concluded that the base under the pavement was sufficiently strong to support the pavement. Consequently, the researchers recommended only pulverizing and stabilizing the areas where the rutting, potholes, and alligator cracking occurred. However, the City of Council Bluffs crews re-stabilized the entire test section. Re-construction of the test section included pulverizing and mixing the seal coat and asphalt-treated subbase, adding limestone aggregate and water, re-grading the road, compacting, and an applying a primer coat (MC150).

Table 7. Council Bluffs pea rock gradation (seal coat cover aggregate)

Sieve size	% passing
1/2"	99
3/8"	95
#4	68
#8	19
#16	10
#30	5
#50	1
#100	1
#200	0.28

Previous to the reconstruction of College Road, most of the traffic consisted of cars accessing Iowa Western Community College. After the reconstruction project for College Road, two construction projects began in the area which required considerable use of tandem-axle dump trucks. As will be described in the results section, the truck traffic resulted in considerable damage to the rebuilt College Road pavement.

Because the City of Council Bluffs owns an older distributor and chip spreader, no design was made for the application of the seal coat, as there was no electronic apparatus on either piece of equipment to control application rates. Application rates were similar to those that the seal coat crew had successfully used in the past. However, these application rates were not measured and confirmed, because the equipment was not equipped to electronically measure application rates and the crews were not in the habit of checking the application rates using manual methods.

Usually, for roads that exhibit distress similar to that which was found on College Road, the City of Council Bluffs pulverizes, reshapes, and re-compacts the built-up seal coat and asphalt-treated base. Virgin aggregate may be added to increase stability, and water may be added to improve compaction. After compaction, the surface is sprayed with an asphalt cut-back primer (usually MC 70 at 0.3 gal/yd^2 and covered with blotting sand. The primer is intended to penetrate into the re-compacted base and provide a measure of water resistance. After the primer has had a week to penetrate, a seal coat is usually placed. Council Bluffs typically uses high-float emulsion and pea rock for its seal coats. Council Bluffs finds that, in comparison to cationic emulsions, the high-float emulsion allows more time to elapse between the spraying of emulsion and the placing of aggregate. This allows greater flexibility in coordinating equipment operations. Also, the high-float emulsion is more likely to properly bind dusty aggregate. Pea rock is used because it is an economical, locally sourced cover aggregate (see Table 8). Council Bluffs has experimented with locally sourced limestone chips, but these have not been sufficiently durable under traffic. Aggregates that are not locally sourced are considered too expensive.

Table 8. Pea rock gradation for Council Bluffs seal coat cover aggregate (mineral aggregate for armor coat)

Sieve size	% retained
3/4"	0
3/8"	0–6
#10	65–100
#50	90–100
#200	96–100

Council Bluffs public officials have found these roads to be satisfactory for rural areas within the city limits. However, it is typical that such roads develop areas of instability, alligator cracks, and then potholes similar to those which College Road experienced. Researchers were asked to recommend a seal coating system that might improve that performance.

Researchers theorized that small cracks may be developing in the seal coat and allowing water to penetrate the base where it initiates instability problems. They recommended the use of a polymer-modified seal coat binder that could resist cracking to a greater degree, even if the base was yielding slightly under traffic. Originally, a high-float polymer-modified emulsion was recommended. However, that emulsion could not be locally manufactured. A cationic polymer-modified emulsion (CRS 2P) was available, so that emulsion was selected for use with this project.

Figure 14. Stabilization of College Road

The following construction procedure was used to pulverize and re-compact the road:

- Scarify the seal coat using ripper teeth on the front of a motor grader.
- Scarify the asphalt-treated base using ripper teeth on the front of a motor grader.
- Work the material into windrows using the motor grader.
- Pulverize and mix the windrowed material with three to four passes of a soil mixer (see Figure 14).
- Add virgin aggregate to strengthen the mix and to raise the grade. (Between 80 and 100 tons were used for this test section.) Add soil from ditches to provide fines to fill the void spaces between the pieces of virgin aggregate.
- Set the crown or super elevation using the motor grader.
- Compact the material using a pneumatic tire roller.
- Apply the primer using a distributor truck. (Before primer was applied, the surface was scarified and re-compacted because the crew thought that the surface was too tightly bound to allow the primer to penetrate.)
- Apply blotting sand using a winter maintenance sand spreader.

Although the City of Council Bluffs preferred to allow the primer to penetrate for a week before placing the seal coat, this test section was constructed at the end of the construction season; it was necessary to seal coat three days after the primer was placed in order to finish before the close of the construction season.

The crew was instructed to use its usual application rate for binder and cover aggregate while seal coating. The chip spreader and distributor were not equipped to measure, adjust, and modify the application rates during the application process. Therefore, the application rates cited herein are estimated.

At the beginning of the seal coat application operation, the crew struggled to coordinate equipment in order to cover the binder and roll the cover aggregate within two minutes, as is recommended for CRS 2P binder. However, after a rhythm was established, the crew accomplished the work in accordance with the expected practice for these materials.

West Des Moines Test Sections

Aspen Drive

Aspen Drive is a residential street located in north-central West Des Moines (see Figure 15 and Figure 16). Before construction, Aspen Drive was a Portland concrete cement (PCC) pavement with an asphalt concrete cement (ACC) overlay of unknown thickness. The street has concrete curbs, gutters, and storm sewers which provide excellent drainage. The major distresses previous to construction were low- to medium-severity reflective cracking and L&T cracking (see Figure 17). Many of the reflective cracks had been sealed in 1991. The test section is located in a subdivision and, based on previous experience, city officials estimated an ADT of approximately 500. The PCI of the test section was 49. Citizen complaints about aesthetics were the main reason that a new surface was desired.

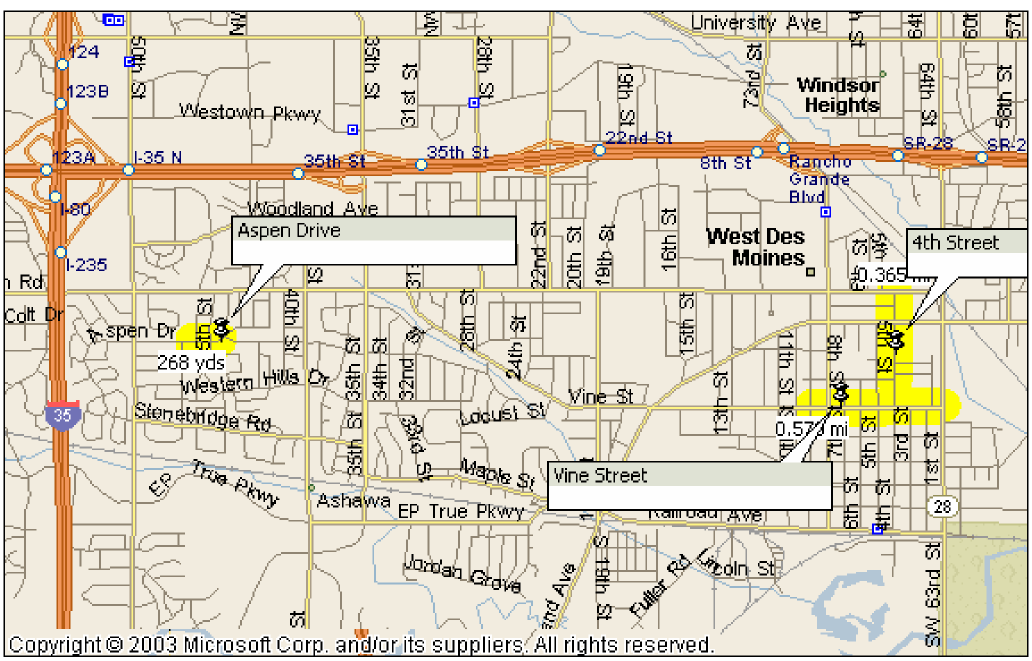

Figure 15. West Des Moines overview map

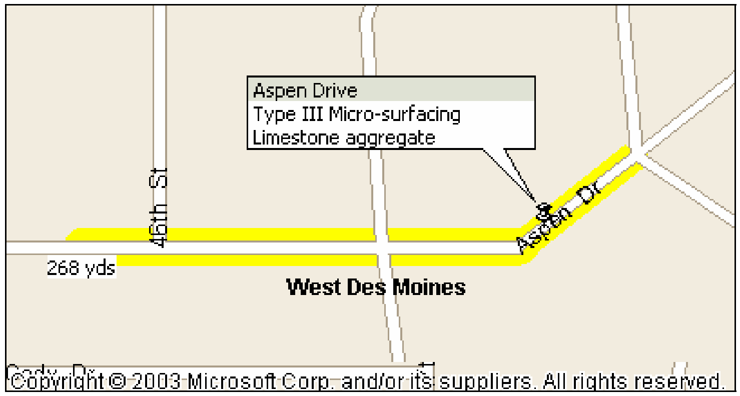

Figure 16. Aspen Drive map

Figure 17. Aspen Drive before construction

Micro-surfacing was selected for Aspen Drive despite the fact that slurry seal is usually considered to be satisfactory for such a low-volume application. This is because the City of West Des Moines wanted to have micro-surfacing test sections on the higher volume roads elsewhere in the city, such as the Fourth Street and Vine Street location described later. A construction contract that included only Fourth Street and Vine Street would not have been sufficiently large to attract contractors; Aspen Drive was added to the contract, because the city desired to maintain this street in the near future. A limestone aggregate with a modified Type III gradation was used for the micro-surfacing mix for Aspen Drive (see Table 9). Further information on the micro-surfacing can be found in “ISSA Recommended Performance Guidelines for Micro-Surfacing” (International Slurry Seal Association 2003).

Table 9. Type III micro-surfacing gradations (ISSA method A143)

Sieve Size	% Passing
3/8"	100
#4	70–90
#8	45–70
#16	28–50
#30	19–34
#50	12–25
#100	7–18
#200	5–15

Researchers had experience in previous phases of this project which indicated that the Type III gradation band could produce an aggregate that is too coarse for good performance; therefore, they specified a modified gradation with more fines (see Table 10). The added fines help the spreader apply a tighter surface with fewer drag marks, as they prevent the larger aggregate from getting stuck underneath the screed by creating more friction between the pavement, the fine material, and coarse material.

Table 10. Type III micro-surfacing gradations (West Des Moines specifications)

Sieve Size	% Passing
3/8"	100
#4	70–100
#8	45–70
#16	28–50
#30	19–34
#50	13–25
#100	10–18
#200	8–15

In the past, contractors have developed slurry seals that cure very quickly like micro-surfacing. These slurry seals set within 1.5 hours, which makes them difficult to distinguish between actual micro-surfacing. Reportedly, a rapidly setting slurry seal is not able to cure within the specified 1.5 hours at night, because it needs heat from the sunlight to cure quickly. To ensure that a contractor is providing micro-surfacing and not a quick-setting slurry seal, some jurisdictions (Mn/DOT in particular) specify placing test sections at night. The contractor is required to lay a short strip of micro-surfacing after sunset. If the surface does not cure within the specified time, the agency has an indication that they may not be getting a proper micro-surfacing mix and can require the contractor to try other test sections until the mix passes.

When micro-surfacing is laid, some pieces of aggregate stand on edge; this increases tire noise (see Figure 18). After the aggregate has been worked down to its side by traffic, the added tire noise diminishes. In order to force the aggregate pieces to lay down more quickly, a requirement of making five passes with a pneumatic tire roller was specified in the contract documents for the construction project. However, during construction, researchers and city engineers concluded that there was no noticeable improvement in aggregate orientation, so the use of the roller was ceased.

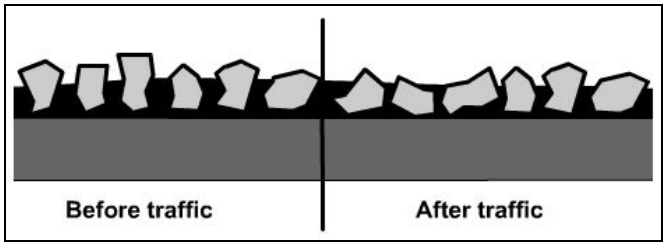

Figure 18. Micro-surfacing aggregate before and after traffic

Fourth Street and Vine Street

Fourth Street is a collector street located on the east side of West Des Moines (see Figure 15 and Figure 19). Before construction, Fourth Street was a PCC pavement with an ACC overlay of unknown thickness. Fourth Street and Vine Street both have concrete curbs, gutters, and storm sewers which provide excellent drainage. The major distresses previous to construction were low-severity reflective cracking and L&T cracking (see Figure 20). Many of the cracks had been sealed in 1993. The test section is located in a residential/commercial area. There is an industrial company on the north end of the test section, so there is a small amount of truck traffic delivering to that business. The estimated ADT is approximately 2,000 for Fourth Street.

Vine Street is a collector street located on the east side of West Des Moines. Before construction, Vine Street was a PCC pavement with an ACC overlay of unknown thickness. The major distresses previous to construction were low-severity reflective cracking and L&T cracking (see Figure 21). There was also a moderate amount of low-severity (1/4 in.–1/2 in.) to medium-severity (1/2 in.–1 in.) rutting. Many of the cracks had been sealed, and the seals were in good condition. The test section is located in a residential/commercial area and has a low amount of truck traffic, which services surrounding retail stores. The estimated ADT is approximately 5,000–6,000.

Both limestone and quartzite aggregate were used for the Type III micro-surfacing mix used on Fourth Street and Vine Street. Researchers and the City of West Des Moines desired to have a direct comparison between quartzite and limestone micro-surfacing aggregate. Typically, quartzite micro-surfacing aggregate is specified because it is thought to have more consistent chemical properties that provide a more predictable reaction with the micro-surfacing emulsion. Although micro-surfacing has the advantage of curing quickly, it also has the disadvantage of reacting and coagulating quickly in the presence of clay minerals. The use of quartzite was thought to eliminate this disadvantage. However, the nearest source of quartzite was in south-eastern South Dakota, and transportation costs added considerably to the total cost of the aggregate. Therefore, it was considered desirable to identify a micro-surfacing aggregate that was sourced within Iowa. Iowa limestone had been used as micro-surfacing aggregate on County Highway N28 in Pocahontas County. Against this background, the City of West Des Moines specified limestone micro-surfacing aggregate.

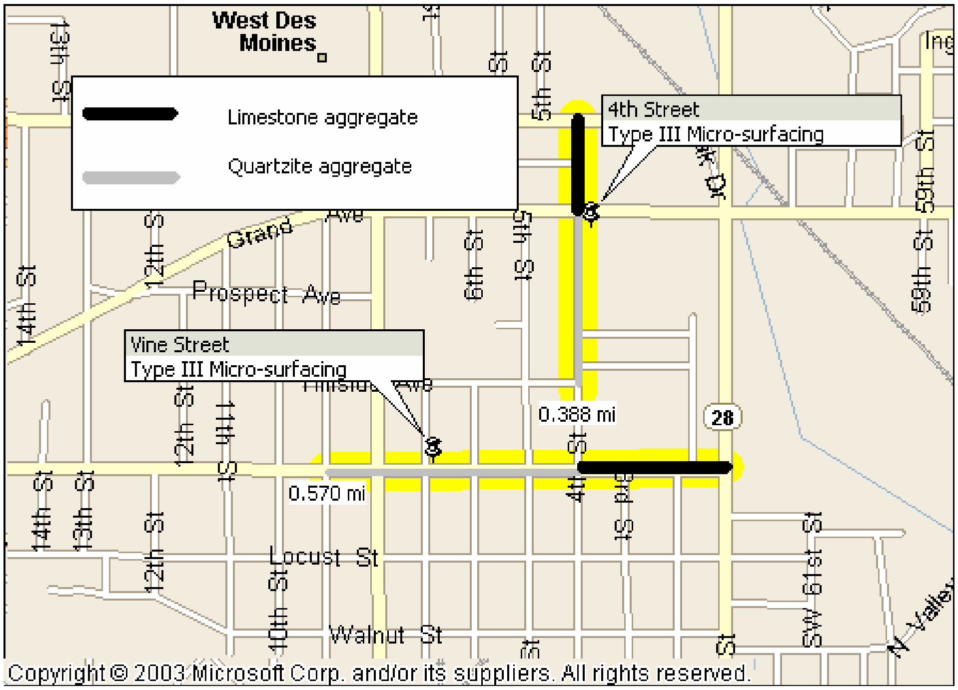

Figure 19. Street map of Vine and Fourth

Figure 20. Fourth Street before construction

Figure 21. Vine Street before construction

Aspen Drive, Fourth Street, and Vine Street Construction

After the specifications were written and finalized, and the plans had been developed, the job was put out to bid. Two contractors responded, and the contract was awarded to Sta-Bilt Construction based out of Harlan, Iowa. Sta-Bilt had been applying micro-surfacing for at least eight years and had been applying the surface to highways in Nebraska throughout the summer that this project took place. Because the contract was relatively small compared to other projects, the West Des Moines project was not scheduled until the end of the summer. Due to equipment breakdowns, the project was further delayed until October.

The first part of the construction was the application of the night test section (see Figure 22). Even though the air temperature dropped to 50°F during application, the micro-surfacing still cured in less than 45 minutes; this indicated that the mix was acceptable. Construction commenced the next day (see Figure 23). The micro-surfacing crew appeared to the researchers to be very experienced. There was concern that the temperatures were lower than desirable; however, they were above the range specified for construction (i.e., the surface should be no less than 50°F and rising).

Figure 22. Night test section construction

Figure 23. Micro-surfacing construction

RESULTS AND DISCUSSION

Cedar Rapids Results

The survey results for Cedar Rapids test sections are summarized and analyzed herein. For detailed results, see Appendix B.

Vermont Avenue

The post-construction survey revealed that the pavement condition index (PCI) for Vermont Avenue was 72, which places it in the rating category of “very good.” A conservative estimate of the original PCI is 56, which falls in the rating category of “good.” (The estimate was based on a photo log and on estimated percentages of L&T cracking and alligator cracking.) This means that there was an estimated increase of 16 points for the PCI. At the time of the post-construction survey, the seal coat was in very good condition with no raveling or bleeding. The main distress was light-severity reflective cracking from the previous seal coat. The chipmat also performed very well. There was no reflective cracking in the areas where the chipmat was placed (see Figure 24). Researchers chose not to place fabric over some areas of alligator cracking in order to provide a comparison. In those places, the alligator cracking quickly reflected through to the new seal coat, even before the start of the subsequent winter (see Figure 25). The average deduct values for the test section are displayed in Figure 26.

There were a few concerns with the chipmat: (1) it would not prevent reflective cracking, (2) it would not bond well to the existing seal coat, and (3) there would be noticeable bleeding over the chipmat. Inspection after the first winter indicated no such distresses had developed. The city engineer, very pleased with the chipmat, is considering the possibility of using it again in the future.

Figure 24. No reflected alligator cracking (chipmat)

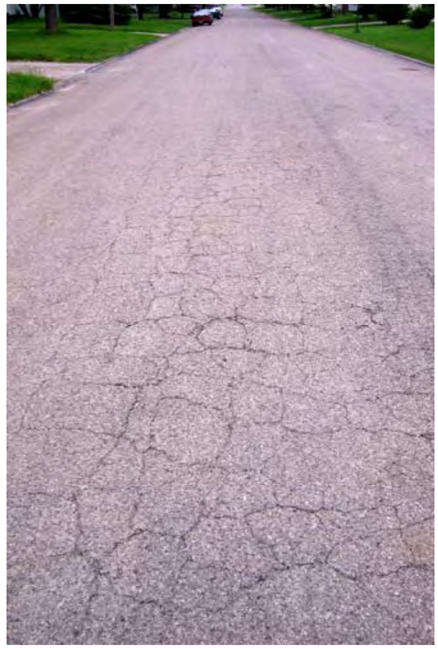

Figure 25. Reflected alligator cracking (no chipmat)

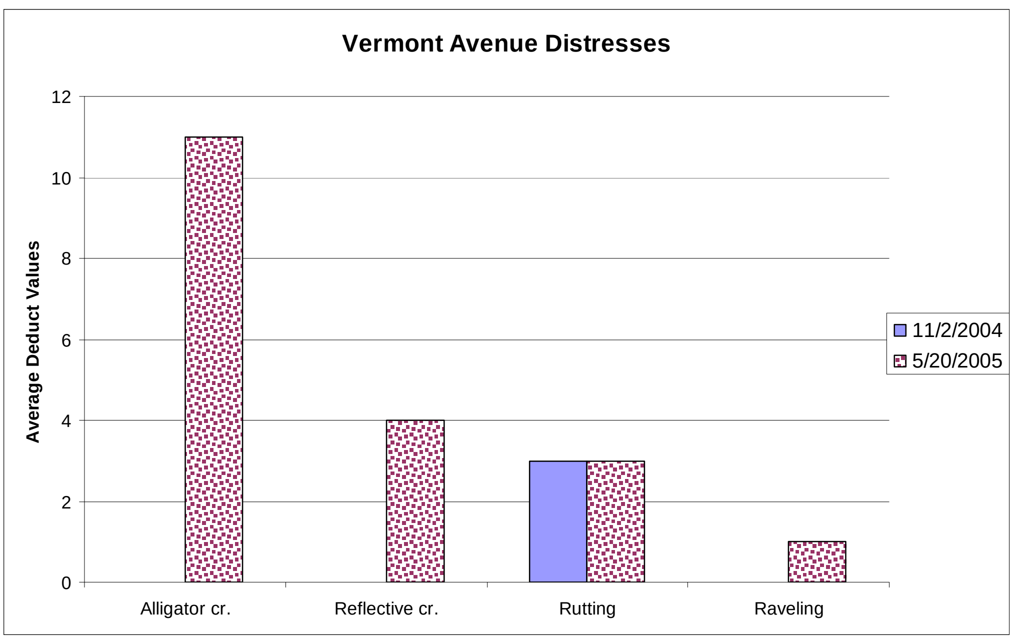

Figure 26. Vermont Avenue deduct values

74th Street in Cedar Rapids

The post-construction survey revealed that the overall PCI for 74th Street was 72 (very good). A conservative estimate of the original PCI is 62 (good). This estimate was based on a photo log of the test section. The estimated increase in the PCI value is 10. As was expected, results varied with each of the various types of aggregates. This “very good” rating is a strong indicator of a pavement with good structural stability. Examination of the actual distress deduct scores indicate very low amounts of cracking, rutting, and alligator cracking, which are all structural-related distresses. However, the test section appears to be in very poor condition because of surface distresses such as raveling and bleeding. These distresses are not weighted as heavily in the calculation of the PCI because they are only surface distresses and are not indicative of a pavement with poor structural stability. The average deduct values for the test section are shown in Figure 27.

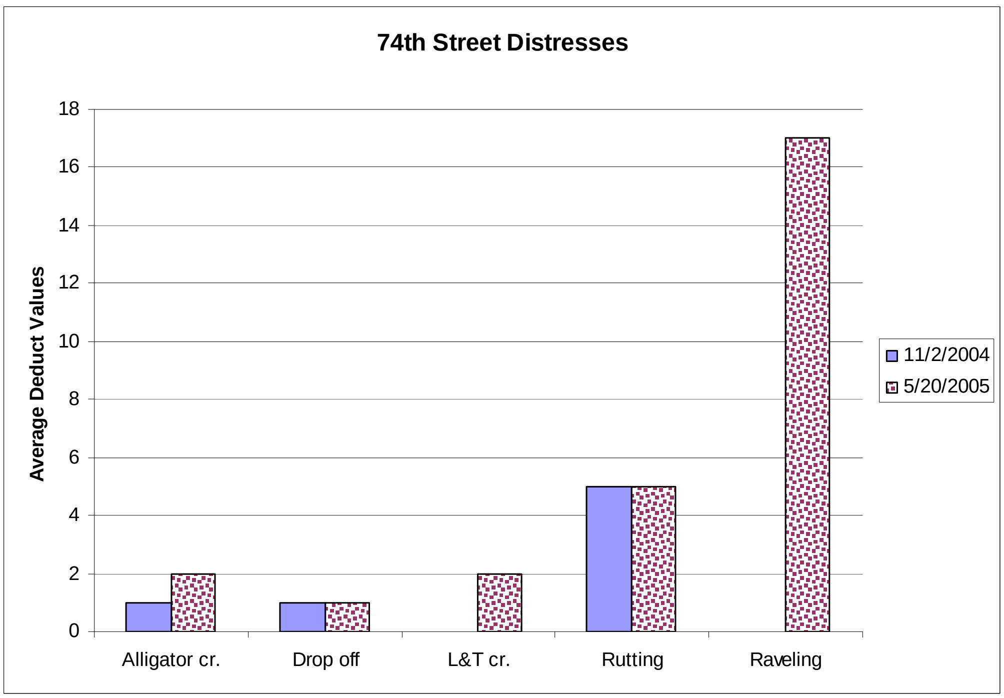

Figure 27. 74th Street deduct values

The section of seal coat that performed the best was the Section I (see Figure 28) with the 3/8-inch pre-coated aggregate. This section yielded a PCI of 81 (very good). Other than slight raveling, the seal coat was performing with no visible distress. The seal coat lost many PCI points because of rutting and other distresses that existed before construction of the new seal coat. Because a seal coat does not add any structure to a pavement, a seal coat does not address structural distresses. It is interesting to note that Section I included the 1000-foot section of the pre-coated aggregate that was not rolled until the day after the aggregate was applied. This is an indication that the emulsion and the pre-coated chips bonded to one another and is evidence of the robustness of the pre-coated chip and high-float emulsion combination.

Figure 28. 74th Street pre-coated chips

The 3/8-inch washed limestone chip section (see Figure 29) did not perform particularly well; its PCI rating was 63 (good). The relatively low PCI was caused by the large amounts of high-severity raveling. Other minor distresses included dips and low-severity rutting which were pre-existing. A large area of the seal coat was heavily raveled due to snowplow damage. The raveling problem might be attributed to poor bonding, caused by the dustiness of the aggregate that was used and the lack of the compaction by the pneumatic tire roller. The aggregate had been placed for three to four hours before the roller seated it. It is possible that the raveling may have been less severe had a roller been used immediately after placement, because much of the raveling was outside the wheel paths. (This is because the chips in the wheel path were seated in the emulsion by the passing traffic.) The city engineer also mentioned that this portion of the test section created large amounts of dust for several days after construction, which caused numerous citizen complaints. The city attempted to reduce the dust by washing the section with a water truck, but this effort resulted in limited success.

Figure 29. 74th Street washed limestone chip

The 3/8-inch pea rock test section (see Figure 30) had more raveling problems in comparison to the test sections that used pre-coated limestone aggregate for the top course. The PCI rating for the 3/8-inch pea rock test section was 66, which is in the performance category of "good." Most of the distress deducts resulted from large amounts of high-severity raveling. Other minor distresses included dips and low-severity rutting which pre-existed construction. This section was similar to the washed limestone chip section, in that there was considerable medium- to high-severity raveling. Again, the raveling in this section may have been caused by dirty aggregate and a lack of rolling by the pneumatic tire roller. Figure 31 shows how much fine material was on the chips, evidenced by the dusty residue left on a hand after handling the aggregate. This section was also the target of complaints by neighboring property owners regarding excessive dust generation.

Figure 30. 74th Street pea rock

Figure 31. Dusty washed limestone and dirty pea rock chips

The double seal coat section—1/2-inch washed limestone chip base with a 3/8-inch pre-coated limestone chip—performed quite well, with an “excellent” PCI rating of 95 (see Figure 32). This section experienced only slight bleeding and other distresses that were present before construction, which cannot be addressed by seal coating. There was one area with medium-severity alligator cracking and rutting; however, these distresses were not included in the survey because they were outside the sample boundaries. The lack of raveling can be attributed to the fact that this test section was rolled by the pneumatic tire roller immediately after the application of both layers of chips. There were concerns that this section would have issues with bleeding; however, as of May 16, 2005, there was no bleeding on this section.

Figure 32. 74th Street double seal coat

Council Bluffs Results

The survey results for Council Bluffs test sections are summarized and analyzed herein. For detailed results, see Appendix C.

College Road in Council Bluffs

The fall 2004 post-construction survey indicated that the road was in “excellent” condition with a PCI near 100. However, by the time the spring 2005 survey was conducted, the road had deteriorated so that that there was little to no improvement in comparison to the pre-construction condition of College Road. The new PCI of the road was 48, which is a “fair” condition rating, and the estimated previous PCI was approximately 30–50. The new PCI value does not include the portion of the test section adjacent to the north construction site (mentioned later) where earthwork was occurring and the resulting truck traffic caused a total failure of the pavement. This portion was left out because it did not represent the condition of the rest of the pavement. (The PCI values for these two sections were 29, which is categorized as poor, and 11, which is categorized as very poor). The average deduct values for College Road, not including the failed sections, are found in Figure 33. It should be noted that, when performing PCI surveys on seal coat roads, the surveyor did not consider construction defects as distresses, because the investigation was attempting to focus on how structure and surface of a well-constructed road would perform. An example of a construction defect is a series of grooves left from a motor grader's ripper teeth before the application of the first seal coat; although the grooves could be considered rutting, they are not a sign of structural distress or of a surface distress and they were thus not included in the survey.

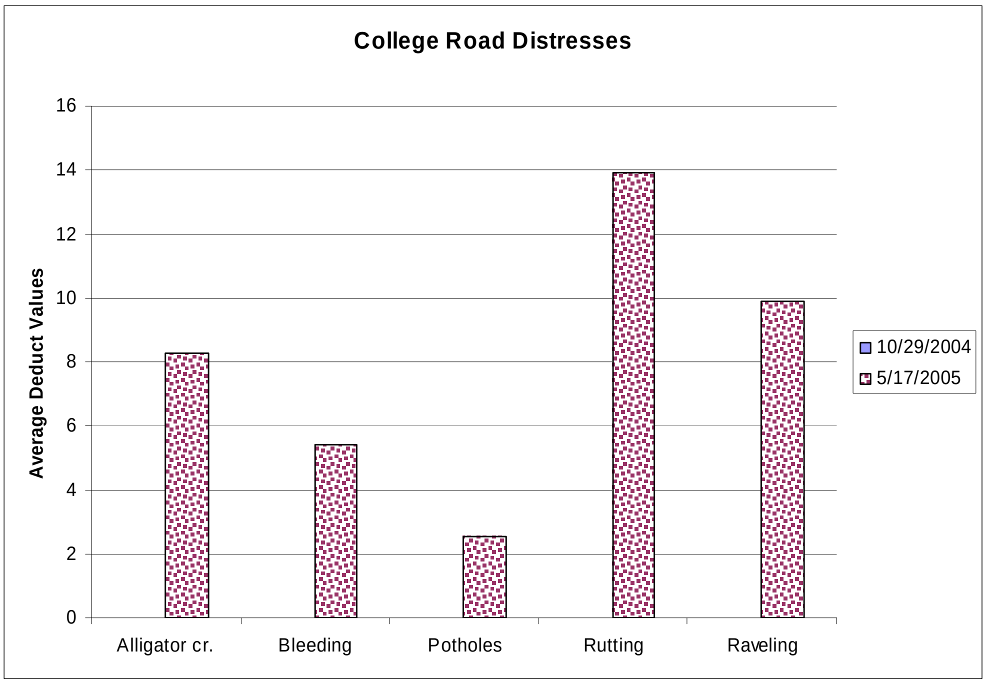

Figure 33. College Road deduct values
(The 10/29/2004 survey had zero deduct values.)

The distresses in the new seal coat were similar to that of the pre-construction condition (see Figure 34). Low- to high-severity rutting, alligator cracking, bleeding, and potholes had developed. When researchers compared a photo log of the test section before construction to the condition of the test section after construction, it was determined that the distresses in the new seal coat were located in the same regions as those of the original seal coat even though the entire road was re-stabilized. As with the original seal coat, the majority of the distresses were located in the outer lane, especially in the outer wheel path. The area adjacent to the entrance of the construction site had failed due to the heavy truck traffic. High-severity rutting, alligator cracking, bleeding, and raveling were the most prominent distresses near the entrance. Interestingly, the areas that were in excellent condition before construction were the same areas that were in good condition for the post-construction survey.

Figure 34. College Road alligator cracking

The intended goal of using the polymer-modified emulsion was to prevent the development of bleeding and to reduce the amount of structural distress—mainly alligator cracking and potholes—caused by small cracks forming in the surface that allow water to reach the subbase and cause the base to become weak. However, the use of the polymer-modified emulsion did not prevent the redevelopment of bleeding and cracking distresses. The recurrence of distress is not necessarily a failure of the polymer-modified emulsion. Challenges during the construction of the test section, the lack of stability of the subbase, and the excessive truck traffic are also likely causes of the failure.

The most probable cause for the various structural failures located throughout the test section was overloading of the pavement caused by the extra truck traffic. After discussions with the city engineer, the college adjacent to the test section removed approximately 350,000 cubic yards of earth, all of which was hauled by tandem-axle dump trucks that used the test section as a part of their haul route. Figure 35 shows the truck route (dashed line) that was used to access Interstate 35. The trucks entered the test section at its south end and drove north to the on-ramp for Interstate 35. The trucks used the test section as a return road as well. It can be reasonably assumed that each truck carried approximately 10–12 cubic yards of earth, which means that in the months after construction, the test section was traversed by approximately

35,000 fully loaded dump trucks. This number does not include traffic to and from the north construction site, which also included dump trucks removing an unknown amount of earth and using College Road to access Interstate 35. According to the city engineer, Iowa Western Community College plans to remove another one million cubic yards, and the test section will be traversed by all of this truck traffic as well.

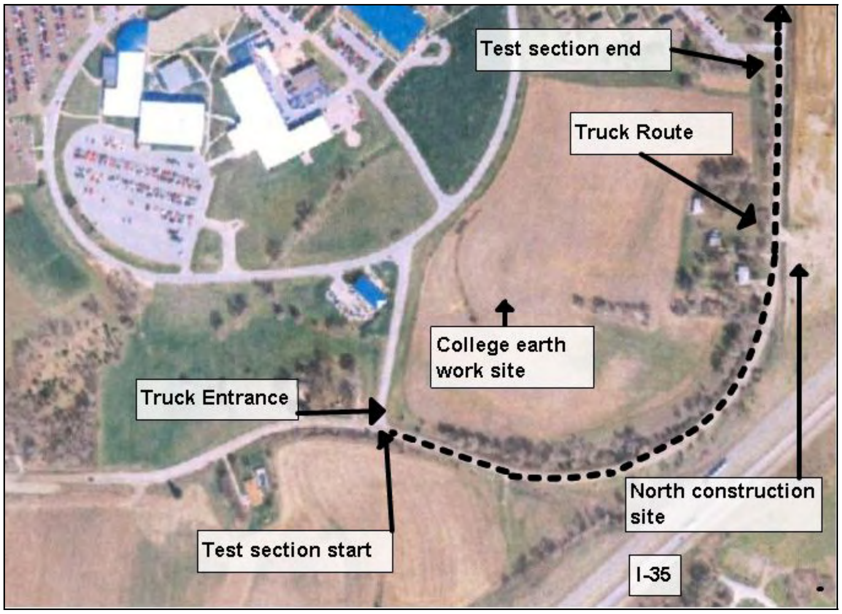

Figure 35. College Road construction map

An analysis was conducted to assess the ability of the College Road pavement to withstand the truck traffic that was imposed on it (see Appendix D). The analysis indicated that an emulsion-mixed base with coarse aggregate six inches deep would be required for the truck traffic. This base requires a structural number of 1.8. (The structural number is an index of the strength of base required to carry a defined load of traffic.) It seems likely that the design and quality control requirements contemplated in the analysis exceed those that were applied to the base for College Road. The existing base was approximately six inches of pulverized seal coat and base material that was wet compacted in lifts with no additive emulsion. The mix did contain some binder from previous seal coats and the emulsion binder from previous stabilization projects. This base likely had a structural number ranging from 0.42 to 0.66. This range is much lower than the required number of 1.8 and is insufficient for the truck traffic. This shows that the existing pavement's structure should not have been expected to support the truck traffic that the pavement experienced.

West Des Moines Results

The survey results for West Des Moines test sections are summarized and analyzed herein. For detailed results, see Appendix E.

Aspen Drive

The post-construction survey revealed that there was considerable improvement in the condition of the road. The original PCI of the Aspen Drive was 49 and the new PCI was 82, an increase of 33 points to a “very good” rating. Figure 36 shows the average deduct values for the various surveys performed on Aspen Drive. Various reflected cracks were the only distresses present in the new micro-surfacing. Many of the original reflected cracks in the overlay also reflected through the new micro-surfacing treatment. This section was the only section for which researchers had the original surveys. (Recall that the others were lost in an auto theft). The original total for all of the cracks on six sample survey sections was 2,802 feet, which includes low-, medium-, and high-severity reflective and L&T cracking (see Figure 37). As of May 16, 2005, the total amount of cracking is 1,605 feet—a 43% decrease in cracking. This number only includes reflective cracking, because the PCC joint cracks as well as the L&T cracks in the overlay reflected through the micro-surfacing but no new L&T cracks will form in the micro-surfacing. This crack reflection is typical of micro-surfacing treatments. The only other distress in the original overlay was light-severity alligator cracking. As of May 16, 2005, none of the alligator cracking had reflected through the micro-surfacing. The micro-surfacing appears to be performing well (see Figure 38). In a few high spots, a snowplow sheared off the high parts of the limestone aggregate, but enough aggregate still remains to cover the original pavement.

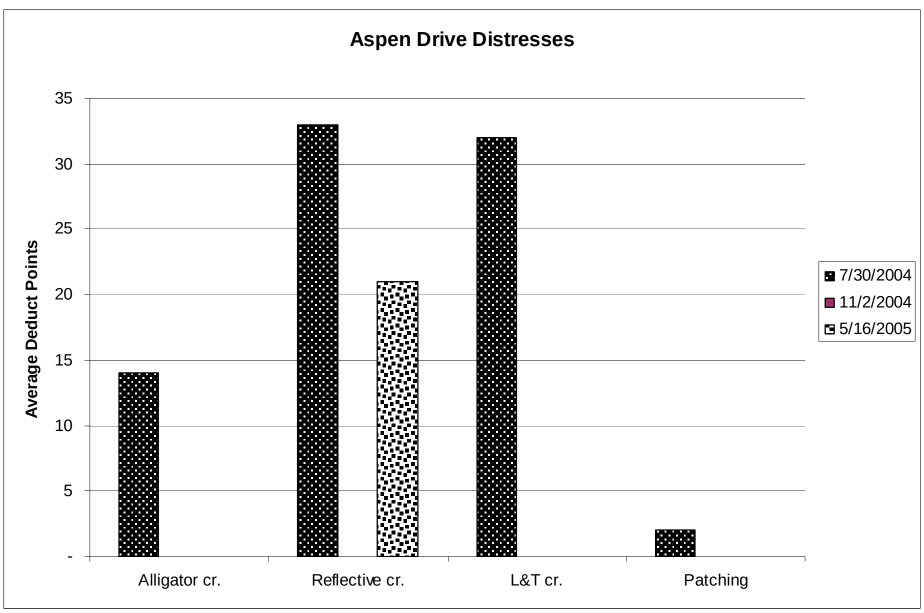

Figure 36. Aspen Drive deduct values

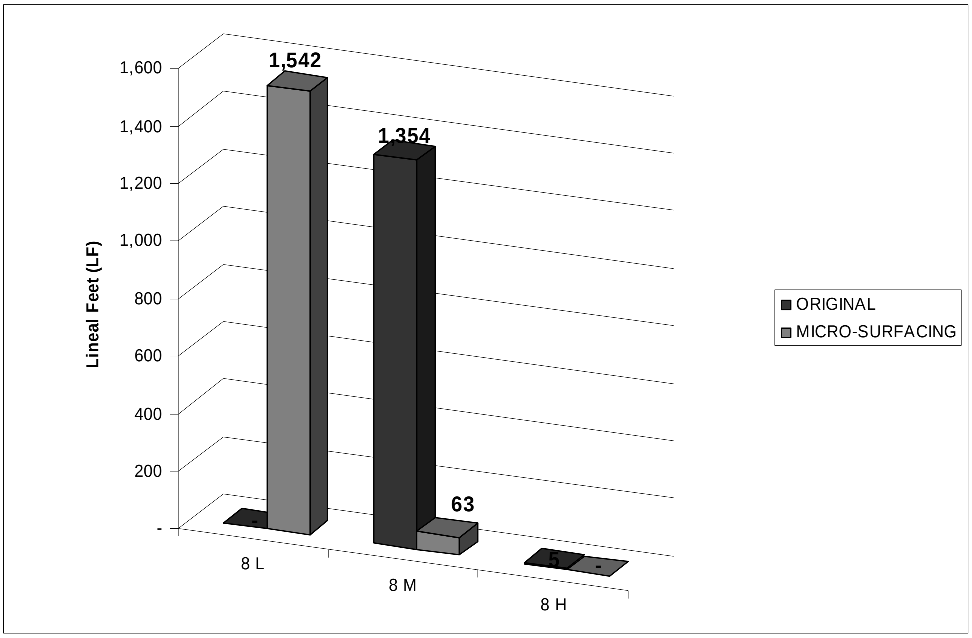

Figure 37. Reflective cracking on Aspen Drive by severity level

Figure 38. Reflective cracking on Aspen Drive

Fourth Street and Vine Street

The post-construction survey revealed that the PCI for Fourth Street increased from an estimated pre-construction PCI of 81 (very good) to 86 (excellent). Because preconstruction survey data was lost in the previously mentioned auto theft, the pre-construction PCI was estimated by surveying Maple Street, a pavement with a condition similar to that of Fourth Street and Vine Street before the application of the micro-surfacing. However, unlike Fourth and Vine Streets, Maple Street not have any rutting, which makes comparison challenging. In order to adjust for rutting, the rutting deduct values from the Vine Street survey (see Figure 39) were included in the Maple Street survey (see Figure 40) to draw a more accurate estimate of the pre-construction condition of Vine Street. The PCI value for Maple Street with the Vine Street rutting adjustment was 70 (good). The final PCI for Vine Street was 80, with a rating of “very good” and a PCI increase of 10.

Similar to Aspen Drive, the primary distress for both Fourth Street and Vine Street was reflected cracking. Vine Street had experienced some light-severity rutting before construction, and the micro-surfacing did not fill in the ruts. (Rut filling was not specified in the contract.) The graphs do not include pre-construction data.

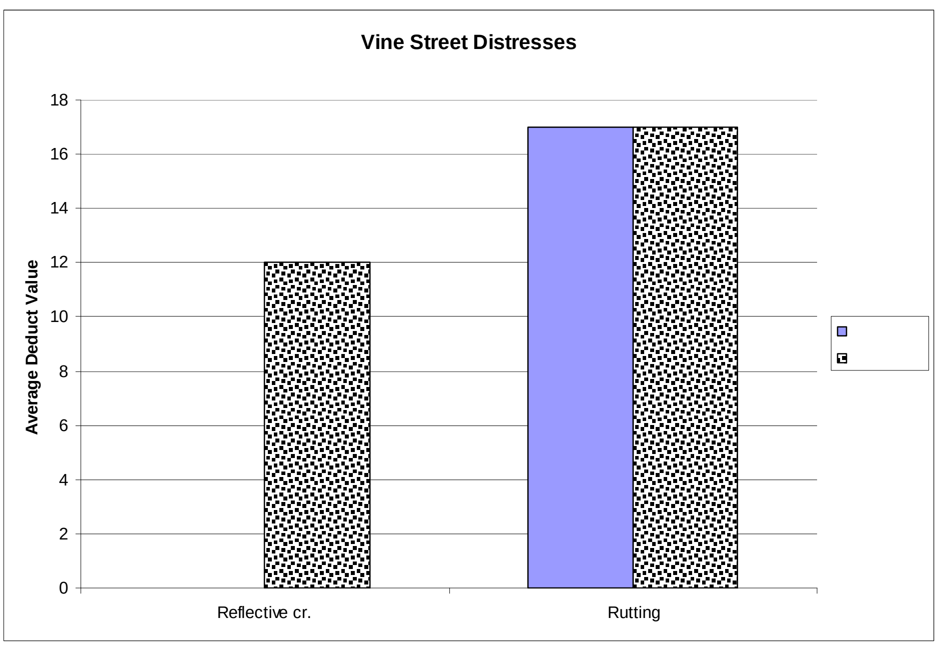

Figure 39. Vine Street deduct values

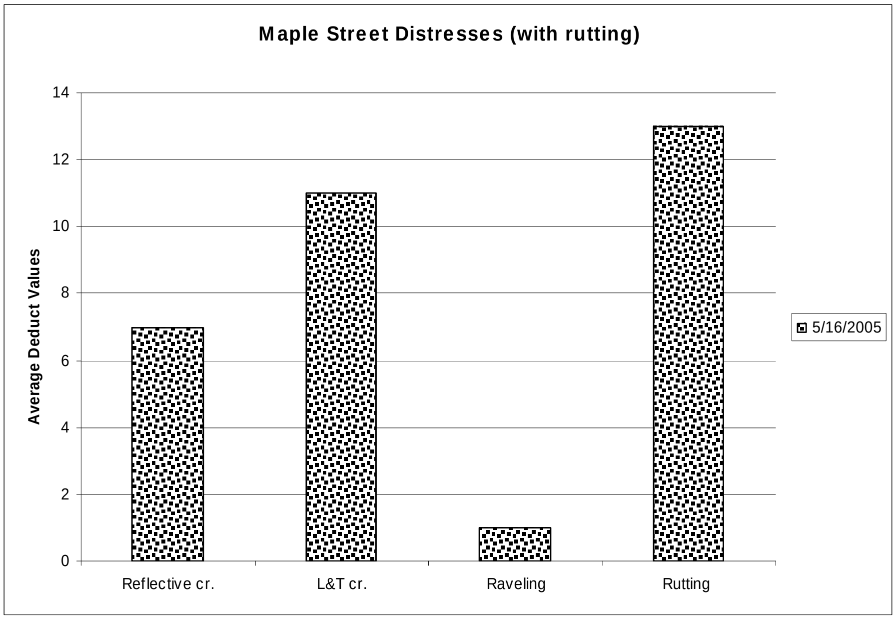

Figure 40. Maple Street deduct values (no TMS) with rutting

Both types of aggregate—quartzite and limestone—were used for both streets, and there was no noticeable difference in performance. The two mixes of micro-surfacing using different aggregates are experiencing the same types and amounts of distresses. The sections of micro-surfacing with limestone aggregate seemed to have a tighter surface texture because there were a higher proportion of fines in the limestone gradation. Figure 41 shows the color of the limestone aggregate in comparison to the quartzite aggregate, which has a pink color.

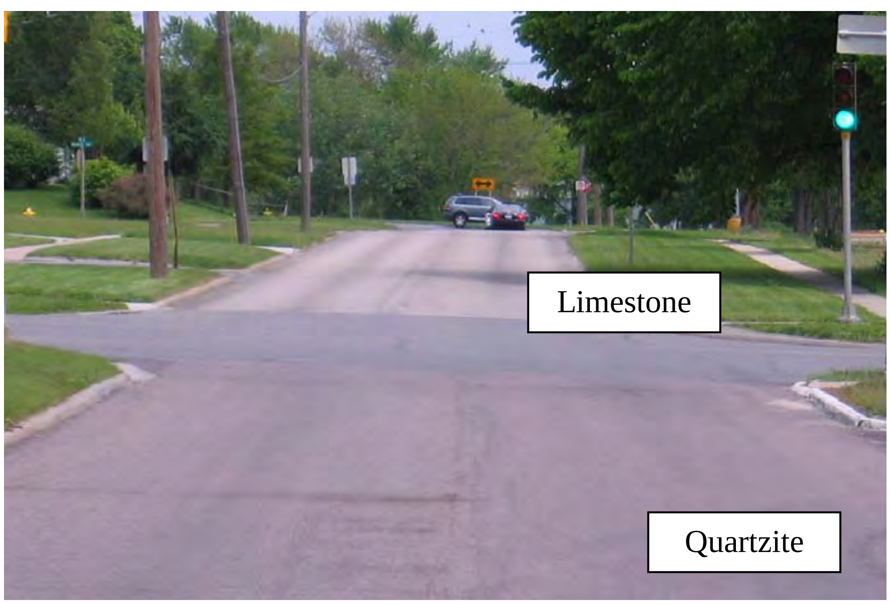

Figure 41. Micro-surfacing on Fourth Street

A common problem with micro-surfacing and slurry seals is delaminating caused by snow plows. However, there was only one spot, approximately five square feet, where a snow plow had completely removed the micro-surfacing mix.

Noise Testing on Fourth Street in West Des Moines

After micro-surfacing has been laid, it is often noisier in comparison to the previous surface, and the type of tire noise produced commonly gives people the perception that the surface is rough in comparison to other surfaces, especially hot mix asphalt. This extra noise is emitted from the tires and is caused by added air space between the tire and the aggregate that is standing on its edge after the micro-surfacing has been laid (see Figure 18). However, after a few months under traffic, the aggregate becomes reoriented by tire contact, producing a smoother surface and a less noisy road. The city engineer in West Des Moines was concerned with the added noise and asked for sound testing to be performed.

Researchers conducted noise level tests to compare tire noise on a control section of a new asphalt overlay with the noise level on the micro-surfacing. A decibel meter, a device that measures the decibel level, was purchased to conduct the tests. The operator of the decibel meter stood on the sidewalk 15 feet away from the traffic, and the test vehicle traveled in the closest lane (see Figure 42). To isolate the tire noise from the test vehicle, the test vehicle coasted by the decibel meter at 25 mph in order to reduce the amount of engine or brake noise that might mask the tire noise. Masking is “a situation where a dominant, or nearly dominant, sound or noise component of a noise source reduces or eliminates the audibility of other sound (or noise) components of a noise source” (Geib and Wood 2001).

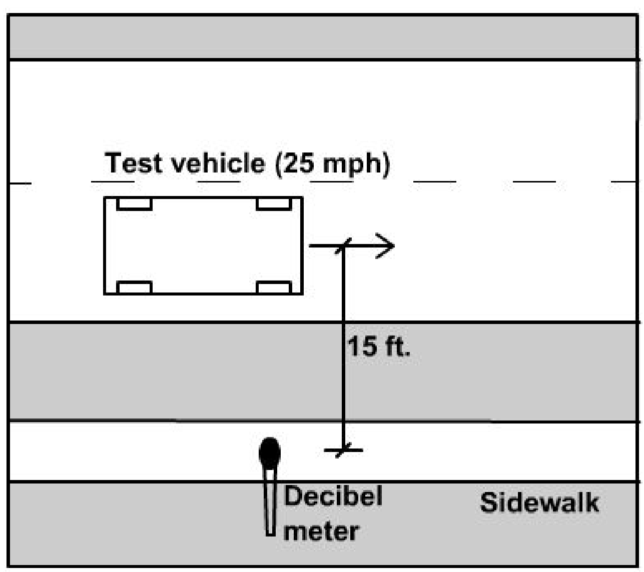

Figure 42. Sound testing layout

Researchers used two different test vehicles: a 2002 Ford Taurus and a 2000 Chevrolet 3500 work truck with dual rear tires. The truck was supplied by the West Des Moines Public Works Department. A sampling of vehicles passing by was also taken to see if there was a difference in ambient noise. In the parlance of statistical experiment design, this constituted a "chunk" sample including any cars, heavy trucks, and city buses that passed the site at the time the test was being conducted. A test was also taken to compare the interior noise in the Ford Taurus when riding on the micro-surfacing to the noise when riding on an unsurfaced asphalt overlay (see Appendix G).

As was expected, there was a difference in sound intensity between the micro-surfacing and the asphalt overlay. The difference was equal to 3.9 dB for the truck, 4.2 dB for the car, 4.8 dB for the inside of the car. However, Mn/DOT defines a difference of 3 dB as barely perceptible; a difference of 5 dB is generally considered to be a substantial change in noise, and a 10 dB change is doubling or halving the perceived loudness (Geib and Wood 2001). After three months of traffic, the differences in average loudness between the micro-surfacing and the asphalt overlay had diminished. The differences in average sound intensity between the two surfaces were 0.4 dB for the truck, 1.3 dB for the car, and 7.2 dB for inside the car (see Table 11). The difference in tire noise from outside the car and truck was no longer perceptible. However, test results indicate that there was a larger difference in interior sound levels during the second test. This larger difference was unexpected, because the exterior noise levels dropped; the added sound is caused by the tires.

Table 11. Differences in average loudness (in decibels)

	January 19, 2005			**June 10, 2005**		
	Car	**Truck**	**Inside car**	**Car**	**Truck**	**Inside car**
Asphalt	67.5	67.3	61.2	72.8	64.8	54.9
Micro-surfacing	71.4	71.5	66.0	73.2	66.0	62.1
Difference	**3.9**	**4.2**	**4.8**	**0.4**	**1.3**	**7.2**

The average sound intensity for the test vehicles during the test in March cannot be compared to the sound intensity during the test in June because the temperature was notably different—36°F for the January 19, 2005 test and 80°F for the June 10, 2005 test—and different vehicles were used for the testing. The reason that different test vehicles were used was that it was not possible to get the same exact vehicles from the Iowa State University Motor Pool. The difference in loudness for each of the test vehicles on each of the surfaces on one test day shows the difference in loudness (see Figure 43 and Figure 44). The chunk sampling of cars, trucks, and buses passing by also showed no difference in the decibel level, with the average decibel level of the micro-surfacing being 1.5 dB higher than that of the asphalt (see Figure 45).

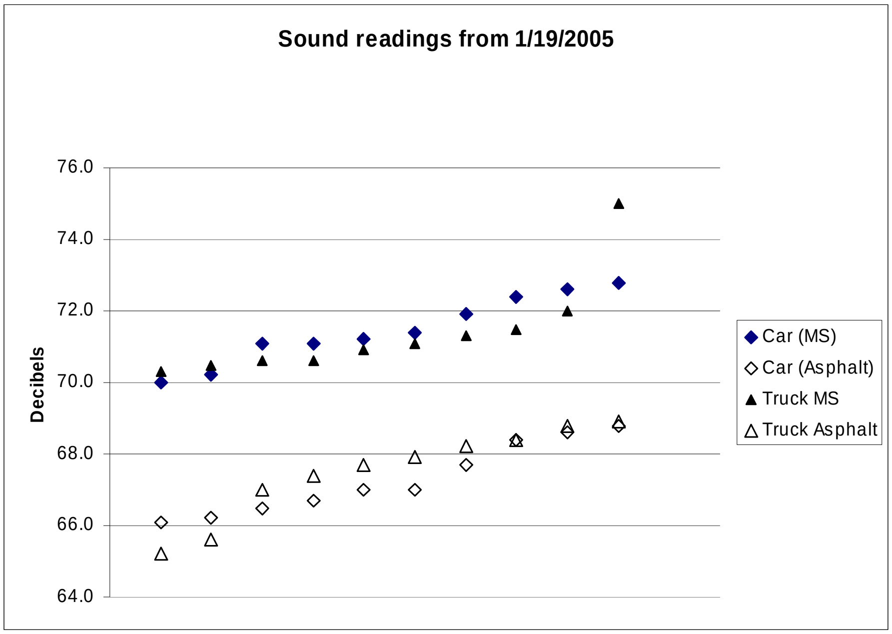

Figure 43. First sound readings (in order of intensity)

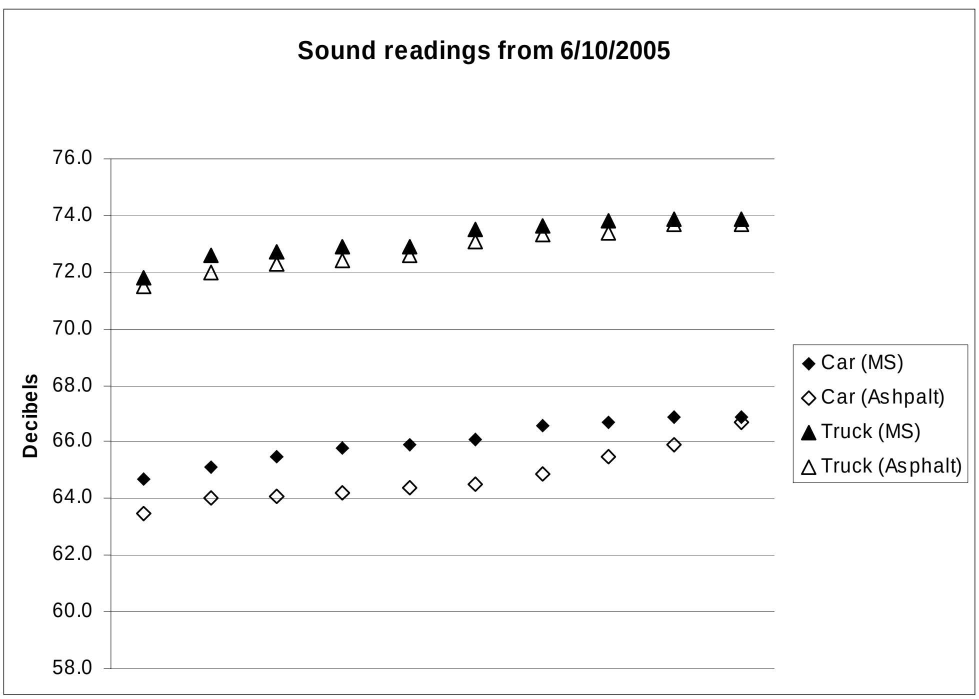

Figure 44. Second sound readings (in order of intensity)

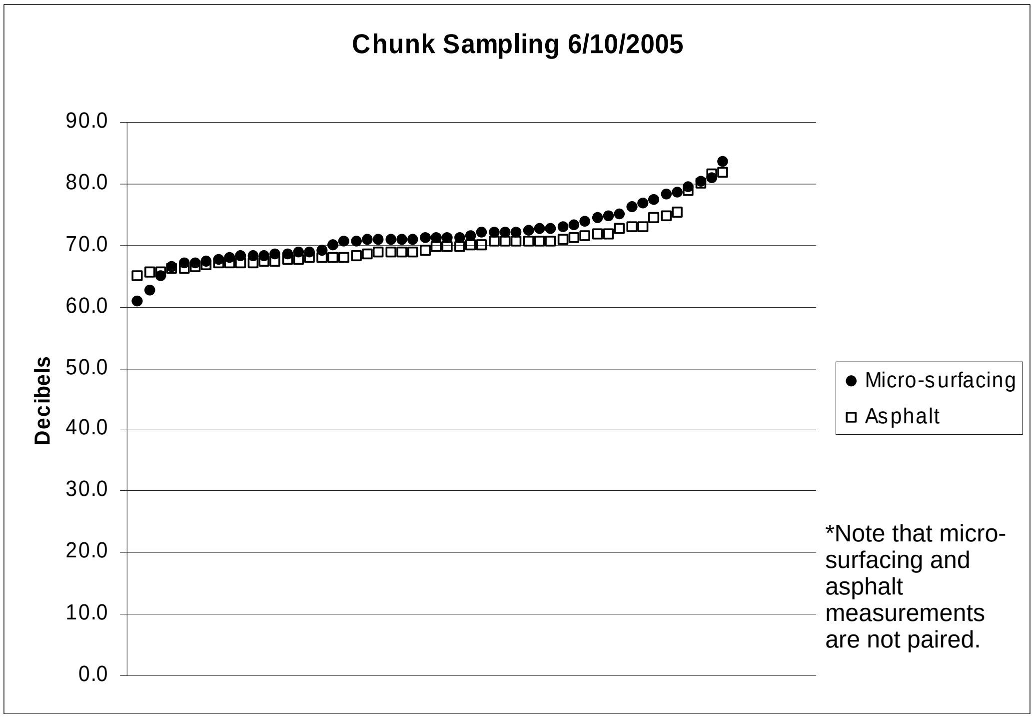

Figure 45. Chunk sampling of cars, buses, and trucks (in order of intensity)

Additional Testing

In addition to the performance surveys described in this section, a survey of each of the demonstration sections was undertaken in November of 2005. The results of these surveys are described in Appendix F.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions from this project were developed after reviewing observations from the various test sections constructed. Statistical analyses were not performed on the test section data to interpret the results. Each test section stands as its own case study and should not be compared to others for the purpose of determining which surface was the most successful. The test sections stand as examples of the various preventive maintenance techniques and materials that can be used to preserve pavements. The various test sections were designed with techniques and materials that are common or available in Iowa, so that cities and counties are able to reproduce the test sections. To some extent, the following conclusions are generalized for similar materials in geographic areas beyond Iowa. Readers should not make such generalizations unless they are certain that the materials and conditions are similar to those of the test sections.

Cedar Rapids Conclusions

- The seal coats in Cedar Rapids that use a pre-coated limestone chips are performing better than the other types of aggregates, including pea rock and washed (un-coated) limestone chips.
- The current program of using high-float emulsion HFE-90 and a pre-coated limestone chip for a seal coat appears to be successful, because this is a very robust combination. This combination has outperformed the other aggregates even though quality control was not rigorous; the chips were not spread promptly after the emulsion was applied or rolled promptly after the chips were spread.
- The washed limestone chip and pea rock aggregate received numerous public complaints due to fugitive dust. These combinations are recommended for areas where dust can be tolerated. The dust on both the washed limestone chip and pea rock aggregate also may have caused a poor bond between the chips and the emulsion. This poor bond may have resulted in the severe raveling that was observed by researchers.
- Emulsion can be used as a tack coat for a geotechnical fabric–reinforced seal coat if the tack coat and fabric are given ample time to cure before the first seal coat is applied. Sand can be used to blot the surface of the geotechnical fabric while the emulsion is curing. Using chipmat with an emulsion as a tack coat appears to be a feasible and cost-effective solution for alligator cracking that does not deflect under load. This conclusion is based on the construction of one demonstration section.

Council Bluffs Conclusions

- The College Road test section has not yielded the desired result with regard to pavement performance as measured by PCI. The College Road test section’s poor performance can likely be attributed to the increase of heavy truck traffic. Approximately 30,000–35,000 loaded tandem-axle dump trucks used College Road as an entrance for a construction site within 6 months; this is not typical daily traffic or typical loads for this road. Had the test section received the same traffic load that was present before the construction took place, it is the researchers' opinion that the test section would not have had the same degree of structural failure.

- A conclusion could not be made from this research project regarding the effectiveness of polymer-modified emulsion. The test section that was used to investigate this topic had a number of construction and traffic issues that muddled the results. Although the benefits of polymers were not demonstrated in this research, literature has shown that the use of polymers aids in chip retention, helps prevent bleeding, reduces temperature susceptibility, and enhances the robustness of the seal coat.

West Des Moines Conclusions

- The use of micro-surfacing was successful, as all three test sections are performing well. There were no apparent differences in the performance of quartzite or limestone aggregate. Since limestone is locally available and less costly, its use should be strongly considered in the future.
- The higher proportion of fines in the limestone aggregate gradation for the micro-surfacing helped create a smoother and tighter surface in comparison to previous micro-surfacing projects on Iowa's system of primary roads (Jahren et al. 1999). The modification of the recommended aggregate gradation should be further tested to verify this finding.
- The use of the pneumatic tire roller to smooth micro-surfacing and reduce noise was not found to result in noticeable improvement (based on one trial).
- The sound testing conducted as part of this project showed that the exterior sound intensity of the micro-surfacing decreases as it is trafficked. After several months of traffic, the exterior loudness of micro-surfacing is similar to that of an HMA surface. The difference in interior noise between hot mix asphalt and micro-surfacing increased from the first measurement (shortly after placement) to the second measurement (three months later).

General Conclusions

- Thin maintenance surfaces are suitable preventive maintenance techniques for a municipal street department's program to use for preserving existing pavements. However, careful attention should be paid to the proper timing of the application and to quality control during construction of the surface. Aggregate and binder selection for seal coats should be taken very seriously, and all options should be considered to determine the best combination that suits the needs of the city.
- Proper construction technique is one of the primary influences on the success of a TMS. Failures of a TMS that occur early in its life can often be traced back to poor construction or quality control.
- Thorough planning is necessary for a successful TMS. If proper planning is not performed, the construction of the surface can be delayed or constructed with poor

quality control. Construction late in the season can be rushed, and the TMS performance can be compromised because the binder in the surface is not given necessary time to cure before the temperature drops.

- Construction of a TMS should not begin until all necessary equipment and materials are onsite. Also, construction should not begin until all necessary traffic control equipment is in place.
- The use of a pneumatic tire roller is important for embedding aggregate into the emulsion for successful seal coat construction. The roller should be used immediately after application of the aggregate to ensure the best embedment. (Apparently, some delay is permissible if high-float emulsion is used.) Although the pre-coated limestone chip seal coat in Cedar Rapids performed well without immediate roller embedment, this is likely an exception due to the unusually robust combination of aggregate and binder that is afforded by the pre-coated limestone chips and high-float emulsion. The other test sections and literature show that the use of a pneumatic tire roller is necessary.

Recommendations

- The use of polymer-modified emulsions should be tested again to determine the value added to a seal coat.
- The recommended aggregate gradation for the Type III micro-surfacing should be further tested to verify the findings from this research.
- Further investigation should be conducted regarding the use of a night test section as a preliminary indication of whether or not the micro-surfacing mixtures will perform properly.
- Further research and testing on the chipmat should be performed to verify the findings from this research.
- Additional noise testing should be performed on other micro-surfacing sections to verify the findings from this research.

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APPENDIX A. COUNCIL BLUFFS DCP RESULTS

SEAL COAT ROADWAY DYNAMIC CONE PENETROMETER TESTING
COLLEGE ROAD
COUNCIL CLUFFS, IOWA

	Test Location									
	1	2	3	4	5					
	Approximate Seal Coat Thickness, (in.)									
	3	4	3	3	2.5					
Penetration Depth (below subgrade).	**Blow Counts per inch**									
1	11	16	13	11	11					
2	16	29	21	13	20					
3	27	30	24	14	17					
4	28	20	17	18	26					
5	30	28	17	15	24					
6	25	16	158	18	22					
7	27	18	12	17	17					
8	25	19	10	15	18					
9	26	9	9	14	13					
10	16	19	8	17	13					
11	18	22	9	14	16					
12	6	22	10	14	9					
13	16	22	10	15	9					
14	16	20	14	14	13					
15	17	30	15	13	12					
16	16	33	15	15	12					
17	18	32	17	15	14					
18	20	29	15	16	15					

APPENDIX B. CEDAR RAPIDS DEDUCT VALUES

The following tables show the deduct values for survey for each test section. The deduct values are broken down into the different distress types for each sample section. Distresses that were not found on the test sections were not included in the tables. The distress identification numbers are designated as follows:

1 – Alligator cracking
2 – Bleeding
4 – Sagging
7 – Edge cracking
8 – Reflective cracking
9 – Shoulder drop-off
13 – Potholes
15 – Rutting
19 – Raveling

Table B.1. 74th Street deduct values

74th Street — Deduct Values — 11/2/2004

		Sample #														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	L	-	-	-	5	7	-	-	-	-	-	-	1	-	-	13
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	L	-	-	-	-	7	7	-	-	-	-	-	-	-	-	14
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	L	-	-	-	-	-	-	3	-	-	-	-	-	-	-	3
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	L	-	22	20	12	-	15	-	-	-	-	-	-	-	-	69
	M	-	13	-	-	-	-	-	-	-	-	-	43	-	-	56
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

74th Street — Deduct Values — 5/20/2005

		Sample #														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	L	-	-	7	-	-	-	-	-	-	-	-	-	-	-	7
	M	-	-	-	-	-	-	-	-	-	-	-	37	-	-	37
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	L	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	L	-	-	4	-	-	4	-	13	-	-	-	-	-	-	21
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	6	5	8	-	-	-	10	-	-	-	29
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	-	-	-	2	-	-	-	-	-	-	-	-	-	-	2
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	2	-	-	-	-	-	-	-	-	-	-	-	2
15	L	-	22	20	12	-	15	-	-	-	-	-	-	-	-	69
	M	-	13	-	-	-	-	-	-	-	-	-	43	-	-	56
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	L	5	-	-	-	5	-	6	2	3	-	-	-	-	-	21
	M	-	-	-	16	22	19	18	15	11	-	-	-	-	-	101
	H	-	-	-	50	-	-	-	31	36	-	-	-	-	-	117

Table B.2. Vermont Avenue deduct values

Vermont Avenue

		Deduct Values											Deduct Values										
		11/2/2004										Total	5/20/2005										Total
		Sample #											Sample #										
		1	2	3	4	5	6	7	8	9	10		1	2	3	4	5	6	7	8	9	10	
1	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	1	14	28	-		40	101
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	L	-	-	-	-	-	-	-	-	-	-	-	12	9	7	3	-	3	3	3	-	3	43
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	L	-	-	14	17	-	-	-	-	-	-	31	-	-	14	17	-	-	-	-	-	-	31
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	L	-	-	-	-	-	-	-	-	-	-	-	2	6	2	-	-	-	-	-	-	-	10
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2

Table B.3. Original estimated deduct values for 74th Street

		Deduct Values														
		Original Estimate														
		Sample #														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	L	-	-	-	-	4	-	-	-	-	-	-	-	-	-	4
	M	38	37	37	-	27	27	20	14	29	40	27	27	-	-	323
	H	-	-	-	70	-	-	2	20	-	-	-	-	-	-	92
4	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	L	-	-	-	-	-	90	-	-	-	-	-	-	-	-	90
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	L	-	22	20	12	-	15	-	-	-	-	-	-	-	-	69
	M	-	13	-	-	-	-	-	-	-	-	-	43	-	-	56
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B.4. Original estimated deduct values for Vermont Avenue

		Vermont Avenue										
		Deduct Values										
		Original Estimate										Total
		Sample #										
		1	2	3	4	5	6	7	8	9	10	
1	L	42	42	42	42	42	42	42	42	42	42	420
	M	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-
8	L	18	18	18	18	18	18	18	18	18	18	180
	M	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-
15	L	-	-	14	17	-	-	-	-	-	-	31
	M	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-
19	L	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-

APPENDIX C. COUNCIL BLUFFS DEDUCT VALUES

The following tables show the deduct values for the surveys of each test section. The deduct values are broken down into the various distress types for each sample section. Distresses that were not observed on the test sections were not included in the tables. The distress identification numbers are designated as follows:

1 – Alligator cracking
2 – Bleeding
6 – Depression
7 – Edge cracking
15 – Rutting
19 – Raveling

Table C.1. College Road deduct values

		College Road																						
		Deduct Values											Deduct Values											
		Fall 2004										Total	Spring 2005											Total
		Sample #											Sample #											
		1	2	3	4	5	6	7	8	9	10		1	2	3	4	5	6	7	8	9	10	
1	L	-	-	-	-	-	-	-	-	-	-	-	32	-	28	24	10	-	-	35	-	-	129
	M	-	-	-	-	-	-	-	-	-	-	-	24	-	-	16	-	-	-	-	40	-	80
	H	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	-	-	-	-	40
2	L	-	-	-	-	-	-	-	-	-	-	-	17	11	10	10	10	10	10	-	12	13	103
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	34	-	21	59
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	10
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	L	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	4
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	2	-	4
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	20	20	72
15	L	-	-	-	-	-	-	-	-	-	-	-	30	-	14	35	14	30	16	-	-	14	153
	M	-	-	-	-	-	-	-	-	-	-	-	14	-	38	24	36	-	-	-	-	-	112
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34	55	-	-	-	64	-	153
19	L	-	-	-	-	-	3	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	57	28	14	99

APPENDIX D. COUNCIL BLUFFS PAVEMENT DESIGN

Dynamic cone penetrometer (DCP) tests were taken on two roads in Council Bluffs—Gifford Road and College Road (see Figure D.1). The first set of DCP tests (referred to as the Terracon DCP) was performed on both Gifford Road and College Road by Terracon, a geotechnical engineering and testing firm. The DCP device employed by Terracon used a 15-pound weight and a 1.37-inch diameter cone, and it did not have a direct correlation to the California bearing ratio (CBR), which was necessary to perform the preliminary pavement design.

Because the Terracon DCP tests could not be correlated, a second DCP (referred to as the Iowa State DCP) was used on Gifford Road. The Iowa State DCP used a 10-pound hammer and a 0.79-inch diameter cone, and the results could be correlated to the CBR. This test was performed by Iowa State University researchers. Both tests taken on Gifford Road were performed in the exact same spots, ensuring that soil stability at each test location would be similar. Due to time limitations, the second DCP device was not used on College Road. The Terracon and Iowa State DCP tests from Gifford Road were compared, allowing researchers to infer what values the Iowa State DCP may have read if it had been used on College Road. Using this comparison, it was estimated that the CBR of College Road's base is 10%–20%, with 10% being the lower bound. With the known CBR, the soil support value (SSV) was found to be 6 (see Figure D.2).

Using the assumptions made about the truck traffic from discussions with the Council Bluffs city engineer, the equivalent single-axle load (ESAL) was calculated to be approximately 88,000. It was assumed that the 35,000 tandem-axle trucks each had 2.5 ESALs (2.5 ESAL ÷ truck × 35,000 trucks = 88,000 ESAL). Knowing the SSV of the base and the ESALs and using a flexible pavement nomograph (see Figure D.3), the required Structural Number (SN) was found to be 1.8 (Regional Factor = 2). To achieve a SN of 1.8, a base requires 6 inches of a designed emulsion-mixed base with coarse aggregate which has a structural coefficient of 0.34 (see Table D.1).

The existing base is approximately 6 inches of material that appears to be the equivalent of 6 inches of recycled asphalt pavement that was wet compacted in lifts. Researchers are of the opinion that the structural coefficient for this material is equivalent to a range from crushed stone to low-stability road mix. Road mix is a mixture of emulsion and gravel mixed by a motor grader. The structural coefficient would range from 0.14 to 0.2 (sandy gravel). So the SN of the existing pavement is approximated at 0.66–1.20, which is less than the required SN of 1.8. A properly designed base course using the types of materials used on College Road would require a thickness between 9 and 13 inches.

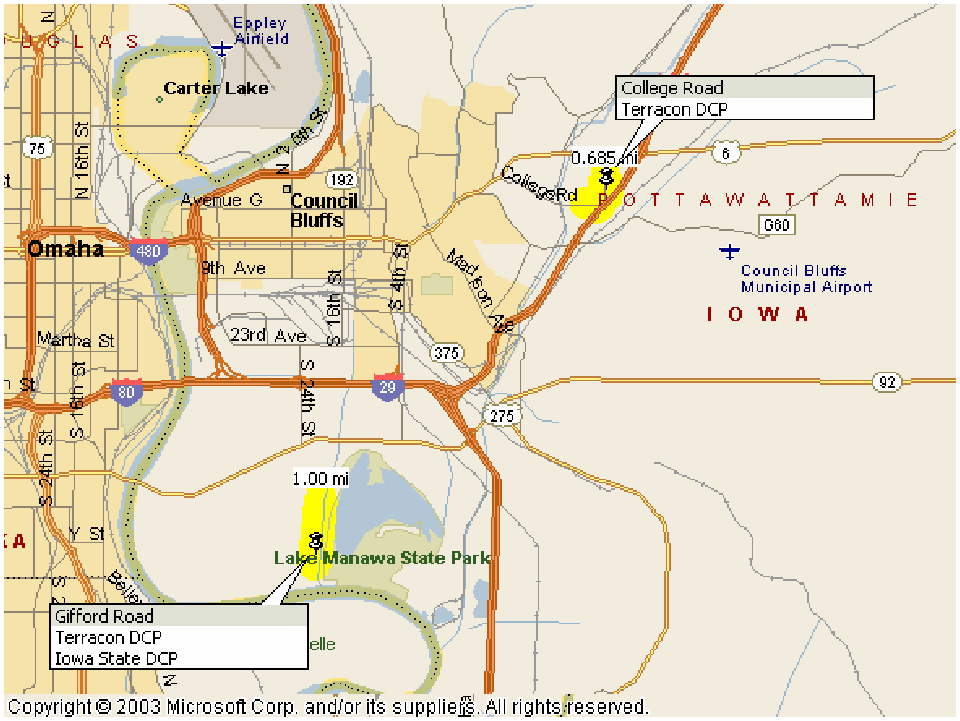


Figure D.1. Overview map of DCP test locations at Gifford Road and College Road

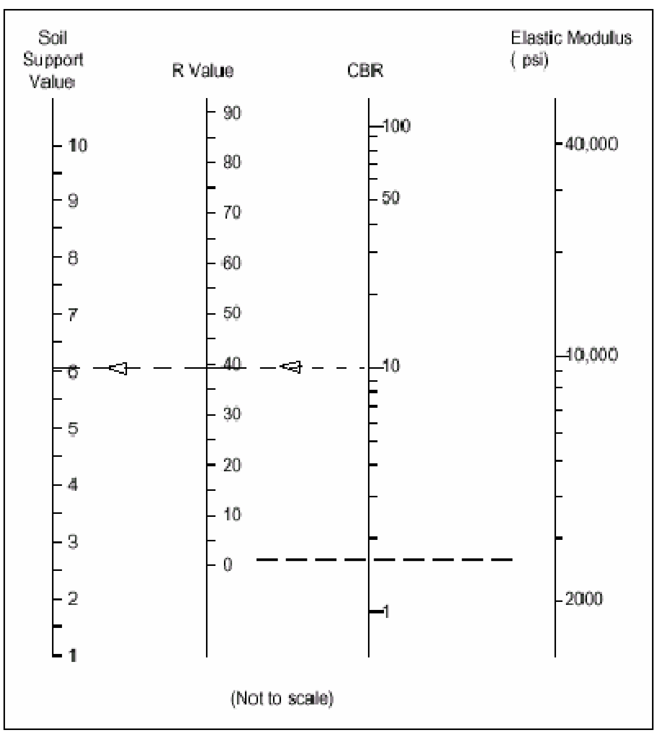
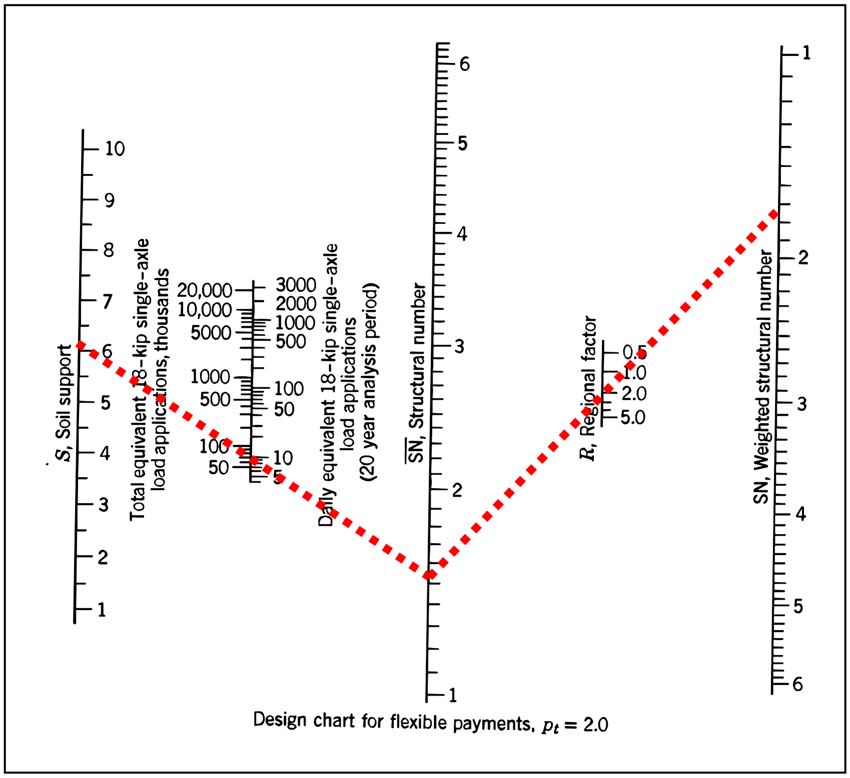


Figure D.2. Illustration of how soil support is determined from other test data (AASHTO 1986)



Design chart for flexible payments, $p_t = 2.0$

Figure D.3. AASHTO flexible pavement design nomograph (Yoder and Witczak 1975)

Table D.1. Structural layer coefficents proposed by AASHTO Committee on Design, October 12, 1961 (Yoder and Witczak 1975)

Pavement Component	Coefficient[b]
Surface course	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44*
Sand asphalt	0.40
Base course	
Sandy gravel	0.07[c]
Crushed stone	0.14*
Cement-treated (no soil-cement)	
Compressive strength @ 7 days	
650 psi or more[d]	0.23[c]
400 psi to 650 psi	0.20
400 psi or less	0.15
Bituminous-treated	
Coarse-graded	0.34[c]
Sand asphalt	0.30
Lime-treated	0.15–0.30
Subbase course	
Sandy gravel	0.11*
Sand or sandy clay	0.05–0.10

* Established from AASHO Road Test data.

[a] From AASHO Interim Guide.

[b] It is expected that each state will study these coefficients and make such changes as experience indicates necessary.

[c] This value has been estimated from AASHO Road Test data, but not to the accuracy of those factors marked with an asterisk.

[d] Compressive strength at 7 days.

APPENDIX E. WEST DES MOINES DEDUCT VALUES

The following tables show the deduct values for survey for each test section. The deduct values are broken down into the various distress types for each sample section. Distresses that were not observed on the test sections were not included in the tables. The distress identification numbers are designated as follows:

1 – Alligator cracking
4 – Bump
8 – Reflective cracking
10 – L&T cracking
11 – Patching
13 – Potholes
15 – Rutting

Table E.1. Vine Street deduct values

		Vine Street																					
		Deduct Values											Deduct Values										
		11/2/2005										Total	5/16/2005										Total
		Sample #											Sample #										
		1	2	3	4	5	6	7	8	9	10		1	2	3	4	5	6	7	8	9	10	
8	L	4	-	-	-	-	-	-	-	-	-	4	6	8	16	13	12	9	12	2	13	9	100
	M	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	15	21
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	L	-	24	38	69	37	-	-	-	-	-	168	-	24	38	69	37	-	-	-	-	-	168
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.2. Fourth Street deduct values

		4th Street																					
		Deduct Values											Deduct Values										
		11/2/2004											5/16/2005										
		Sample #										Total	Sample #										Total
		1	2	3	4	5	6	7	8	9	10		1	2	3	4	5	6	7	8	9	10	
8	L	-	-	-	-	-	-	-	-	-	-	-	12	25	12	12	10	18	12	10	12	14	137
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	8	9
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.3. Aspen Drive deduct values

		Aspen Drive														
		Deduct Values								Deduct Values						
		7/30/2004						Total		5/16/2005						Total
		Sample #								Sample #						
		1	2	3	4	5	6		avg.	1	2	3	4	5	6	
1	L	6	12	-	27	4	2	51	9	-	-	-	-	-	-	-
	M	-	-	28	-	-	-	28	5	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	L	-	-	-	-	9		9	2	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	L	-	-	-	-	-	-	-	-	18	14	14	28	24	14	112
	M	28	32	32	31	32	39	194	32	-	-	-	6	4	-	10
	H	-	-	-	-	5	-	5	1	-	-	-	-	-	-	-
10	L	16	17	10	10	13	10	76	13	-	-	-	-	-	-	-
	M	-	14	19	13	22	21	89	15	-	-	-	-	-	-	-
	H	-	-	12	14	-	-	26	4	-	-	-	-	-	-	-
11	L	8	9	5	27	17	-	66	11	-	-	-	-	-	-	-
	M	-	-	26	-	-	-	26	4	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	11	-	-	-	-	-	11	2	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.4. Maple Street deduct values

		Maple Street															
		Deduct Values								Deduct Values							
		5/16/2005 (w/o rutting)							Total	5/16/2005 (w/ rutting)							Total
		Sample #								Sample #							
		1	2	3	4	5	6	7		1	2	3	4	5	6	7	
8	L	12	10	8	10	11	9	8	68	12	10	8	10	11	9	8	68
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	L	5	15	12	14	15	15	13	89	5	15	12	14	15	15	13	89
	M	-	3	-	-	-	-	-	3	-	3	-	-	-	-	-	3
	H	-	-	-	5	12	-	-	17	-	-	-	5	12	-	-	17
11	L	6	-	-	-	5	-	-	11	6	-	-	-	5	-	-	11
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L	-	-	3	-	-	-	-	3	-	-	3	-	-	-	-	3
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	L	-	-	-	-	-	-	-	-	-	24	38	31	37	-	-	130
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX F. NOVEMBER 2005 INSPECTION RESULTS

In addition to the performance surveys described in the main body of the report, a survey of each of the demonstration sections was undertaken in November of 2005. The results of the latter surveys are described in this appendix. The pre- and post-construction performance of the demonstration sections is also summarized and reviewed.

Cedar Rapids

Vermont Avenue

The PCI of Vermont Avenue in November of 2005 was 83, unchanged from that of May 2005. Figure F.1 summarizes how the PCI changed over the pre- through post-construction cycle. As the November 2005 survey was being conducted, the researchers noted the locations of the chipmat repairs and noted that alligator cracking had not yet reflected through in these locations. In contrast, the May 2005 survey had indicated that alligator cracks had reflected through in locations where chipmat was not applied (Figure F.2).

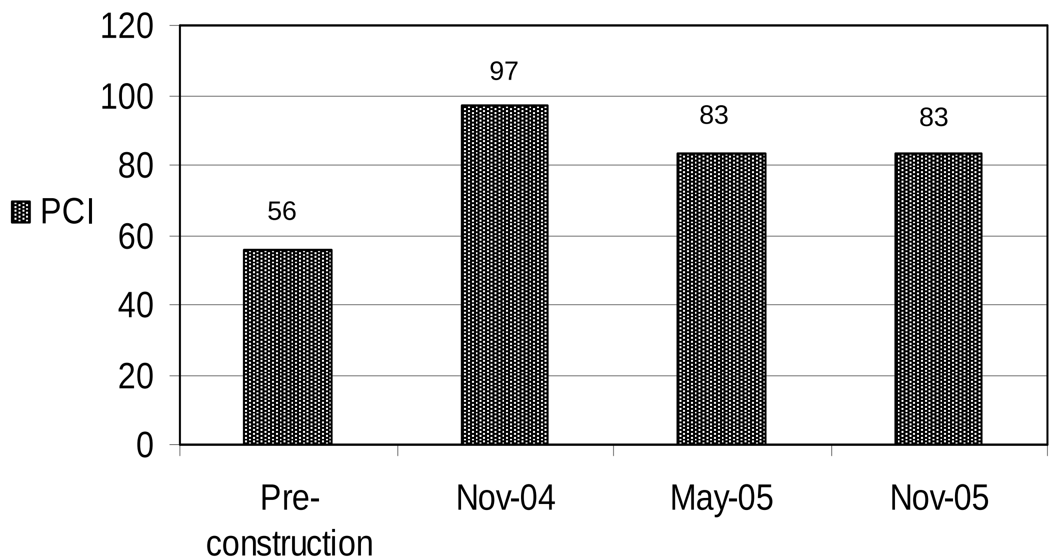


Figure F.1. Changes in PCI for Vermont Avenue

Figure F.2. Vermont Avenue in November 2005 (digitally enhanced photo)

74th Street

By November of 2005, the PCI of all the demonstration sections on 74th Street had decreased from the values observed in May of 2005. The most prominent distress that increased was bleeding, which was heavy in places, especially in locations that withstood the forces of turning and stopping vehicles. In some cases, the bleeding occurred in places where the aggregate was stripped off by snow plows. For the purposes of PCI calculations, these areas were designated with a combination of raveling and bleeding. A few patches had been placed since the last survey.

The washed limestone and pre-coated pea rock had the lowest PCIs (61 and 68, respectively), while the single pre-coated limestone and the double seal coat had the highest (76 and 75 respectively). Figure F.3 summarizes how the PCIs changed over the pre- through post-construction cycle, while Figures F.4 though F.7 provide representative images of each of the sections. In comparing these sections, the effects that rutting had on the PCI calculation were not included. This is because a seal coat is not intended to improve road performance with regard to rutting and because there were noticeable differences in the amount of rutting from one road section to another, which would have made comparisons difficult.

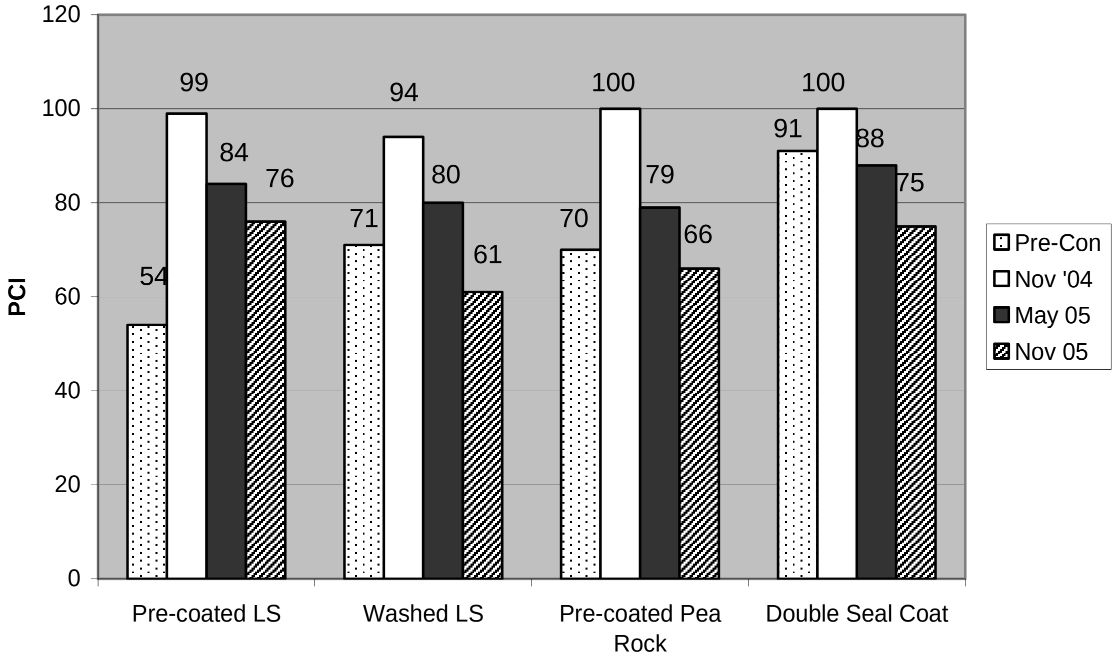


Figure F.3. Changes in PCI for 74th Street

Figure F.4. Typical view of pre-coated limestone on 74th Street (digitally enhanced photo)

Figure F.5. Typical view of washed limestone on 74th Street (digitally enhanced photo)

Figure F.6. Typical view of pre-coated pea rock on 74th Street (digitally enhanced photo)

Figure F.7. Typical view of double seal coat on 74th Street (digitally enhanced photo)

Council Bluffs Results

College Road

When researchers arrived to inspect college road in October of 2005, it had been completely rebuilt with a pulverized and compacted base and a seal coat surface. PCI calculations were not conducted, since that road had completely failed and had been rebuilt.

West Des Moines

Aspen Drive

The PCI for Aspen Drive essentially remained the same (changed from 82 to 81) during the period from May to November of 2005. Figure F.8 summarizes how the PCI changed over the pre- through post-construction cycle.

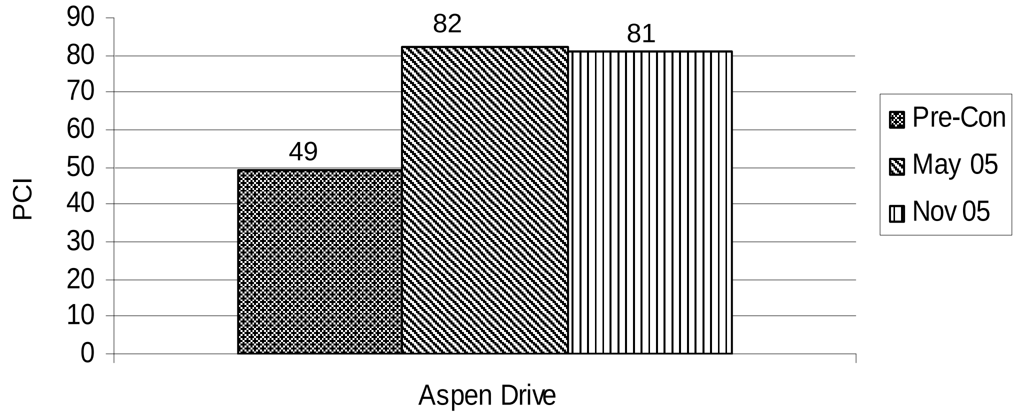
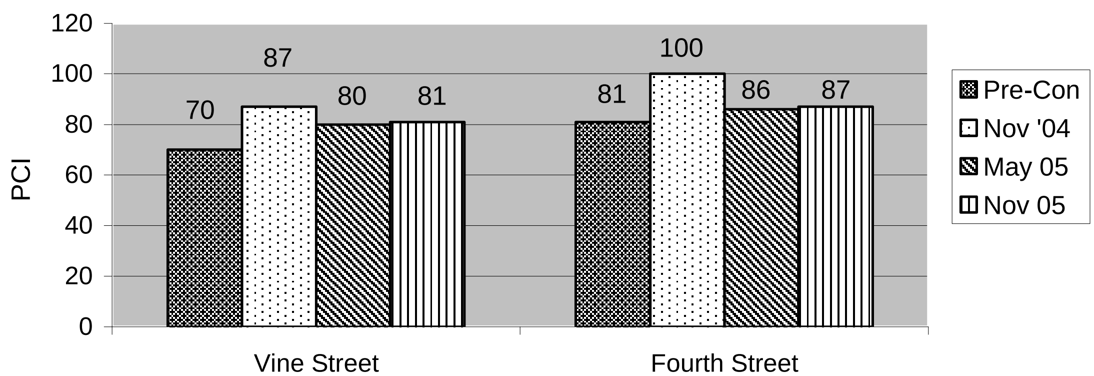


Figure F.8. Changes in PCI for Aspen Drive

Fourth Street and Vine Street

As with Aspen Drive, Fourth Street and Vine Street only experienced slight changes in PCI during the period from May to November of 2005. Figure F.9 summarizes how the PCI changed over the pre- through post-construction cycle.



F.9. Changes in PCI for Vine Street and Fourth Street

Summary and Conclusions

Except for 74th Street in Cedar Rapids and for College Road in Council Bluffs, the demonstration sections experienced little change from May to November of 2005. During the same time period, the PCI ratings for 74th street decreased. The largest decreases were for the washed limestone and pre-coated pea rock sections (19 and 13 points, respectively). The pre-coated limestone and double seal coat each experienced 8 point decreases. The decreases were mostly due to increased bleeding and the appearance of more patches. For College Road, the test road had failed due to heavy construction truck traffic and had been completely rehabilitated.

The observation of the demonstration sections was extended over the first summer to determine the extent to which the treatments are subject to distresses caused by hot summer temperatures. Roads that are seal coated and subjected to heavy traffic are most likely to fail in bleeding. 74th Street falls into this category. The micro-surfacing in West Des Moines was not subject to bleeding, even though Vine Street and Fourth Street were some of the most heavily trafficked streets in this investigation. Vermont Avenue had lighter traffic than 74th Street and thus did not suffer distress caused by raveling.

APPENDIX G. WEST DES MOINES SOUND RESULTS

Table G.1. Fourth Street sound levels for micro-surfacing and asphalt surfaces

Microsurfacing, 4th St						
	1/19/2005	1/19/2005	1/19/2005	6/9/2005	6/9/2005	6/9/2005
Trial	**Truck**	**Car**	**Inside Car**	**Truck**	**Car**	**Inside Car**
1	70.3	70.0	65.5	71.8	64.7	61.0
2	70.5	70.2	66.0	72.6	65.1	61.4
3	70.6	71.1	66.0	72.7	65.5	61.7
4	70.6	71.1	66.5	72.9	65.8	62.0
5	70.9	71.2		72.9	65.9	62.0
6	71.1	71.4		73.5	66.1	62.1
7	71.3	71.9		73.6	66.6	62.6
8	71.5	72.4		73.8	66.7	63.8
9	72.0	72.6		73.9	66.9	
10	75.0	72.8		73.9	66.9	
Average	71.4 dB	71.5 dB	66.0 dB	73.2 dB	66.0 dB	62.1 dB

Asphalt, 4th St.						
	1/19/2005	1/19/2005	1/19/2005	6/9/2005	6/9/2005	6/9/2005
Trial	**Truck**	**Car**	**Inside Car**	**Truck**	**Car**	**Inside Car**
1	65.2	66.1	60.8	71.5	63.5	54.0
2	65.6	66.2	61.2	72.0	64.0	54.5
3	67.0 (oth	66.5	61.4	72.3	64.1	54.8
4	67.4	66.7	61.4	72.4	64.2	55.5
5	67.7	67.0		72.6	64.4	55.5
6	67.9	67.0		73.1	64.5	
7	68.2	67.7		73.3	64.9	
8	68.4	68.4		73.4	65.5	
9	68.8	68.6		73.7	65.9	
10	68.9	68.8		73.7	66.7	
Average	67.5 dB	67.3 dB	61.2 dB	72.8 dB	64.8 dB	54.9 dB

Difference	3.9 dB	4.2 dB	4.8 dB	0.4 dB	1.3 dB	7.2 dB

Table G.2. Bulk sample results of micro-surfacing and asphalt surface sound levels

	Bulk Sampling 6/9/2005			
	Micro-surfacing (dB)	Asphalt (dB)		
	60.7	64.8		
	62.5	65.4		
	64.9	65.5		
	66.5	66.1		
	67.0	66.2		
	67.0	66.3		
	67.3	66.8		
	67.7	66.9		
	68.0	66.9		
	68.1	67.0		
	68.2	67.1		
	68.3	67.2		
	68.5	67.3		
	68.5	67.6		
	68.7	67.6		
	68.8	67.8		
	69.1	67.8		
	69.9	67.8		
	70.4	67.8		
	70.6	68.1		
	70.8	68.4		
	70.8	68.9		
	70.9	68.9		
	70.9	68.9		
	70.9	68.9		
	71.0	69.1		
	71.0	69.5		
	71.1	69.7		
	71.2	69.7		
	71.5	69.9		
	71.9	70.0		
	71.9	70.4		
	72.1	70.4		
	72.1	70.5		
	72.4	70.6		
	72.6	70.6		
	72.7	70.6		
	72.8	70.7		
	73.1	71.0		
	73.8	71.3		
	74.4	71.6		
	74.6	71.8		
	75.0	72.6		
	76.1	72.9		
	76.7	73.0		
	77.2	74.4		
	78.1	74.7		
	78.4	75.3		
	79.4	78.9		
	80.3	80.0		
	80.9	81.5		
	83.5	81.7	Difference	
Average	71.6	70.1	1.5	dB