CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 12-005
UILU-ENG-2012-2012
ISSN: 0197-9191

BEST PRACTICES FOR IMPLEMENTATION OF TACK COAT: PART 2, FIELD STUDY

Prepared By

Imad L. Al-Qadi
Alejandro Salinas Cortina
Khaled I. Hasiba
Hasan Ozer
Zhen Leng
University of Illinois at Urbana-Champaign

Enad Mahmoud
Bradley University

Derek C. Parish
Stephen J. Worsfold
Illinois Department of Transportation

Research Report ICT-12-005

A report of the findings of
ICT-R27-100
Best Practices for Implementation of Tack Coat

Illinois Center for Transportation

July 2012

Technical Report Documentation Page

1. Report No.
FHWA-ICT-12-005

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Best Practices for Implementation of Tack Coat: Field Study (Part 2)

5. Report Date
July 2012

6. Performing Organization Code

7. Author(s)
Imad L. Al-Qadi, Alejandro Salinas Cortina, Khaled I. Hasiba,Hasan Ozer, Zhen Leng, Derek C. Parish

8. Performing Organization Report No.
ICT-12-005
UILU-ENG-2012-2012

9. Performing Organization Name and Address
Illinois Center for Transportation
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 N. Mathews Ave. MC-250

10. Work Unit (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Illinois Department of Transportation
Bureau of Materials and Physical Research
126 East Ash Street
Springfield, IL 62704-9766

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Interface bonding between pavement layers is a key factor affecting the performance of any pavement structure. Over the years, several studies have been performed to better understand bonding between pavement layers. The first phase of this study was a laboratory assessment, which analyzed different parameters to better characterize the interlayer bond in pavements. Phase 2 of the study was a field validation and evaluation. This report, based on the results of phase 2, focuses on optimizing in-situ tack coat application rate and field installation. The main objectives of phase 2 were to validate the lab-determined optimum residual application rate for tack coat materials on a milled hot-mix asphalt (HMA) surface and to evaluate field performance of tack coat materials. Several parameters were analyzed, including the cleaning method prior to tack coat application, the paving procedure, tack coat type, and existing pavement surface texture. Tack coat materials used were SS-1h, SS-1hp, and SS-1vh (non-track tack coat). For the cleaning methods, the conventional procedures, broom and vacuum, were used on most of the sections and were compared to air-blast cleaning. Two paving procedures were studied: the conventional paving method using a distributor truck and a regular paver, and the spray paver, which applies tack coat and paves at the same time. Twenty-six sections were constructed on Interstate 80 in Illinois, and 19 sections were built on Illinois Route 98. The Interstate 80 test sections were constructed on three existing pavement surfaces: milled HMA, milled Portland cement concrete (PCC), and fresh binder stone mastic asphalt (SMA). Two tests were used to analyze interface bonding: the interface shear test and the torque bond test. The test section on Illinois Route 98 was constructed on a milled surface. All specimens were cored in the field and tested at the Illinois Center for Transportation (ICT) using the Interface Shear Test Device (ISTD). The results showed similar bond strength for the two types of cleaning methods; however, air-blast cleaning required use of a lower optimum residual application rate in the field to achieve the same bond strength. The bond strength at the interface when tack coat was applied with a spray paver is similar to the bond strength achieved when a conventional paver was used. The optimum residual application rate for milled surfaces obtained from the laboratory was 0.06 gal/yd2 (0.27 L/m2). This rate was validated at both test sites. The optimum residual application rate obtained for fresh binder SMA was 0.02 gal/yd2 (0.09 L/m2). SS-1vh performed better than any other tack coat material studied, and SS-1hp performed better than SS-1h. Identification of the optimum tack coat application rate will help ensure cost-effective and efficient tack coat application and will enhance pavement performance. It will also help the industry to better optimize resources and improve pavement performance.

17. Key Words

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
59, plus appendixes

22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT

This report is based on the results of Project ICT-R27-100, Best Practices for Implementation of Tack Coat. ICT-R27-100 was conducted in cooperation with the Illinois Center for Transportation, the Illinois Department of Transportation, and the U.S. Department of Transportation, Federal Highway Administration.

The authors acknowledge the assistance of Jeff Kern and James Meister, research engineers at the Illinois Center for Transportation, Derek C. Parish, Technical Review Panel (TRP) chair, Stephen J. Worsfold, and the members of the TRP for ICT-R27-100.

DISCLAIMER

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

EXECUTIVE SUMMARY

Interface bonding between pavement layers is a key factor affecting the performance of any pavement structure. Over the years, several studies have been performed to better understand bonding between pavement layers. The first phase of this study was a laboratory assessment, which analyzed different parameters to better characterize the interlayer bond in pavements. Phase 2 of the study was a field validation and evaluation. This report, based on the results of phase 2, focuses on optimizing in-situ tack coat application rate and field installation. The main objectives of phase 2 were to validate the lab-determined optimum residual application rate for tack coat materials on a milled hot-mix asphalt (HMA) surface and to evaluate field performance of tack coat materials. Several parameters were analyzed, including the cleaning method prior to tack coat application, the paving procedure, tack coat type, and existing pavement surface texture. Tack coat materials used were SS-1h, SS-1hp, and SS-1vh (non-track tack coat). For the cleaning methods, the conventional procedures, broom and vacuum, were used on most of the sections and were compared to air-blast cleaning.

Two paving procedures were studied: the conventional paving method using a distributor truck and a regular paver, and the spray paver, which applies tack coat and paves at the same time.

Twenty-six sections were constructed on Interstate 80 in Illinois, and 19 sections were built on Illinois Route 98. The Interstate 80 test sections were constructed on three existing pavement surfaces: milled HMA, milled Portland cement concrete (PCC), and fresh binder stone mastic asphalt (SMA).

Two tests were used to analyze interface bonding: the interface shear test and the torque bond test. The test section on Illinois Route 98 was constructed on a milled surface. All specimens were cored in the field and tested at the Illinois Center for Transportation (ICT) using the Interface Shear Test Device (ISTD).

The results showed similar bond strength for the two types of cleaning methods; however, air-blast cleaning required use of a lower optimum residual application rate in the field to achieve the same bond strength. The bond strength at the interface when tack coat was applied with a spray paver is similar to the bond strength achieved when a conventional paver was used. The optimum residual application rate for milled surfaces obtained from the laboratory was 0.06 gal/yd^2 (0.27 L/m^2). This rate was validated at both test sites. The optimum residual application rate obtained for fresh binder SMA was 0.02 gal/yd^2 (0.09 L/m^2). SS-1vh performed better than any other tack coat material studied, and SS-1hp performed better than SS-1h.

Identification of the optimum tack coat application rate will help ensure cost-effective and efficient tack coat application and will enhance pavement performance. It will also help the industry to better optimize resources and improve pavement performance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

Insufficient interface bonding between existing and new pavement layers is a critical problem that has concerned researchers for the past 50 years. Pavements are composed of several layers intended to be well-bonded to each other, structurally acting as a single layer. Structural performance depends not only on the strength of the pavement layers but also on the bonding strength between layers. Poor bonding can lead to various types of distress, including debonding, slippage cracking, compaction difficulties, and early fatigue cracking, and it contributes to a reduction in pavement life. Proper interfacial bonding strength can be achieved with use of an appropriate tack coat, including type, rate, preparation, and application method. Tack coat is a light application of water-diluted asphaltic material applied on an existing pavement to ensure adequate strength between layers and to provide monolithic behavior of the pavement layers (Romanoschi, 1999).

Several laboratory and field studies have evaluated interface bonding between pavement layers and investigated the mechanisms of failure at the interface. These studies also investigated the factors affecting interlayer strength, including application rate, curing time, temperature, surface texture, tack coat material type, normal pressure, and softening point of the tack coat material (Bae et al., 2010; Canestrari and Santagata, 2005; Canestrari et al., 2005; Chen and Huang, 2010; Al-Qadi et al., 2008; Leng et al., 2008; Leng et al., 2009; Mohammad et al., 2009; Mohammad et al., 2010; Mohammad et al., 2002; Mohammad and Button, 2005; Santagata et al., 2008; Sholar et al., 2004; Tashman et al., 2006; Uzan et al., 1978; West et al., 2005; Woods, 2004; Yildrim et al., 2005).

The proper application of tack coat is an important quality-control parameter in paving projects. Several studies found that achieving maximum interfacial bonding requires an optimum application rate for the tack coat (Asphalt Institute, 1989). Under-applying tack coat material can cause insufficient bonding, resulting in debonding and fatigue cracking. Over-application of tack coat can introduce slippage of the upper layer, resulting in slippage cracking, and difficulties in compaction due to movement of the HMA under the heavy load of compactors, which contribute to a reduction in pavement life. Slippage cracking typically occurs at areas where braking or acceleration take place, resulting in slide or deformation of the overlay in a crescent or half-moon shape in the direction of traffic. Figure 1.1 shows a typical slippage crack problem. Slippage cracking can reduce the structural integrity of the pavement and increase the effect of the tire-applied shear stresses. These problems have a detrimental impact on ride quality.

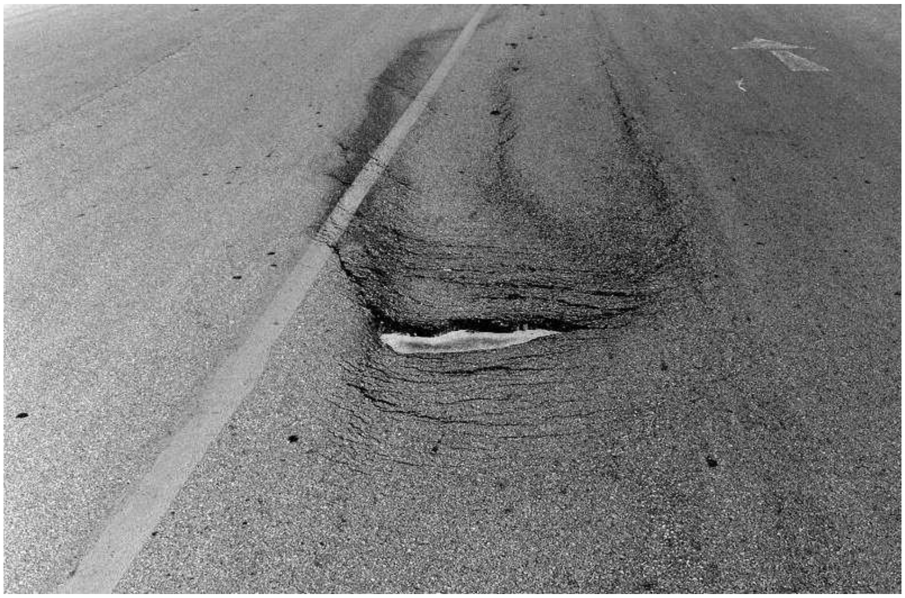


Figure 1.1. Slippage cracking (Asphalt Institute, n.d.).

Tack coat material is commonly applied at a specified rate, so it is important to distinguish between application rate and tack coat residual rate. Tack coat application rate is the amount of diluted asphalt applied in the field. This includes the amount of water added to liquefy the tack coat material to make it more fluid and easier to distribute in the field. The residual application rate is the amount of asphalt residue after water evaporates. Uniformity in distribution is an important parameter that controls consistency in bonding strength along the paved sections. Mohammed and Button (2005) concluded that uniform application of tack coat at the optimum application rate, with approximately 90% to 95% of the surface covered, provided the maximum strength between layers.

Other factors can affect pavement strength performance in the field, including pavement texture, pavement temperature, tack coat type, curing time of tack coat, aggregate type and gradation, and cleanliness and dryness of the surface. Studies show that milling the surface increases shear resistance at the interface between pavement layers (Leng et al., 2008). This occurs due to the increase in contact and friction between layers and the interlock between layers achieved by milling the existing surface. West et al. (2005) and Sholar et al. (2004) found that coarser mixes provide higher interface bonding strength than fine mixes. This is due to higher friction and better aggregate interlock, but smaller NMAS (Nominal Maximum Aggregate Size) pavement benefits more from tack coat application. Tashman (2008) found that curing time can significantly affect bonding strength when tack coat is applied to a nonmilled surface, but it insignificantly increases the strength when applied to a milled surface. Canestrari and Santagata (2005) observed a reduction in shear strength when temperature was increased.

A study conducted at the Illinois Center for Transportation (ICT) at the University of Illinois at Urbana-Champaign investigated the strength characteristics of an HMA–PCC interface by direct-shear testing and accelerated pavement testing (APT). The laboratory specimens were prepared using lab-prepared HMA compacted on top of field

PCC cores. Asphalt mixes used in this study were SM-9.5 surface and IM-19.5A binder. Three tack coat materials were evaluated (SS-1h and SS-1hp emulsions and RC-70 cutback) and applied at residual rates ranging from no tack coat to 0.09 gal/yd^2 (0.405 L/m^2). Tack coat was applied on different PCC surface textures (smooth, transverse tinning, longitudinal tinning, and milling). Bonding strength was also evaluated at various temperatures (50°F, 68°F, and 80°F; 10°C, 20°C, and 30°C) and under two moisture conditions, dry and saturated (Leng et al., 2008). The direct-shear testing device used in the ICT study is shown in Figure 1.2.

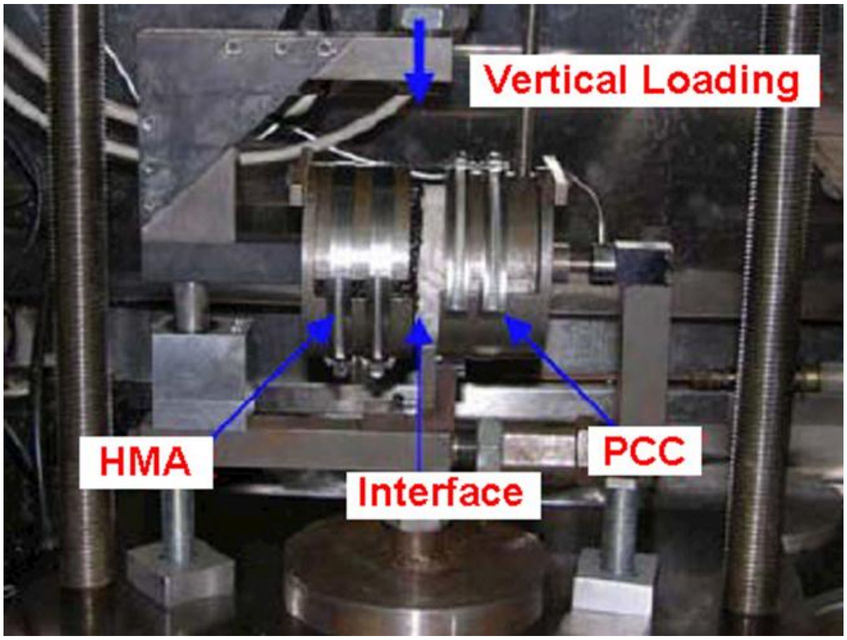


Figure 1.2. Direct-shear apparatus developed at ICT (Leng et al., 2008).

This device accommodates 3.94-in (100-mm) diameter specimens and can run both monotonic and cyclic loading tests. Shear interface strength was evaluated with a monotonic mode of loading at a constant displacement rate of 0.47 in/min (12 mm/min). The study found that the surface mix provided higher bonding strength than the binder mix. Asphalt emulsions showed a significant increase in shear strength compared to cutbacks; however, there was no significant difference between SS-1h and SS-1hp. The optimum residual application rate of the tack coat materials was 0.04 gal/yd^2 (0.18 L/m^2). Moreover, milling was found to provide the highest shear strength, while tinning direction did not have a significant effect on interface bonding. Lowering the temperature increased the strength, but that might not be the case at extremely low temperatures (below the glassy transition temperature), where the brittle behavior of tack coat can decrease strength at the interface. Moisture conditioning severely decreased interlayer strength between HMA and PCC layers (Leng et al., 2008).

To validate the laboratory results, accelerated paving testing was performed. Twenty-five sections were constructed and loaded with the Accelerated Transportation Loading ASsembly (ATLAS) machine at the centerline of the pavement (Leng et al., 2009). Figure 1.3 shows the ATLAS machine.

Figure 1.3. ATLAS machine (Leng et al., 2009).

The tensile strain at the interface was measured (using H-type strain gauges) for selected sections to evaluate the potential for interfacial slippage. Primary rutting was also analyzed for different sections. Three tack coat materials (SS-1hp, SS-1h, and RC-70) were evaluated and applied at residual rates of 0.02, 0.04, and 0.09 gal/yd^2 (0.09, 0.18, and 0.405 L/m^2). The asphalt binder PG 64-22 was also used and was applied at 0.04 gal/yd^2 (0.18 L/m^2). Two cleaning methods were evaluated (broom cleaning and air blasting). Tack coat was applied over various PCC surface textures (smooth, milled, transverse, and longitudinal tinned).

Results of the APT conformed to the outcome of the laboratory study. The asphalt emulsions provided lower strains at the interface compared to RC-70 (cutback). PG 64-22 provided the highest shear strength at the interface, and milling the surface provided better bonding and rutting resistance compared to tinned and smooth surfaces. Well-cleaned PCC surfaces resulted in lower interface shear rutting. The APT validated the lab-determined optimum residual application rate: 0.04 gal/yd^2 (0.18 L/m^2) provided the lowest interface strains and shear rutting (Leng et al., 2009).

As part of this study, a laboratory evaluation was conducted to evaluate the bonding characteristics of tack coat when applied between HMA layers. This study assessed the performance of four tack coat materials: three emulsions [SS-1hp, high float emulsion (HFE), and SS-1vh] and the asphalt binder PG 64-22. The residual application rate was optimized at a range from no tack coat to 0.08 gal/yd^2 (0.36 L/m^2). In addition, the tack coat materials were cured for 15 min, 2 hr, and 24 hr to study the effect of curing time. The test was conducted at various temperatures (5°F, 41°F, 77°F, and 113°F; –15°C, 5°C, 25°C, and 45°C) to examine bonding strength sensitivity to temperature. The tack coat materials were applied over various surface textures (unmilled aged nontrafficked, unmilled aged, and milled aged HMA). The bottom HMA layers of the lab-prepared specimens were field cores. Two surface mixes, SM-9.5 mm NMAS and SM-4.75 mm NMAS, were compacted on top of the field cores after the tack coat was applied. Interface bonding was tested using the ISTD designed at ICT (see Figure 3.1 in Chapter 3).

The outcome of the lab study is an optimum residual application rate of tack coat: 0.04 gal/yd^2 (0.18 L/m^2) for unmilled aged and aged non-trafficked surfaces and 0.06 gal/yd^2 (0.27 L/m^2) for a milled aged surface. SS-1vh provided the highest shear strength compared to other tack coat materials. In addition, curing time significantly influenced the shear strength at the interface. When curing time was increased from 15 min to 2 hr, bonding was significantly improved. Milling the surface improves the interface bonding. In addition, lowering the test temperature improves the interlayer strength; however, this may not be valid when testing temperature is below the glassy transition temperature (T_g). Surface mix (SM-9.5 mm NMAS) provides better bonding and interlock than leveling binder (SM-4.75 mm NMAS) when the surface mixes are compacted over milled and unmilled aged cores.

This study is a continuation of the aforementioned laboratory study and aims to validate its findings under field conditions. Twenty-six sections were constructed on Interstate 80 (I-80) to determine the optimum residual tack coat application and to study the effects of surface texture and surface cleanliness. Two tack coat materials were used (SS-1hp and SS-1vh) and applied over milled HMA and fresh binder SMA. The milled surface was cleaned by brooming and by air-blast cleaning. On Illinois Route 98 (IL-98), three tack coat materials (SS-1h, SS-1hp, and SS-1vh) were applied at the verified residual application rates. Again, the effect of cleaning was examined using the broom and air-blast cleaning methods. Curing time was studied by using different construction techniques (a tack coat distributor followed by a conventional paver, and a spray paver).

This report focuses on the field study and provides details about the experiment, including testing devices, construction process, experimental methodology, specimen preparation, and results.

1.1 PROBLEM STATEMENT

Interface bonding between pavement layers is one of the most significant factors affecting pavement performance and service life. Tack coat materials are bonding agents between pavement layers. Loss of bonding or poor bonding between pavement layers can cause early pavement distresses. Hence, an optimum tack coat application rate needs to be determined, and a suitable application process must be identified. In addition, the interface tack coat performance under various loading conditions, application rates, paving methods, surface textures, and cleaning method should be quantified.

1.2 OBJECTIVE

This report is Part 2 of a set of two. This report focuses on the field validation, while Part 1 focuses on the laboratory study. Hence, the objectives of this part of the study were to validate the optimum tack coat application rate, as identified in the laboratory; to investigate field-optimal tack coat application; and to evaluate field performance of tack coat materials. The ultimate goal of the study was to identify the best methods for applying tack coat to optimize tack coat material, application rate, placement method, and pavement cleaning technique.

1.3 SCOPE

The field phase of the study evaluated tack coat performance in-situ and identified the critical parameters contributing to interface shear strength between HMA layers. The field study evaluated results obtained from the laboratory phase. Among the parameters examined in the field study were tack coat residual application rate, cleaning method, tack coat type, curing time, paving method and interlayer surface roughness. A custom-designed Interface Shear Test Device (ISTD) and a bond torque test were used to evaluate the field-obtained cores.

CHAPTER 2 CURRENT STATE OF KNOWLEDGE

Several field and laboratory tests, including direct shear, torque, and tensile strength tests, were conducted to evaluate the interface bonding between pavement bound layers when tack coat is applied and to examine the key factors that influence bonding integrity. This section describes the influence of some of these factors. In addition, it provides a summary of the tack coat application and HMA paving equipment used in the field.

Mohammed et al. (2009) evaluated three tack coat materials (CRS-1, SS-1h, and trackless) and an asphalt cement (PG 64-22) at an optimum residual rate of 0.053 gal/yd^2 (0.23 L/m^2). The test was conducted at temperatures ranging from 86°F to 176°F (30°C to 80°C). The Louisiana Tack Coat Quality Tester (LTCQT) was used to evaluate interface bond strength of tack coats in the field. LTCQT is a pull-off test that measures the maximum tensile strength in the field. The study found that an increase in viscosity of the material leads to an increase in tensile strength. In addition, a direct relationship was found between tensile strength and the corresponding softening point of the material. An increase in the softening point correlated to an increase in the optimum temperature.

Another study by Mohammed et al. (2010) examined the effect of tack coat type, application rate, surface type, and surface texture using a full-scale test. Five tack coat materials (SS-1h, SS-1, CRS-1, trackless, and PG 64-22) were evaluated in that research. Three application rates 0.03, 0.062, and 0.15 gal/yd^2 (0.14, 0.28, and 0.7 L/m^2) were applied on four surface types (existing HMA, new HMA, existing PCC, and milled HMA). No confinement and 20 psi (138 kPa) pressure was applied during lab testing. Wetness and cleanness of the surface were examined. The interface strength was measured using the LTCQT. The study found an optimum application rate of 0.15 gal/yd^2 (0.7 L/m^2). Milled HMA was found to provide the highest interface bonding followed by PCC, existing HMA, and new HMA. Small amounts of water decrease the interface bond significantly when PG 64-22 is used, but this influence is minor when emulsions are used. Laboratory-prepared specimens were found to overestimate shear strength compared to the field cores.

Sholar et al. (2004) reported on three test pavement sections constructed to analyze several parameters that interfere with bonding between HMA layers: application rate, surface texture and condition, and mix type. The authors recommended an optimum residual application rate of 0.06 gal/yd^2 (0.26 L/m^2). Curing time of tack coat was also evaluated and reported: It was concluded that shear strength increased with curing time.

Tashman et al. (2006) reported on the construction of 14 test pavement sections and analyzed the effects of curing time, application rate, and milled and nonmilled surfaces. Three devices were used in their study: FDOT shear tester, torque bond test, and UTEP pull-off test. The shear and torque test results showed that milling improves bonding between layers. Curing time was reported as not being a factor that influenced bonding. The pull-off test showed greater strength only in the nonmilled sections.

West et al. (2005) reported on the construction of several test sections in seven projects across Alabama. Cores were obtained from each section and tested in the lab. The study's major finding was that milling increased interface bonding between layers.

The authors also reported on the use of the Novachip spreader in one project, which resulted in greater bond strength.

2.1. TACK COAT

Tack coat is a very light application of bituminous material sprayed on an existing nonporous surface by means of a distributor (Asphalt Institute, 1989). Tack coat acts as a bonding agent between pavement layers. The primary types of products used as tack coat are cationic and anionic emulsions and cutback asphalts. The latter are not as common because of environmental concerns. Sometimes a virgin binder is used as a tack coat; however, this practice is not common. This section discusses application equipment available in the market, as well as the tack coat application process.

Strong bonding between pavement layers is essential to avoid different types of distress caused by slippage or debonding. An optimum tack coat application rate is necessary to provide reliable and cost-effective interface bonding. Various studies have shown that interface bonding strength can be increased by increasing the application rate to an optimum rate, after which point the strength begins to decrease (Leng et al., 2008). In addition, pavement surfaces with different ages may require various application rates to provide proper bonding between existing layer and overlay.

Mohammad et al. (2002) found an optimum residual application rate for CRS 2P emulsion of 0.02 gal/yd^2 (0.09 L/m^2). In their study of six tack coat materials, that type of emulsion showed the greatest interface shear strength. Chen and Huang (2010) found an optimum residual application rate for CRS emulsion to be close to 0.027 gal/yd^2 (0.12 L/m^2). In their study, two emulsions were analyzed. However, it is important to consider the many factors that can cause variation in the application rate, such as surface type, temperature, curing time, mix type, and tack coat material.

2.2 TACK COAT APPLICATION EQUIPMENT

Traditionally, an asphalt distributor truck is used for tack coat application. However, many equipment companies have begun to integrate a tack coat tank and a spray bar into pavers. Two such pavers, which are discussed below, are the Vögele Super 1800-2 with spray jet module (Vögele Wirtgen Group, 2009) and the spray paver manufactured by Roadtec (Roadtec, 2008). In this study, Roadtec’s spray paver was used for the Illinois Route 98 project.

2.2.1 SPRAY JET MODULE BY VÖGELE

As shown in Figure 2.1 (a), the Spray Jet Module is attached to a traditional paver. The standard emulsion tank holds up to 528.34 gal (2,000 L); however, an extra tank holds 1,320.86 gal (5,000 L) and can be attached to the hopper of the paver, as shown in Figure 2.1 (b). A material transfer vehicle (MTV) must be used with the second tank. The Spray Jet Module is equipped with sensors and a computer in order to achieve a proper application of the tack coat at the desired rate. The machine is versatile: It can be used as a conventional paver as well, and the transformation takes approximately 6 hr (Vögele Wirtgen Group, 2009).

One of the most important advantages of this paver is that no vehicle passes over the tack coat (possibly removing it). In addition, innovative technology helps ensures complete surface coverage with tack coat, which reduces operating costs and increases productivity on a job site.

(a) (b)

Figure 2.1. Spray jet module by Vögele (Vögele Wirtgen Group, 2009).

2.2.2 SPRAY PAVER BY ROADTEC

The Roadtec spray paver (Figure 2.2) is a noteworthy advance in paver technology. The spray paver is equipped with a 2,100-gal (7,949.36-L) tank for the emulsion and self-cleaning valves with a sophisticated microprocessor that precisely controls the application rate of the tack coat. These advantages reduce construction time and mitigate many of the costs of using an asphalt distributor truck (Roadtec, 2008).

This paver requires use of a material transfer vehicle to operate. However, it can also be used as a conventional paver without tack coat distribution to the surface. As discussed earlier, many economic advantages can accrue from using such equipment. Accordingly, the interface bonding achieved by this machine was analyzed in the field evaluation.

Figure 2.2. Spray paver by Roadtec (Roadtec, 2008).

2.3 PROPER APPLICATION OF TACK COAT MATERIALS

Proper application of tack coat is one of the most important factors in achieving good interface bonding and ensuring paving quality. To achieve proper application of a tack coat, two elements are required: uniformity and amount of application. However, many other factors can influence the application (Mohammed and Button, 2005):

- Height of the spray bar in the asphalt distributor truck
- Size of nozzles
- Orientation of nozzles
- Pressure of the application
- Temperature of tack coat

All of these factors must be calibrated in the asphalt distributor truck before tack coat application.

The best uniformity of tack coat is achieved by overlapping the material, as shown in Figure 2.3. The surface over which the tack coat is applied must be completely clean and free of moisture, in order to achieve desired interface bonding.

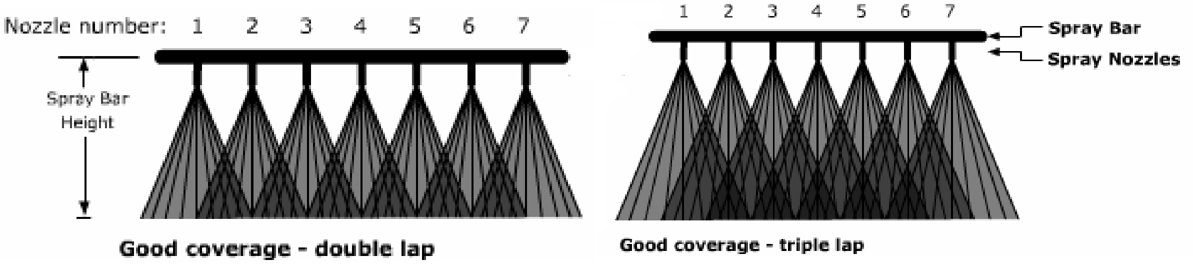


Figure 2.3. Correct application of tack coat (Mohammed and Button, 2005).

Recently, a product characterized as non-track tack coat (SS-1vh) was released to the market in an attempt to solve the problem of tracking the tack coat with vehicles passing in front of the paver. A few studies have analyzed the product's performance (Bae et al., 2010). This material was studied in this research and its performance compared to SS-1h and SS-1hp.

A complete literature review is presented in Appendix A of Part 1 of this report, Best Practices for Implementation of Tack Coat: Laboratory Study

CHAPTER 3 RESEARCH APPROACH

This chapter presents the performance tests used in this research. The research was conducted on two highway projects: I-80 and IL-98. The description and testing scope for both projects are presented. In addition, the methodology adapted to prepare and test specimens in the laboratory is explained.

3.1 TACK COAT PERFORMANCE TESTS

Two tests were used in this research: the interface shear test using the ISTD and the torque bond test. Complete descriptions of both tests follow.

3.1.1 INTERFACE SHEAR TEST

The Interface Shear Test Device (ISTD), as shown in Figure 3.1, was custom-designed to evaluate bonding strength between pavement layers. The ISTD evaluates tack coat bonding between HMA layers and HMA–PCC layers. It measures the change in shear loading, dilation, and shear displacement.

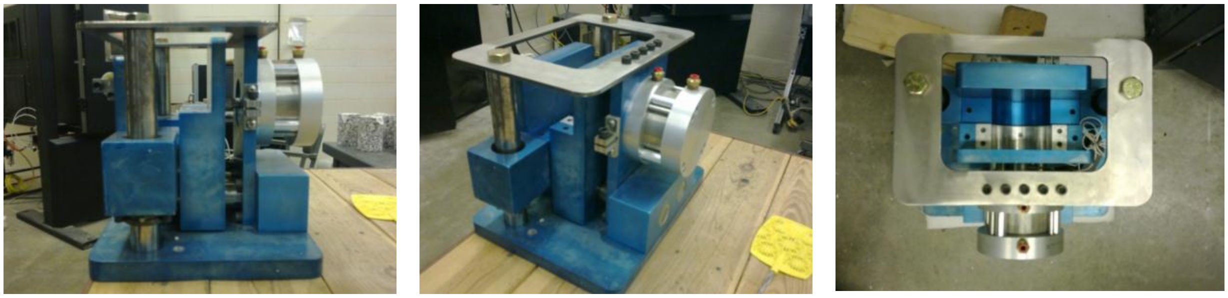


Figure 3.1. Interface Shear Test Device (ISTD).

The dimensions of the device allow specimens to be placed into a servo-hydraulic testing machine. Tests can be conducted in a monotonic loading mode that measures maximum shear load and its corresponding shear displacement to evaluate interface strength. In addition, this device can be used to perform fatigue shear tests by applying cyclic loads at desired frequencies to better simulate field conditions. Both test modes can be conducted with either constant loading or displacement rates at various normal loading levels. In monotonic testing mode, shear load, and displacement are measured along with testing time. Results can be presented as a relationship between shear strength and displacement. Figure 3.2 illustrates a typical load-displacement curve at 20 psi (0.137 MPa) normal pressure.

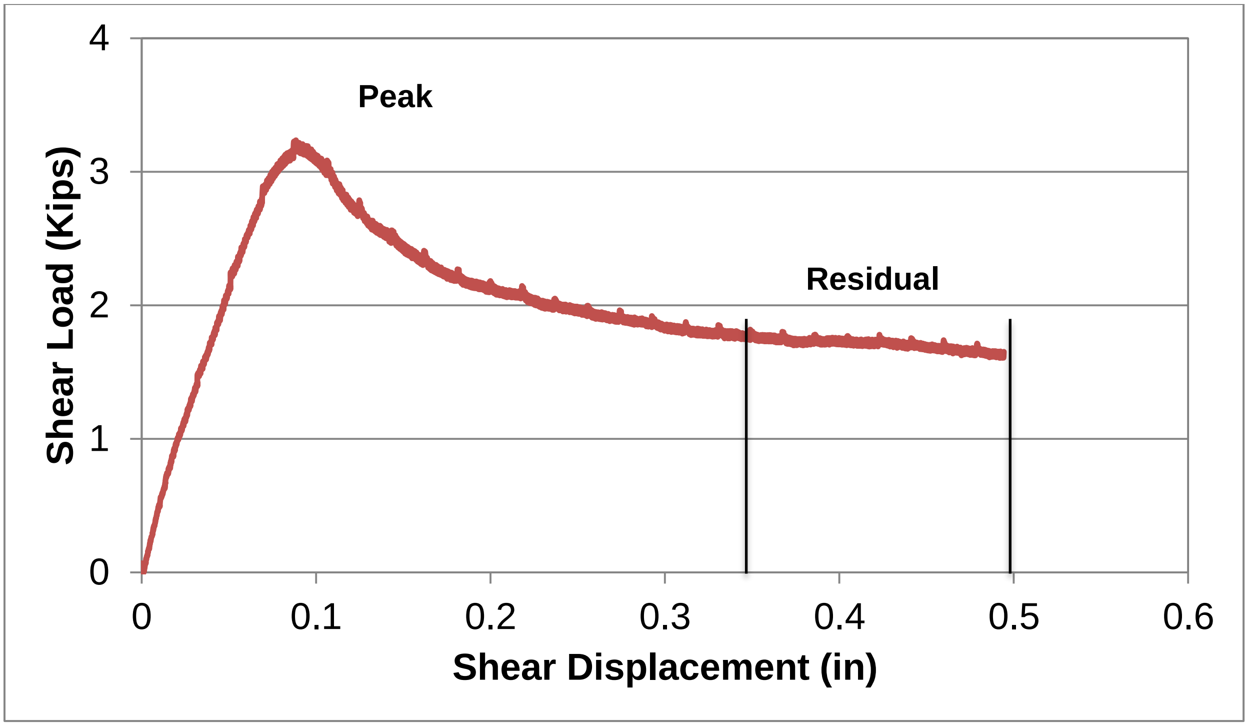


Figure 3.2. Typical shear load–displacement curve.

The mechanism of testing depends primarily on three parts of the device: the shear load stroke, the normal pressure load cell, and the specimen housing chamber. Two load cells, 10 and 22 kips (44 and 97.8 kN), were used for this test. This permits consideration of high shear loading between layers when relatively high normal pressure is applied. An air-pressure actuator connected to a miniature load cell with a capacity of 2 kips (8.9 kN) was used as a normal pressure system to simulate vertical loading at the interface due to tire contact pressure on the pavement surface.

This device allows both static and dynamic normal loads to be applied on the specimen. The housing chamber holds the specimen steady during testing. The device can accommodate 3.93- and 5.90-in (100- and 150-mm) diameter specimens with heights ranging from 3.7 to 4.3 in (94 to 109 mm). To allow dilation during the test, it is recommended that specimens be between 3.70 and 3.86 in (94 and 98 mm) long. If the specimen is too short, steel fillers with the same diameter as the specimen can be used to align the interface in the middle of the gap, where shear is applied. Two linear variable differential transducers (LVDTs) were used to measure both shear displacement and dilation. Dilation is defined as enlargement of the specimen at an axis perpendicular to the shear load direction.

The ISTD was placed in an environmental chamber that can maintain temperatures ranging from -40°F to 302°F (-40°C to 150°C), which were required to evaluate temperature effects on tack coat shear performance. The specimen was placed in the housing chamber, and both layers were capped to control their movement. One layer was held stationary, while the other layer was moved at a certain shearing displacement rate that allowed shear at the interface to take place. The loading was aligned and centered above the interface with an S-shaped aluminum part. Shear load, shear displacement, and dilation were recorded with a data acquisition system.

The test was performed using a monotonic displacement-controlled testing mode at a shear rate of 0.005 in/s (0.127 mm/s). A normal pressure of 1 psi (0.0069 MPa) was applied to ensure minimum confinement of the specimen. A high normal pressure caused aggregate breakage at the interface and resulted in greater shear loads. This could mask the tack coat contribution at the interface. The specimens were initially designed at a diameter of 3.97 in (100 mm) and a height of 4 in (103 mm). Although the cabin can accommodate specimens up to 4.3 in (109 mm), the dilation of many of them was higher than 0.3 in (6 mm), which resulted in a greater normal load application on the specimen. To maintain the 1 psi normal pressure, specimens were shortened to 3.70 to 3.86 in (94 to 98 mm) to accommodate any possible dilation; this specimen size was used throughout the study.

The interface bonding was analyzed by computing a uniform shear strength, τ, at the pavement interlayer as follows:

$$\tau = \frac{P}{A} \tag{3.1}$$

where

τ = shear strength (psi)
P = shearing load (lb)
A = specimen interface area (in^2)

3.1.2 TORQUE BOND TEST

The torque bond test has been used as an in-situ test to determine bond strength of HMA layers; however, it can also be performed in the lab on core specimens. This test requires a high degree of coring precision in properly function in the field. The procedure followed was obtained from the British Board of Agrément (2008). For the site test method, coring must be made to a depth of 0.787 in (20 mm) below the interface. It is recommended that six cores be tested from each section, evenly spaced along a diagonal across the mat. In addition, the surface must be dry and clean in order to use the bonding material for the plate. A steady rate of torque should be applied to the specimen; following that, the torque wrench must sweep at a 90° angle in 30 ± 15 s. It is crucial that torque be applied on the same plane as the plate. Finally, torque is recorded, as well as temperature of the interface and diameter of the specimen (measured in at least at two locations).

For the laboratory-performed test, it is important to extract the core at least 3.15 in (80 mm) below the interface, without damage. In the lab, specimen preparation includes cutting the core to a specific height to ensure that the interface extends at least 0.787 ± 0.394 in (20 ± 10 mm) above the rim of the mold. The metal plate was fixed to the mold with adhesive material. The core was conditioned for a minimum of 4 hr, but not more than 16 hr, at a temperature of 68°F ± 4°F (20°C ± 2°C). The core was placed in the mold and fixed, after which point the test was performed. Figure 3.3 depicts all steps of the torque bond test.

In this study, a laboratory torque test was determined to be the best option due to heavy traffic in the construction project. To calculate the bond strength of each specimen, the following formula was used.

$$\tau = \frac{12M\times 10^{6}}{\pi D^{3}} \tag{3.2}$$

where

τ = interlayer bond strength (kPa)
M = peak torque at failure (N·m)
D = diameter of core (mm)

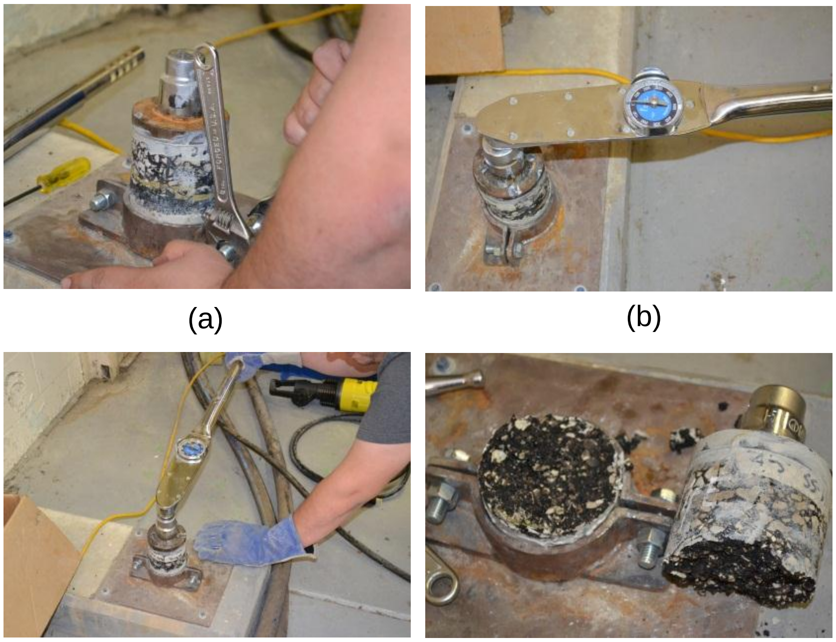

(a) (b)
(c) (d)

Figure 3.3. Torque bonding test: (a) Clamping the specimen, (b) Setting the torque device, (c) Applying torque to the specimen, and (d) Tested specimen.

3.2 FIELD PROJECT DESCRIPTION

In this section, a description of both projects is presented. Materials, application, and testing scope for each project are addressed.

3.2.1 INTERSTATE 80 (I-80)

Construction of the overlay on Interstate 80 was performed at night. Twenty-six sections were built in order to analyze the various parameters that may affect bonding between pavement layers. Those parameters are presented and discussed in Chapter 5.

3.2.1.1 DESCRIPTION OF THE PROJECT

In April 2011, the Illinois Department of Transportation (IDOT) initiated a project for improvements of a 22-mi (35.41-km) portion of I-80. The work consists primarily of resurfacing and adding a third lane. Resurfacing is planned for the portion of I-80 from the Grundy County line to U.S. Route 30. The project also includes rehabilitation of 29 bridges and resurfacing of all ramps and interstate shoulders along that portion. A third lane will be added in each direction from U.S. Route 30 (Lincoln Highway) to U.S. Route 45 (LaGrange Road) to improve traffic flow and safety, especially in the region of the I-80/I-355 interchange. In addition, IDOT plans to build noise walls in certain locations, construct median shoulders along both sides of I-80, and perform drainage and bridge-widening work. Figure 3.4 is a map of the project.

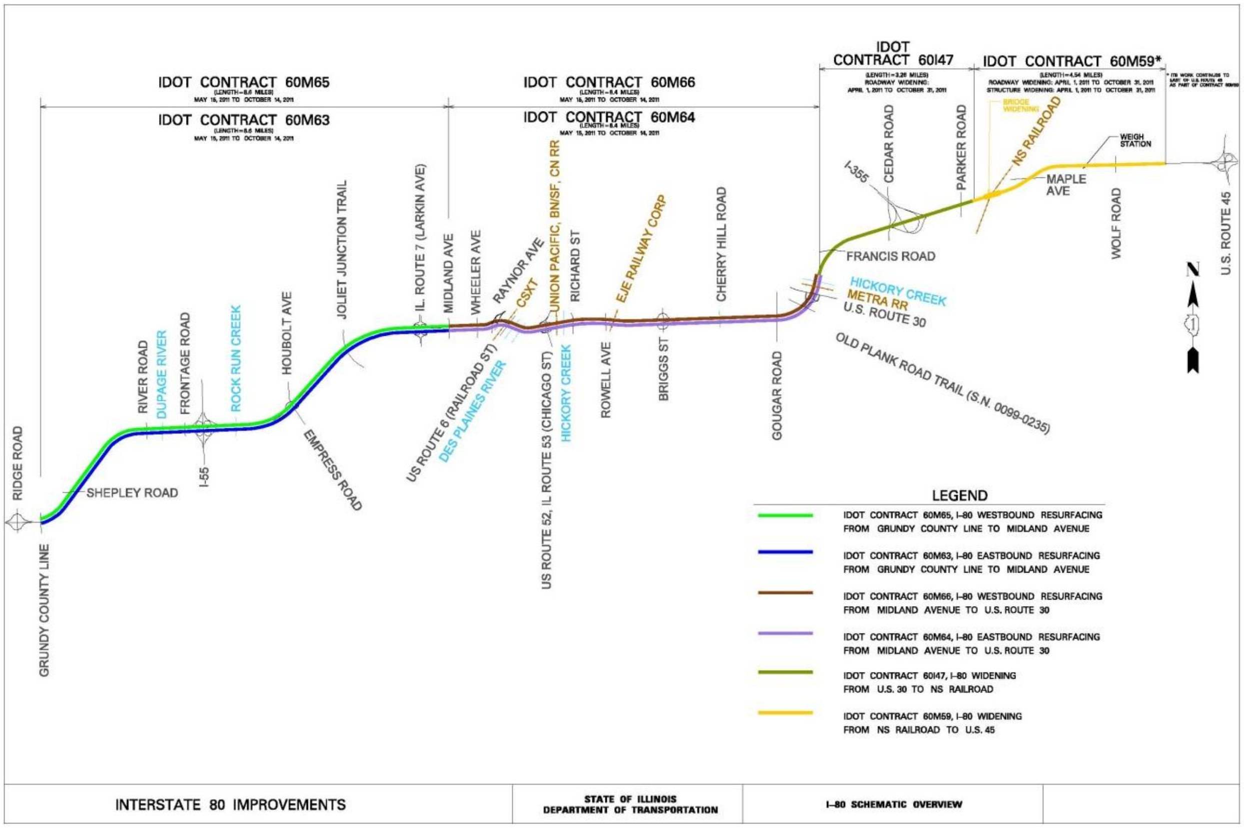
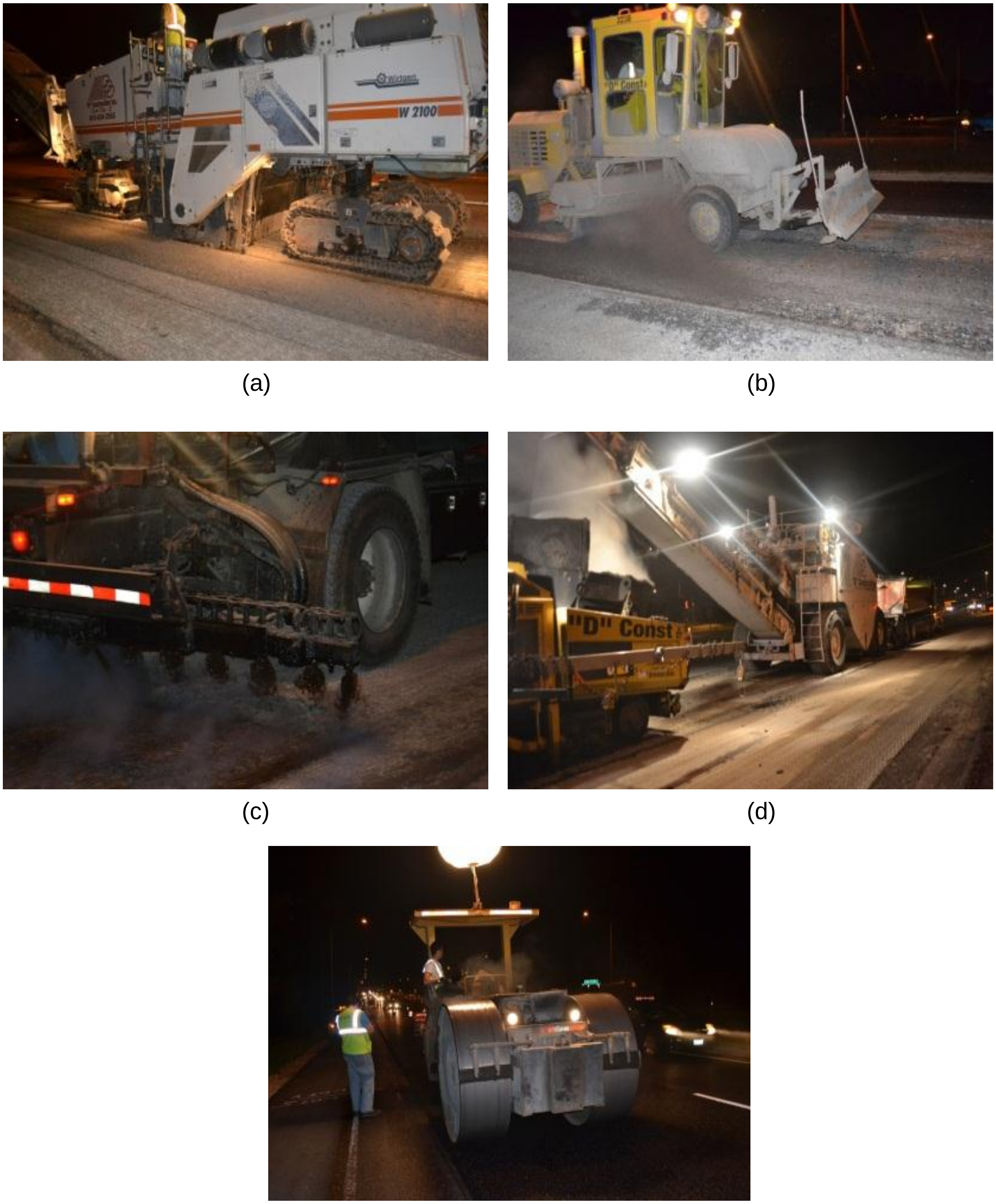


Figure 3.4. Interstate 80 project diagram.

Construction on I-80 was performed during the night. It consisted of milling 4 in (10.16 cm) of an asphalt layer and replacing it with 2 in (5.08 cm) of binder SMA mix and 2 in (5.08 cm) of surface SMA mix. The construction process started with milling the asphalt, then cleaning was done using a broom and vacuum equipment. After cleaning, the tack coat was applied by a distributor truck at a specified residual rate. The overlay was placed in two layers—first, 2 in (5.08 cm) of binder SMA mix, and then 2 in (5.08 cm) of surface SMA mix. Compaction was conducted by three static rollers, and the smaller roller being used to finalize the compaction. The targeted air voids for both mixes was 3.5%. Figure 3.5 shows the construction process for this project.



(a)

(b)

(c)

(d)

(e)

Figure 3.5. Construction process on I-80 project: (a) Milling, (b) Cleaning, (c) Tack coat application, (d) Paving, and (e) Compaction.

3.2.1.2 TACK COAT APPLICATION TECHNIQUE

In this project, the tack coat was applied using a distributor truck, as shown in Figure 3.6. The tack coat application temperature was 170°F (76.7°C) for SS-1h and 175°F (79.4°C) for SS-1vh. The tack coat residual application rate was verified in-situ using geotextile squares (1 × 1 ft; 0.3048 × 0.3048 m). This verification was performed at the beginning of each day of work as part of the quality assurance (QA) process.

Figure 3.6. Tack coat application with distributor truck.

3.2.1.3 TESTING SCOPE

The field study evaluated the effect of various parameters that influence bonding between pavement layers, including application rate, interface texture, surface mix type, surface cleanliness, curing time, and tack coat type. The testing matrix is show in Figure 3.7. For the I-80 project, SS-1hp and SS-1vh tack coat materials were applied at a range of residual rates from 0.02 to 0.08 gal/yd^2 (0.09 to 0.36 L/m^2) at intervals of 0.02 gal/yd^2 (0.09 L/m^2). Figure 3.8 illustrates the test pavement sections plan for this project.

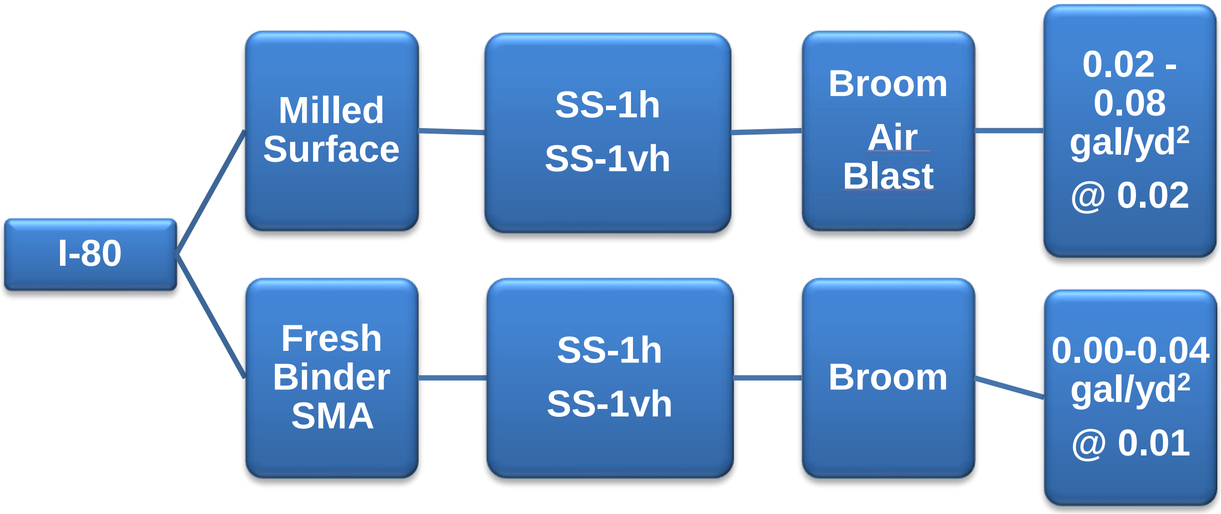
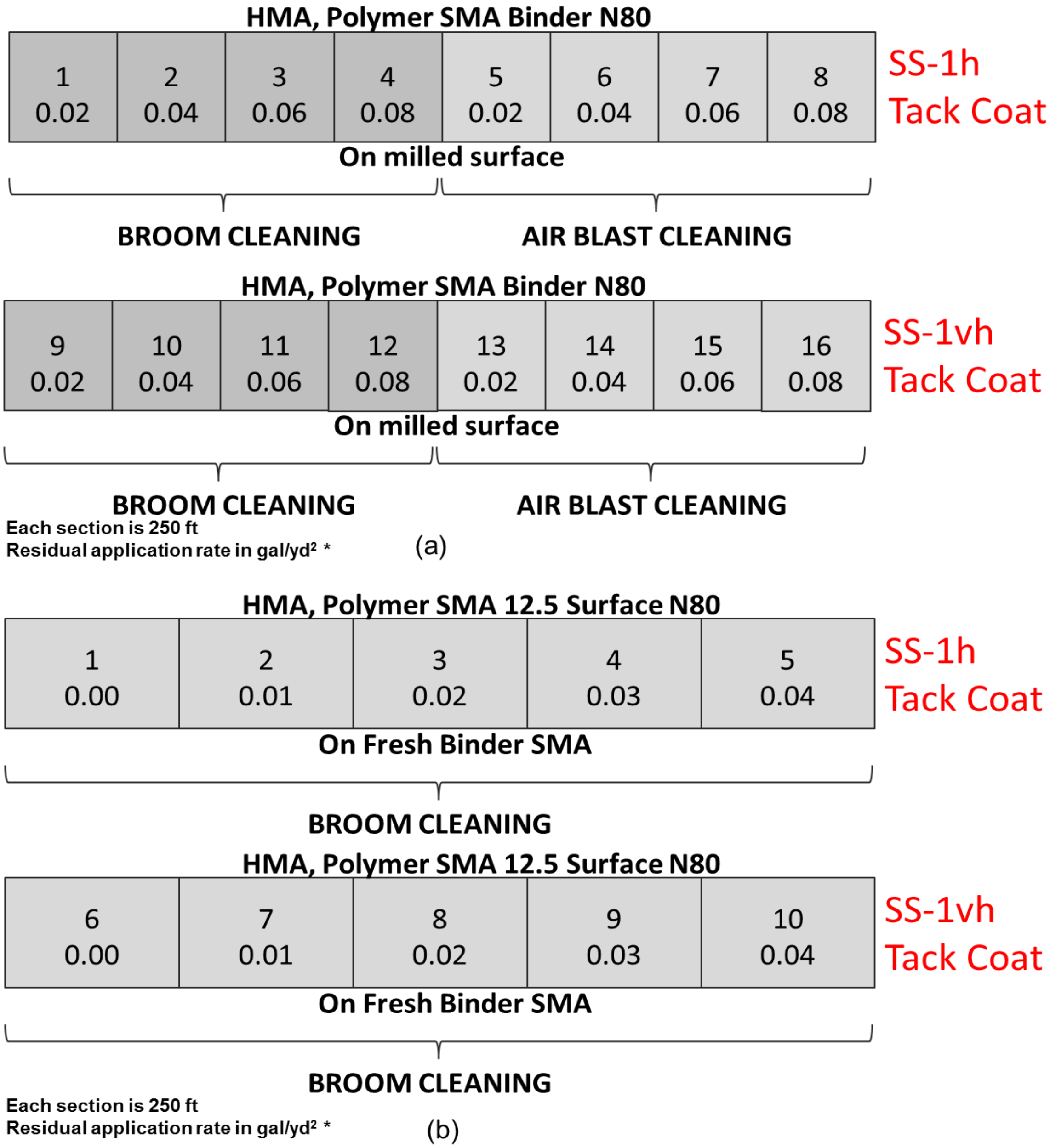


Figure 3.7. Testing matrix for I-80 project.

Two cleaning methods (broom and air blast) were used in the evaluation of both tack coat materials. For these 16 sections, polymer SMA binder mix N80 was paved after applying tack coat. Five more sections for each tack coat material (10 sections in total) at five various rates (0, 0.01, 0.02, 0.03, and 0.04 gal/yd^2) (0, 0.045, 0.09, 0.14, and 0.18 L/m^2) were applied to evaluate the optimum residual application rate on top of new HMA. In these sections, polymer SMA 12.5-mm surface mix N80 was paved as an overlay on top of unmilled new HMA.



*1 gal/yd^2 = 4.5 L/m^2

Figure 3.8. Field construction plan for I-80 project: (a) SMA binder N80 on top of milled HMA and (b) SMA 12.5 surface N80 on top of fresh binder SMA.

3.2.2 ILLINOIS ROUTE 98 (IL-98)

The construction on Illinois Route 98 was done during the day. Nineteen sections were built in order to analyze parameters that potentially affect interface bonding between pavement layers. Those parameters are presented and discussed in Chapter 5 of this report.

3.2.2.1 DESCRIPTION OF THE PROJECT

This project is located in Tazewell County along Illinois Route 98, from 0.04 mi (0.06 km) east of Erie Avenue in Morton (station 90+20) to 0.15 mi (0.24 km) east of Parkway Drive in North Pekin (station 450+85). The project consists of pavement patching, milling, resurfacing, pavement marking, and other related collateral work. The route crosses both rural and urban sections as follows: from Erie Avenue to Lampe Road (urban), from Lampe Road to Springfield Road (rural), from Springfield Road to Bartruff Lane (urban), and from Bartruff Lane to the end of the project (rural). Figure 3.9 shows the localization of the project. The proposed improvements consist of the following:

- Hot-mix asphalt removal
- Pavement patching, both Class D (16 in; 40.64 cm) and partial depth (6 in; 15.24 cm)
- Aggregate shoulders
- Miscellaneous safety and temporary work

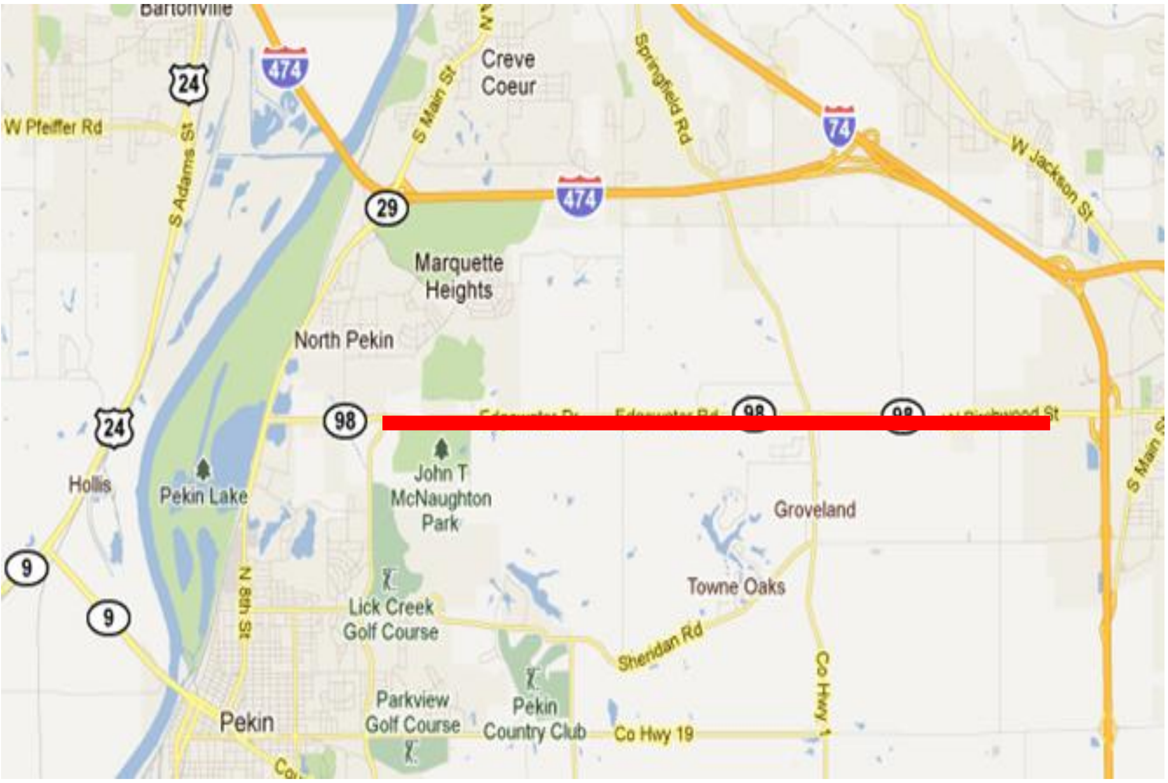


Figure 3.9. Illinois Route 98 project localization.

The project also specifies the use of a non-track tack coat (SS-1vh) and a spray paver. Specifically, a spray paver was required for the full length of the eastbound lane. Three tack coat materials were evaluated: SS-1h, SS-1hp and SS-1vh. All sections were constructed in the eastbound lane of the project, at a length of 200 ft (60.96 m) each. The non-track tack coat was applied on the same day as the paving of those sections. The SS-1h and SS-1hp were applied the day before paving for overnight curing. Approved spray pavers per project contract specifications were the Roadtec SP-200 or Vögele Super 1800-2 with spray jet module; for this project, the former was used. All the sections were paved with the spray paver, but on sections where the tack coat was already placed, the sprayer was turned off; these sections are referred to as "conventional paver."

Air-blast cleaning was specified for the milled pavement at five different sections with SS-1h, SS-1hp and SS-1vh for the conventional paver sections. The spray paver sections also specified air-blast cleaning for two sections with two tack coat materials, SS-1h and SS-1hp. In addition to cleaning, coring of the finished surface course was required at multiple locations to study bond strength for each configuration. A total of nine cores were obtained from each section; to reduce variability the cores were taken from middle of the lane. Figure 3.10 shows the construction process followed in this project.

(a) (b) (c) (d) (e)

Figure 3.10. Construction process on IL-98 project: (a) Cleaning, (b) Tack coat measurement verification, (c) Tack coat application, (d) Paving, and (e) Compaction.

3.2.2.2 TACK COAT APPLICATION TECHNIQUE

In this project, the tack coat was applied using a distributor truck and a spray paver, as shown in Figure 3.11. The tack coat application temperature was 170°F (76.7°C) for SS-1h and SS-1hp and 175°F (79.4°C) for SS-1vh. The tack coat residual application rate was verified in-situ using geotextile squares (1 × 1 ft; 0.3048 × 0.3048 m). This verification was done at the beginning of each day of work as part of the quality assurance (QA) process for equipment performance.


(a) (b)

Figure 3.11. (a) Tack coat application with distributor truck, (b) Tack coat application with spray paver.

3.2.2.3 TESTING SCOPE

The IL-98 Project included 19 sections that were constructed to evaluate the performance of three tack coat materials (SS-1h, SS-1hp, and SS-1vh). The tack coats were applied at a residual rate ranging from 0.02 to 0.08 gal/yd^2 (0.09 to 0.36 L/m^2) at intervals of 0.02 gal/yd^2 (0.09 L/m^2), as shown in Figure 3.12. The tack coat was applied over a milled HMA surface. Figure 3.13 shows the construction plan for this project.

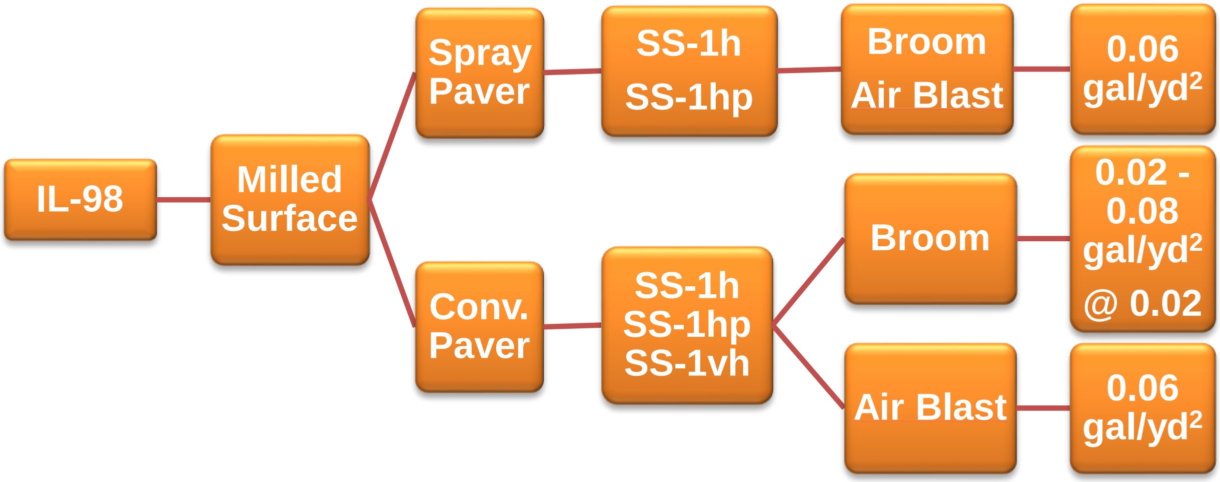
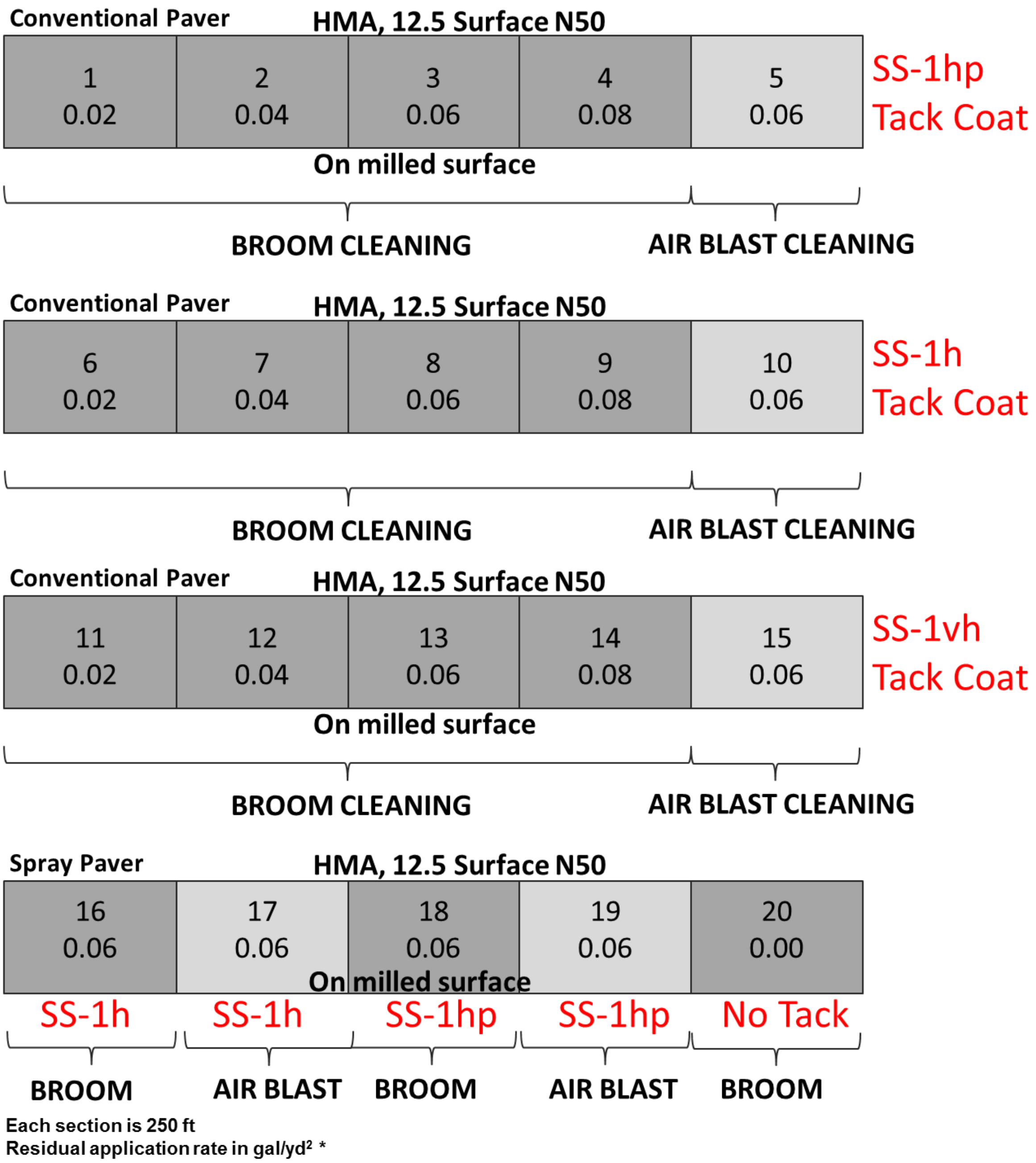


Figure 3.12. Test matrix for IL-98 Project.



* 1 gal/yd^2 = 4.5 L/m^2

Figure 3.13. Field construction plan for IL-98 Project: HMA 12.5 surface N50 mix on top of milled surface.

For this project, the curing time of tack coat was assessed using two different paving construction processes (tack coat sprayed with a distributor followed by a conventional paver, and the spray paver). With the spray paver, the tack coat was distributed approximately 1 ft (30 cm) before paving, which represents an insufficient amount of time for complete curing. Thus, curing was taking place due to the heat from the paving process. Only SS-1h and SS-1hp were distributed using the spray paver at a constant residual application rate of 0.06 gal/yd^2 (0.27 L/m^2).

The cleaning effect was studied in the spray paver sections by applying both broom and air-blast cleaning methods. For the conventional paving sections, SS-1h and SS-1hp tack coats were sprayed 24 hr before paving, which allowed the tack coat to cure completely. SS-1vh was applied approximately 30 min before paving. This material requires much less time to cure since it contains a harder binder that allows for faster evaporation of water. In addition, the heat of paving accelerated evaporation, ensuring complete curing during paving. Tack coat materials were sprayed at different residual application rates for different sections (0.02, 0.04, 0.06, and 0.08 gal/yd^2; 0.09, 0.18, 0.27, and 0.36 L/m^2). The surface cleanliness effect was also evaluated using broom and air-blast cleaning techniques. Only a section for each of the three materials was air blasted, and the tack coat was applied at a residual application rate of 0.06 gal/yd^2 (0.27 L/m^2).

3.2.3 CHALLENGES AND RECOMMENDATIONS

During construction of the I-80 and IL-98 projects, some difficulties were overcome that are worthy of mention.

- In the I-80 Project, problems were encountered with distribution of the non-track tack coat. The distributor truck was clogged for several days, requiring major repair. To avoid a clogging problem, the tack coat must be maintained at a constant temperature of 175°F (79.44°C). This problem was not experienced on the IL-98 Project. After the problem was corrected, the distributor truck was used in both projects for the tack coat application, as shown in Figure 3.14.
- For the I-80 project, some sections were milled beyond the desired depth and reached the PCC. For those sections (sections with SS-1vh), the analysis considered binder SMA on top of PCC.
- For the IL-98 project, per manufacturer recommendations, the non-track tack coat (SS-1vh) was not placed in the spray paver because of the possibility that the heat of the mix would clog the equipment.
- For any project, it is recommended that application rates for the distributor and the spray paver be verified at the beginning of the project. The verification can be done with the use of geotextile squares (1 × 1 ft; 0.3048 × 0.3048 m), like those shown in Figure 3.10 b).

(a) (b)

Figure 3.14. SS-1vh application with the distributor truck: (a) I-80 project and (b) IL-98 project.

CHAPTER 4 MATERIALS & SPECIMEN PREPARATION

4.1 MATERIALS

This study involved the use of various HMA and tack coat materials on two different projects (I-80 and IL-98). In this section, the detail properties for these materials are presented.

4.1.1 INTERSTATE 80

In the I-80 project, polymer SMA binder mix N80 was paved after applying a tack coat over the milled surface. Polymer SMA 12.5-mm surface mix N80 was paved after applying a tack coat over the new polymer SMA binder N80. The aggregate gradation and mix properties are presented in Table 4.1. Two tack coat materials were used in this project (SS-1h, and SS-1vh). The properties of these materials are presented in Table 4.2.

Table 4.1. I-80 Mix Design.

Property			**Passing Ratio**	
	Sieve Size		**SMA Binder 12.5**	**SMA Surface 12.5**
	(mm)	**(in)**		
Aggregate Gradation	25.4	1	100.0	100.0
	19	3/4	100.0	100.0
	12.5	1/2	91.0	85.5
	9.5	3/8	64.0	65.0
	4.75	#4	30.0	27.0
	2.36	#8	21.0	18.0
	1.18	#16	17.0	15.0
	0.6	#30	13.0	12.0
	0.3	#50	11.0	11.0
	0.15	#100	9.0	9.0
	0.075	#200	7.5	7.7
Asphalt Cement Grade			PG 70-28	PG 70-28
Asphalt Content (%)			6.2	6.0
Maximum Specific Gravity			2.494	2.959

Table 4.2. Tack Coat Properties, I-80 Project.

Tack Coat Property	**SS-1h**	**SS-1vh**
Specific Gravity @ 60°F (15.6°C)	1.016	1.03
Asphalt Residue Rate by Volume (%)	62.2	56.1
Glassy Transition Temperature (°C)*	—	2.78

*1°C = 33.8°F

4.1.2 ILLINOIS ROUTE 98

For Project IL-98, only one HMA was used along all sections of the study (HMA N50 surface mix). Table 4.3 provides the aggregate gradations and HMA properties. Three tack coat materials were used in this project (SS-1h, SS-1hp, and SS-1vh). The properties of these materials are presented in Table 4.4.

Table 4.3. IL-98 Mix Design.

Property			Passing Ratio
	Sieve Size		HMA N50 Surface
	(mm)	(in)	
Aggregate Gradation	25.0	1	100.0
	19.0	3/4	100.0
	12.5	1/2	100.0
	9.5	3/8	97.0
	4.75	#4	54.0
	2.36	#8	32.0
	1.18	#16	23.0
	0.6	#30	18.0
	0.3	#50	10.0
	0.15	#100	6.0
	0.075	#200	5.1
Asphalt Cement Grade			PG 70-28
Asphalt Content (%)			5.8
Maximum Specific Gravity			2.485

Table 4.4. Tack Coat Properties.

Tack Coat Property	SS-1hp	SS-1h	SS-1vh
Specific Gravity @ 60°F (15.6°C)	1.017	1.016	1.03
Asphalt Residue Rate by Volume (%)	61.1	62.2	56.1
Glassy Transition Temperature (°C)*	2.50	—	2.78

*1°C = 33.8°F

4.2 SPECIMEN PREPARATION

The composite specimens were cored from the field at least 24 hr after construction to allow for maximum curing of the HMA. The specimens were cored at a 4-in (100-mm) diameter and were obtained from wheel paths and the centerline to examine any difference in performance due to trafficking during construction. Coring was performed slowly to avoid breaking the interface by the rotational force of the coring machine. In addition, slow coring helped the operator maintain a vertical coring direction, resulting in better specimens. Figure 4.1 shows a sample of cored specimens from IL-98 project.

Figure 4.1. A sample of cored specimens from the IL-98 project.

The specimens were labeled, dried, and transported to the lab, where they were stored at 53.6°F (12°C) to avoid creep of HMA (Figure 4.2). The specimens had to be cut at specific dimensions to fit inside the specimen housing chamber in the testing device. The interface was visually marked using yellow crayon, as shown in Figure 4.3. The required height was marked and the specimen cut to a length of 3.77 to 3.86 in (96 to 98 mm) for ISTD specimens and 4.53 to 4.72 in (115 to 120 mm) for torque test specimens using a water-cooled 5-mm-blade saw, as shown in Figure 4.4.

(a) (b) (c)

Figure 4.2. (a) Specimens storage inside the climatic room, (b) Climatic storage room, and (c) Temperature controlled at 53.6°F (12°C).

Figure 4.3. Interface labeled with yellow crayon.

Figure 4.4. Water-cooled 5-mm-blade saw.

The specimens were then dried for 24 hr. For some specimens, the adhesion between the milled HMA and the PCC was lost, which left only 1 in (25 mm) of milled HMA. To achieve the required height for the specimen, an extension of PCC was attached to the bottom with epoxy. The specimens and extensions were clamped, and the epoxy was left to cure for 24 hr to ensure full adhesion. During application of SS-1vh, most of the HMA layer was fully milled, and the PCC layer was exposed. The binder HMA was laid over the PCC directly after applying the tack coat. This resulted in a reduction in interface strength due to the lower bonding strength at PCC–HMA interfaces. After drying, the specimens were stored at 41°F (5°C) until testing. Then, before testing commenced, the specimens were warmed in a temperature chamber until they reached 77°F (25°C).

CHAPTER 5 TESTS RESULTS AND DISCUSSION

This section includes the analysis of test results from both projects. The optimum tack coat application rate, surface type, cleaning method, tack coat type, and paving method are some of the effects on interface bonding strength discussed in this chapter.

5.1 INTERSTATE 80

The direct shear and torque bond test results were analyzed to determine the effects of the parameters considered in this study. Two core specimens were tested with each of the devices to ensure repeatability. Both the average and the coefficient of variation (COV) were calculated. The results presented below are discussed in two sections: milled surface and fresh binder SMA.

5.1.1 MILLED SURFACE

Three categories were analyzed for the milled surface as a bottom layer: the effects of surface type (milled HMA and milled PCC), cleaning method (conventional method using broom equipment and conventional method with broom followed by air blast), and optimum tack coat application rate. The results of these tests are presented in Tables 5.1 and 5.2. As presented in the tables, the COVs for the ISTD were better and more consistent than those of the torque bond test. Complete tables of results are presented in Appendix A of this report.

Table 5.1. ISTD Results for Field Evaluation on I-80 on Top of Milled Surface.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Average Shear Strength (psi)**	Standard Deviation	COV (%)
1	**SS-1h**	**Milled HMA**	**Broom Equipment**	**0.02**	**110.7**	**12.2**	**11.0**
2				**0.04**	**108.1**	**15.9**	**14.7**
3				**0.06**	**131.3**	**7.2**	**5.5**
4				**0.08**	**115.9**	**8.3**	**7.2**
5			**Broom Equipment + Air Blast**	**0.02**	**129.9**	**2.6**	**2.0**
6				**0.04**	**132.2**	**7.8**	**5.9**
7				**0.06**	**126.5**	**8.3**	**6.6**
8				**0.08**	**86.2**	**1.6**	**1.8**
9	**SS-1vh**	**Milled PCC**	**Broom Equipment**	**0.02**	**60.8**	**3.8**	**6.2**
10				**0.04**	**80.2**	**0.7**	**0.8**
11				**0.06**	**73.4**	**10.9**	**14.9**
12				**0.08**	**73.0**	**12.3**	**16.8**
13			**Broom Equipment + Air Blast**	**0.02**	**39.4**	**2.2**	**5.7**
14				**0.04**	**81.4**	**15.6**	**19.2**
15				**0.06**	**67.9**	**9.2**	**13.5**
16				**0.08**	**64.9**	**12.2**	**18.9**

*1 gal/yd^2 = 4.5 L/m^2
**1 psi = 0.0069 MPa

Table 5.2. Torque Bond Test Results for Field Evaluation on I-80 on Top of Milled Surface.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Avg. Bond Strength (psi)**	Standard Deviation	COV (%)
1	SS-1h	Milled HMA	Broom Equipment	0.02	151.0	5.9	3.9
2				0.04	130.2	19.6	15.0
3				0.06	155.1	3.9	2.5
4				0.08	135.7	19.6	14.4
5			Broom Equipment + Air Blast	0.02	149.6	7.8	5.2
6				0.04	142.7	2.0	1.4
7				0.06	95.6	21.6	22.5
8				0.08	113.6	31.3	27.6
9	SS-1vh	Milled PCC	Broom Equipment	0.02	63.7	23.5	36.9
10				0.04	115.0	29.4	25.6
11				0.06	123.3	17.6	14.3
12				0.08	131.6	9.8	7.4
13			Broom Equipment + Air Blast	0.02	90.0	17.6	19.6
14				0.04	123.3	5.9	4.8
15				0.06	146.8	15.7	10.7
16				0.08	126.0	5.9	4.7

*1 gal/yd^2 = 4.5 L/m^2
**1 psi = 0.0069 MPa

5.1.1.1 EFFECT OF SURFACE TYPE

According to the initial matrix of the study, the project included milling 4 in (100 mm) of HMA and replacing it with 12.5-mm SMA binder. However, at some locations, the milling reached the PCC layer beneath the HMA. This problem occurred on the sections where SS-1vh was applied. This provided an opportunity to evaluate another factor in addition to milled HMA surface that was not initially part of study scope: PCC surface.

In the laboratory phase of this study, it was found that non-track tack coat performed better than SS-1hp on a milled HMA surface. In the field study, it was found that SS-1h over milled HMA performed better than SS-1vh over milled PCC. Thus, it can be concluded that milled HMA has greater shear and torque strength than that of milled PCC.

5.1.1.2 EFFECT OF CLEANING METHOD

Previous studies showed that air-blast cleaning significantly improves interface bonding (Leng et al., 2009). However, this method is inconvenient in the field, especially in an urban area where the dust cloud can be hazardous. The method is also time consuming, which reduces work efficiency. The cleaning process used in this study is shown in Figure 5.1.


(a) (b)

Figure 5.1. Cleaning methods: (a) Broom and vacuum, (b) Air blast.

Shear and torque tests were performed on the specimens that were cored after construction. The results exhibited some variability between cores, based on different cleaning methods, as shown in Figure 5.2. According to the results of the ISTD on the milled HMA surface, the SS-1h tack coat showed similar behavior at the optimum tack coat application rate, regardless of cleaning method. At the lower application rate, air-blast cleaning showed greater shear strengths; however, when the application rate was higher than the optimum, the broom cleaning method showed greater shear strength because the remaining dust reduced the effective tack coat rate. The optimum residual application rate is 0.06 gal/yd^2 (0.27 L/m^2) for broom cleaning, while for air-blast cleaning the optimum rate was reduced to 0.04 gal/yd^2 (0.18 L/m^2). Hence, air blasting can reduce the optimum application rate for milled HMA using SS-1h as tack coat.

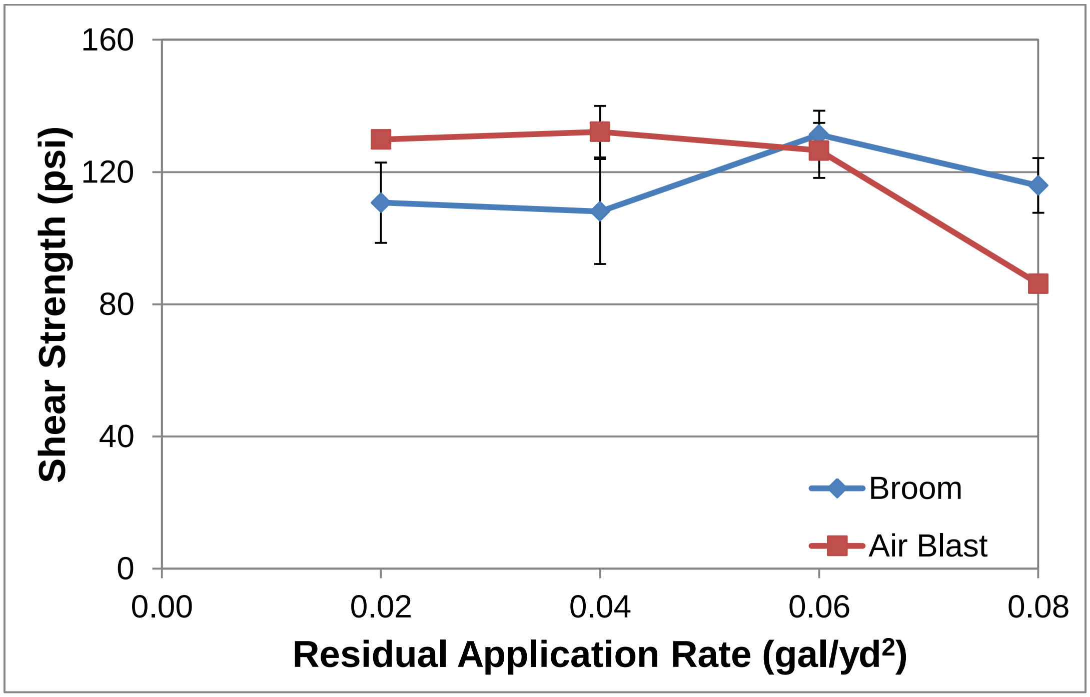


Figure 5.2. Shear strength for milled HMA using SS-1h as tack coat.

In the case of SS-1vh over milled PCC using the ISTD, the difference between cleaning methods was not critical (as illustrated in Figure 5.3). The broom and air-blast cleaning methods produced similar results, and the optimum rate obtained for both methods was 0.04 gal/yd^2 (0.18 L/m^2), which is in agreement with an earlier study by Al-Qadi et al. (2009).

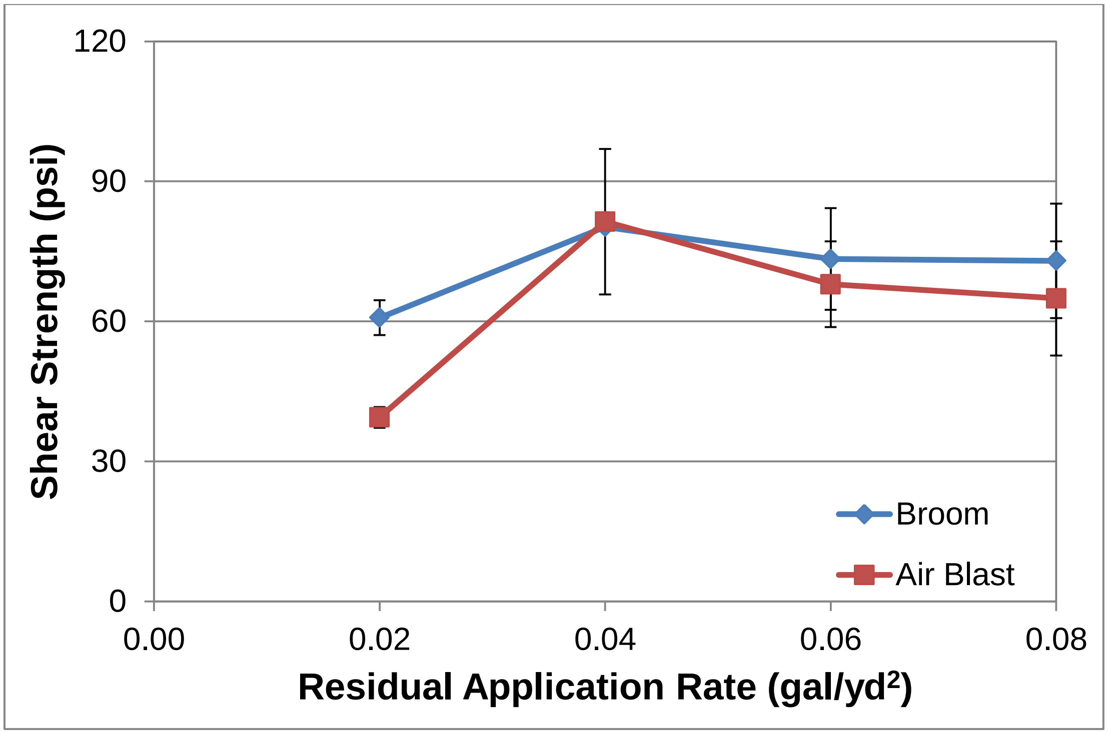


Figure 5.3. Shear strength for milled PCC using SS-1vh tack coat.

The torque bond test showed trends similar to the ISTD. The maximum bond strength attained, when all application rates of SS-1h were considered, was the same for both cleaning methods in the case of milled HMA. However, optimum application where maximum bond strength was attained is different for each cleaning method. Figure 5.4 illustrates these results for SS-1h on milled HMA surface. Similar to the results of the ISTD, air blasting reduced the optimum application rate from 0.06 gal/yd^2 (0.27 L/m^2) to 0.04 gal/yd^2 (0.18 L/m^2). On the other hand, the broom-cleaning method yielded the best bond strength at 0.08 gal/yd^2 (0.36 L/m^2) with SS-1vh tack coat over PCC, whereas the air-blast method yielded maximum bond strength at 0.06 gal/yd^2 (0.27 L/m^2) for the same materials and surface type, as seen in Figure 5.5. It is important to note that both test results showed a similar trend of reduction in the application rate when air-blast cleaning was used, compared to broom cleaning only. Hence, air blasting does not improve interface bonding; however, it can reduce the amount of tack coat needed to achieve the best bond between layers.

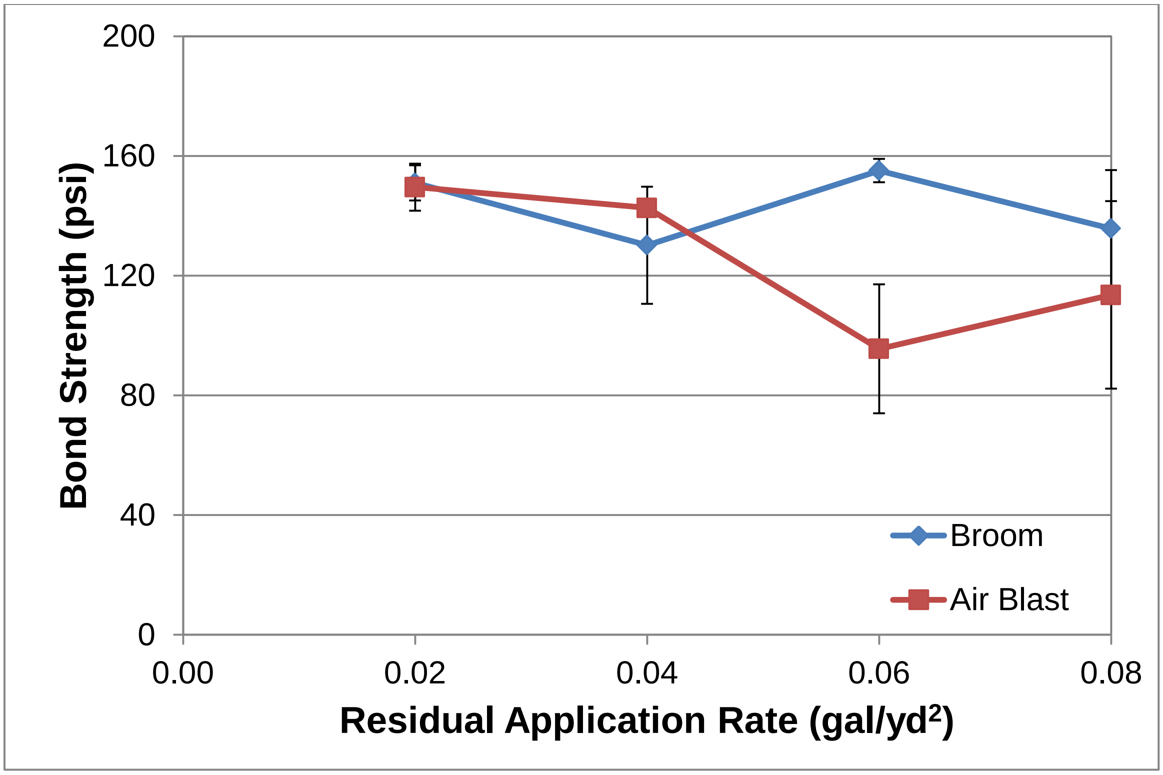


Figure 5.4. Bond strength for milled HMA using SS-1h tack coat.

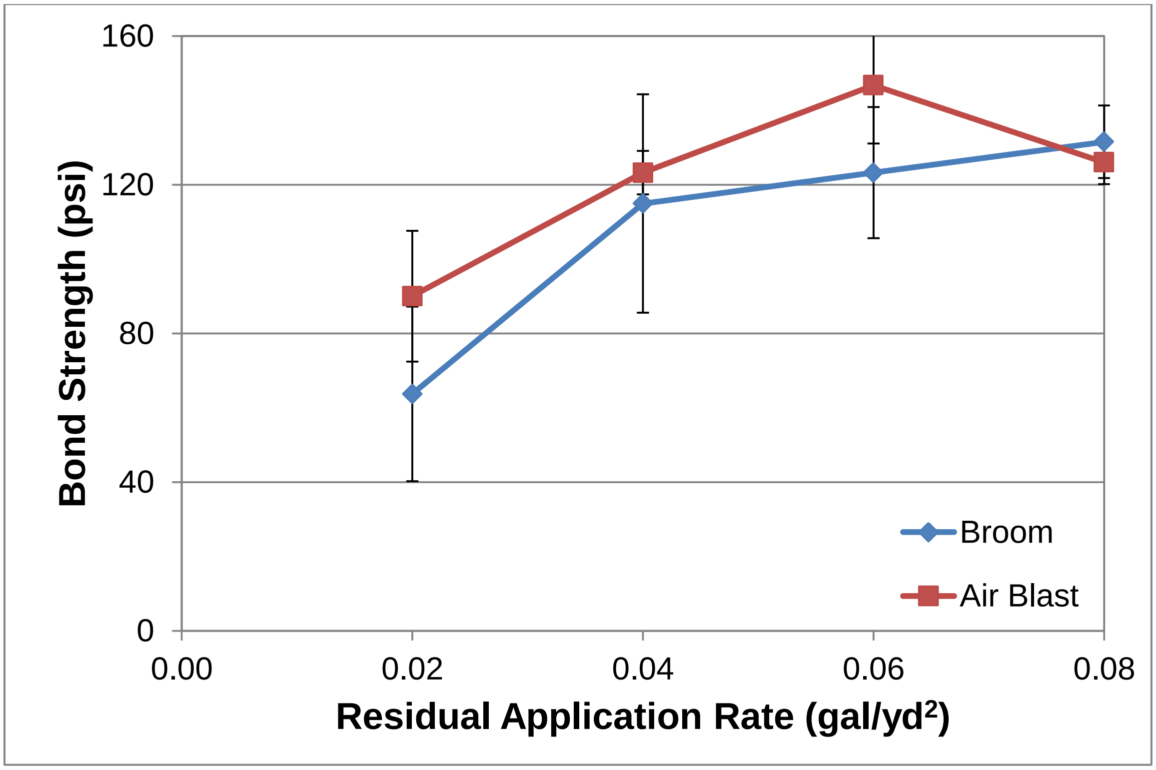


Figure 5.5. Bond strength for milled PCC using SS-1vh tack coat.

5.1.1.3 TACK COAT OPTIMUM APPLICATION RATE

Optimizing the amount of material used in the field is crucial in every construction project. In a previous study performed at the Illinois Center for Transportation (ICT) at the University of Illinois at Urbana-Champaign on PCC surfaces, it was reported that the optimum application rate depended on pavement surface type (milled, aged, or new HMA) (Leng et al., 2008). Table 5.3 shows the optimum application rate for various emulsion types, surface types, and cleaning methods. The change in optimum rate can be attributed to different testing mechanisms.

Table 5.3. Optimum Application Rates.

Testing Method	Tack Coat	Surface Type	Cleaning Method	Optimum Res. App. Rate (gal/yd^2)*
Shear	**SS-1h**	**Milled HMA**	**Broom**	**0.06**
			Air Blast	**0.04**
	SS-1vh	**Milled PCC**	**Broom**	**0.04**
			Air Blast	**0.04**
Torque	**SS-1h**	**Milled HMA**	**Broom**	**0.06**
			Air Blast	**0.02**
	SS-1vh	**Milled PCC**	**Broom**	**0.08**
			Air Blast	**0.06**

*1 gal/yd^2 = 4.5 L/m^2

The optimum tack coat application rate recommended for a particular job will depend on surface type, the cleaning method used in the field, and tack coat type. Comparing results from both test devices used in this study, the ISTD showed lower COVs than the torque bond test. It can be noted that the ISTD better represents field conditions than the torque test and provided greater accuracy; in that testing method, constant normal stresses are applied and fewer inherent errors occur as the shear is directly applied at the interface. The torque bond test, however, can still be used as a field index test.

5.1.2 BINDER SMA

An overlay of surface SMA was paved on top of freshly applied binder SMA. Two tack coat materials were used (SS-1h and SS-1vh) at five residual application rates (0.00, 0.01, 0.02, 0.03, and 0.04 gal/yd^2; 0.00, 0.045, 0.09, 0.14 and 0.18 L/m^2). Only one cleaning method, broom equipment, was used. A total of ten sections were built, and cores from these sections were tested. Two parameters were analyzed: optimum tack coat application rate and the effect of tack coat type. The results of these tests are presented in Tables 5.4 and 5.5. Complete tables of results are presented in Appendix A of this report.

Table 5.4. ISTD Results for Field Evaluation on I-80 on Top of Fresh Binder SMA.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Average Shear Strength (psi)**	Standard Deviation	COV (%)
1	SS-1h	Binder SMA	Broom Equipment	0.00	92.2	11.9	13.0
2				0.01	80.2	6.8	8.5
3				0.02	85.8	18.4	21.5
4				0.03	75.0	2.5	3.3
5				0.04	69.8	6.6	9.4
6	SS-1vh			0.00	92.2	11.9	13.0
7				0.01	88.8	8.3	9.3
8				0.02	106.8	1.7	1.5
9				0.03	101.4	2.9	2.9
10				0.04	98.5	11.3	11.5

*1 gal/yd^2 = 4.5 L/m^2

**1 psi = 0.0069 MPa

Table 5.5. Torque Bond Test Results for Field Evaluation on I-80 on Top of Fresh Binder SMA.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Avg. Bond Strength (psi)**	Standard Deviation	COV (%)
1	SS-1h	Binder SMA	Broom Equipment	0.00	128.8	2.0	1.5
2				0.01	130.2	19.6	15.0
3				0.02	141.3	3.9	2.8
4				0.03	137.1	9.8	7.1
5				0.04	117.7	13.7	11.6
6	SS-1vh			0.00	142.7	13.7	9.6
7				0.01	144.0	11.8	8.2
8				0.02	128.8	29.4	22.8
9				0.03	159.3	13.7	8.6
10				0.04	153.7	21.5	14.0

*1 gal/yd^2 = 4.5 L/m^2

**1 psi = 0.0069 MPa

5.1.2.1 TACK COAT OPTIMUM APPLICATION RATE

Optimizing the application rate of a tack coat material will improve job quality, reduce costs, and increase service life of the pavement. When an overlay is applied on top of a fresh HMA, the application rate for the tack coat material is reduced. This is because part of the fresh binder in the bottom mix acts as a bonding agent between layers. This finding has also been reported by researchers in previous studies (Mohammed et al., 2005).

In this project, two tack coat materials were tested (SS-1h and SS-1vh). The results of the ISTD are presented in Figure 5.6; SS-1vh showed an optimum application rate of 0.02 gal/yd^2 (0.09 L/m^2). Although the SS-1h had the greatest shear strength at no application rate, the difference between this value and that for 0.02 gal/yd^2 (0.09 L/m^2) rate was not statistically different. The bond strength obtained from the torque test showed that the optimum residual application rate for SS-1h is 0.02 gal/yd^2 (0.09 L/m^2) and for the SS-1vh is 0.03 gal/yd^2 (0.14 L/m^2), as shown in Table 5.5.

The optimum residual application rate that is recommended for an overlay on top of fresh HMA is 0.02 gal/yd^2 (0.09 L/m^2), based on the test results and statistical analysis performed on the collected data.

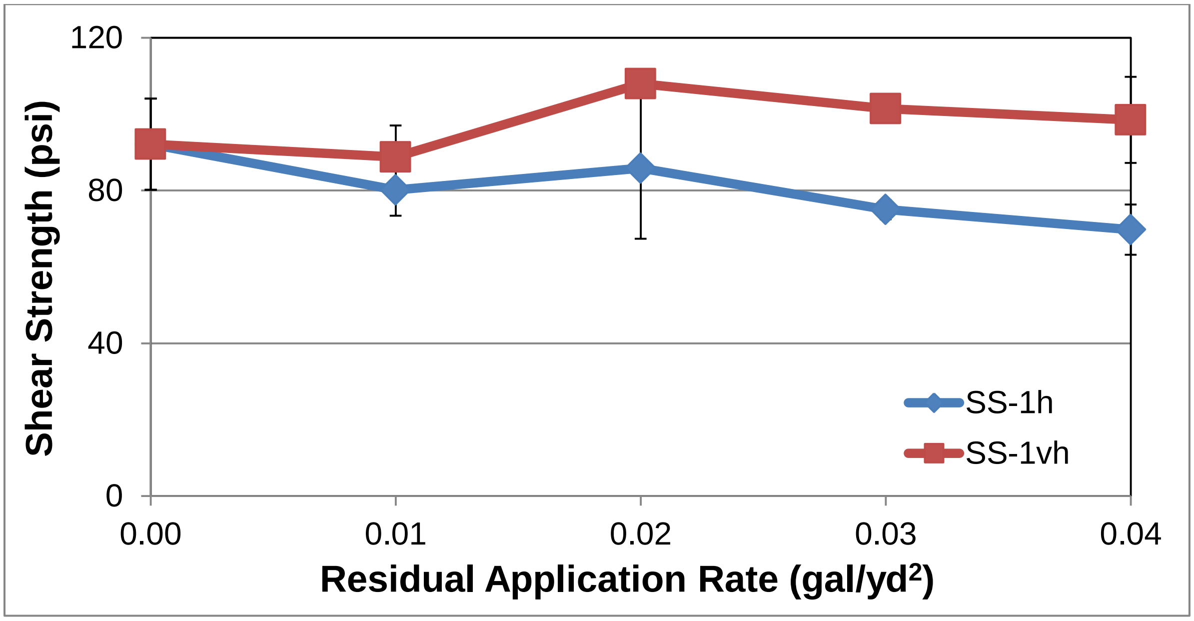


Figure 5.6. Shear strength for surface SMA on top of fresh binder SMA.

5.1.2.2 EFFECT OF TACK COAT TYPE

Two tack coat materials were analyzed: SS-1h and SS-1vh. As illustrated in Figure 5.6, the results of the ISTD showed that SS-1vh performs better than SS-1h at each application rate. For bond strength, a similar trend was observed. Therefore, the use of SS-1vh as tack coat material is recommended.

The same results were obtained in the laboratory phase of this study. In general, SS-1vh performed better than SS-1hp, high float emulsion (HFE), and PG-64-22.

5.2 ILLINOIS ROUTE 98

As previously explained, the IL-98 project had a single surface (milled HMA); however, two construction methods were investigated (conventional paver and spray paver). A total of 19 sections were built in order to observe the effects of the paving method, cleaning procedure, tack coat type, and optimum application rate.

Shear and torque tests were performed on cored specimens; however, the results obtained from the torque test were not consistent. This was because the existing HMA was weaker than the interface; thus, during testing, the majority of the specimens experienced failure in the bottom mix. This demonstrates that the bonding at the interface was relatively very strong. Therefore, the analysis was done using only the results from the ISTD, as presented in Table 5.6. Complete tables of results are presented in Appendix A of this report.

Table 5.6. ISTD Results for Field Evaluation on IL-98 on Top of Milled Surface.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Average Shear Strength (psi)**	Standard Deviation	COV (%)
1 CP	SS-1hp	Milled HMA Surface	Broom	0.02	87.3	8.8	10.0
2 CP				0.04	89.4	6.5	7.3
3 CP				0.06	101.1	4.2	4.2
4 CP				0.08	109.4	2.4	2.2
5 CP			Air Blast	0.06	97.9	7.0	7.2
6 CP	SS-1h		Broom	0.02	80.6	3.9	4.9
7 CP				0.04	78.3	5.8	7.5
8 CP				0.06	65.4	5.6	8.5
9 CP				0.08	62.5	2.8	4.4
10 CP			Air Blast	0.06	89.4	11.0	12.3
11 CP	SS-1vh		Broom	0.02	136.3	7.6	5.6
12 CP				0.04	159.8	4.6	2.9
13 CP				0.06	147.7	14.7	10.0
14 CP				0.08	94.2	4.8	5.1
15 CP			Air Blast	0.06	102.5	6.7	6.6
16 SP	SS-1h		Broom	0.06	89.1	0.4	0.5
17 SP			Air Blast	0.06	71.4	4.6	6.4
18 SP	SS-1hp		Broom	0.06	96.0	0.2	0.2
19 SP			Air Blast	0.06	88.8	3.5	4.0
20 CP	No tack		Broom	0.00	56.4	7.3	13.0

*1 gal/yd^2 = 4.5 L/m^2

**1 psi = 0.0069 MPa

CP = conventional paver; SP = spray paver

5.2.1 TACK COAT OPTIMUM APPLICATION RATE

The optimum application rate was analyzed using only the conventional paving method. Three tack coat materials (SS-1h, SS-1hp and SS-1vh) were applied on top of milled HMA at four application rates (0.02, 0.04, 0.06 and 0.08 gal/yd^2; 0.09, 0.18, 0.27 and 0.36 L/m^2). As shown in Figure 5.7, a clear optimum can be observed for SS-1vh at an application rate of 0.04 gal/yd^2 (0.18 L/m^2). However, for SS-1hp (and to a less extent SS-1h) there was no clear peak in the trend. During the construction of these particular sections, the two tack coat materials were applied a day in advance of paving due both to logistical issues and to follow a common practice in the state of Illinois. These sections were kept un-trafficked until the tack coat material was completely cured; however, they were open to traffic afterwards. This practice might have an effect on the results.

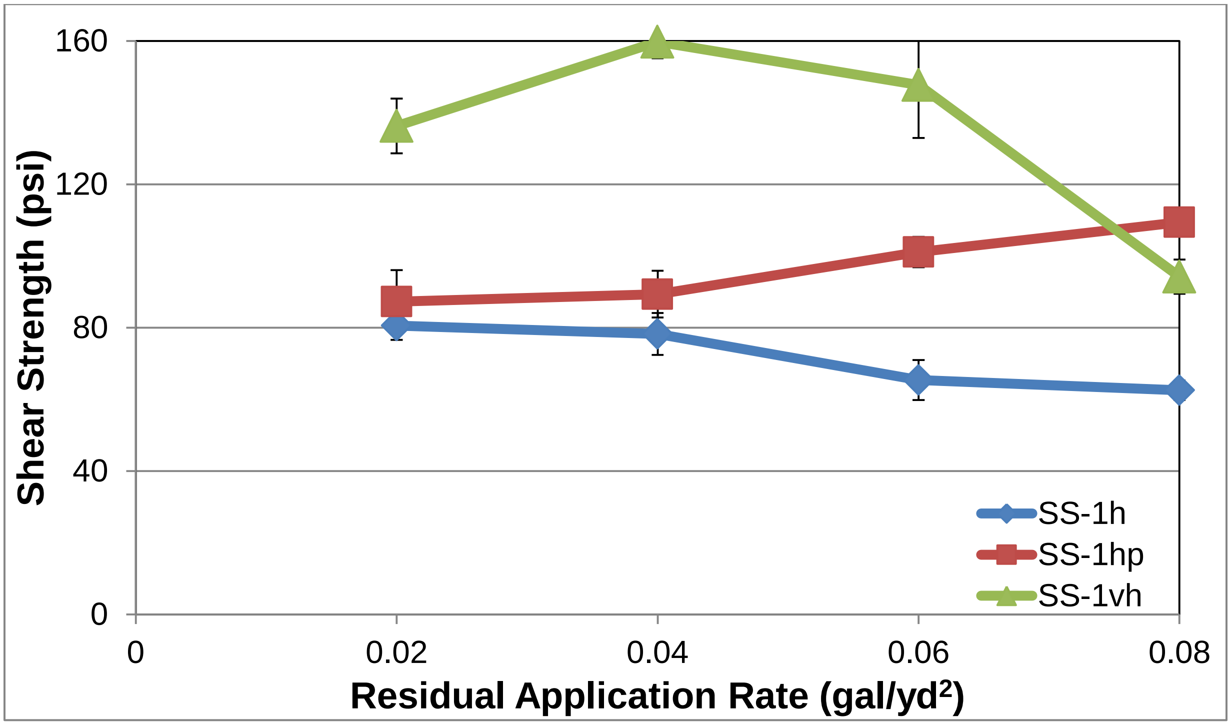


Figure 5.7. Shear strength for milled surfaces.

The laboratory phase of this study found that the optimum application rate for milled HMA surfaces is 0.06 gal/yd^2 (0.27 L/m^2). The field evaluation for the I-80 project obtained the same result. In this particular project, for the SS-1vh the optimum was less, but the results reveal that it is not statistically different than 0.06 gal/yd^2 (0.27 L/m^2). Therefore the use of 0.06 gal/yd^2 (0.27 L/m^2) as an optimum residual application rate for milled surfaces is recommended.

5.2.2 EFFECT OF TACK COAT TYPE

Selecting the correct tack coat for a particular project will improve its service life. As seen in Figure 5.7, SS-1vh had the best performance among the tack coat materials considered. This was observed throughout this study.

In the field, it is easier for contractors to work with SS-1h than with SS-1hp. However, as shown in Figure 5.7, the shear strength developed at the interface was greater when using SS-1hp. Therefore, this material will significantly enhance the pavement life, compared to SS-1h.

5.2.3 IMPACT OF PAVING METHOD

For this project, two paving methods were used, differentiated by the time of tack coat application. In the conventional method, the tack coat was applied by a distributor truck at the desired rate, followed by the material transfer vehicle and the paver driving on top of the tack coat. The curing time was dependent on the material. The spray paver itself applied the tack coat 1 ft (30 cm) in front of the mix. The impact of these two procedures was analyzed to quantify the effect of curing time in the field and to help optimize the construction process.

As seen in Figure 5.8, the spray paver sections showed equal or greater shear strength for both tack coat materials when broom cleaning was used. When air-blast cleaning was used, shear strength for the sections with the spray paver was less. This is likely because, as shown in the I-80 results, the air blast reduces the optimum application rate. Therefore, at the rate of 0.06 gal/yd^2 (0.27 L/m^2) and use of air-blast cleaning, the conventional paver performed better. The effect of air-blast cleaning in the spray paver must be compared with other application rates. The results are shown in Figure 5.9.

A life-cycle cost analysis (LCCA) of the paving methods and use of tack coat materials is presented in Chapter 6.

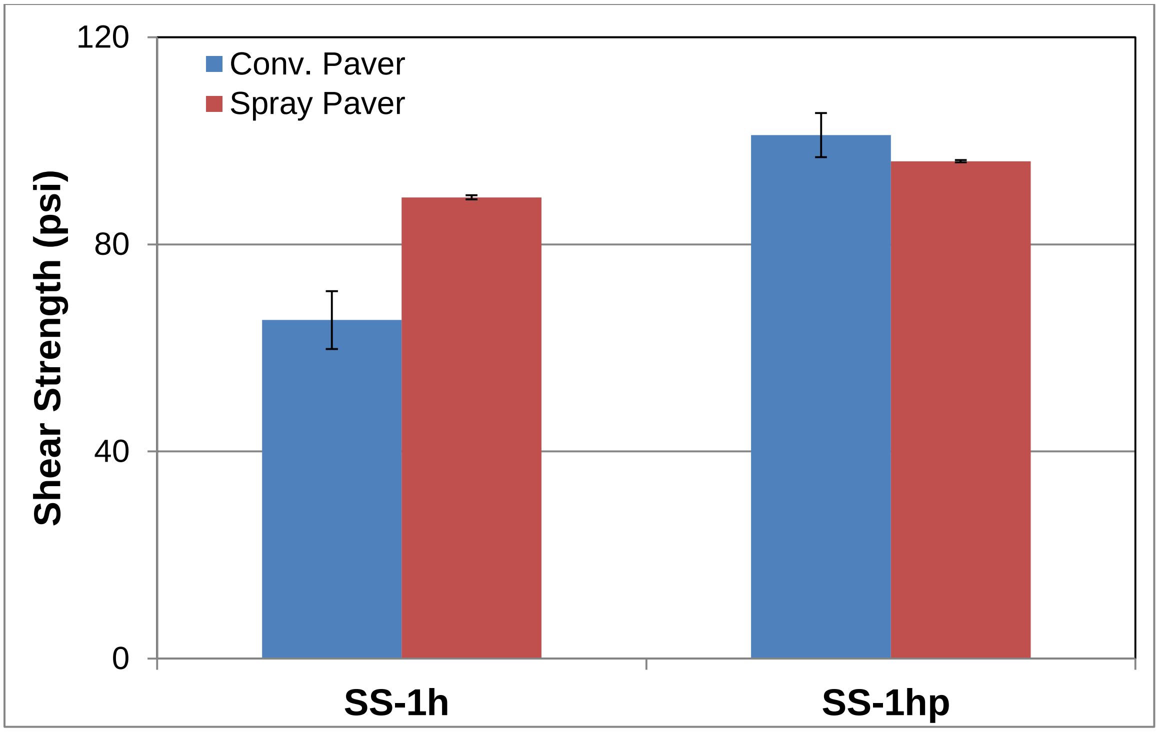


Figure 5.8. Shear strength for both paving methods used with broom cleaning.

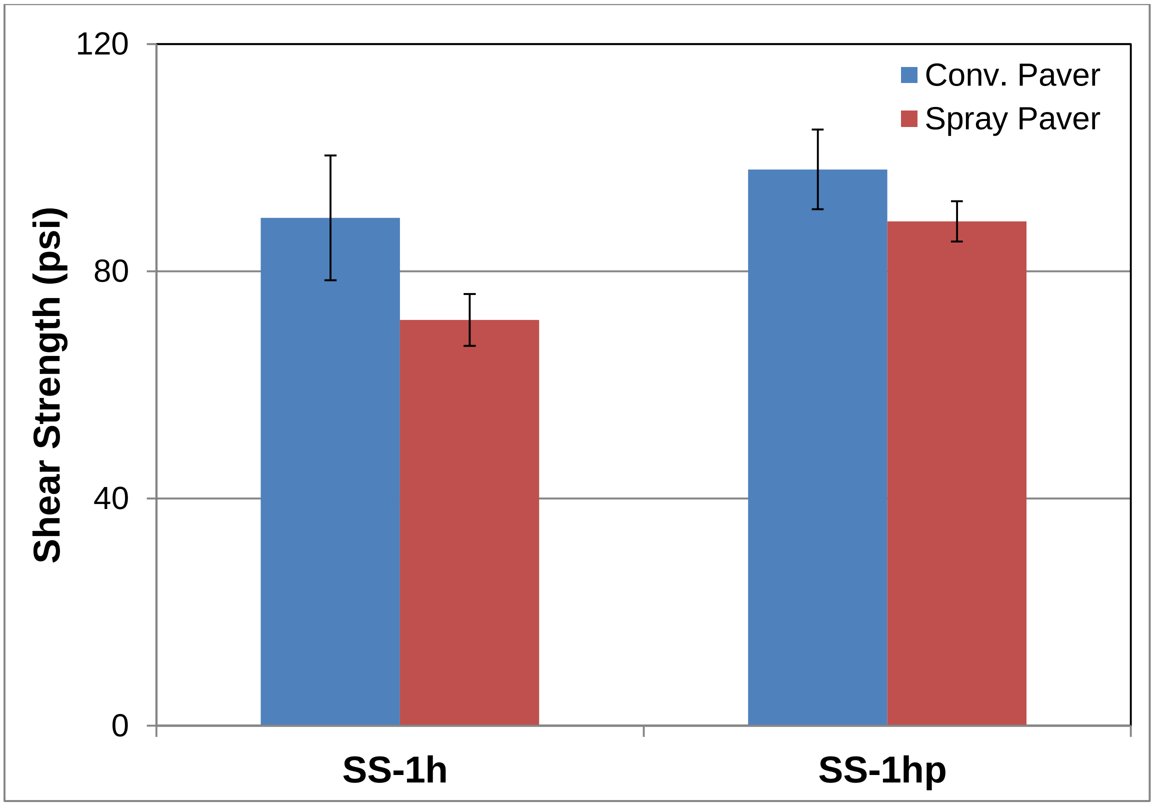


Figure 5.9. Shear strength for both paving methods used with the air-blast cleaning method.

5.2.4 EFFECT OF CLEANING METHOD

Many researchers have investigated the effect of surface cleanliness (Leng et al., 2009) and have reported better performance with air-blast cleaning. However, as mentioned previously, air blasting cannot be used in all projects because it is time consuming and produces dust clouds.

As depicted in Figure 5.10, air-blast cleaning performs equally well or better with SS-1h and SS-1hp emulsions; however, a reduction in shear strength was observed when SS-1vh emulsion was used with a conventional paving method. This reduction could be because the optimum application rate for SS-1vh is 0.04 gal/yd^2 (0.18 L/m^2) for this cleaning method. This was also seen on the I-80 project. Similar results were observed when the spray paver was used, as shown in Figure 5.11.

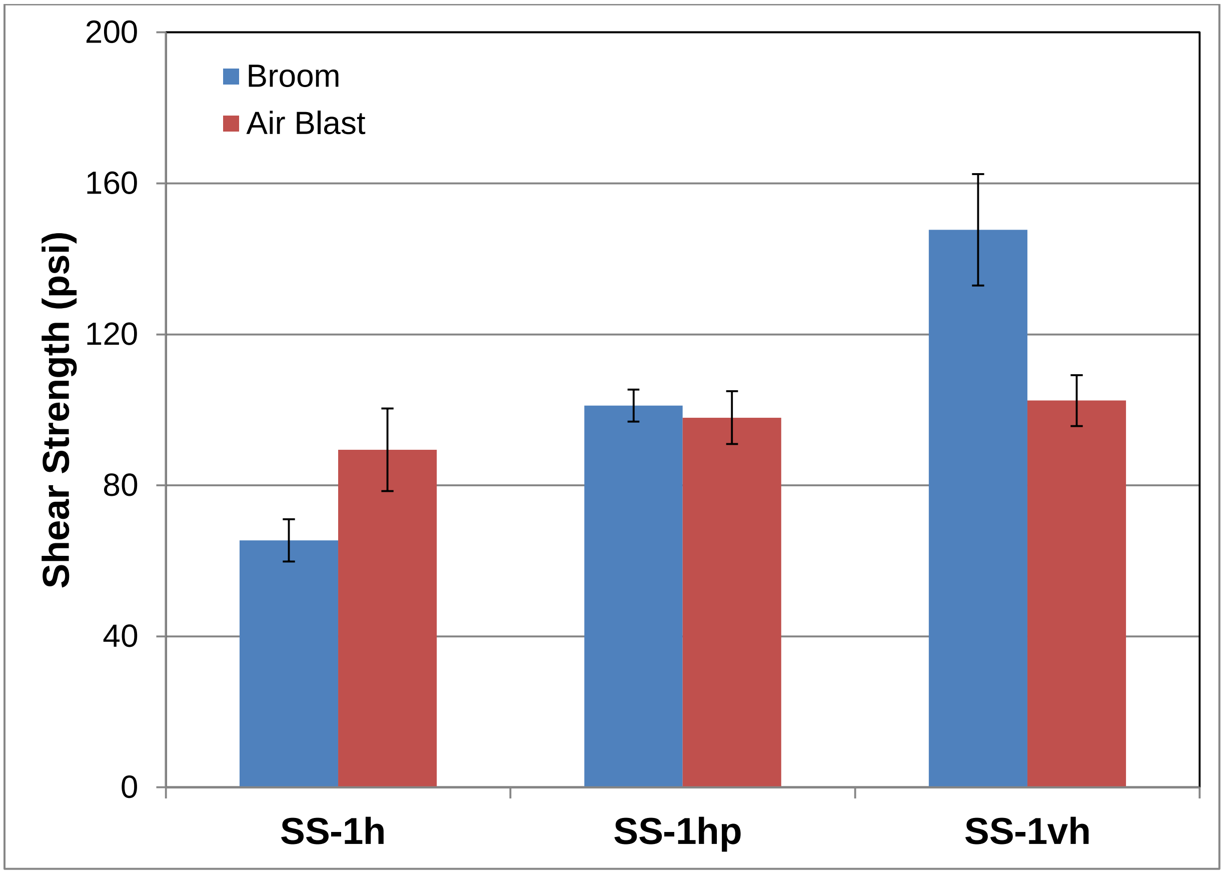


Figure 5.10. Shear strength for both cleaning methods using conventional paving practices.

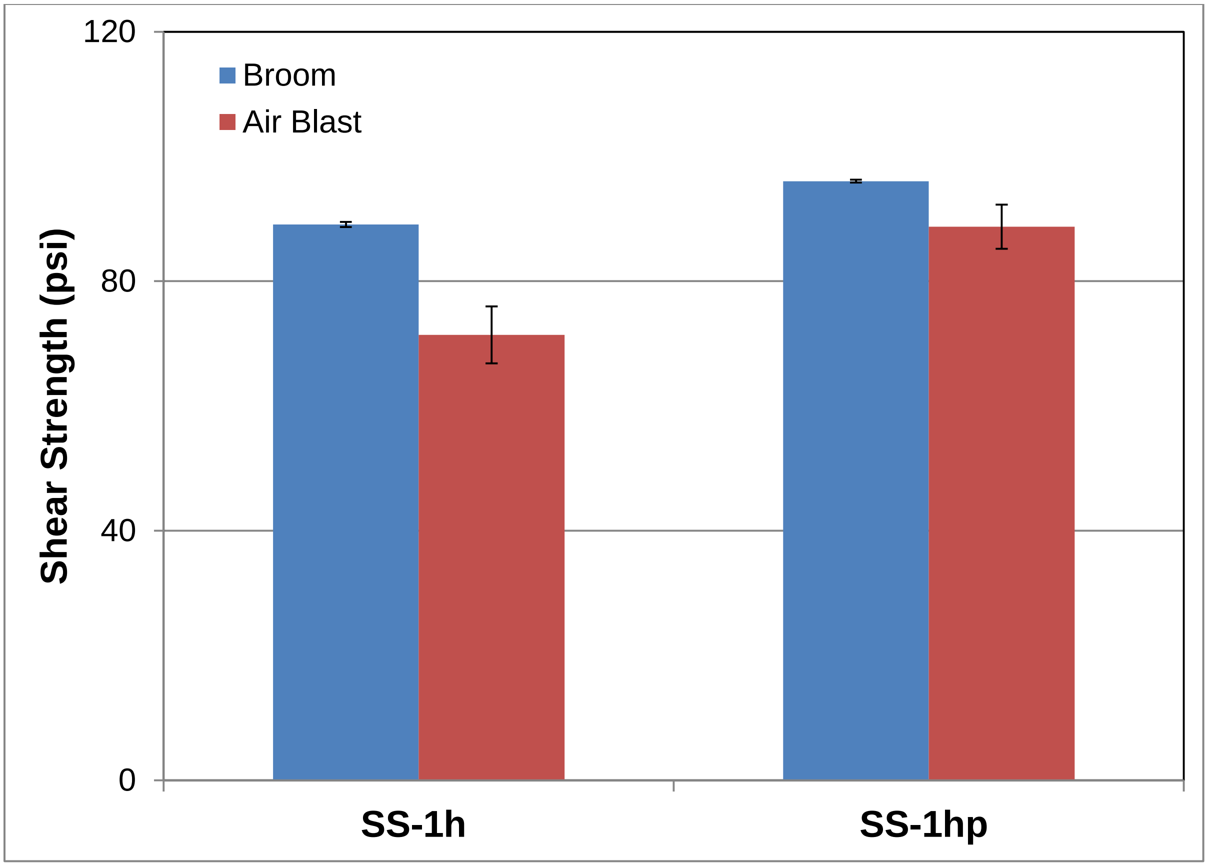


Figure 5.11. Shear strength for both cleaning methods using a spray paver.

CHAPTER 6 LIFE CYCLE COST ANALYSIS

Life-cycle cost analysis (LCCA) provides decision makers with economic information about a particular project or product. By definition, LCCA is “a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment” (Walls and Smith, 1998). Thus, for this particular project, where the main objective was to evaluate performance of tack coat materials in the field, LCCA was the primary tool used.

The LCCA was performed on three tack coat materials (SS-1h, SS-1hp, and SS-1vh) and on two paving methods (conventional paver and spray paver) to compare and optimize costs. The analysis was performed on both field projects (I-80 and IL-98). For this evaluation, it was assumed that the spray paver was used at both construction sites and that the SS-1vh was applied by the spray paver. This allowed comparison of both paving methods and the three tack coat materials under the same conditions. It also allowed for the investigation of time-based user cost, since the IL-98 project was constructed during the day and the I-80 at night. The costs were obtained from the construction companies involved in these projects. The cost of each material and method was calculated by determining their agency and user costs. Deterministic and probabilistic analyses were performed using FHWA’s software, RealCost.

6.1 AGENCY COSTS

Agency costs are those related to the construction, maintenance, and rehabilitation of a particular project. For this study, only the rehabilitation costs were considered. All other costs were estimated to be equal. The analysis period was only one year, to make comparison possible between tack coat materials and paving methods. The entire length of each project was analyzed, and its duration depended on the paving method and tack coat material used. For the probabilistic analysis the agency cost was considered with a normal distribution and a standard deviation of 3% of the costs in each case.

6.1.1 INTERSTATE 80

For the I-80 project, the traffic-closing time considered was 9 p.m. to 5 a.m. When using the conventional paver, tack coat was applied at 9 p.m., and the paving process started at 11 p.m. when using SS-1h and SS-1hp—a total of 6 hr of paving. The cost for idle time was also considered. For SS-1vh, curing time was 15 min, which results in a total of 7.75 hr of paving. In the case of the spray paver, the paving process was 8 hr because no tack coat curing time was needed. These assumptions were based on the optimum tack coat curing time of 2 hr per the findings of the laboratory study (Hasiba, 2012).

The project duration was calculated based on the total tons of mix placed during the project, divided by the actual average tons per hour times the number of paving hours. The total HMA amount was 124,417.42 tons, and the average laid was 253.20 tons/hr. For the conventional paving method, the cost of a distributor truck and material was included in the total tack coat cost. That cost was calculated based on a residual optimum application rate of 0.06 gal/yd^2 (0.27 L/m^2) times the area of the entire project. A cost of $23.04/ton of HMA laid was used, excluding HMA material cost. For the spray paver, the cost of a heating truck for the tack coat material was assumed to be $100.00/hr. The same residual optimum application rate for the conventional paver was used for the spray paver, along with an assumed cost of $24.54/ton of HMA laid. The agency costs are presented in Table 6.1.

Table 6.1. Interstate 80, Agency Cost Calculation.

	Alternative	**Paving Days**	**Tack Coat Material Cost ($)**	**Paving Cost ($)**	**Idle Time Cost ($)**	**Agency Cost ($)**
Conv. Paver	SS-1h	81.9	198,242.04	2,866,577.36	148,783.32	3,213,602.72
	SS-1hp	81.9	256,354.57	2,866,577.36	148,783.32	3,271,715.25
	SS-1vh	63.4	374,250.26	2,866,577.36	—	3,240,827.62
Spray Paver	SS-1h	61.4	165,992.15	3,053,203.49	—	3,219,195.64
	SS-1hp	61.4	223,524.08	3,053,203.49	—	3,276,727.57
	SS-1vh	61.4	338,493.70	3,053,203.49	—	3,391,697.19

6.1.2 ILLINOIS ROUTE 98

For the IL-98 project, tack coats SS-1h and SS-1hp using the conventional paving method and two paving durations were studied. The tack coat materials were cured for 2 hr, as recommended by the laboratory study. In the first duration case, the assumption was made that tack coat application would occur at 5 a.m. and that paving would start at 7 a.m. and be completed by 5 p.m. In the second duration case, the tack coat application was assumed to start at 7 a.m., with paving starting at 9 a.m. and being completed by 5 p.m. This resulted in a total of 10 paving hr per day in the first case and 8 paving hr per day in the second. The first case also included the extra cost of the distributor, flaggers, and crew for the assumed amount of overtime. For the second case, the cost of 2 hr idle time was taken into consideration. In the case of SS-1vh, a curing time of 15 min was used; hence, paving time was established at 9.75 hr. For the spray paver, there is no curing time, resulting in a total of 10 paving hr. Although each contractor determines the optimum time for paving, which depends on several other variables, the focus of this analysis was to perform a comparison between the two practices.

The total amount of mix was 8,195.90 tons, laid at a rate of 194.26 tons/hr. For the conventional paving method, the cost of a distributor truck, flaggers, and material was included in the tack coat cost. That cost was calculated based on a residual optimum application rate of 0.06 gal/yd^2 (0.27 L/m^2) times the area of the entire project. A cost of $2.50/ton of HMA laid was used in the analysis. That cost included equipment and two operators only. For the spray paver, the cost of a heating truck for the tack coat material was assumed at $100.00/hr. The same residual optimum application rate was used as in the conventional paving process: a cost of $4.00/ton of HMA laid, which included costs for the equipment and two operators only. The agency costs are presented Table 6.2.

Table 6.2. Illinois Route 98, Agency Cost Calculation.

	Alternative	Paving Days	Tack Coat Material Cost ($)	Paving Cost ($)	Extra Cost ($)	Idle Time Cost ($)	Agency Cost ($)
Conv. Paver	SS-1h starting at 5 a.m.	4.2	18,671.44	20,489.75	2,231.00	—	41,392.19
	SS-1hp starting at 5 a.m.	4.2	27,455.41	20,489.75	3,314.99	—	51,260.15
	SS-1h starting at 7 a.m.	5.3	18,671.44	20,489.75	—	2,636.90	41,798.09
	SS-1hp starting at 7 a.m.	5.3	27,455.41	20,489.75	—	2,636.90	50,582.06
	SS-1vh starting at 7 a.m.	4.2	28,982.34	20,489.75	—	—	49,472.09
Spray Paver	SS-1h	4.2	12,854.61	32,783.60	—	—	45,638.21
	SS-1hp	4.2	17,309.94	32,783.60	—	—	50,093.54
	SS-1vh	4.2	26,213.32	32,783.60	—	—	58,996.92

6.2 USER COSTS

User costs are those sustained by a road user over the expected performance life of the pavement. These costs are primarily caused by delays resulting from construction, maintenance, or rehabilitation during the life of the project. For the purposes of this study, an analysis over one year was undertaken. User costs were calculated using FHWA's software, RealCost. Both deterministic and probabilistic analyses were performed.

A triangular distribution was chosen for the discount rate, using 3% as the minimum, 4% as the most likely value, and 5% as the maximum. Each project has different traffic information, as shown in Table 6.3. The free-flow capacity for each project was calculated with RealCost, using input provided from traffic information. For the queue dissipation capacity, a normal distribution was used using 1818 vphpl (vehicles per hour per lane) as the mean value and 144 as the standard deviation (Walls and Smith, 1998). The values of user time per vehicle class were used in a triangular distribution and are presented in Table 6.4 (Walls and Smith, 1998). The all-items consumer price index (CPI) was used to convert the values to 2011 dollars, as shown in Table 6.4. The CPI is 224.939 for 2011, and it was 152.4 for 1996, according to the Bureau of Labor Statistics (BLS, n.d.). The traffic hourly distribution is the default given by the software. The speed limit was reduced from 65 mph (105 km/h) in the I-80 project and from 55 mph (89 km/h) in the IL-98 project to a work zone speed limit of 45 mph (72 km/h). For the work zone duration, the input is dependent on each alternative analyzed; a normal distribution with a 10% standard deviation was used. For the I-80 project, the work zone capacity is 1,340 vphpl according to Walls and Smith (1998); however, for the IL-98 project, it was assumed a value of 700 vphpl. The LCCA was performed, and the results are presented in the following section. More details on the analysis are in Appendix B.

Table 6.3. Traffic Data for I-80 and IL-98.

Traffic Data	I-80	IL-98
Annual average daily traffic (AADT)	104200	9600
Single-unit trucks as a percentage of AADT (%)	2.9	1.8
Combination of trucks as a percentage of AADT (%)	7.7	0.8

Table 6.4. User Time Values for 1996 and 2011.

Value of User Time ($/hour)	Year 1996			Year 2011		
Vehicle Class	**Minimum ($)**	**Most Likely ($)**	**Maximum ($)**	**Minimum ($)**	**Most Likely ($)**	**Maximum ($)**
Passenger vehicles	10.00	11.58	13.00	14.76	17.09	19.19
Single-unit trucks	17.00	18.54	20.00	25.09	27.36	29.52
Combination trucks	21.00	22.31	24.00	31.00	32.93	35.42

6.3 DETERMINISTIC RESULTS

The analysis performed on I-80 and IL-98 considered two paving methods (conventional paver and spray paver) and three tack coat materials (SS-1h, SS-1hp, and SS-1vh). Tables 6.5 through 6.7 show the deterministic results for each tack coat material.

Table 6.5. Costs for SS-1h.

Project/Alternative	SS-1h		
	Agency Cost ($)	**User Cost ($)**	**Total ($)**
I-80, Conventional paver	3,213,602.72	299,860.81	3,513,463.53
I-80, Spray paver	3,219,195.64	249,700.90	3,468,896.54
IL-98, Conventional paver starting at 5 a.m.	41,392.19	9,070.50	50,462.69
IL-98, Conventional paver starting at 7 a.m.	41,798.09	11,136.00	52,934.09
IL-98 Spray paver	45,638.21	9,875.30	55,513.51

Table 6.6. Costs for SS-1hp.

Project/Alternative	SS-1hp		
	Agency Cost ($)	**User Cost ($)**	**Total ($)**
I-80, Conventional paver	3,271,715.25	299,860.81	3,571,576.06
I-80, Spray paver	3,276,727.57	249,700.90	3,526,428.47
IL-98, Conventional paver starting at 5 a.m.	51,260.15	8,824.80	60,084.95
IL-98, Conventional paver starting at 7 a.m.	50,582.06	11,136.00	61,718.06
IL-98 Spray paver	50,093.54	9,875.30	59,968.85

Table 6.7. Cost for SS-1vh.

Project/Alternative	SS-1vh		
	Agency Cost ($)	User Cost ($)	Total ($)
I-80, Conventional paver	3,240,827.62	232,126.69	3,472,954.31
I-80, Spray paver	3,391,697.19	249,700.90	3,641,398.08
IL-98, Conventional paver starting at 7 a.m.	49,472.09	8,824.80	58,296.89
IL-98, Spray paver	58,996.92	9,875.30	68,872.22

Figures 6.1 and 6.2 present the cost for each project, based on various paving methods and tack coat materials.

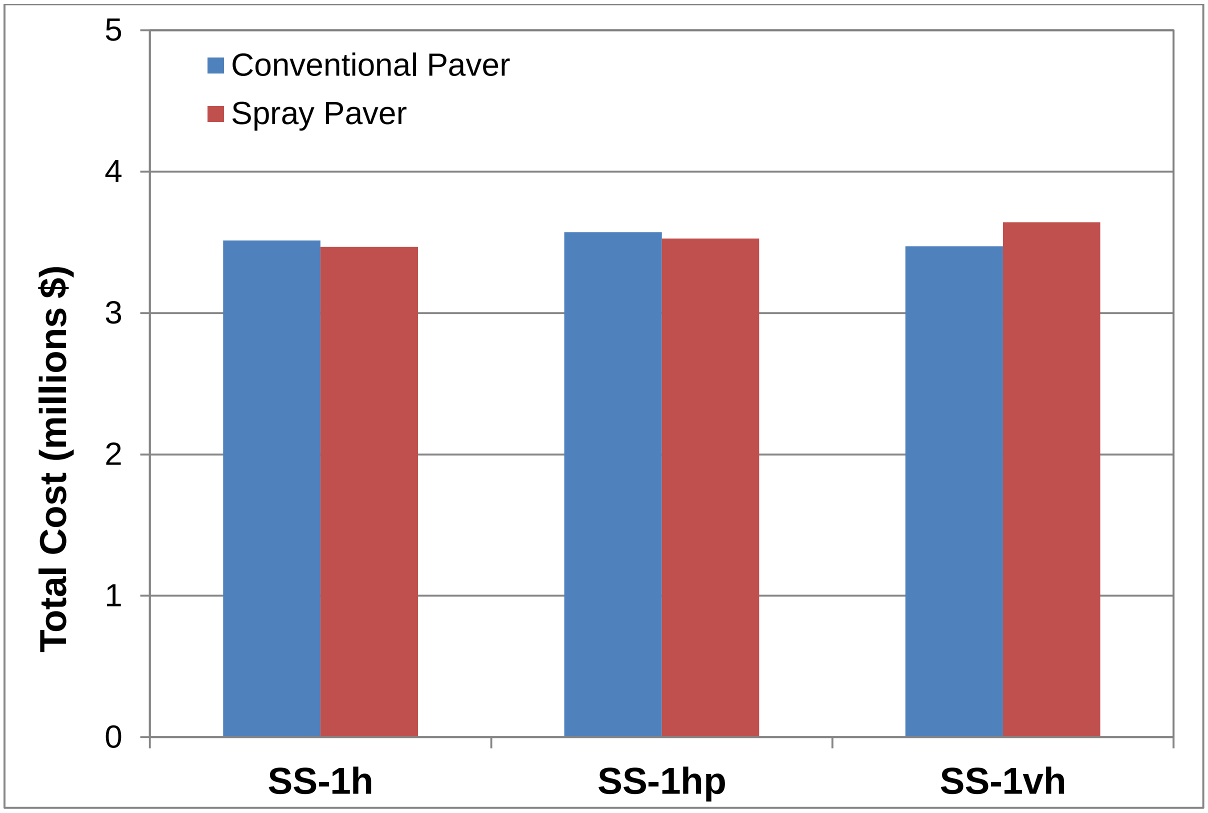


Figure 6.1. Total cost for I-80.

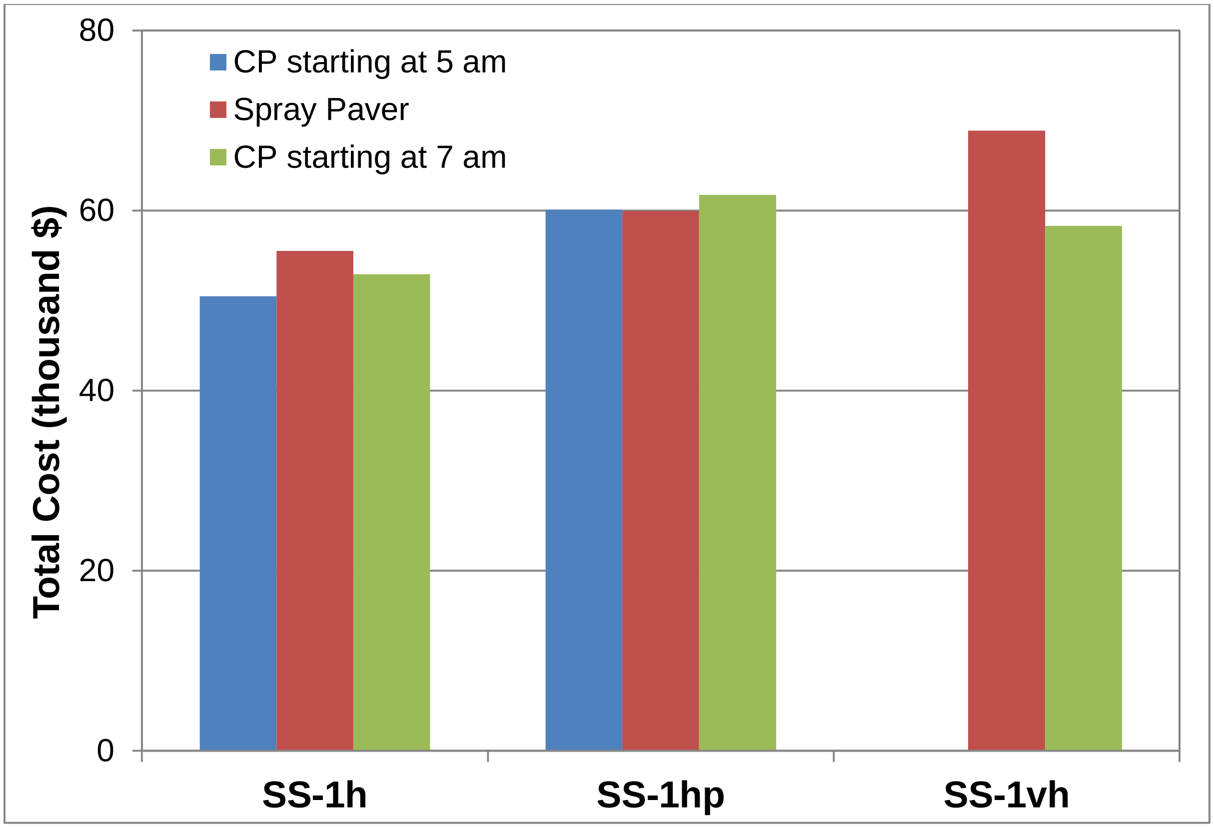


Figure 6.2. Total cost for IL-98.

As shown in Figure 6.1, there is a small reduction in total cost when the spray paver was used, compared to use of the conventional paver, for SS-1h and SS-1hp tack coats. However, that was not the case when using SS-1vh. The increase in cost when using the spray paver with SS-1vh was due to high cost of the materials. The SS-1vh was found to be the most cost effective material when used with the conventional paver. It will eliminate the cost of the idle time and increase the paving time. This could be significant for contractor, especially when project performance bonuses are considered.

This trend might be different for various project sizes, as shown in Figure 6.2. In the case of the IL-98 project, the conventional paving method will be more cost effective than the spray paver. SS-1h is the most cost effective when used in small projects. In this analysis, the main factors affecting total cost were tack coat curing time and construction duration. Figures 6.3 through 6.8 show the percentages corresponding to agency and user costs for each analysis per tack coat material. The LCCA performed will help agencies select an optimized alternative method for tack coat application.

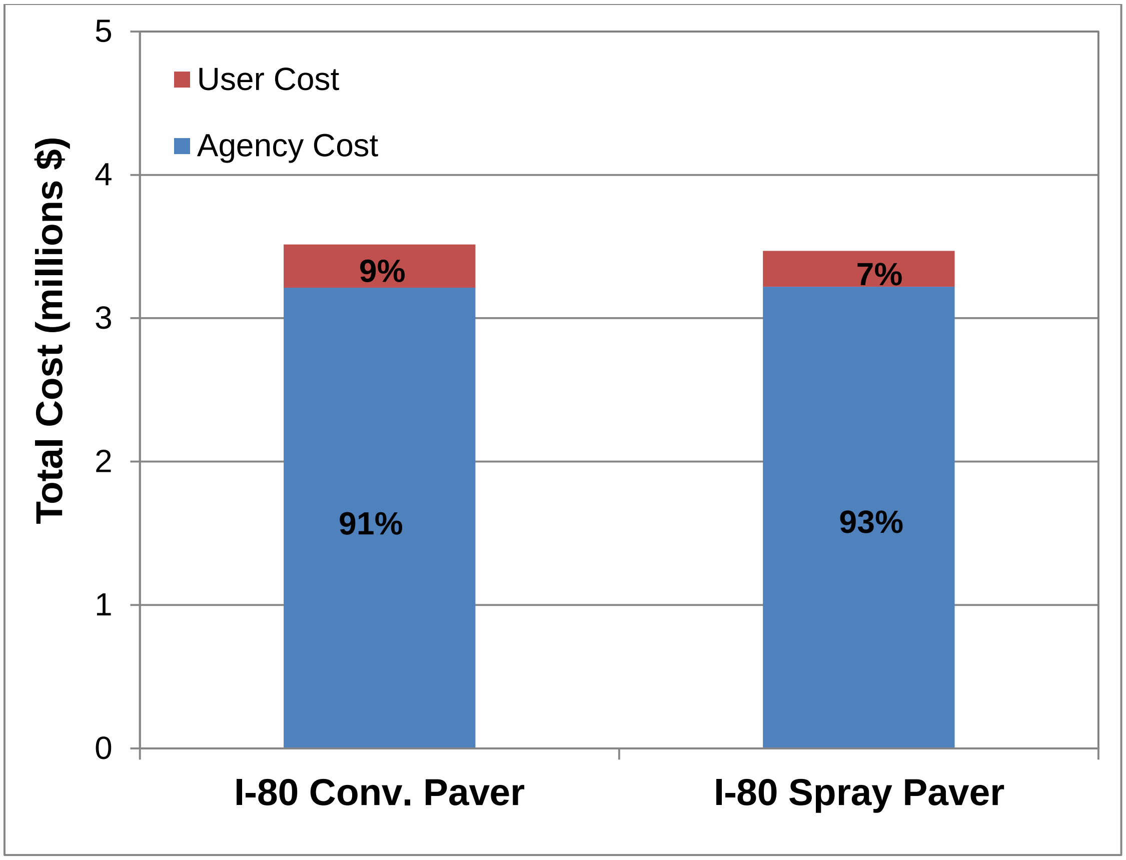


Figure 6.3. Agency and user costs for SS-1h on the I-80 project.

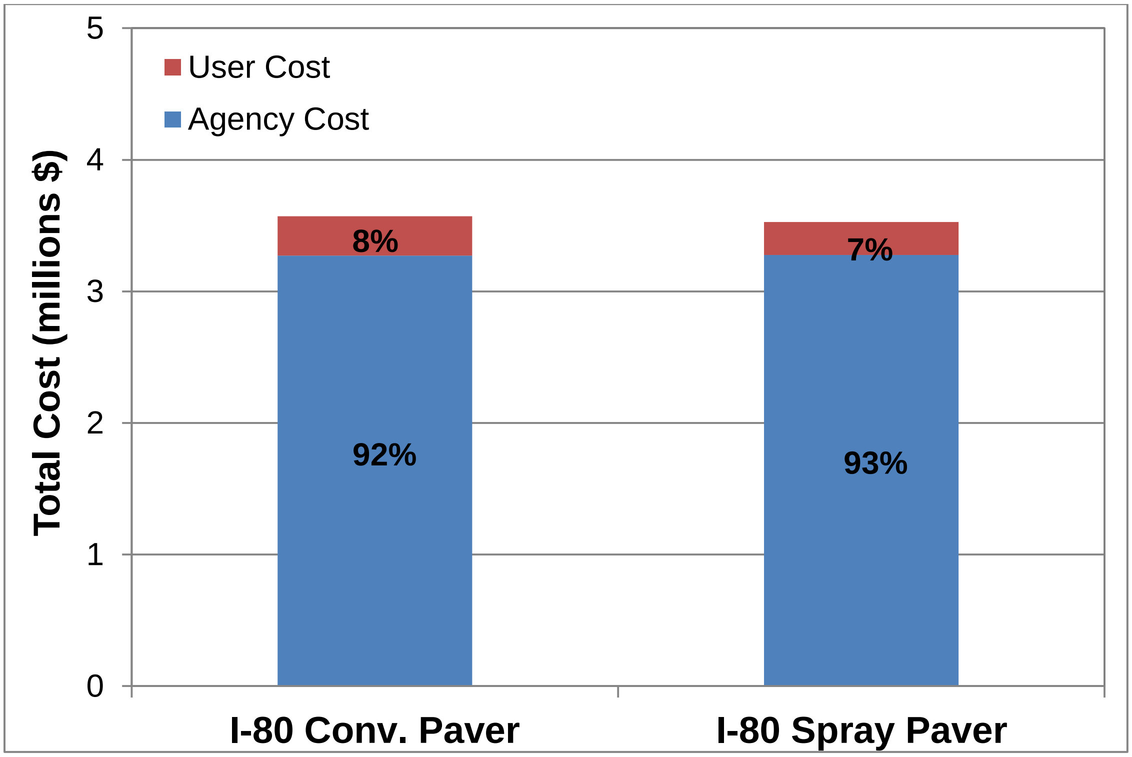


Figure 6.4. Agency and user costs for SS-1hp on the I-80 project.

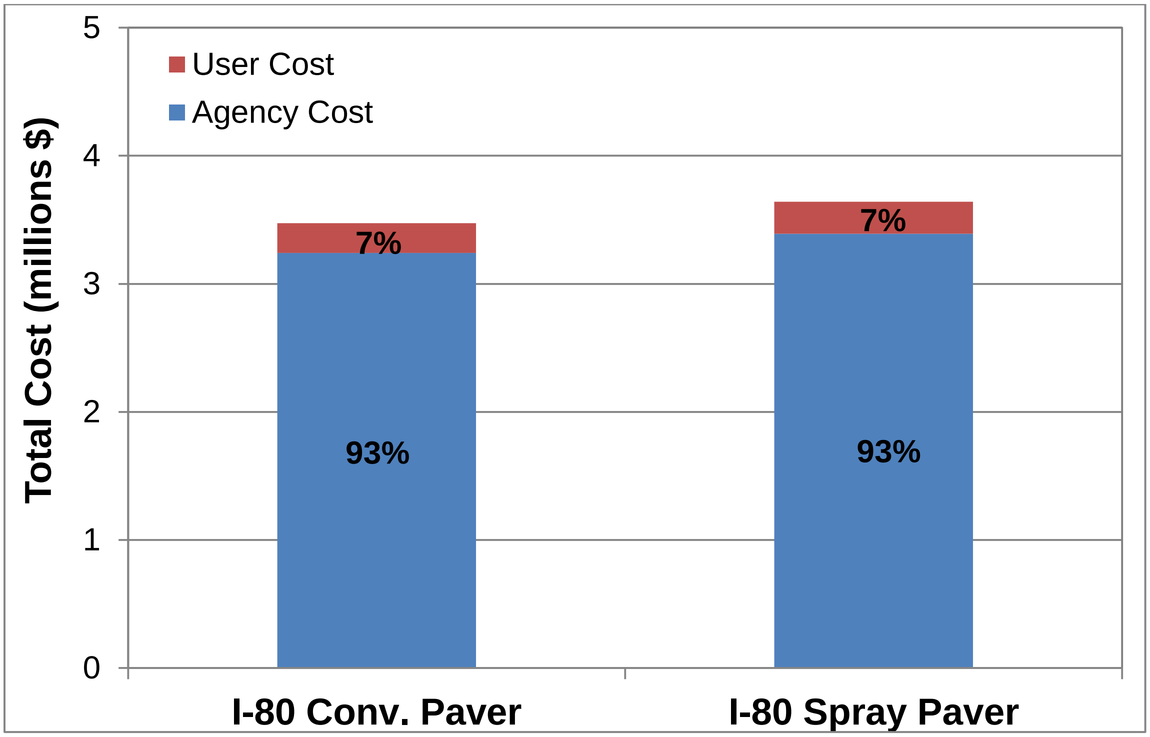


Figure 6.5. Agency and user costs for SS-1vh on the I-80 project.

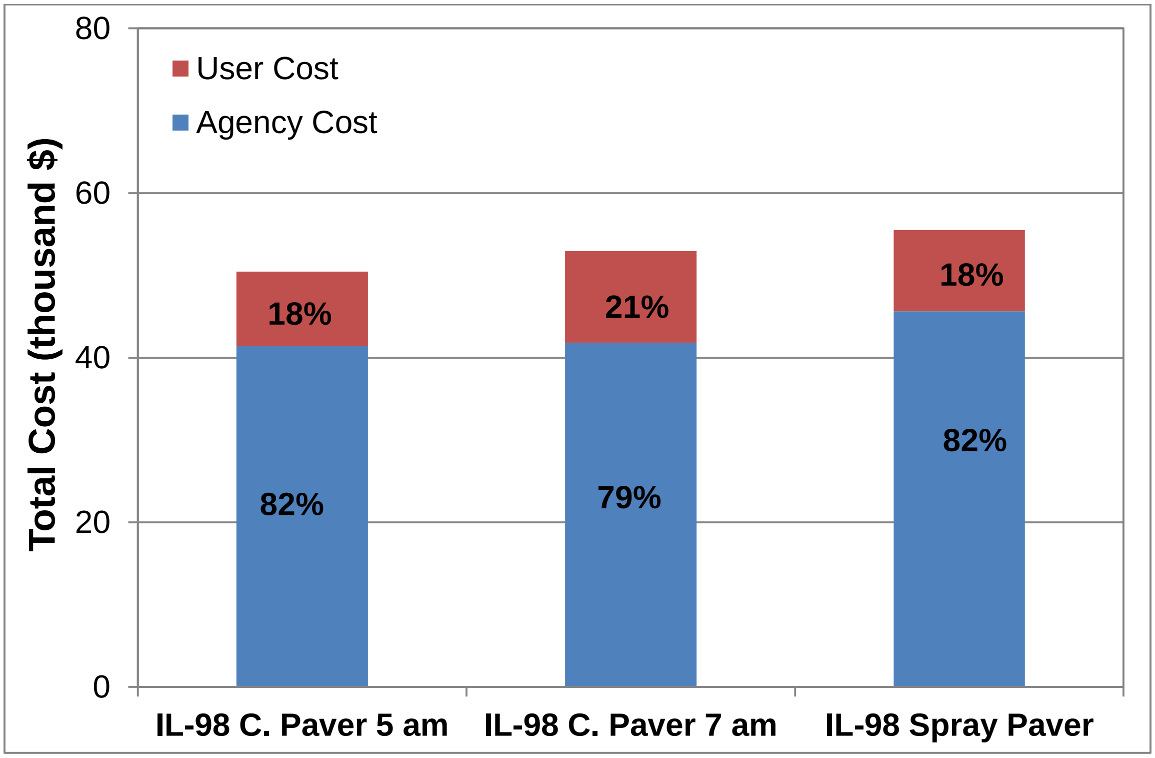


Figure 6.6. Agency and user costs for SS-1h on the IL-98 project.

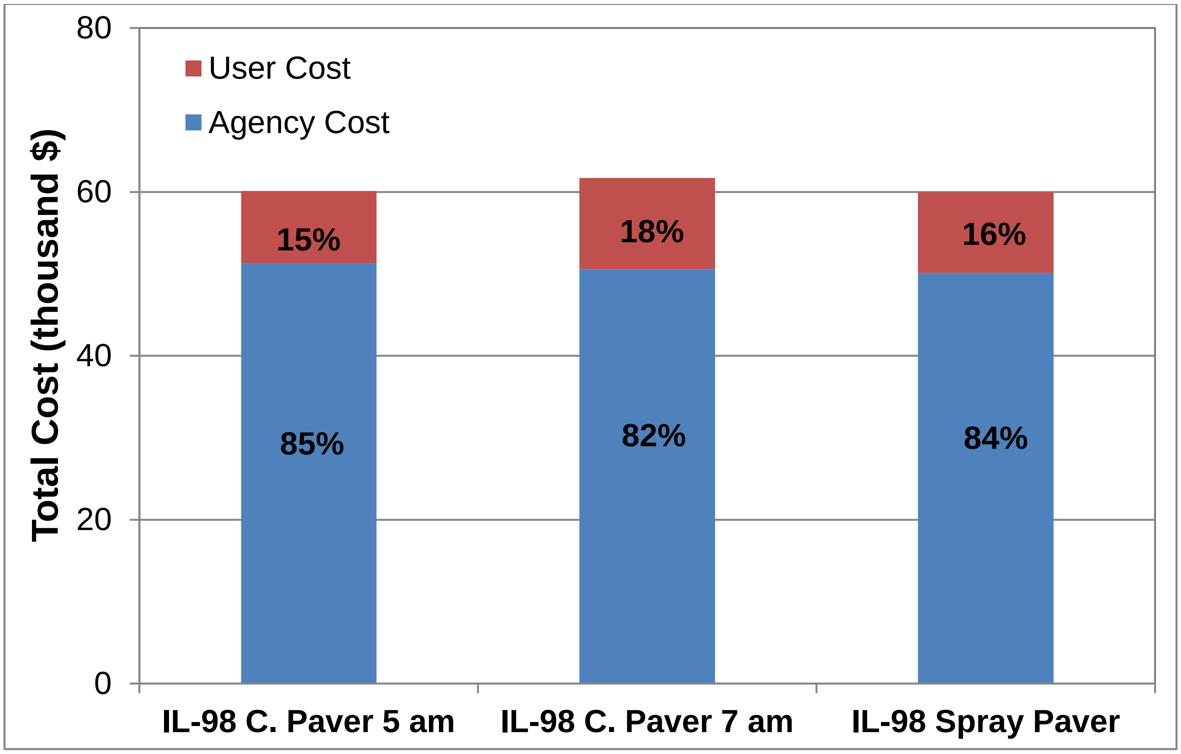


Figure 6.7. Agency and user costs for SS-1hp on the IL-98 project.

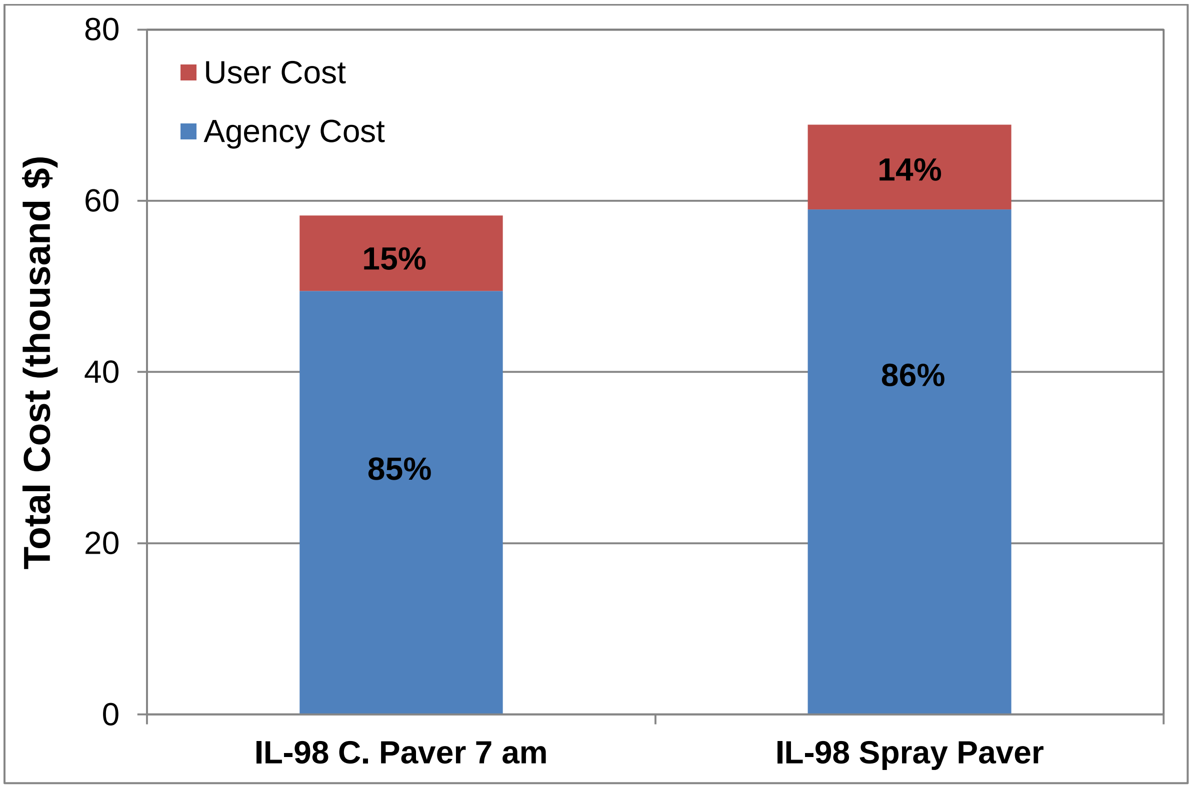


Figure 6.8. Agency and user costs for SS-1vh on the IL-98 project.

In general, the spray paver is a relatively new piece of equipment; a reduction in this equipment cost will dramatically influence the outcome reported herein. Similarly, the cost of SS-1vh tack coat is expected to be reduced the more it is applied. An important factor that was not considered in the analysis was the impact of tack coat material and application process on pavement service life, but that could make a significant difference in pavement service life. The study found that SS-1vh had the greatest interface shear strength compared to other tested tack coats; hence, its cost effectiveness is expected to increase.

6.4 PROBABILISTIC RESULTS

Probabilistic analysis was performed to quantify the risk and uncertainty of different variables. Inputs used in the analysis are dependent on several factors and therefore will produce uncertain variables. Probabilistic analysis can provide help in making the right decision about tack coat application and paving equipment. The RealCost software used variables with probability distributions for this analysis. Up to 2,000 iterations were simulated by the software; results are presented in Tables 6.8 through 6.11. As would be expected, user cost has the most impact on uncertainty.

Table 6.8. Probabilistic Results, Total Cost for Conventional Paver, I-80 Project.

Total Cost						
Total Cost (Present Value)	**SS-1h**		**SS-1hp**		**SS-1vh**	
	Agency Cost ($1000)	**User Cost ($1000)**	**Agency Cost ($1000)**	**User Cost ($1000)**	**Agency Cost ($1000)**	**User Cost ($1000)**
Mean	3,213.57	304.41	3,266.48	307.36	3,239.60	237.69
Standard Deviation	99.87	128.23	99.14	130.41	98.40	114.67
Minimum	2,924.52	209.64	2,975.59	197.52	2,921.95	162.15
Maximum	3,541.43	3,581.74	3,602.89	3,728.76	3,557.89	3,150.51

Table 6.9. Probabilistic Results, Total Cost for Spray Paver, I-80 Project.

Total Cost						
Total Cost (Present Value)	**SS-1h**		**SS-1hp**		**SS-1vh**	
	Agency Cost ($1000)	**User Cost ($1000)**	**Agency Cost ($1000)**	**User Cost ($1000)**	**Agency Cost ($1000)**	**User Cost ($1000)**
Mean	3,219.17	253.49	3,271.48	255.94	3,390.44	255.68
Standard Deviation	100.08	106.78	99.24	108.59	103.06	123.36
Minimum	2,929.52	174.57	2,980.29	164.48	3,057.76	174.43
Maximum	3,547.70	2,982.59	3,608.22	3,105.02	3,723.79	3,389.03

Table 6.10. Probabilistic Results, Total Cost for Conventional Paver, IL-98 Project.

Total Cost (Present Value)	SS-1h Starting at 5 a.m.		SS-1hp Starting at 5 a.m.		SS-1h Starting at 7 a.m.		SS-1hp Starting at 7 a.m.		SS-1vh Starting at 7 a.m.	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	41.36	9.07	51.30	8.80	41.81	11.16	50.60	11.15	49.57	8.84
Standard Deviation	1.17	1.02	1.43	0.97	1.23	1.29	1.48	1.28	1.47	0.97
Minimum	37.56	5.99	46.91	5.86	37.67	6.85	46.04	7.53	44.58	5.98
Maximum	45.31	12.58	56.24	12.05	46.34	16.20	55.19	15.36	54.46	12.21

Table 6.11. Probabilistic Results, Total Cost for Spray Paver, IL-98 Project.

Total Cost (Present Value)	SS-1h		SS-1hp		SS-1vh	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	45.60	9.84	50.02	9.94	58.98	9.90
Standard Deviation	1.45	1.04	1.51	1.07	1.79	1.06
Minimum	41.40	6.81	45.58	6.26	53.19	6.70
Maximum	50.36	12.96	55.16	15.11	64.77	12.82

Probabilistic analysis supports the decision-making process by allowing selection of the risk factor for a particular project. However, the analysis has to be performed for each project because of various uncertainties in input between projects. As shown in Tables 6.8 through 6.11, the minimum and maximum values are the best and worst scenarios that can occur for the tasks analyzed. It should be noted that user cost has high uncertainty compared to the agency cost.

CHAPTER 7 CONCLUSION

Interface bond strength is a parameter that must be considered in the design of pavement projects. Interface bonding loss can result in many distresses and reduce pavement service life. Several parameters were studied in the laboratory and in the field. Data were obtained from the field projects on I-80 and IL-98, and recommendations were made in order to improve tack coat performance at layer interfaces. In addition to tack coat materials and installation approach, other factors affect performance of the tack coat, including pavement surface cleanliness, tack coat application rate, and surface texture.

In the two projects studied for this report, three tack coats were used (SS-1h, SS-1hp, and SS-1vh). Three surfaces were analyzed (milled HMA, milled PCC, and fresh binder SMA), along with two cleaning methods (broom and air blast), Two paving procedures, conventional paver and spray paver, were evaluated. Interface shear and torque tests were performed using strain-controlled monotonic loading on field-obtained cores. Laboratory tests were conducted in triplicate.

The following findings, conclusions, and recommendations for further studies resulted from this research.

7.1 FINDINGS

The following findings, based on field testing and data analysis, could serve as preliminary guidelines to help practitioners efficiently and effectively apply optimum tack coat to enhance pavement performance:

- An application rate of 0.06 gal/yd^2 (0.27 L/m^2) for milled surfaces provided better bonding, while an application rate of 0.02 gal/yd^2 (0.09 L/m^2) is needed for freshly placed HMA.
- SS-1vh provided the best interface bonding; it performed better than the SS-1hp and SS-1h, and it is more cost effective according to the LCCA. However, SS-1hp performed better than SS-1h.
- Air-blast cleaning could reduce the optimum residual application rate while maintaining bond strength.
- The spray paver is very promising equipment. It provided similar results as distributor trucks. Its main advantage is time and cost effectiveness, while a drawback could be functional problems during paving.
- LCCA showed that for large construction projects, SS-1h and SS-1hp are more cost effective than SS-1hv when using the spray paver.
- Tack coat curing time is an important parameter. The optimum value was 2 hr, according to results of the laboratory phase of this study (Hasiba, 2012).

7.2 CONCLUSIONS

The objective of this research was successfully achieved through the application of tack coat at two field projects and considering several parameters that may affect interface performance. The study resulted in an optimized tack coat material, application rate, pavement cleaning technique, and placement method. Guidelines for field application were developed. This study recommends the following:

- An application rate of 0.06 gal/yd^2 (0.27 L/m^2) as an optimum residual application rate for overlay on top of milled surfaces.
- An application rate of 0.02 gal/yd^2 (0.09 L/m^2) as an optimum residual application rate for overlays on top of recently applied HMA.
- Use of SS-1vh, or SS-1hp if SS-1vh is not available.
- A minimum of 2 hr curing time for SS-1h and SS-1hp.

7.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations are offered for future research:

- Further investigation on the spray paver and its performance is needed, including its use with SS-1vh.
- Long-term performance of the sections investigated in this research should be monitored.
- Milling operation quality affects bond strength between pavement layers; this effect should be investigated.
- Guidelines for tack coat application type and operation should be developed based on laboratory performance tests or long-term field performance.
- Environmental effects and moisture damage at the interface should be considered and properly investigated in the future.

REFERENCES

Al-Qadi, I., Carpenter, S., Leng, Z., Ozer, H., and Trepanier, J. (2009). Tack Coat Optimization for HMA Overlay: Accelerated Pavement Testing Report. Report No. FHWA-ICT-09-035, Federal Highway Administration, University of Illinois, Urbana-Champaign.

Al-Qadi, I., Carpenter, S., Leng, Z. and Ozer, H. (2008). Tack Coat Optimization for HMA Overlays: Laboratory Testing. Report No. FHWA-ICT-08-023, Federal Highway Administration, University of Illinois, Urbana-Champaign.

Asphalt Institute. (No date.). Asphalt Pavement Distress Summary. Retrieved from https://www.asphaltinstitute.org/public/engineering/Maintenance_Rehab/Distress_Summary.asp

Asphalt Institute. (1989). *The Asphalt Handbook*. MS-4, Asphalt Institute, Lexington, KY.

Bae, A., Mohammad, L. N., Elseifi, M. A., Button, J. and Patel, N. (2010). Effects of Temperature on Interface Shear Strength of Emulsified Tack Coats and Its Relationship to Rheological Properties. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2180, pp. 102–109.

British Board of Agrément. (2008). Guidelines Document for the Assessment and Certification of Thin Surfacing Systems of Highways. Bucknalls Lane, U.K.

Bureau of Labor Statistics (BLS). (No date.). Annual Average Indexes, 2011 (Tables 1A-23A). Retrieved from: http://www.bls.gov/cpi/cpid11av.pdf.

Canestrari, F., and Santagata, E. (2005). Temperature Effect on the Shear Behavior of Tack Coat Emulsions Used in Flexible Pavements. *The International Journal of Pavement Engineering*, Vol. 6, No. 1, pp. 39–46.

Canestrari, F., Ferrotti, G., Partl, M., and Santagata, E. (2005). Advanced Testing and Characterization of Interlayer Shear Resistance. Paper submitted for the TRB 84th Annual Meeting, Washington D.C., Jan 9–13, 2005 (Section AFK40).

Chen, J., and Huang, C. (2010). Effects of Surface Characteristics on Bonding Properties of Bituminous Tack Coat. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2180, pp. 142–149.

Federal Highway Administration (FHWA). (2004). Life-Cycle Cost Analysis: RealCost User Manual. Office of Asset Management, Federal Highway Administration, Washington, D.C.

Hasiba, K. (2012). Development of Testing Approach for Tack Coat Application Rate at Pavement Layer Interfaces. Master's Thesis, University of Illinois at Urbana-

Champaign.

Leng, Z., Al-Qadi, I. L., Carpenter, S. H., and Ozer, H. (2009). Interface Bonding Between Hot-Mix Asphalt and Various Portland Cement Surfaces: Assessment of Accelerated Pavement Testing and Measurement of Interface Strain. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2127, pp. 20–28.

Leng, Z., Ozer, H., Al-Qadi, I. L., and Carpenter, S. H. (2008). Interface Bonding Between Hot-Mix Asphalt and Various Portland Cement Surfaces: Laboratory Assessment. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2057, pp. 46–53.

Mohammad, L., Bae, A., Elseifi, M., Button, J., and Scherocman, J. (2009). Evaluation of Bond Strength of Tack Coat Materials in the Field. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2126, pp. 1–11.

Mohammad, L., Bae, A., Elseifi, M., Button, J., and Patel, N. (2010). Effects of Pavement Surface Type and Sample Preparation Method on Tack Coat Interface Shear Strength. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2180, pp. 93–101.

Mohammad, L. N., Abdur Raqib, M., and Huang, B. (2002). Influence of Asphalt Tack Coat Materials on Interface Shear Strength. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1789, pp. 56–65.

Mohammad, L., and Button, J. (2005). Optimization of Tack Coat for HMA Placement. Final Contract Report No. NCHRP Project 9-40, National Cooperative Highway Research Program, Louisiana Transportation Research Center and Texas Transportation Institute.

Roadtec, an Astec Industries Company (2008). Spray Paver SP-200. Equipment Information.

Romanoschi, S. A. (1999). Characterization of Pavement Layer Interfaces. PhD dissertation. Louisiana State University, Baton Rouge.

Santagata, F. A., Partl, M. N., Ferrotti G., Canestrari, F., and Flisch, A. (2008). Layer Characteristics Affecting Interlayer Shear Resistance in Flexible Pavements. *Journal of the Association of Asphalt Paving Technologists*, Vol. 77, pp. 221–256.

Sholar, G., Page, G., Musselman, J., Upshaw, P., and Moseley, H. (2004). Preliminary Investigation of a Test Method to Evaluate Bond Strength of Bituminous Tack Coats. *Journal of the Association of Asphalt Paving Technologists*. Vol. 73, pp. 771–801.

Tashman, L. (2008). Evaluation of Construction Practices That Influence the Bond Strength at the Interface between Pavement Layers. *Journal of Performance of*

Constructed Facilities, Vol. 22, No. 3, pp. 154–161.

Tashman, L., Kitae, N., and Papagiannakis, T. (2006). Evaluation of the Influence of Tack Coat Construction Factors on the Bond Strength Between Pavement Layers. Report WCAT 06-002. Washington Center for Asphalt Technology, Washington State University, Pullman, WA.

Uzan, J., Livneh, M., and Eshed, Y. (1978). Investigation of Adhesion Properties between Asphaltic-Concrete Layers. *Journal of the Association of Asphalt Paving Technologists*, Vol. 47, pp. 495–521.

Vögele Wirtgen Group (2009). Vögele Super 1800-2 with Spray Jet Module. Equipment Information.

Walls, J., and Smith M. R. (1998). Pavement Division Interim Technical Bulletin: Life-Cycle Cost Analysis in Pavement Design—Interim Technical Bulletin. FHWA-SA-98-079, U.S. Department of Transportation, Federal Highway Administration, Washington D.C.

West, R. C., Zhang, J., and Moore, J. (2005). Evaluation of Bond Strength between Pavement Layers. NCAT Report 05-08, National Center for Asphalt Technology, Auburn University.

Woods, M. E. (2004). Laboratory Evaluation of Tensile and Shear Strengths of Asphalt Tack Coats. Master's Thesis, Mississippi State University.

Yildrim, Y., Smith, A. F., and Korkmaz, A. (2005). Development of a Laboratory Test Procedure to Evaluate Tack Coat Performance. *Turkish Journal of Engineering and Environmental Sciences*, No. 29, pp. 195–205.

APPENDIX A: RESULTS TABLES

A complete set of tables for the results obtained from the two tests performed on each project are presented in this section.

Table A1. ISTD Results for Field Evaluation on I-80 on Top of Milled Surface per Specimen.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Peak Load (lb)**	Shear Strength (psi)***	Average Shear Strength (psi)	Standard Deviation	COV (%)
1	SS-1h	Milled HMA	Broom Equipment	0.02	1499.3	119.3	110.7	12.2	11.0
					1283.2	102.1			
2				0.04	1217.0	96.8	108.1	15.9	14.7
					1499.0	119.3			
3				0.06	1714.4	136.4	131.3	7.2	5.5
					1586.0	126.2			
4				0.08	1383.0	110.1	115.9	8.3	7.2
					1530.6	121.8			
5			Broom Equipment + Air Blast	0.02	1655.1	131.7	129.9	2.6	2.0
					1609.1	128.0			
6				0.04	1591.5	126.6	132.2	7.8	5.9
					1730.2	137.7			
7				0.06	1515.7	120.6	126.5	8.3	6.6
					1663.9	132.4			
8				0.08	1097.6	87.3	86.2	1.6	1.8
					1069.6	85.1			
9	SS-1vh	Milled PCC	Broom Equipment	0.02	730.5	58.1	60.8	3.8	6.2
					797.2	63.4			
10				0.04	1002.3	79.8	80.2	0.7	0.8
					1014.2	80.7			
11				0.06	824.9	65.6	73.4	10.9	14.9
					1019.0	81.1			
12				0.08	808.1	64.3	73.0	12.3	16.8
					1026.1	81.7			
13			Broom Equipment + Air Blast	0.02	515.4	41.0	39.4	2.2	5.7
					475.5	37.8			
14				0.04	883.9	70.3	81.4	15.6	19.2
					1160.9	92.4			
15				0.06	935.3	74.4	67.9	9.2	13.5
					772.3	61.5			
16				0.08	924.7	73.6	64.9	12.2	18.9
					707.1	56.3			

*1 gal/yd^2 = 4.5 L/m^2

**1 lb = 4.45 N

***1 psi = 0.0069 MPa

Table A2. Torque Bond Test Results for Field Evaluation on I-80 on Top of Milled Surface per Specimen.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Peak Torque (N·m)**	Bond Strength (psi)***	Average Bond Strength (psi)	Standard Deviation	COV (%)
1	SS-1h	Milled HMA	Broom Equipment	0.02	265.0	146.8	151.0	5.9	3.9
					280.0	155.1			
2				0.04	260.0	144.0	130.2	19.6	15.0
					210.0	116.3			
3				0.06	285.0	157.9	155.1	3.9	2.5
					275.0	152.4			
4				0.08	270.0	149.6	135.7	19.6	14.4
					220.0	121.9			
5			Broom Equipment + Air Blast	0.02	280.0	155.1	149.6	7.8	5.2
					260.0	144.0			
6				0.04	255.0	141.3	142.7	2.0	1.4
					260.0	144.0			
7				0.06	200.0	110.8	95.6	21.6	22.5
					145.0	80.3			
8				0.08	165.0	91.4	113.6	31.3	27.6
					245.0	135.7			
9	SS-1vh	Milled PCC	Broom Equipment	0.02	85.0	47.1	63.7	23.5	36.9
					145.0	80.3			
10				0.04	245.0	135.7	115.0	29.4	25.6
					170.0	94.2			
11				0.06	200.0	110.8	123.3	17.6	14.3
					245.0	135.7			
12				0.08	250.0	138.5	131.6	9.8	7.4
					225.0	124.7			
13			Broom Equipment + Air Blast	0.02	140.0	77.6	90.0	17.6	19.6
					185.0	102.5			
14				0.04	215.0	119.1	123.3	5.9	4.8
					230.0	127.4			
15				0.06	285.0	157.9	146.8	15.7	10.7
					245.0	135.7			
16				0.08	235.0	130.2	126.0	5.9	4.7
					220	121.9			

*1 gal/yd^2 = 4.5 L/m^2

**1 N·m = 0.74 lb·ft

***1 psi = 0.0069 MPa

Table A3. ISTD Results for Field Evaluation on I-80 on Top of Fresh Binder SMA per Specimen.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Peak Load (lb)**	Shear Strength (psi)***	Average Shear Strength (psi)	Standard Deviation	COV (%)
1	SS-1h	Binder SMA	Broom Equipment	0.00	1166.9	92.9	92.2	11.9	13.0
					1303.9	103.8			
					1004.1	79.9			
2				0.01	947.2	75.4	80.2	6.8	8.5
					1068.0	85.0			
3				0.02	1242.1	98.8	85.8	18.4	21.5
					914.7	72.8			
4				0.03	964.9	76.8	75.0	2.5	3.3
					920.4	73.2			
5				0.04	935.0	74.4	69.8	6.6	9.4
					818.2	65.1			
6	SS-1vh			0.00	1166.9	92.9	92.2	11.9	13.0
					1303.9	103.8			
					1004.1	79.9			
7				0.01	1041.9	82.9	88.7	8.3	9.3
					1188.5	94.6			
8				0.02	1342.5	106.8	108.0	1.7	1.5
					1372.0	109.2			
9				0.03	1248.2	99.3	101.4	2.9	2.9
					1300.5	103.5			
10				0.04	1338.0	106.5	98.5	11.3	11.5
					1137.4	90.5			

*1 gal/yd^2 = 4.5 L/m^2
**1 lb = 4.45 N
***1 psi = 0.0069 MPa

Table A4. Torque Bond Test Results for Field Evaluation on I-80 on Top of Fresh Binder SMA per Specimen.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Peak Torque (N·m)**	Bond Strength (psi)***	Average Bond Strength (psi)	Standard Deviation	COV (%)
1	SS-1h	Binder SMA	Broom Equipment	0.00	230.0	127.4	128.8	2.0	1.5%
					235.0	130.2			
2				0.01	260.0	144.0	130.2	19.6	15.0%
					210.0	116.3			
3				0.02	260.0	144.0	141.3	3.9	2.8%
					250.0	138.5			
4				0.03	235.0	130.2	137.1	9.8	7.1%
					260.0	144.0			
5				0.04	230.0	127.4	117.7	13.7	11.6%
					195.0	108.0			
6	SS-1vh			0.00	275.0	152.4	142.7	13.7	9.6%
					240.0	133.0			
7				0.01	245.0	135.7	144.0	11.8	8.2%
					275.0	152.4			
8				0.02	270.0	149.6	128.8	29.4	22.8%
					195.0	108.0			
9				0.03	270.0	149.6	159.3	13.7	8.6%
					305.0	169.0			
10				0.04	250.0	138.5	153.7	21.5	14.0%
					305.0	169.0			

*1 gal/yd^2 = 4.5 L/m^2
**1 N·m = 0.74 lb·ft
***1 psi = 0.0069 MPa

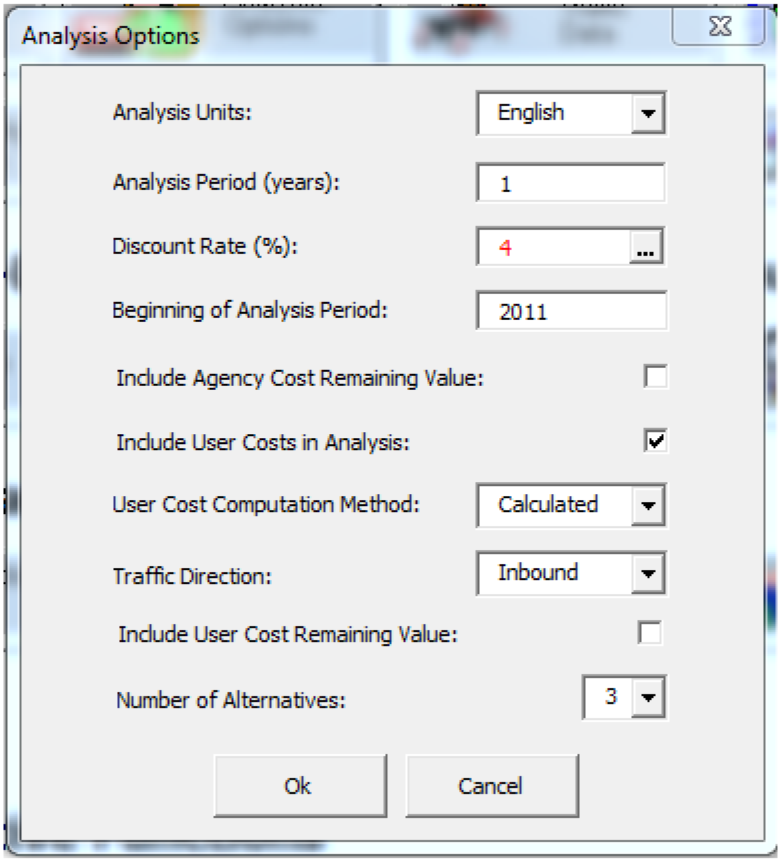
Table A5. ISTD Results for Field Evaluation on IL-98 on Top of Milled Surface per Specimen.

Section	Tack Coat	Bottom Mix	Cleaning Method	Residual App. Rate (gal/yd^2)*	Peak Load (lb)**	Shear Strength (psi)***	Average Shear Strength (psi)	Standard Deviation	COV (%)
1 CP	**SS-1hp**	**Milled HMA**	**Broom**	**0.02**	**1159.6**	**92.3**	**87.3**	**8.7**	**10.0%**
					1161.2	**92.4**			
					970.0	**77.2**			
2 CP				**0.04**	**1116.1**	**88.8**	**89.4**	**6.5**	**7.3%**
					1207.7	**96.1**			
					1044.6	**83.1**			
3 CP				**0.06**	**1254.0**	**99.8**	**101.1**	**4.2**	**4.2%**
					1330.0	**105.8**			
					1227.2	**97.7**			
4 CP				**0.08**	**1388.5**	**110.5**	**109.4**	**2.4**	**2.2%**
					1396.4	**111.1**			
					1340.4	**106.7**			
5 CP			**Air Blast**	**0.06**	**1129.8**	**89.9**	**97.9**	**7.0**	**7.2%**
					1293.5	**102.9**			
					1268.6	**101.0**			
6 CP	**SS-1h**		**Broom**	**0.02**	**993.5**	**79.1**	**80.6**	**3.9**	**4.9%**
					974.9	**77.6**			
					1068.6	**85.0**			
7 CP				**0.04**	**968.8**	**77.1**	**78.3**	**5.8**	**7.5%**
					918.6	**73.1**			
					1063.0	**84.6**			
8 CP				**0.06**	**771.9**	**61.4**	**65.4**	**5.6**	**8.5%**
					902.2	**71.8**			
					791.4	**63.0**			
9 CP				**0.08**	**810.3**	**64.5**	**62.5**	**2.8**	**4.4%**
					761.3	**60.6**			
10 CP			**Air Blast**	**0.06**	**1227.0**	**97.6**	**89.4**	**11.0**	**12.3%**
					967.0	**77.0**			
					1177.0	**93.7**			
11 CP	**SS-1vh**		**Broom**	**0.02**	**1818.5**	**144.7**	**136.3**	**7.6**	**5.6%**
					1632.2	**129.9**			
					1686.0	**134.2**			
12 CP				**0.04**	**1977.0**	**157.3**	**159.8**	**4.6**	**2.9%**
					2073.8	**165.0**			
					1972.2	**156.9**			
13 CP				**0.06**	**1725.1**	**137.3**	**147.7**	**14.7**	**10.0%**
					1987.1	**158.1**			
14 CP				**0.08**	**1128.0**	**89.8**	**94.2**	**4.8**	**5.1%**
					1247.6	**99.3**			
					1176.4	**93.6**			
15 CP			**Air Blast**	**0.06**	**1347.7**	**107.2**	**102.5**	**6.7**	**6.6%**
					1227.8	**97.7**			
16 SP	**SS-1h**		**Broom**	**0.06**	**1123.1**	**89.4**	**89.1**	**0.4**	**0.5%**
					1115.8	**88.8**			
17 SP			**Air Blast**	**0.06**	**863.2**	**68.7**	**71.4**	**4.6**	**6.4%**
					865.7	**68.9**			
					963.7	**76.7**			
18 SP	**SS-1hp**		**Broom**	**0.06**	**1208.9**	**96.2**	**96.0**	**0.2**	**0.2%**
					1205.0	**95.9**			
19 SP			**Air Blast**	**0.06**	**1083.9**	**86.3**	**88.8**	**3.5**	**4.0%**
					1146.9	**91.3**			
20 CP	**No tack**		**Broom**	**0.00**	**774.1**	**61.6**	**56.4**	**7.3**	**13.0%**
					644.1	**51.3**			

*1 gal/yd^2 = 4.5 L/m^2; **1 lb = 4.45 N; ***1 psi = 0.0069 MPa; CP = conventional paver; SP = spray paver

APPENDIX B: REALCOST SOFTWARE

The following figures show the FHWA RealCost software, with data input.



Analysis Units: English

Analysis Period (years): 1

Discount Rate (%): 4

Beginning of Analysis Period: 2011

Include Agency Cost Remaining Value: ☐

Include User Costs in Analysis: ☑

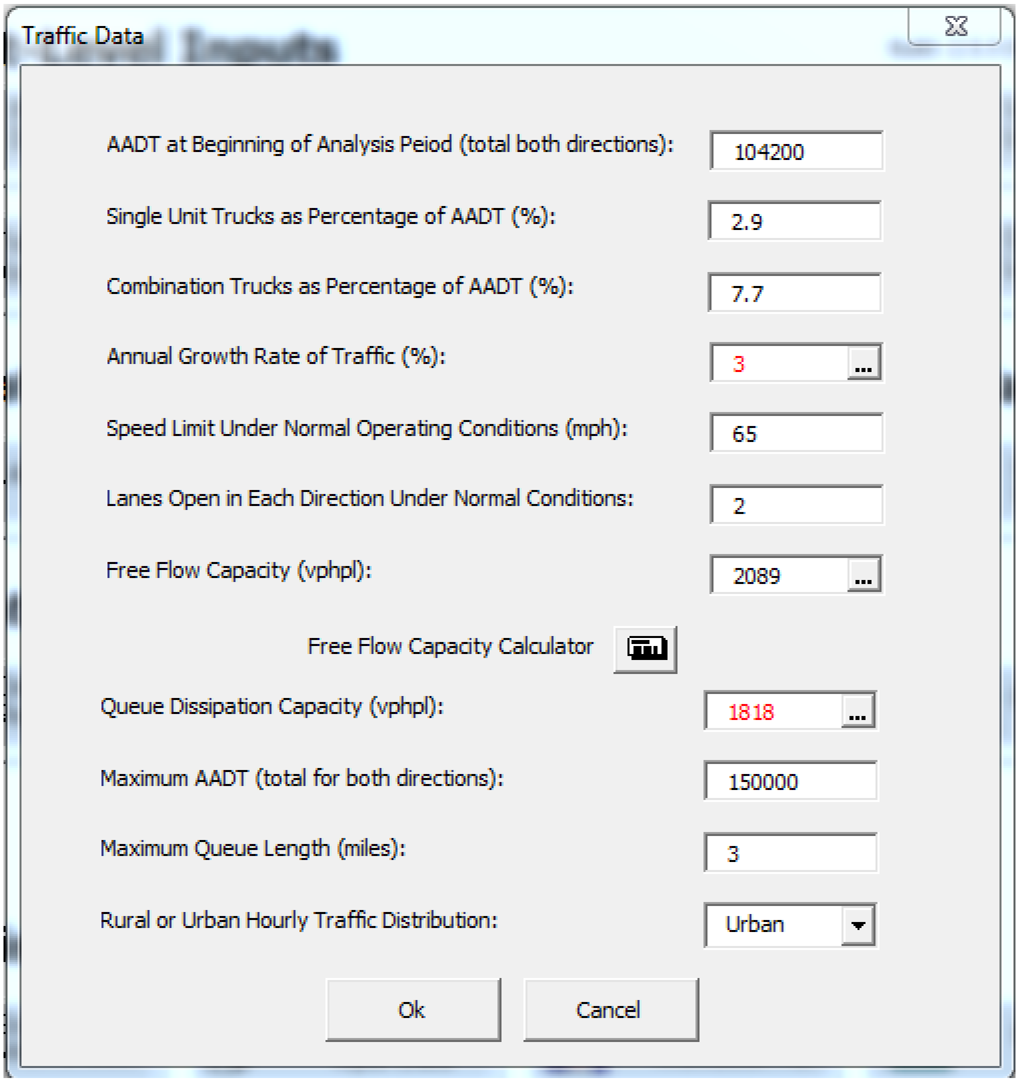
User Cost Computation Method: Calculated

Traffic Direction: Inbound

Include User Cost Remaining Value: ☐

Number of Alternatives: 3

Figure B1. Analysis options, same for all cases.



AADT at Beginning of Analysis Peiod (total both directions): 104200

Single Unit Trucks as Percentage of AADT (%): 2.9

Combination Trucks as Percentage of AADT (%): 7.7

Annual Growth Rate of Traffic (%): 3

Speed Limit Under Normal Operating Conditions (mph): 65

Lanes Open in Each Direction Under Normal Conditions: 2

Free Flow Capacity (vphpl): 2089

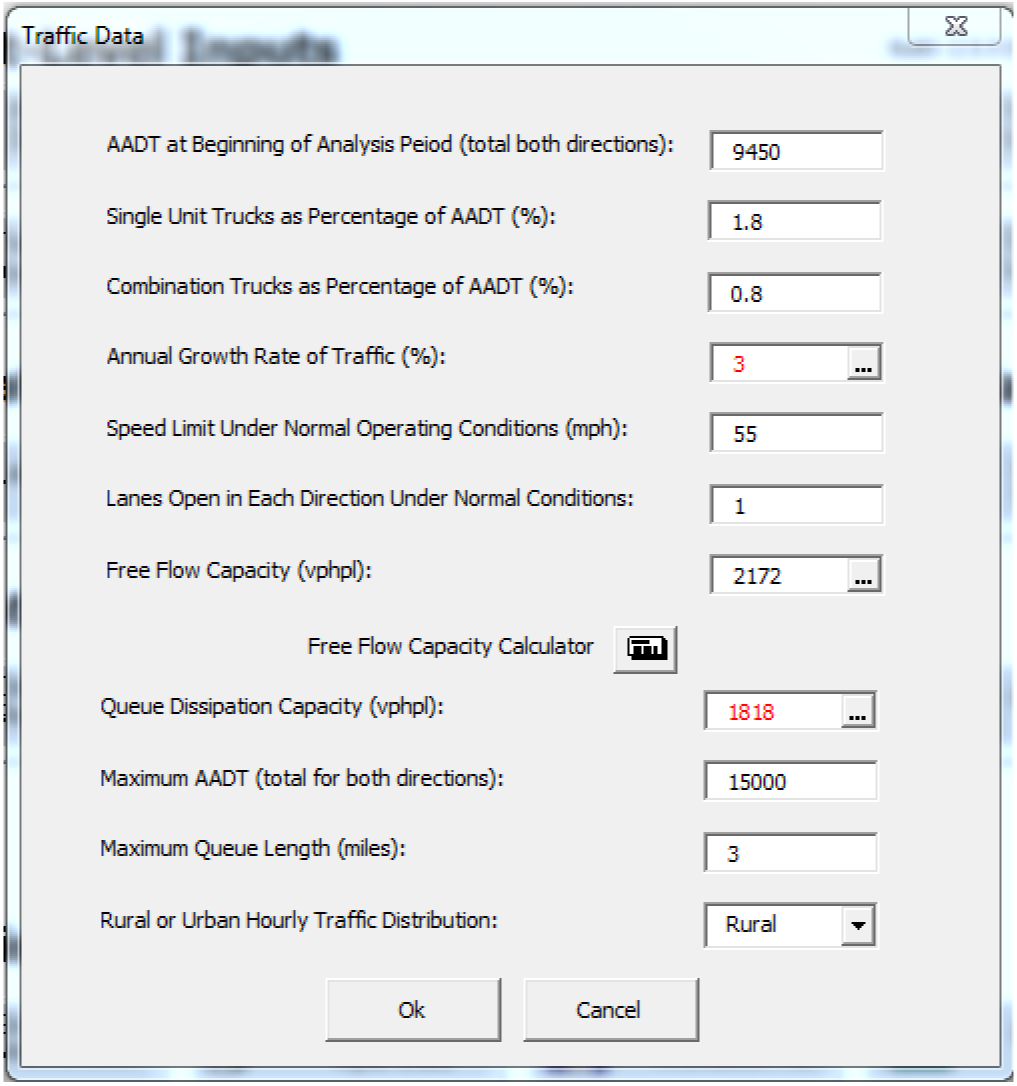
Queue Dissipation Capacity (vphpl): 1818

Maximum AADT (total for both directions): 150000

Maximum Queue Length (miles): 3

Rural or Urban Hourly Traffic Distribution: Urban

Figure B2. Traffic data for I-80 project.


Traffic Data

AADT at Beginning of Analysis Peiod (total both directions): 9450

Single Unit Trucks as Percentage of AADT (%): 1.8

Combination Trucks as Percentage of AADT (%): 0.8

Annual Growth Rate of Traffic (%): 3

Speed Limit Under Normal Operating Conditions (mph): 55

Lanes Open in Each Direction Under Normal Conditions: 1

Free Flow Capacity (vphpl): 2172

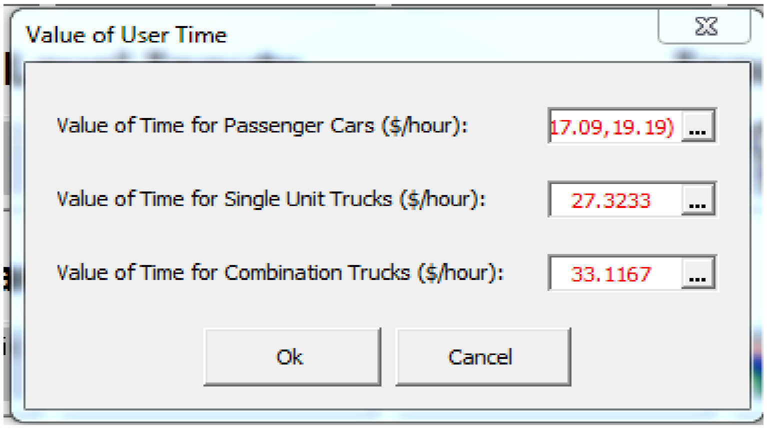
Queue Dissipation Capacity (vphpl): 1818

Maximum AADT (total for both directions): 15000

Maximum Queue Length (miles): 3

Rural or Urban Hourly Traffic Distribution: Rural

Figure B3. Traffic Data for IL-98 project.

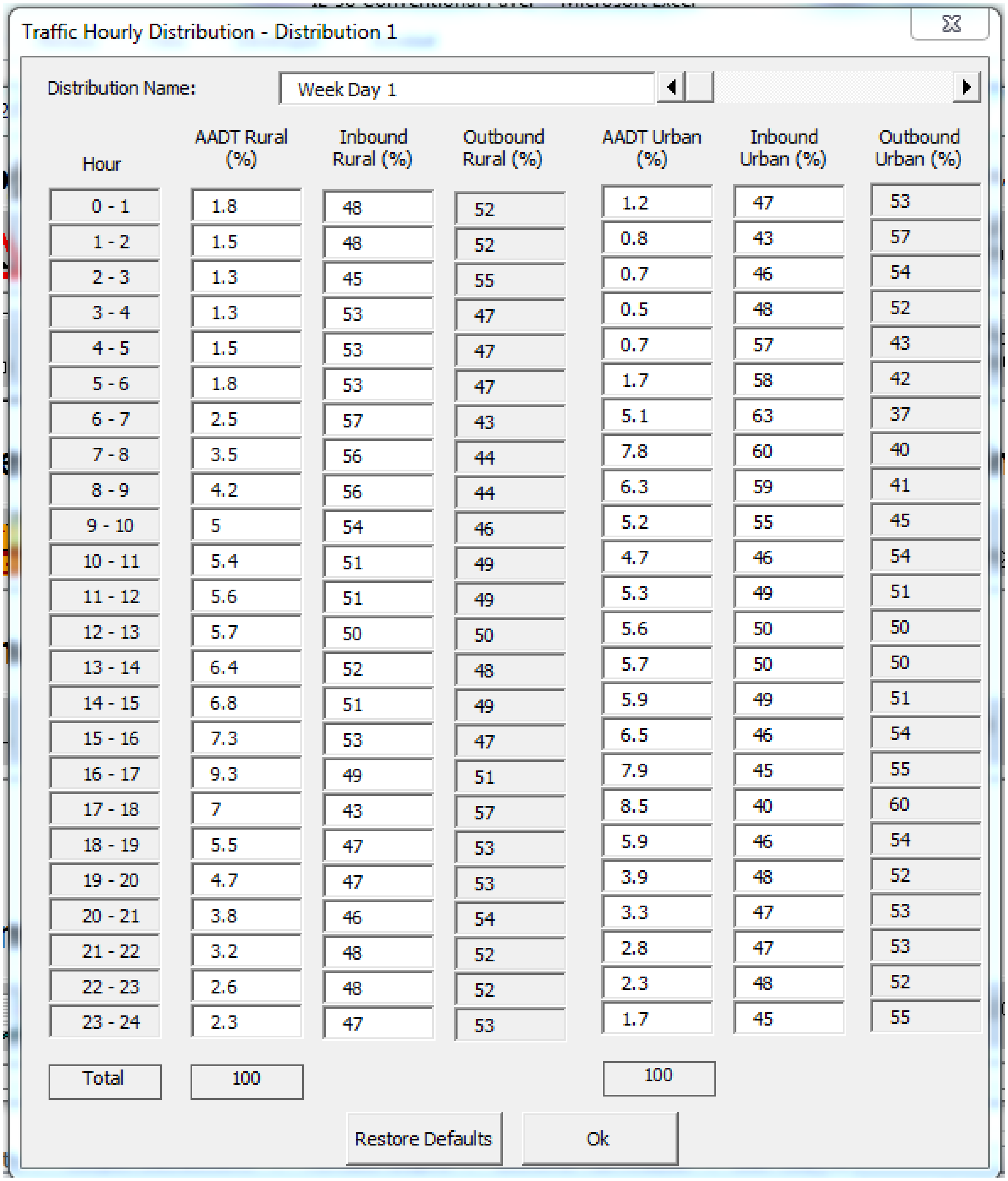

Value of User Time

Value of Time for Passenger Cars ($/hour): 17.09,19.19)

Value of Time for Single Unit Trucks ($/hour): 27.3233

Value of Time for Combination Trucks ($/hour): 33.1167

Figure B4. Value of user time, same for all cases.

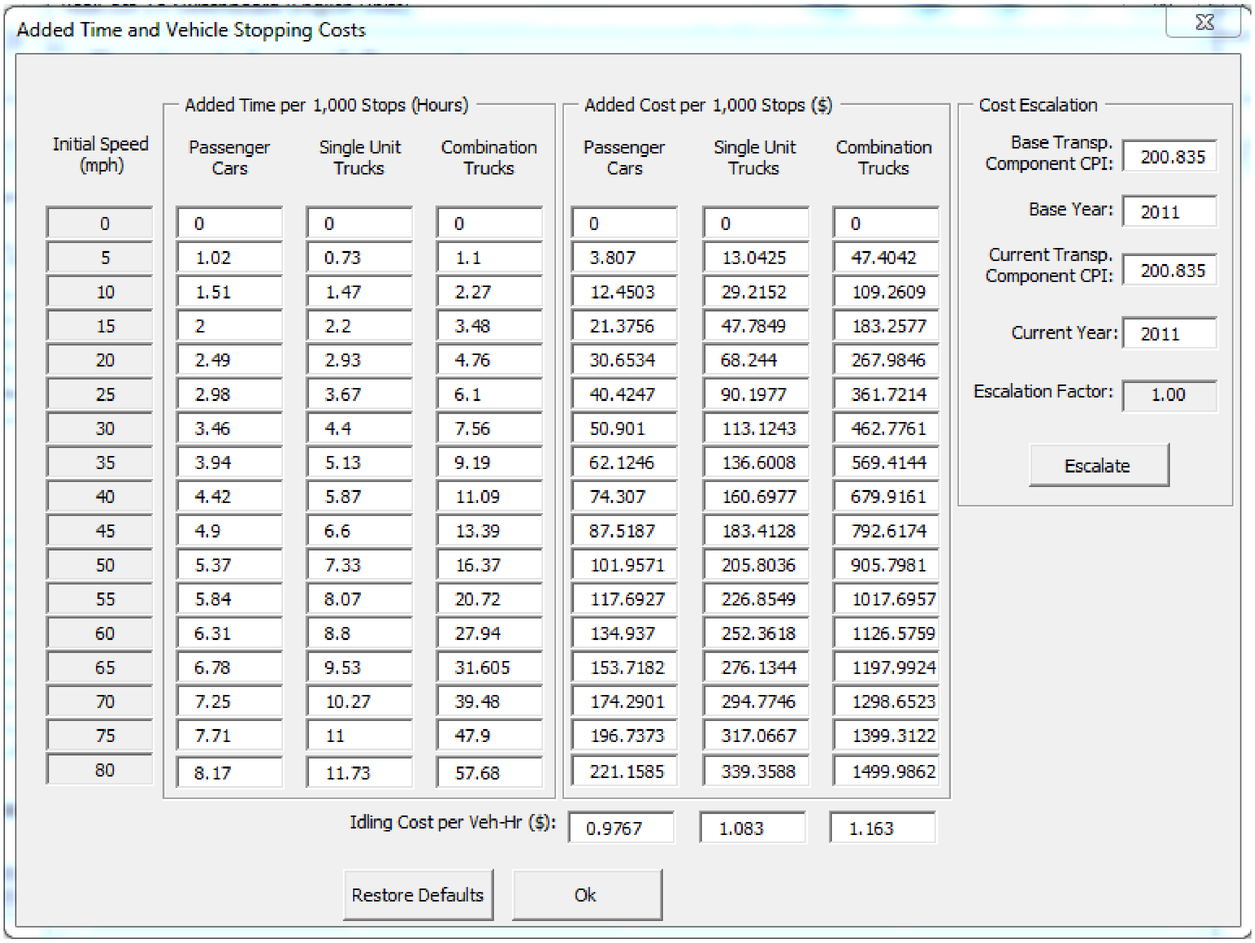


Traffic Hourly Distribution - Distribution 1

Distribution Name: Week Day 1

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.8	48	52	1.2	47	53
1 - 2	1.5	48	52	0.8	43	57
2 - 3	1.3	45	55	0.7	46	54
3 - 4	1.3	53	47	0.5	48	52
4 - 5	1.5	53	47	0.7	57	43
5 - 6	1.8	53	47	1.7	58	42
6 - 7	2.5	57	43	5.1	63	37
7 - 8	3.5	56	44	7.8	60	40
8 - 9	4.2	56	44	6.3	59	41
9 - 10	5	54	46	5.2	55	45
10 - 11	5.4	51	49	4.7	46	54
11 - 12	5.6	51	49	5.3	49	51
12 - 13	5.7	50	50	5.6	50	50
13 - 14	6.4	52	48	5.7	50	50
14 - 15	6.8	51	49	5.9	49	51
15 - 16	7.3	53	47	6.5	46	54
16 - 17	9.3	49	51	7.9	45	55
17 - 18	7	43	57	8.5	40	60
18 - 19	5.5	47	53	5.9	46	54
19 - 20	4.7	47	53	3.9	48	52
20 - 21	3.8	46	54	3.3	47	53
21 - 22	3.2	48	52	2.8	47	53
22 - 23	2.6	48	52	2.3	48	52
23 - 24	2.3	47	53	1.7	45	55
Total	100			100		

Figure B5. Traffic hourly distribution, same for all cases.



Added Time and Vehicle Stopping Costs

Initial Speed (mph)	Added Time per 1,000 Stops (Hours)			Added Cost per 1,000 Stops ($)		
	Passenger Cars	Single Unit Trucks	Combination Trucks	Passenger Cars	Single Unit Trucks	Combination Trucks
0	0	0	0	0	0	0
5	1.02	0.73	1.1	3.807	13.0425	47.4042
10	1.51	1.47	2.27	12.4503	29.2152	109.2609
15	2	2.2	3.48	21.3756	47.7849	183.2577
20	2.49	2.93	4.76	30.6534	68.244	267.9846
25	2.98	3.67	6.1	40.4247	90.1977	361.7214
30	3.46	4.4	7.56	50.901	113.1243	462.7761
35	3.94	5.13	9.19	62.1246	136.6008	569.4144
40	4.42	5.87	11.09	74.307	160.6977	679.9161
45	4.9	6.6	13.39	87.5187	183.4128	792.6174
50	5.37	7.33	16.37	101.9571	205.8036	905.7981
55	5.84	8.07	20.72	117.6927	226.8549	1017.6957
60	6.31	8.8	27.94	134.937	252.3618	1126.5759
65	6.78	9.53	31.605	153.7182	276.1344	1197.9924
70	7.25	10.27	39.48	174.2901	294.7746	1298.6523
75	7.71	11	47.9	196.7373	317.0667	1399.3122
80	8.17	11.73	57.68	221.1585	339.3588	1499.9862
Idling Cost per Veh-Hr ($):				0.9767	1.083	1.163

Cost Escalation

Base Transp. Component CPI: 200.835

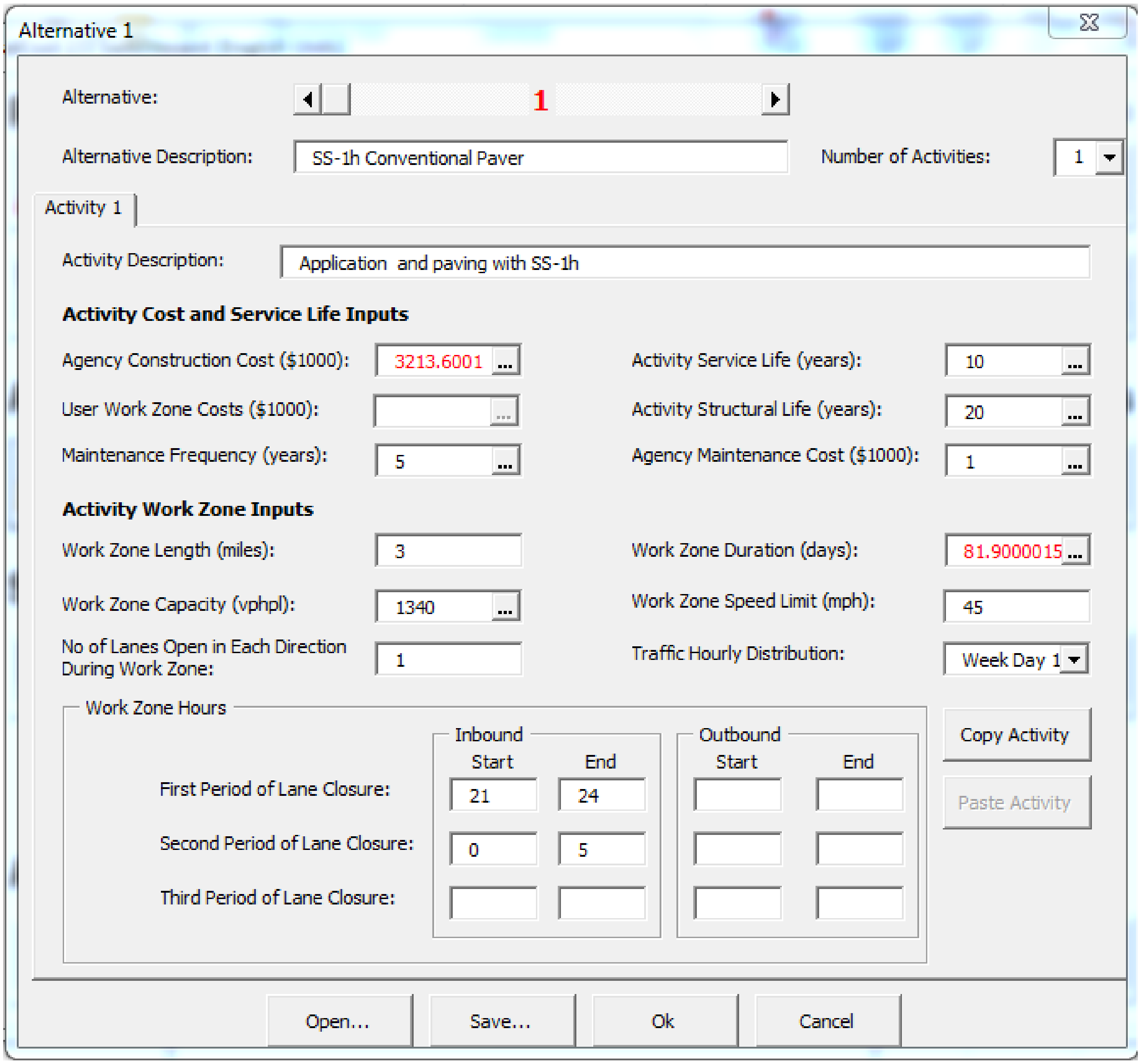
Base Year: 2011

Current Transp. Component CPI: 200.835

Current Year: 2011

Escalation Factor: 1.00

Figure B6. Added time and vehicle stopping costs, same for all cases.



Alternative: 1

Alternative Description: SS-1h Conventional Paver

Number of Activities: 1

Activity Description: Application and paving with SS-1h

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3213.6001

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 81.9000015

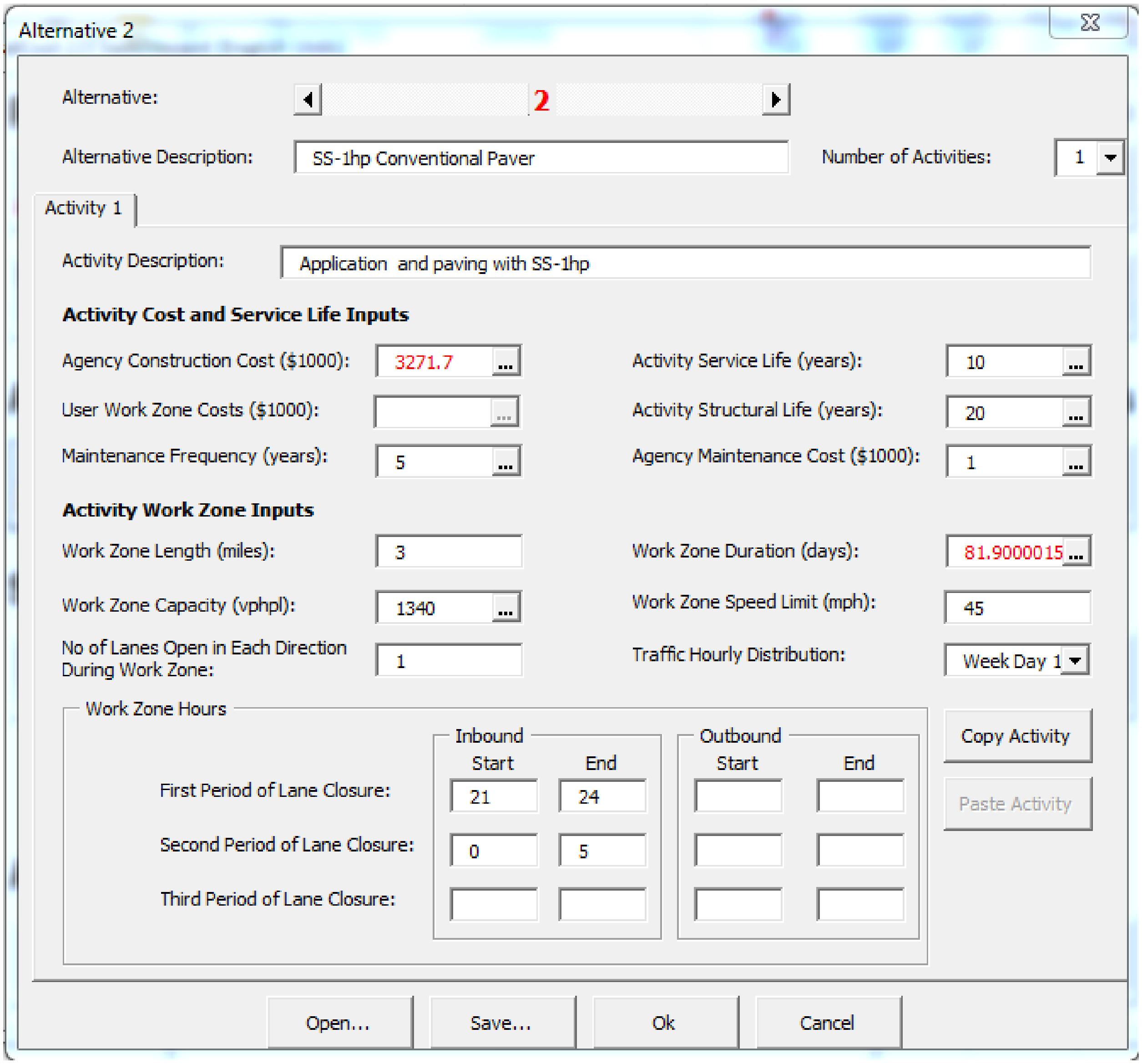
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B7. Alternative 1: Conventional paver, SS-1h, I-80 project.



Alternative: 2

Alternative Description: SS-1hp Conventional Paver

Number of Activities: 1

Activity Description: Application and paving with SS-1hp

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3271.7

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 81.9000015

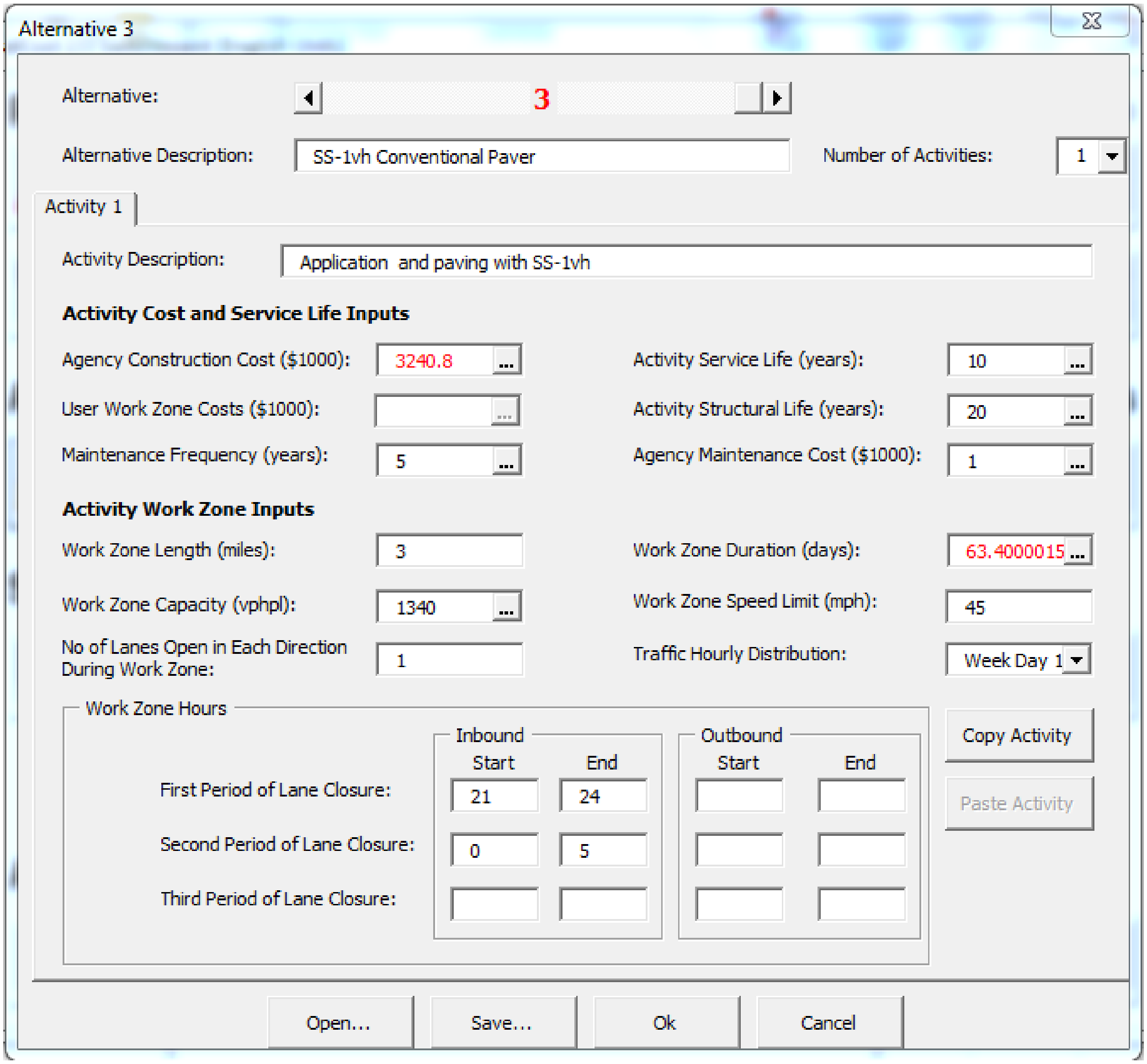
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B8. Alternative 2: Conventional paver, SS-1hp, I-80 project.



Alternative: 3

Alternative Description: SS-1vh Conventional Paver

Number of Activities: 1

Activity Description: Application and paving with SS-1vh

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3240.8

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 63.4000015

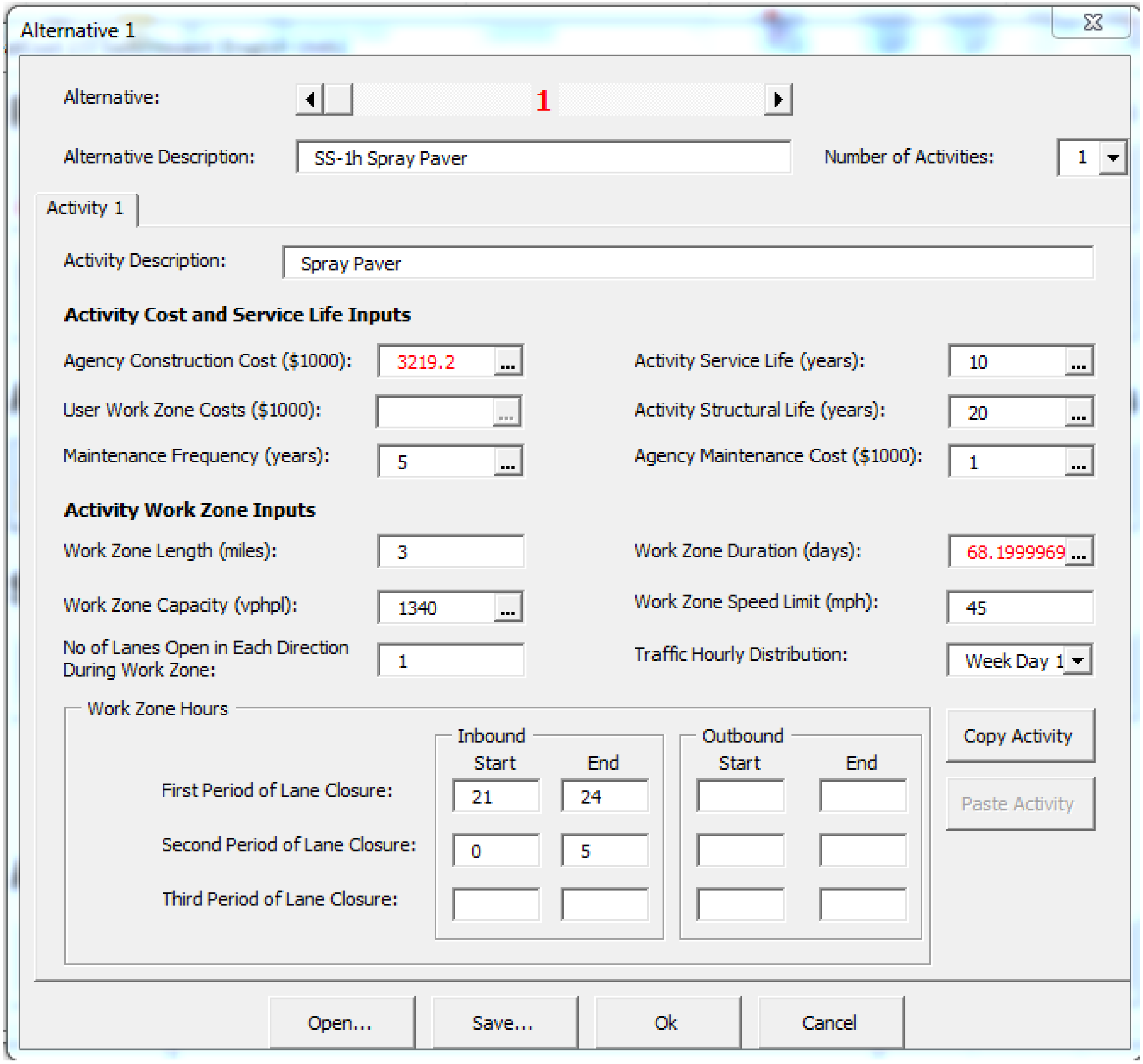
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B9. Alternative 3: Conventional paver, SS-1vh, I-80 project.



Alternative: 1

Alternative Description: SS-1h Spray Paver

Number of Activities: 1

Activity Description: Spray Paver

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3219.2

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 68.1999969

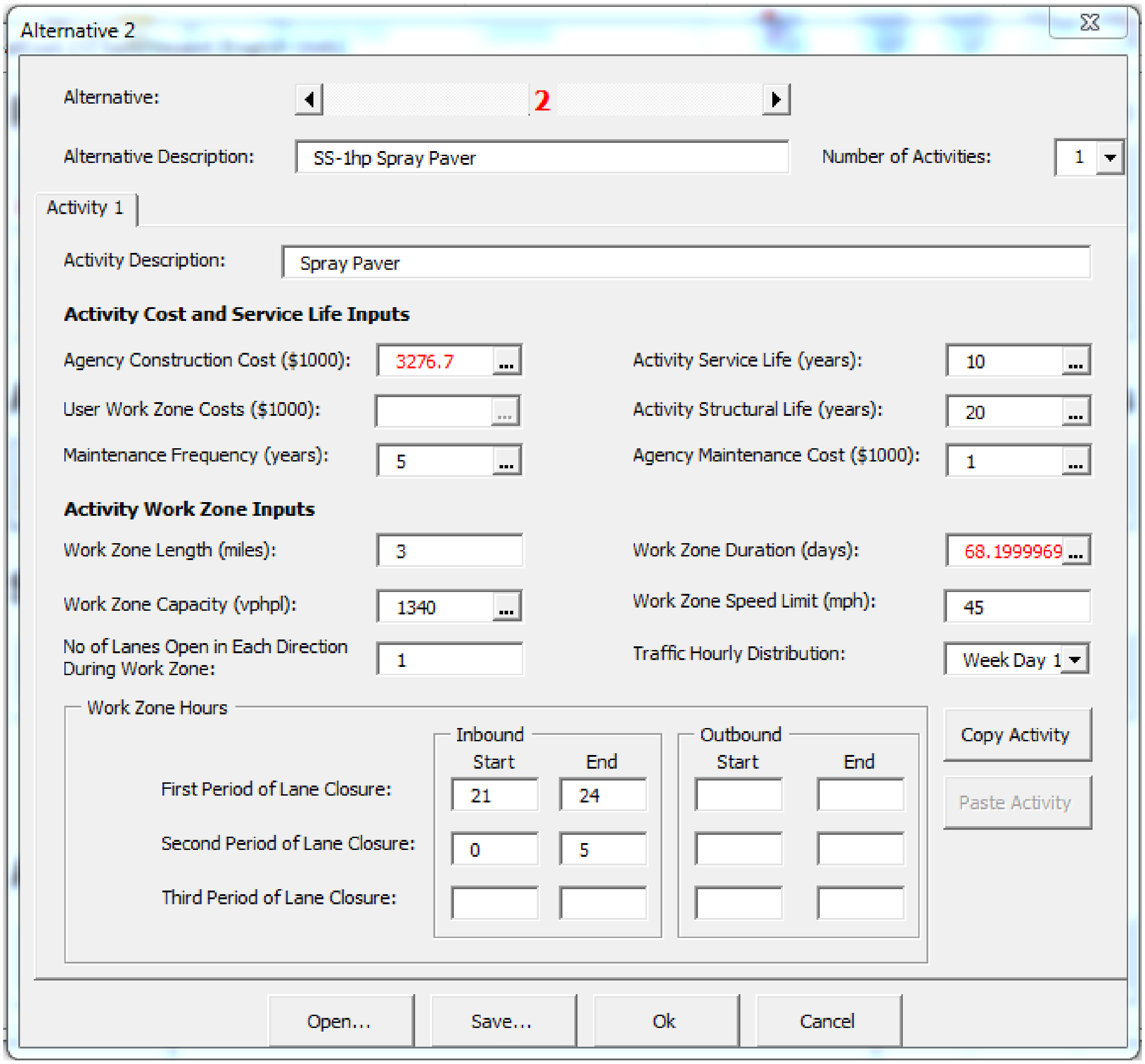
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B10. Alternative 1: Spray paver, SS-1h, I-80 project.



Alternative: 2

Alternative Description: SS-1hp Spray Paver

Number of Activities: 1

Activity Description: Spray Paver

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3276.7

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 68.1999969

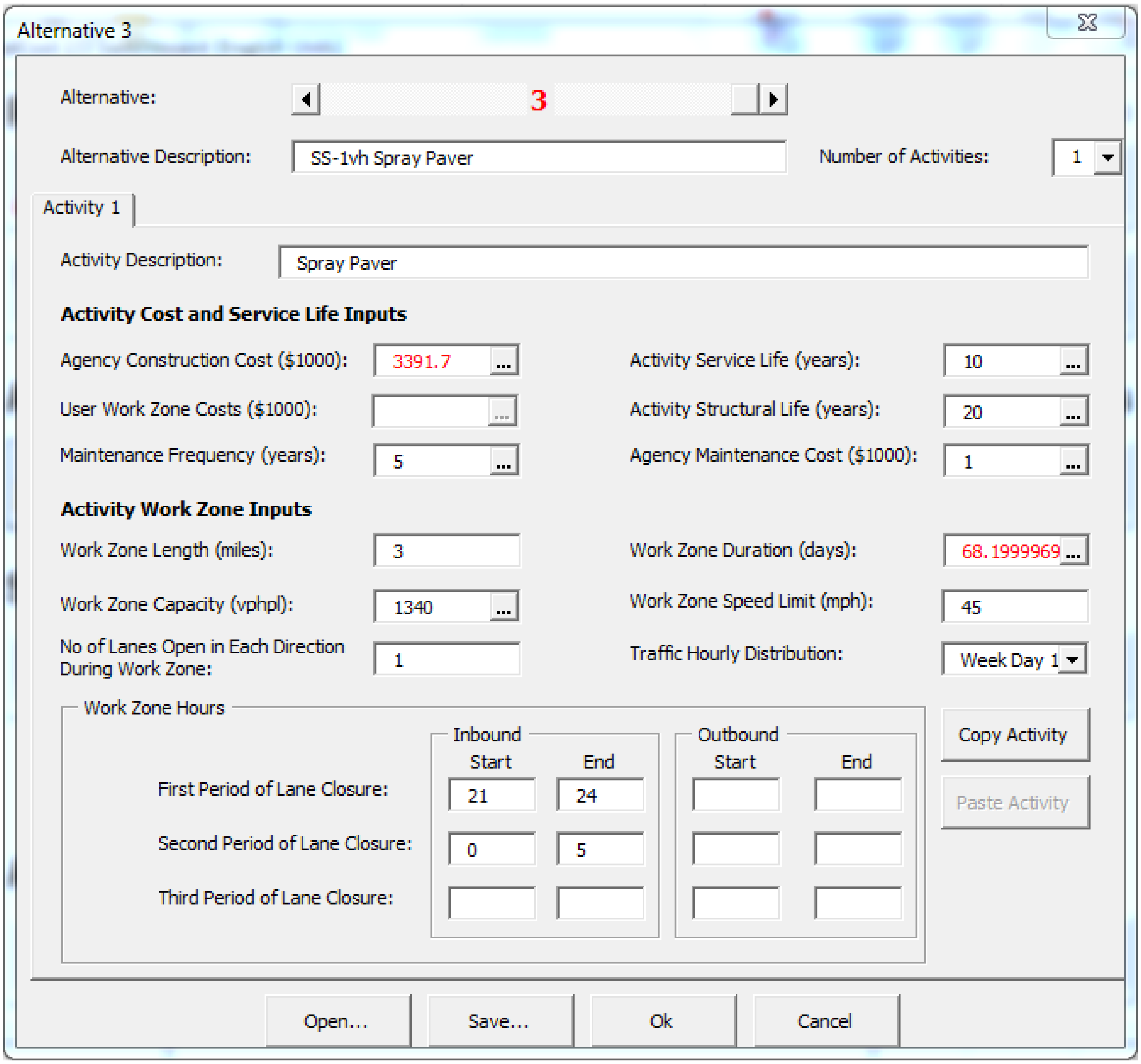
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B11. Alternative 2: Spray paver, SS-1hp, I-80 project.



Alternative: 3

Alternative Description: SS-1vh Spray Paver

Number of Activities: 1

Activity Description: Spray Paver

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 3391.7

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 1340

No of Lanes Open in Each Direction During Work Zone: 1

Work Zone Duration (days): 68.1999969

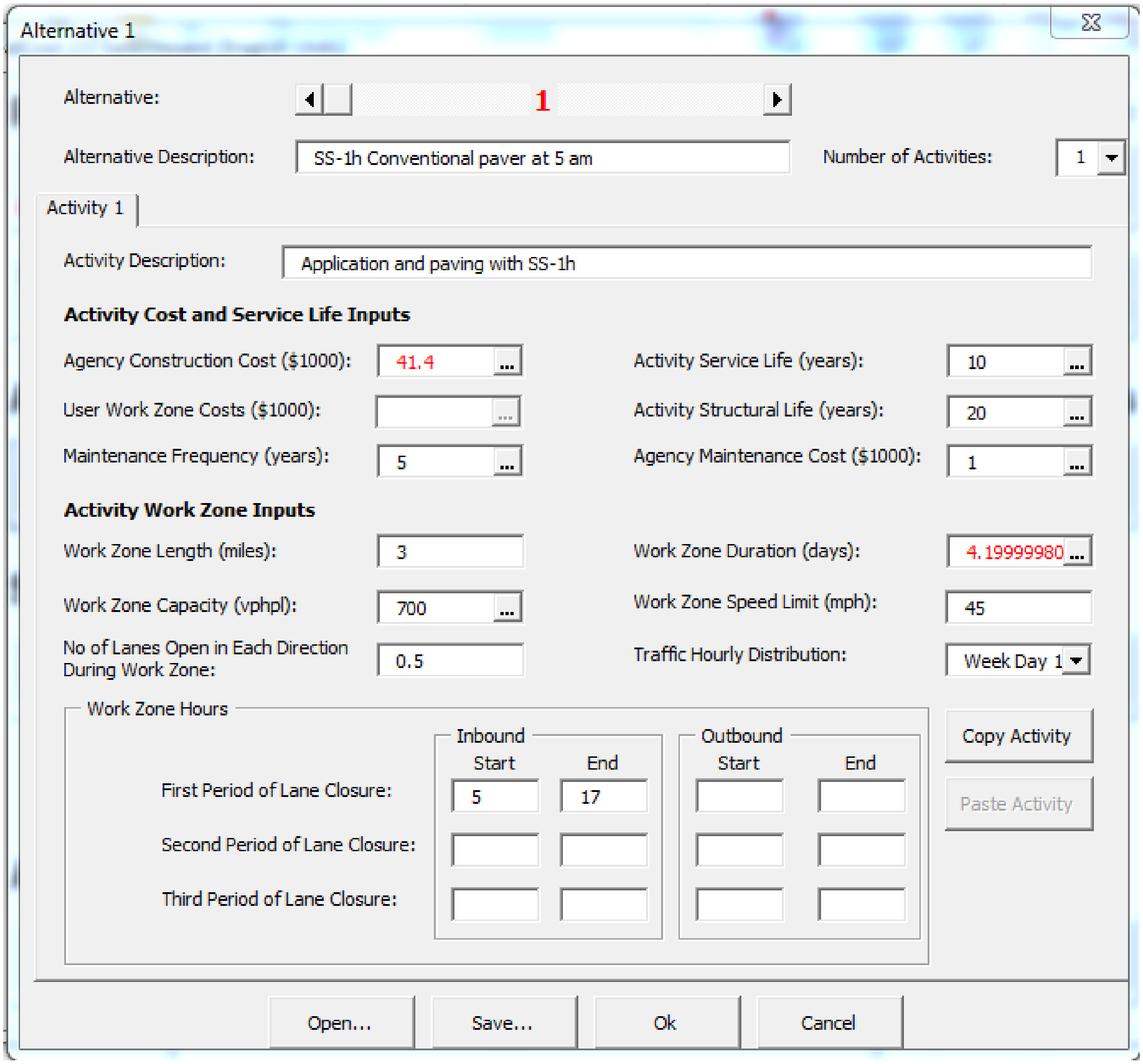
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	21	24		
Second Period of Lane Closure:	0	5		
Third Period of Lane Closure:				

Figure B12. Alternative 3: Spray paver, SS-1vh, I-80 project.



Alternative: 1

Alternative Description: SS-1h Conventional paver at 5 am

Number of Activities: 1

Activity Description: Application and paving with SS-1h

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 41.4

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 700

No of Lanes Open in Each Direction During Work Zone: 0.5

Work Zone Duration (days): 4.19999980

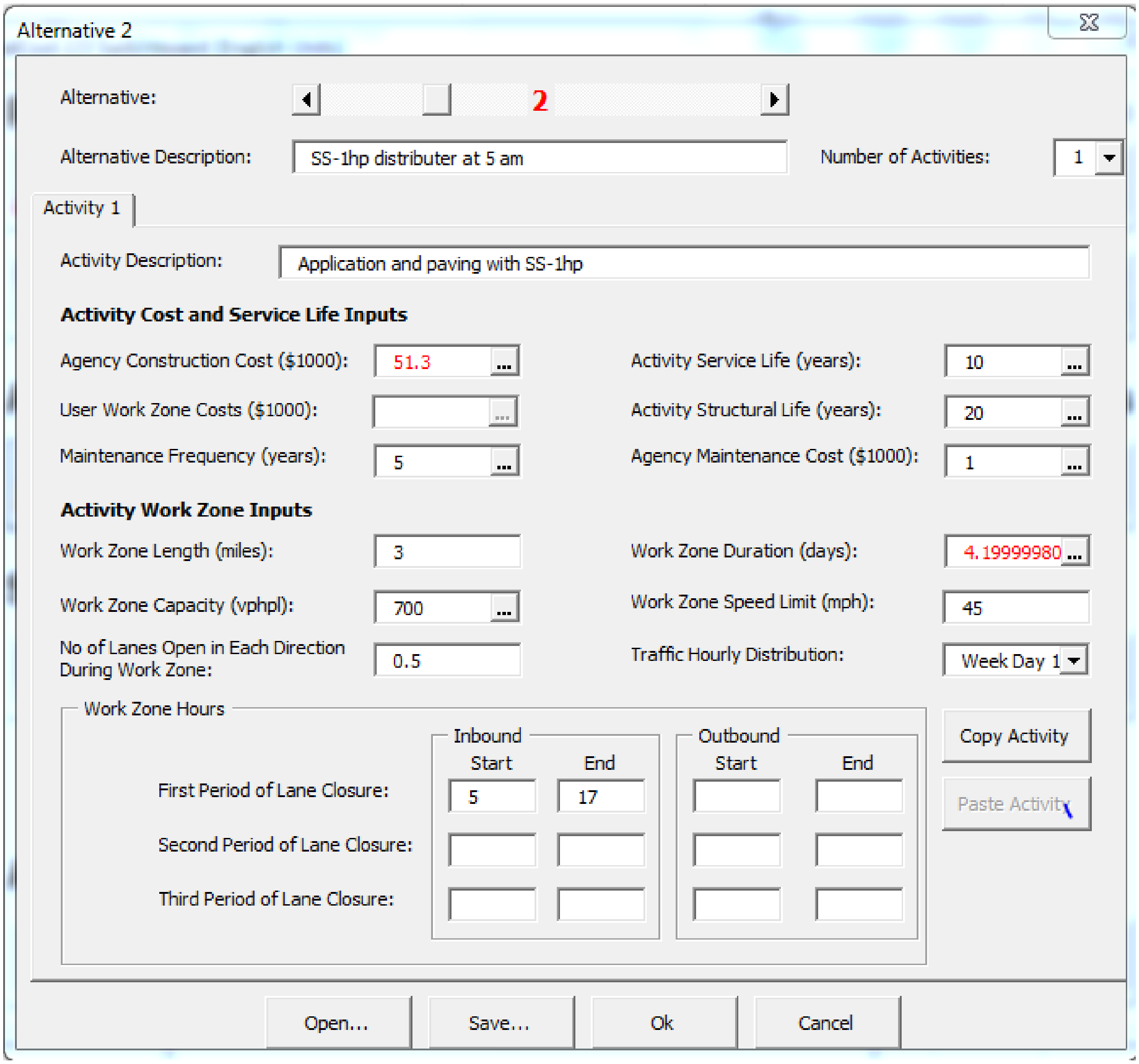
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	5	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B13. Alternative 1: Conventional paver, SS-1h starting at 5 a.m., IL-98 project.


Alternative 2

Alternative: 2

Alternative Description: SS-1hp distributer at 5 am

Number of Activities: 1

Activity 1

Activity Description: Application and paving with SS-1hp

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 51.3

Activity Service Life (years): 10

User Work Zone Costs ($1000):

Activity Structural Life (years): 20

Maintenance Frequency (years): 5

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Duration (days): 4.19999980

Work Zone Capacity (vphpl): 700

Work Zone Speed Limit (mph): 45

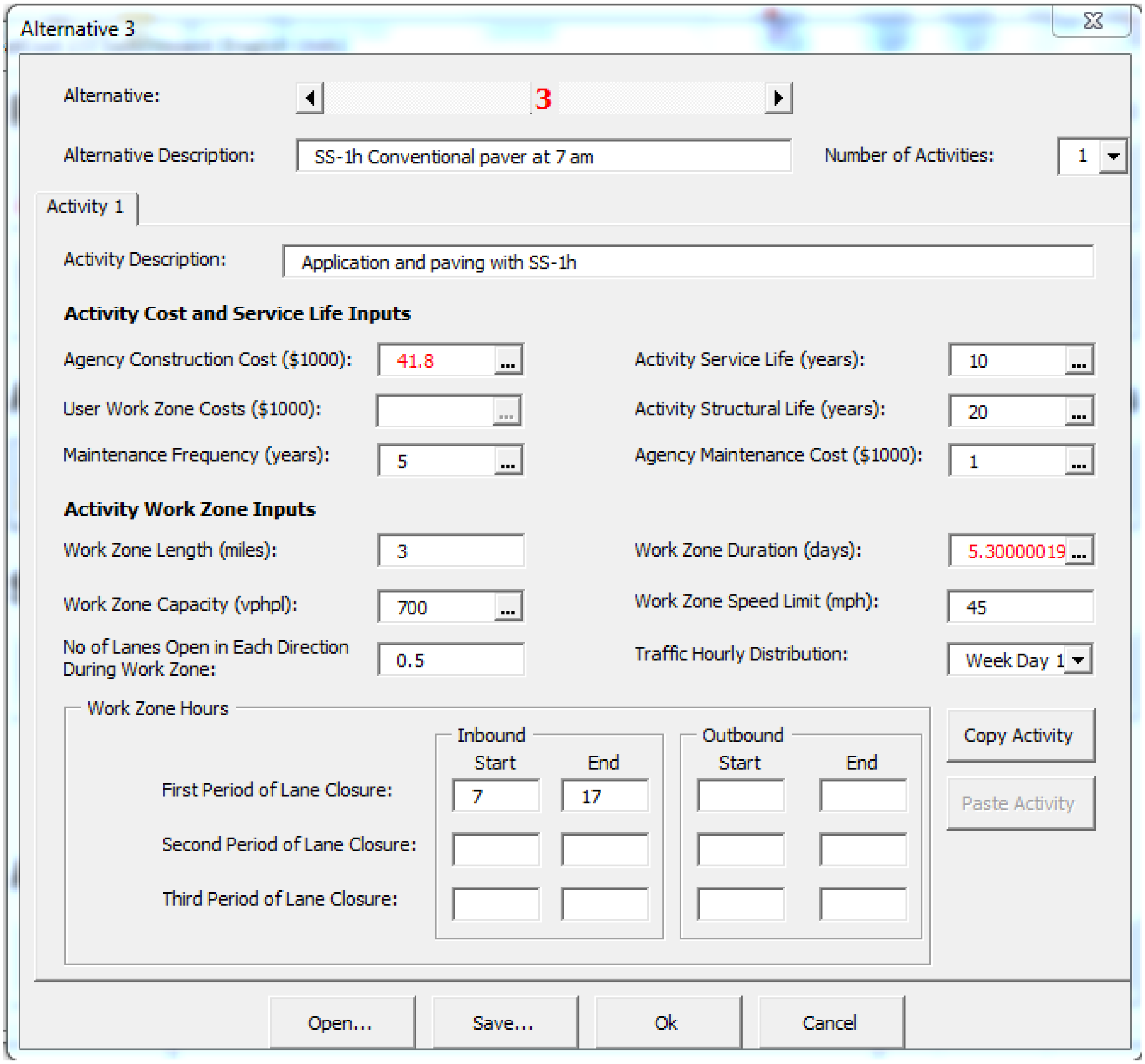
No of Lanes Open in Each Direction During Work Zone: 0.5

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	5	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B14. Alternative 2: Conventional paver, SS-1hp starting at 5 a.m., IL-98 project.



Alternative: 3

Alternative Description: SS-1h Conventional paver at 7 am

Number of Activities: 1

Activity 1

Activity Description: Application and paving with SS-1h

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 41.8
Activity Service Life (years): 10
User Work Zone Costs ($1000):
Activity Structural Life (years): 20
Maintenance Frequency (years): 5
Agency Maintenance Cost ($1000): 1

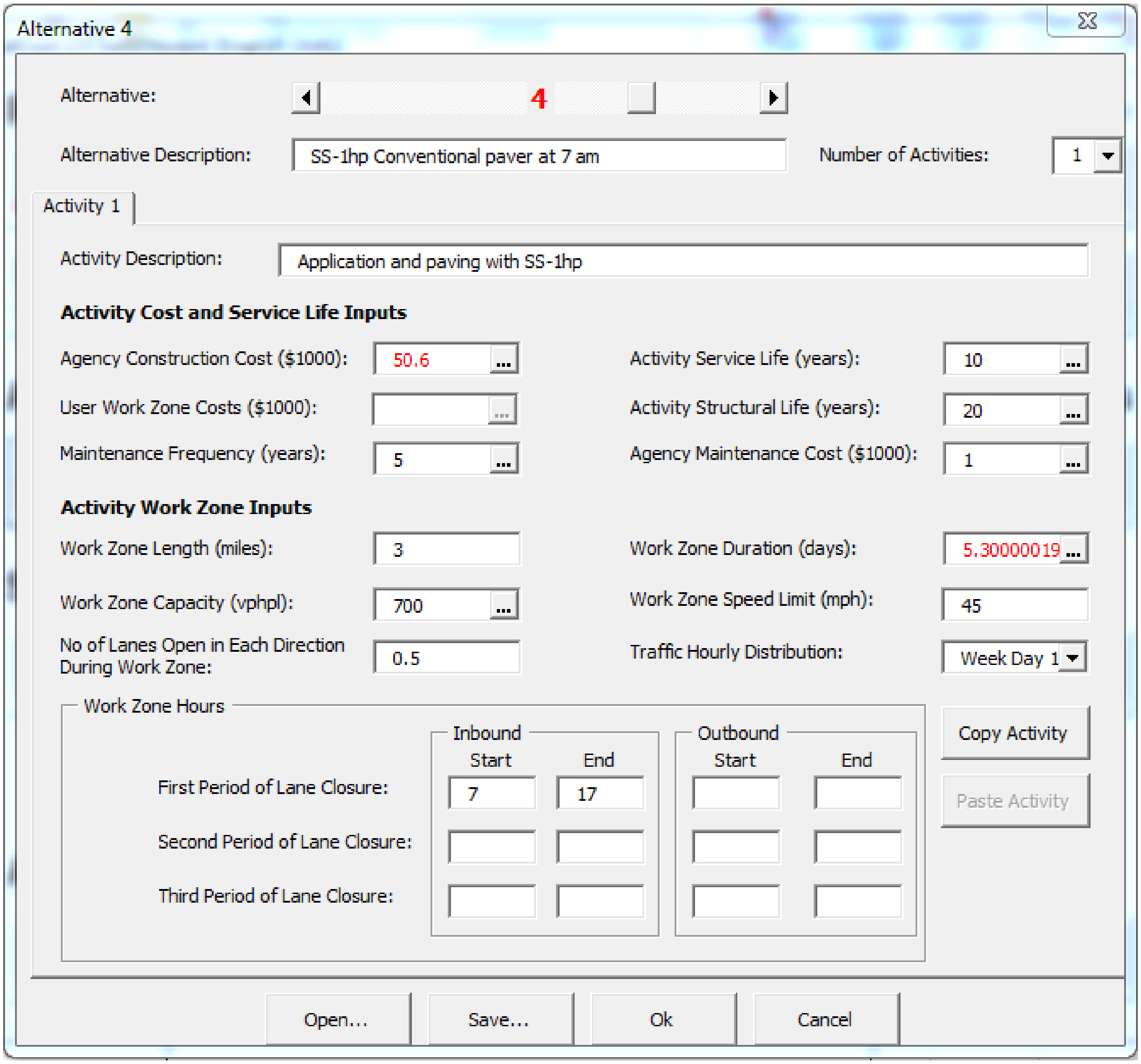
Activity Work Zone Inputs

Work Zone Length (miles): 3
Work Zone Duration (days): 5.30000019
Work Zone Capacity (vphpl): 700
Work Zone Speed Limit (mph): 45
No of Lanes Open in Each Direction During Work Zone: 0.5
Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B15. Alternative 3: Conventional paver, SS-1h starting at 7 a.m., IL-98 project.



Alternative: 4

Alternative Description: SS-1hp Conventional paver at 7 am

Number of Activities: 1

Activity Description: Application and paving with SS-1hp

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000):	50.6	Activity Service Life (years):	10
User Work Zone Costs ($1000):		Activity Structural Life (years):	20
Maintenance Frequency (years):	5	Agency Maintenance Cost ($1000):	1

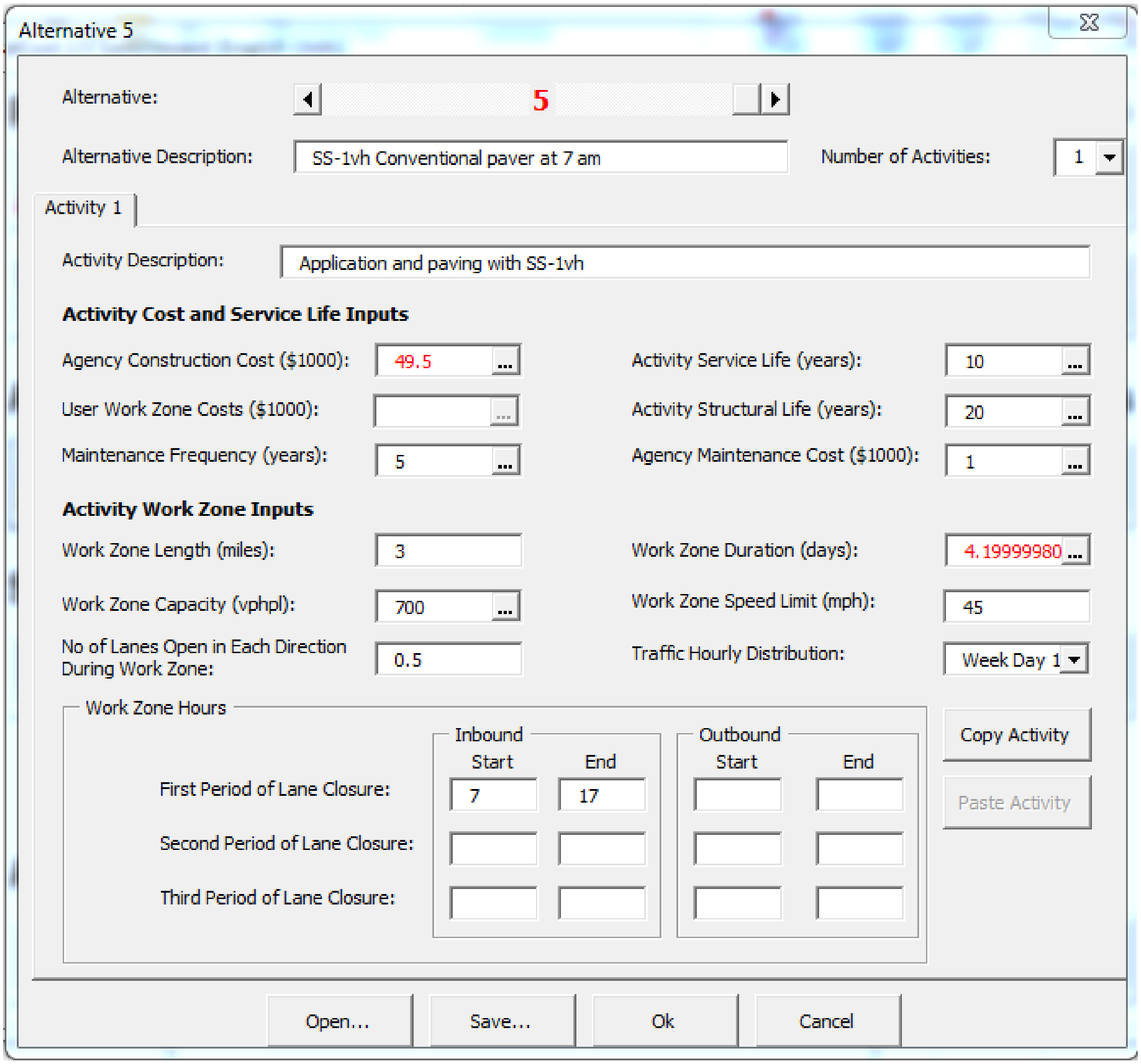
Activity Work Zone Inputs

Work Zone Length (miles):	3	Work Zone Duration (days):	5.30000019
Work Zone Capacity (vphpl):	700	Work Zone Speed Limit (mph):	45
No of Lanes Open in Each Direction During Work Zone:	0.5	Traffic Hourly Distribution:	Week Day 1

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B16. Alternative 4: Conventional paver, SS-1hp starting at 7 a.m., IL-98 project.



Alternative: 5

Alternative Description: SS-1vh Conventional paver at 7 am

Number of Activities: 1

Activity Description: Application and paving with SS-1vh

Agency Construction Cost ($1000): 49.5

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 700

No of Lanes Open in Each Direction During Work Zone: 0.5

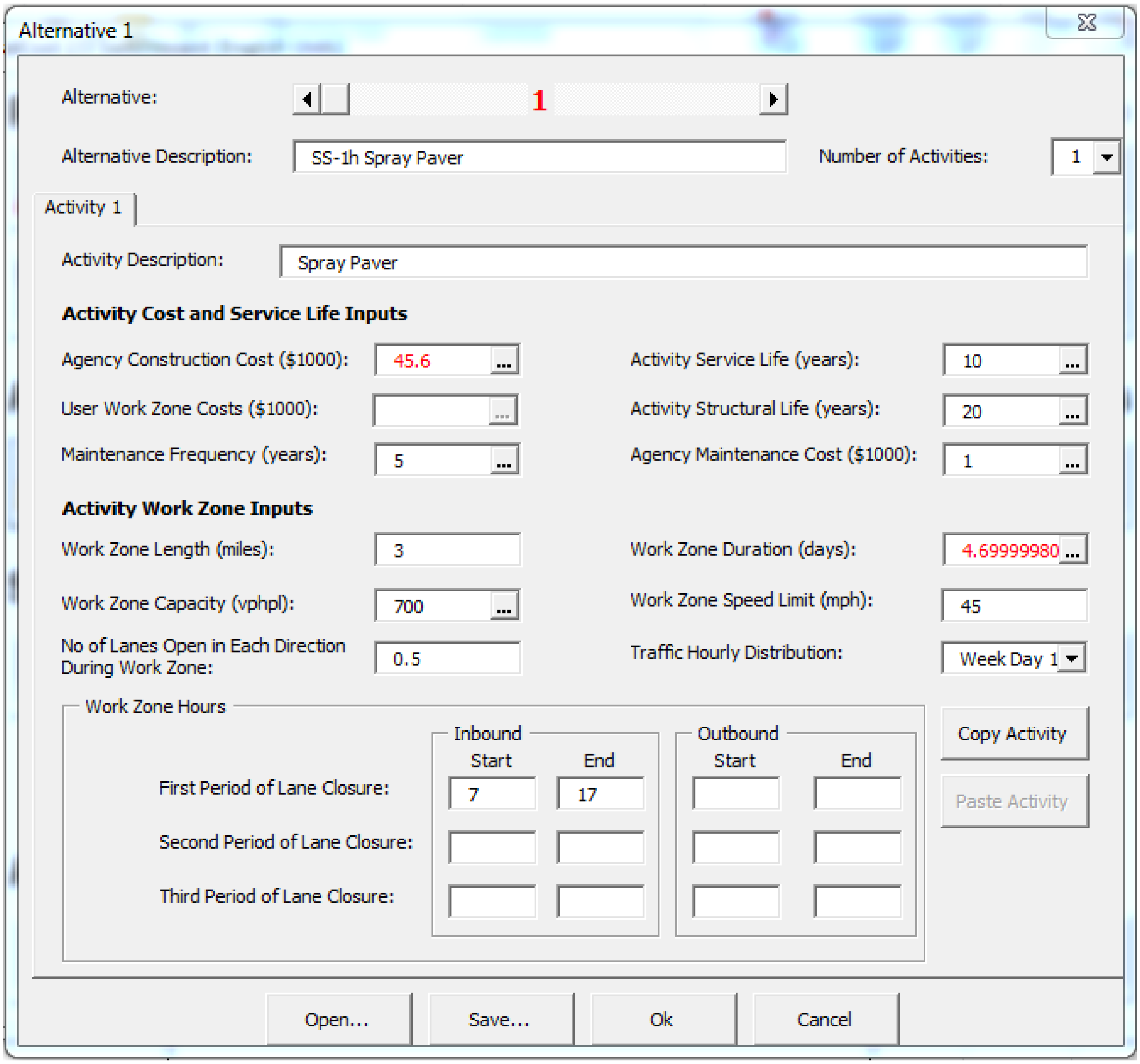
Work Zone Duration (days): 4.19999980

Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B17. Alternative 5: Conventional paver, SS-1vh starting at 7 a.m., IL-98 project.



Alternative 1

Alternative: 1

Alternative Description: SS-1h Spray Paver

Number of Activities: 1

Activity 1

Activity Description: Spray Paver

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 45.6
User Work Zone Costs ($1000):
Maintenance Frequency (years): 5
Activity Service Life (years): 10
Activity Structural Life (years): 20
Agency Maintenance Cost ($1000): 1

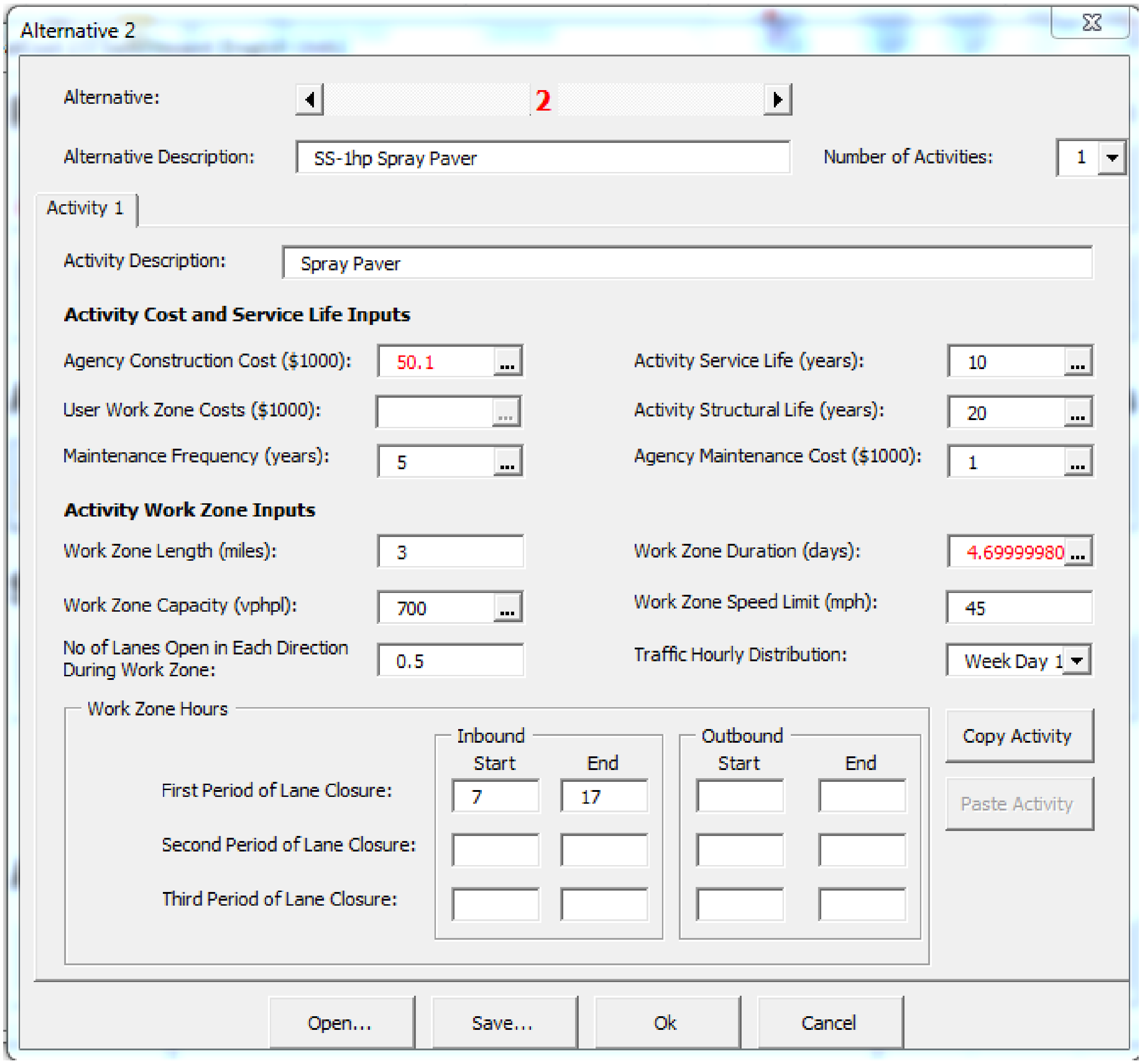
Activity Work Zone Inputs

Work Zone Length (miles): 3
Work Zone Capacity (vphpl): 700
No of Lanes Open in Each Direction During Work Zone: 0.5
Work Zone Duration (days): 4.69999980
Work Zone Speed Limit (mph): 45
Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B18. Alternative 1: Spray paver, SS-1h, IL-98 project.



Alternative 2

Alternative: 2

Alternative Description: SS-1hp Spray Paver

Number of Activities: 1

Activity Description: Spray Paver

Activity Cost and Service Life Inputs

Agency Construction Cost ($1000): 50.1

User Work Zone Costs ($1000):

Maintenance Frequency (years): 5

Activity Service Life (years): 10

Activity Structural Life (years): 20

Agency Maintenance Cost ($1000): 1

Activity Work Zone Inputs

Work Zone Length (miles): 3

Work Zone Capacity (vphpl): 700

No of Lanes Open in Each Direction During Work Zone: 0.5

Work Zone Duration (days): 4.69999980

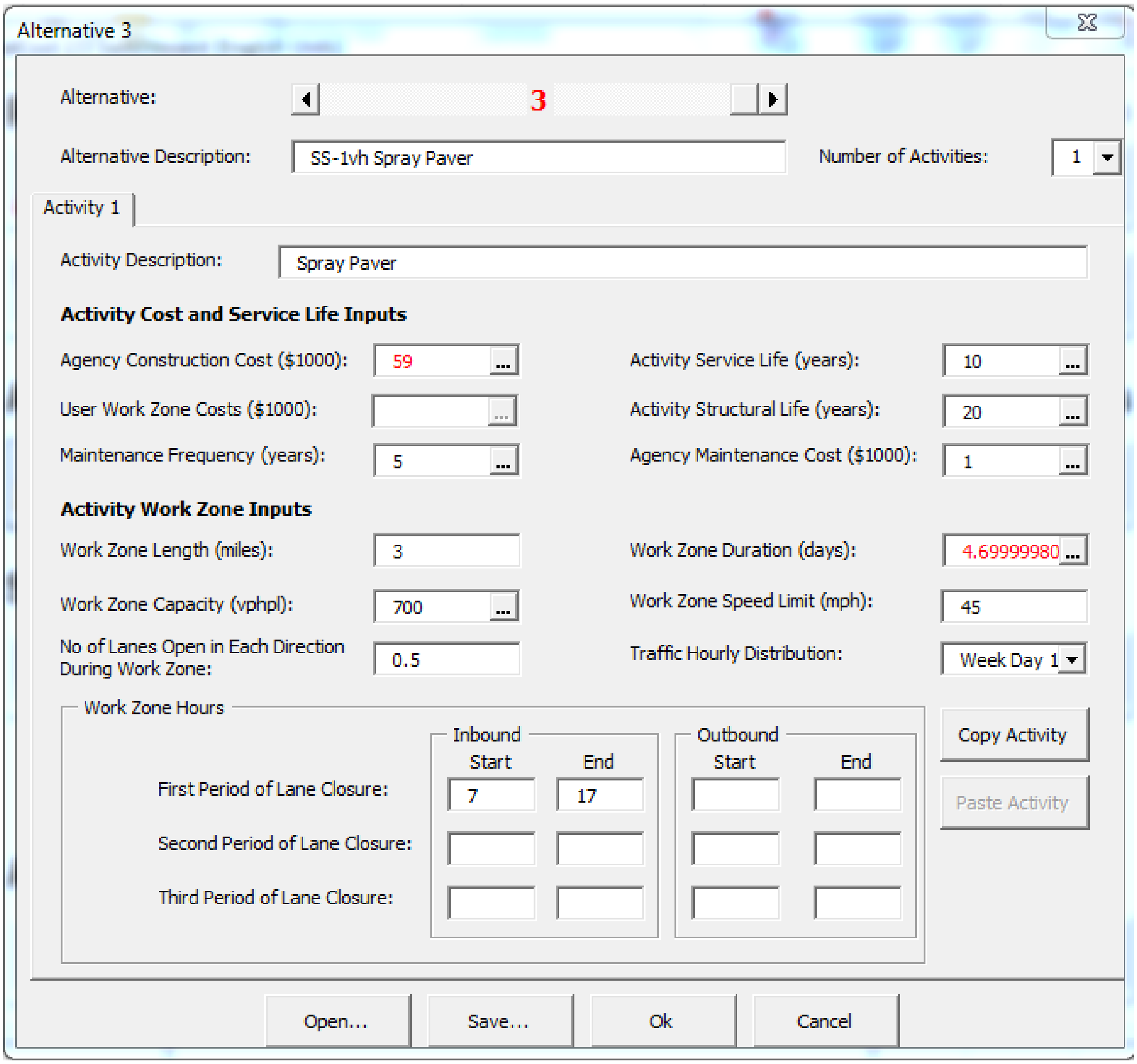
Work Zone Speed Limit (mph): 45

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound Start	Inbound End	Outbound Start	Outbound End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B19. Alternative 2: Spray paver, SS-1hp, IL-98 project.



Alternative: 3

Alternative Description: SS-1vh Spray Paver

Number of Activities: 1

Activity Description: Spray Paver

Agency Construction Cost ($1000): 59

Activity Service Life (years): 10

User Work Zone Costs ($1000):

Activity Structural Life (years): 20

Maintenance Frequency (years): 5

Agency Maintenance Cost ($1000): 1

Work Zone Length (miles): 3

Work Zone Duration (days): 4.69999980

Work Zone Capacity (vphpl): 700

Work Zone Speed Limit (mph): 45

No of Lanes Open in Each Direction During Work Zone: 0.5

Traffic Hourly Distribution: Week Day 1

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	7	17		
Second Period of Lane Closure:				
Third Period of Lane Closure:				

Figure B20. Alternative 3: Spray paver, SS-1vh, IL-98 project.

Illinois Department
of Transportation

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN