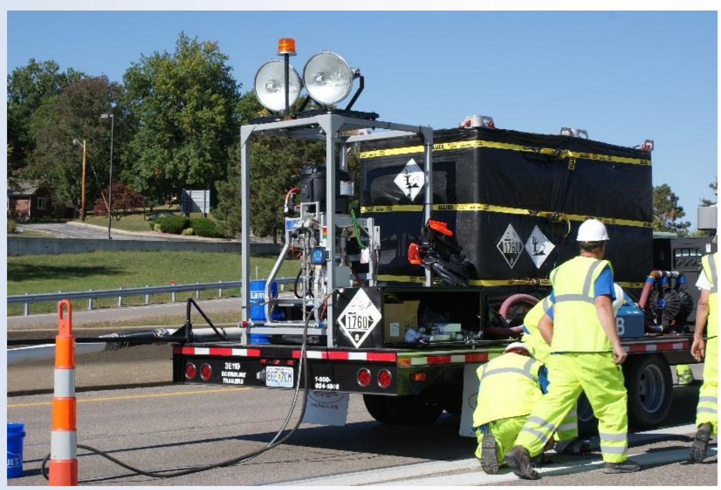
Missouri Demonstration Project:

The Use of High-Friction Surface Treatments on Missouri Highways

Final Report
March 2015

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.



U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. "Innovations" is an inclusive term used by HfL to encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community's culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decision makers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl.

NOTICE

1. Report No.	2. Government Accession No	3. Recipient's Catalog No
3. Title and Subtitle Missouri Demonstration Project: The Use of High-Friction Surface Treatments on Missouri Highways		5. Report Date March 2015 6. Performing Organization Code
7. Authors Jay Bledsoe		8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit No. (TRAIS) C6B 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officer's Representative: Julie Zirlin
Contracting Officer's Task Manager: Ewa Flom

16. Abstract
As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Missouri Department of Transportation was awarded a $120,000 grant to demonstrate the use of high-friction surfaces as a durable and cost-effective method to increase safety on Missouri highways. This report documents the placement of high-friction surfaces at four locations around the State. A study of the crash history in these areas indicated a need to improve friction to reduce the number of incidents that could be related to friction. This report details the innovation used to rehabilitate two segments of I-44 in Phelps County, one segment of US 54 in Cole County, and several locations on MO 179 near the intersection with US 54, also in Cole County.

Although not directly comparable in terms of benefits, the cost of the four HFST projects was substantially greater than would have been the case with traditional ultra-thin bonded asphalt wearing surface. Costs for the installed HFST ranged from $17 to $21.5 per square yard compared to a cost of $4.12 per square yard for a traditional ultra-thin bonded asphalt wearing surface, resulting in additional cost of more than $520,000 for all four locations. However, the additional costs were significantly less compared to costs associated with realigning the section of the roadway to address run-off-road ROR crashes.

The friction numbers obtained with this innovation far exceeded those that would be expected with the ultra-thin bonded asphalt wearing surface, which translates to fewer post-construction accident rates. Using crash data from the first year following one of the four projects, the reduction of 27 crashes during the period at just this one location results in a savings of about $966,300, or nearly twice the additional cost of HFST placement all four locations combined. Using present worth cost of crashes and MODOT's target of 20 percent reduction in accidents results in a minimum savings of $4,136,000, over the 9-year life of the treatment.

The use of high-friction surfaces resulted in extremely high friction numbers, far above those generally recorded for traditional surface treatments. The experience gained on these successful projects will help Missouri use high-friction surfaces more routinely on future projects.

17. Key Words	18. Distribution Statement
High-Friction Surface, safety	No restriction. This document is available to the public through the Highways for LIFE website: http://www.fhwa.dot.gov/hfl/

Security Classif.(of this report)	19. Security Classif. (of this page)	20. No. of Pages	21. Price
Unclassified	Unclassified	45	

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND SYMBOLS

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
dB(A)	A-weighted decibel
DOT	Department of Transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HFST	high friction surface treatment
IRI	International Roughness Index
MODOT	Missouri Department of Transportation
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
PDO	property damage only
ROR	run-off-road
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
UBAWS	ultra-thin bonded asphalt wearing surface

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—has provided incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than $5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the highway project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications in fiscal years since 2006. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, and contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA's Offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management Team; the Division offices; and the HfL team. After evaluating and rating the applications and supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one that the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
    - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
    - Facility safety after construction—At least 20 percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
    - Faster construction—At least 50 percent reduction in the time highway users are impacted, compared to traditional methods.
    - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
    - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
    - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.
    - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

- **User Satisfaction**
  - User satisfaction—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4-plus on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Missouri DOT's HfL demonstration project, which involved the application of high-friction surface treatments at four locations around the State. The report presents project details relevant to the HfL program, including safety and construction congestion. HfL performance metrics and economic analysis lessons learned are also discussed.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

Safety is the Missouri DOT's number one priority. From 2005 to 2013, the Missouri DOT reduced the number of fatalities on the 33,700 centerline miles of roads they maintain from 1,257 to 757. This reflects a nearly 40 percent reduction in fatalities over an 8-year period and demonstrates a commitment to improving the safety of Missouri highways.

Since 2005, the DOT has implemented several innovative technologies intended to improve safety. Many, such as median guard cable and rumble strips, have become standard improvements applied across the State. Other programs that have contributed to improved safety include the replacement of 802 bridges that were either structurally deficient or functionally obsolete through the Safe and Sound Bridge Program, as well as the increased use of diverging diamond interchanges, J-turns, and roundabouts.

The HfL project undertaken by the Missouri DOT involved a single innovative technology: the application and use of high-friction surface treatments (HFST). The experience gained through this project is expected to better enable the Missouri DOT to provide a long-term solution to the challenges related to maintaining the safety of their highway facilities. All of the projects let for the application of HFST were contracted using traditional contracting methods. HFST was bid per square yard, installed, as would have been the case for the traditional ultra-thin bonded asphalt wearing surface (UBAWS). HFST will expand the alternatives available in Missouri with respect to providing a safer transportation system to the traveling public.

HFL PERFORMANCE GOALS

The successful implementation of an HfL project was assessed with respect to how safety, construction congestion, and quality were addressed during the construction of the project. On most HfL projects, data are collected before, during, and after construction, as appropriate, to demonstrate that the featured innovations can be deployed while simultaneously meeting the HfL performance goals in these areas:

- **Safety**
    - Work zone safety during construction—No motorist incidents were reported during construction. The Missouri DOT exceeded the HfL requirements for work zone safety.
    - Worker safety during construction—No worker injuries occurred during construction, which exceeded the goal of less than a 4.0 rating on the OSHA 300 form.
    - Facility safety after construction—The installation of the HFST is expected to dramatically improve the safety of the facility after construction. Preliminary indications support this conclusion.
- **Construction Congestion**
    - Faster construction—Three of the four locations included in this HfL project consisted of only the application of the HFST. In these cases, the construction

time was approximately the same as would have been required for the construction of the most likely alternative, the application of a microsurfacing or UBAWS. The fourth project involved the application of HFST to several small areas of a larger overlay project. Compared to these alternatives, the goal of reducing the construction time by 50 percent was not achieved. However, compared to realignments, which is more comparable with meeting the post-construction safety goals of the project, the HFST was constructed in a significantly shorter time and achieving the goal of reducing the construction time by 50 percent.

    - Trip time during construction—The length of the work zones used on these projects was very short, and in general the work was performed at night when traffic volume was low. The only restriction to the public was the delay introduced by lowered speed limits within the work zone itself. Due to the short nature of the work zone, it can be assumed that the goal less than 10 percent increase in trip time compared to the average preconstruction speed was met.
    - Queue length during construction—Given the capacity of roadways included in these projects and the lower traffic levels experienced during nighttime construction, no queue length greater than 0.5 miles was observed.
- **Quality**
    - Due to the extremely short nature of the projects, no goal was established for noise or smoothness.
    - Durability of the surface was a definite consideration. The aggregate used on these projects was considered the best available and should outperform the traditional UBAWS in terms of retaining its frictional properties.
- **User Satisfaction**
    - User satisfaction—No user satisfaction survey was conducted on these projects due to the relative short length and short duration of the construction.

ECONOMIC ANALYSIS

The costs of delivering this HfL project were compared to the most likely traditional alternative technique, in this case a UBAWS. The cost of the four HFST projects was substantially greater than would have been the case with traditional solutions. Costs for the installed HFST ranged from $17 to $21.5 per square yard compared to a cost of $4.12 per square yard for a traditional UBAWS (based on statewide average bid costs). If we assume that the quantities of materials would remain the same for either treatment, the additional cost was more than $520,000 for all four locations.

The additional costs of HFST were significantly less compared to costs associated with realigning the section of the roadway to address run-off-road (ROR) crashes. While UBAWS is the closest treatment for comparison analysis, the friction numbers obtained with HFST far exceed those that would be expected with the traditional UBAWS, and there is an expectation of a greater service life as well. These two factors offset some of the high initial cost. HFST is a treatment that is most suited for locations where you need a friction demand above and beyond what can be provided with UBAWS and the costs associated with realignment to improve safety are prohibitive.

Using crash data from the first year following one of the four projects, the reduction of 27 crashes during the period at just this one location results in a savings of about $966,300, or nearly twice the additional cost of HFST placement all four locations combined. Using present worth cost of crashes and MODOT's target of 20 percent reduction in accidents results in a minimum savings of $4,136,000, over the 9-year life of the treatment.

Lessons Learned

There were several issues identified that could help provide for more successful application of this technology in the future:

- There are many specifications in use around the country with respect to the application of high-friction surfaces. This leads to issues, as contractors, material suppliers, equipment developers, etc. attempt to shape specifications in each State. It should be noted that there now is an American Association of State Highway and Transportation Officials (AASHTO) Provisional Specification for HFST, PP 79-14.
- It is important to gain knowledge from as many subject matter experts as possible before entertaining such projects to avoid issues with contracting and construction. FHWA proved to be an invaluable resource in this area, acting as a clearinghouse for national experience.
- Temperature at the time of HFST placement is critical. All projects were originally slated for night work, but delaying some of the construction into the fall months resulted in difficulty obtaining the required nighttime temperatures.
- Placement of an HFST over new asphalt requires a minimum 30-day cure before application of the surface to ensure desired bonding.
- While the most common binder in use in Missouri is epoxy, some new polymeric resins that can be applied over a wider range of temperatures should be investigated. Projects let in Missouri after the completion of the HfL projects have this as an option.

Conclusions

In spite of the significant additional cost, there are locations where the application of an HFST is appropriate because of the geometrics and crash history of the area. Much of the additional cost can be attributed to the use of the epoxy resin used as a binder and the extremely high-quality aggregate used. Also, at this time, there are a limited number of contractors in the area with the knowledge and equipment necessary to perform the work.

The friction numbers resulting from the application of HFST technology show a level of friction not achieved with any previous treatment used by Missouri DOT and should result in a measurable increase in safety for the locations selected.

PROJECT DETAILS - GENERAL

BACKGROUND

The Missouri DOT HfL demonstration project consisted of the application of HFST at four locations around the State. One project included two separate locations, both on I-44 in Phelps County. The remaining two locations were in Cole County, on US 54 and MO 179. Three of the locations were on the mainline of four-lane divided highways, and the fourth was composed of several critical locations near the intersection of US 54 and MO 179. Figure 1 shows a map of all the project locations.

Figure 1. Map. General project locations.

The projects selected had a history of wet-weather crashes, and MoDOT believed that increased friction would provide a major benefit with regards to reducing wet-weather crashes. The projects ranged in length from a few hundred feet to about 0.9 miles.

HIGH-FRICTION SURFACE TREATMENTS

Maintaining sufficient friction has always been considered critical with respect to minimizing certain types of highway crashes. It is particularly critical in horizontal curves and in areas of heavy breaking, such as intersections. FHWA data indicate that while horizontal curves account for only about 5 percent of the nation's mileage, these locations are responsible for nearly 25 percent of fatal crashes.(1) HFSTs provide exceptional friction characteristics when compared to most traditional surface treatments. Because of the high initial cost, HFSTs are generally applied to short sections of highway using resin or polymer binders and extremely high-quality aggregates. This provides a very durable surface much less likely to wear or polish than traditional overlay materials.

Because of the thickness and required bond, HFSTs should only be applied to pavements in good condition. Research indicates that, under these conditions, a service life of 7 – 12 years can be expected.(2) A report commissioned by Transit New Zealand showed 30 percent reduction in wet crashes following the application of HFST.(3)

HFST are composed of two materials, a thermosetting polymer resin binder (usually epoxy, modified polyester, or urethane) and a very hard, durable aggregate. Bauxite is the most commonly used material.

Bauxite is the principal ore from which aluminum is obtained. Although several aggregates have been tested for their durability, at this time, only calcined bauxite has met the conditions necessary to be considered a high-friction surface. Calcined bauxite has a rating of about 9 on the Mohs hardness scale. There are limited sources in the US, and much of the supply comes from either China or India. In this case, the calcined bauxite originated in China and was obtained through a regional distributer.

Missouri DOT expects to use the lessons learned under this demonstration project to systematically address other locations in the State that could benefit from additional pavement friction. The material used for all four locations was identical, and specified in a job special provision developed specifically for the HfL projects. The specification for the epoxy binder is shown in table 1. Specifications for the aggregate were listed in the same job special provision and are shown in table 2.

Table 1. Epoxy binder specifications.

Property	Test Method	Requirements	
		Epoxy Resin	**MMA**
Ultimate Tensile Strength	AASHTO M-235	2,000 – 5,000 psi	1,500 – 5,000 psi
Elongation at break point	AASHTO M-235	30 – 70 %	30 – 70 %
Compressive Strength	ASTM C-579	1,600 psi minimum	1,600 psi minimum
Compressive Strength	AASHTO M-235	1,000 psi min.at 3 hours. 5,000 psi min. at 7 days.	1,000 psi min.at 3 hours. 2,000 psi min. at 7 days.
Water Absorption	AASHTO M-235	1 % max.	1 % max.
Durometer	ASTM D-2240	60 – 80	40 - 75
Hardness (Shore D)			
Viscosity	ASTM D-2556	Class C: 30 – 70 poises	Class C: 12 – 20 poises
Gel Time	AASHTO M-235	Class C: 10 minutes minimum	Class C: 10 minutes minimum
Cure Rate (dry through time)	ASTM D-1640	3 hour max.	3 hour max.
Adhesive Strength at 24 hours	ASTM C-1583	250 psi min. or 100% substrate failure	250 psi min. or 100% substrate failure

Table 2. Calcined bauxite aggregate specifications.

Property	Test Method	Requirement
Polish Stone Value	AASHTO T-279	65 min.
Resistance to Degradation	AASHTO T-96	20% max.
Aggregate Grading	AASHTO T-27	No. 4 Passing 100% min. No. 6 Passing 95% min. No. 16 Percent Passing 5% max.
Moisture Content	AASHTO T-255	0.2% max.
Aluminum Oxide	ASTM C-25	87% min.

PROJECT DETAILS – US 54, COLE COUNTY

BACKGROUND

The first of the HFST projects completed under this HfL project was placed near the Madison Street exit from US 54 in Jefferson City. The location is shown in figure 2. The project spans a distance of only about 0.2 miles and is concentrated at a curve with a history of road departure crashes.

Figure 2. Photo. US 54, Jefferson City, Missouri near Madison Street Exit (courtesy: Google Earth).

At this location, US 54 is a 4-lane divided facility carrying nearly 30,000 vehicles per day. The existing pavement was an asphalt pavement with paved shoulders in good condition. The HFST was applied over a UBAWS that had been applied approximately 5 years earlier.

PROJECT DESCRIPTION

The improvement was limited to the application of the HFST on both the driving and passing lanes, in both the eastbound and westbound directions of travel. The HFST was composed of an epoxy binder followed by the application of a very hard, durable aggregate, in this case, calcined bauxite. Figure 3 shows the cross section for the innovation at the US 54 location.

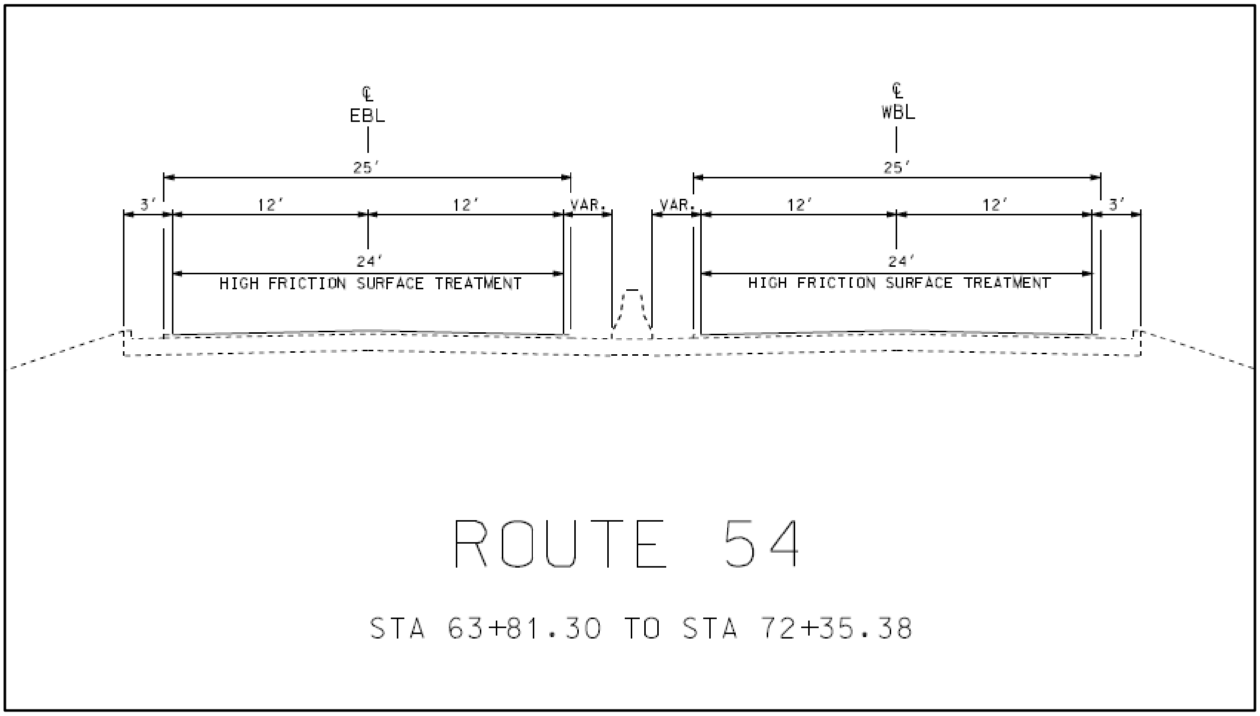


Figure 3. Diagram. Cross section of HFST used on US 54, Cole County.

The project was awarded in September 2013 at a cost of $84,333. The HFST component of the bid was $77,435, with the remainder used for mobilization, striping removal, and lighting for nighttime operations.

Construction began on October 13, 2013, and was completed on October 17, 2013. It was originally estimated that the construction would take only 2 days, but cold weather at night prevented continuous work. Before the HFST was applied, the roadway was broomed to remove any loose material that might affect the bond of the HFST. The surface of the roadway prior to application of the HFST is shown in figure 4.

Any wide cracks or small potholes were air blasted and filled with epoxy material prior to application of the HFST. Duct tape was used to cover existing lane markings as protection from the epoxy, eliminating the need to restripe immediately after surfacing (see figure 5). The actual surfacing consisted of the application of the epoxy resin to the surface by use of a handheld wand (figure 6). The epoxy material was then spread over the entire surface to be treated using a notched squeegee (figure 7).

Once the epoxy was applied, the aggregate was blown onto the surface. Specially equipped dump trucks provided surface material to a trailer that both mixed and delivered the epoxy and distributed the bauxite through a large hose using compressed air (see figures 8 and 9). The rate of application was not critical, as any material that did not sink into the epoxy was recovered for later use. The critical factor was making sure that the entire surface was covered. If necessary, hand application supplemented the initial application. The HFST was allowed to cure overnight to ensure stability before brooming and opening to traffic. Figure 10 shows the texture of the final surface.

Figure 4. Photo. Surface prior to application.

Figure 5. Photo. Workers cover existing lane markings before application of HFST.

Figure 6. Photo. Application of epoxy to road surface.

Figure 7. Photo. Epoxy spread using notched squeegee.

Figure 8. Photo. Dump truck supplying surface to distribution trailer.


Figure 9. Photo. Surface material blown onto recently placed epoxy binder.

Figure 10. Photo. Final HFST texture.

DATA ACQUISITION AND ANALYSIS

As appropriate, safety, construction congestion, and quality data were collected before and during the project construction to determine if this project met the HfL performance goals. The primary objective of this data acquisition and analysis was to quantify the project performance, to provide an objective basis to determine the feasibility of the project innovations, and to demonstrate that the innovations can be used to do the following:

- Achieve a safer work environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Produce a high-quality project and gain user satisfaction.

This section discusses how well the Missouri DOT project met the specific HfL performance goals related to these areas.

Safety

The HfL performance goals for safety include satisfying the following criteria:

- Meeting worker and motorist safety goals during construction.
- Reduction in fatalities and injuries after construction.

Table 3 shows the crash history and rate calculations for the eastbound and westbound segments for a 3-year period prior to construction.

Table 3. Pre-construction crash rates on US 54.

Route	Reference	Length (miles)	No. of crashes 10/13/2010 to 10/13/2013			Total	Crash Rate (crashes/ 100 million vehicle miles traveled)	
			Fatal	Injury	PDO		3-Year Rate	3-Year Rate (Statewide)
US 54 E	Log mile 167.21 to Log mile 167.421	0.211	0	13	32	45	1,552	N/A
US 54 W	Log mile 104.456 to Log mile 104.627	0.17	0	18	33	51	1,978	N/A

PDO = property damage only

The HFST was applied between two other geometric features, the ramp to and from Madison Street and another horizontal curve to the east of the project, resulting in a very short segment (~0.2 mi) to be evaluated. Because of the short length of the segment, although accident rates before construction can be compared to accident rates following construction for the segment, it is not appropriate to compare it to statewide rates, which are based on entire classes of roadways that span much longer distances of the order of several miles.

There were four crashes initially reported within the project limits between the date the construction began and the date of final completion of the HFST. However, none occurred during the actual existence of the work zone. All occurred during daytime hours when no workers were present. Because the project limits were so short, and given the nature of crash reporting, further review of the crashes was conducted. The individual crash reports indicate that only one crash occurred within the limits of the surfacing, a rear end crash resulting from traffic backed up westbound attempting to exit to Jefferson Street. Of the other three crashes, two occurred at the eastbound exit to Jefferson Street just before the application started and one initiated in the horizontal curve before the treatment in the westbound direction, with the vehicle coming to rest within the project limits. Since none of the crashes occurred during construction, the HfL goal of a work zone crash rate less than or equal to the preconstruction rate is considered to be achieved.

Because there was more than a year between the completion of this project and construction of the remaining three locations included in this HfL demonstration project, some data were available on postconstruction crashes. Using the data presented above, in the 3-year period prior to construction there were 96 crashes within the project limits, or about 32 per year. At the time of this report only five crashes have been reported during the first year after construction. While these data are preliminary, it would appear that the HFST has contributed to a dramatic reduction in crashes at this location.

Construction Congestion

The standard HfL goals for construction congestion relate to three main objectives: a reduction in total construction time of 50 percent, average trip time increased by no more than 10 percent, and no queue length greater than 0.5 miles.

Construction Time

The normal solution for a horizontal curve exhibiting more crashes than expected would be the application of a UBAWS to increase friction. Missouri DOT staff assumed that the time to construct the HFST was approximately the same as that required to apply a UBAWS. Much of the construction time is used in the process of moving the paving operation from one lane to another or from one direction to another. This process is considered to be the same for each solution, and therefore the overall time is considered to be equal. No significant reduction in construction time was realized relative to UBAWS. However, compared to realignments, the HFST was constructed in a significantly shorter time and achieved the goal of reducing the construction time by 50 percent.

Travel Time

This roadway segment spanned only about 0.2 miles. Work was mostly performed at night, during periods of lower traffic volume. The contractor was allowed to complete a portion of the work during limited daytime hours, due to issues with nighttime temperatures that were lower than allowable (and expected), but only during non-peak travel periods. The length of the work zone was such that no significant change in travel time was observed.

Queue Length

With construction activities taking place almost entirely at night, the reduced traffic volume precluded any significant queue length during paving operations, thus meeting the HfL goal of no queue greater than one-half mile.

Quality

The normal HfL indicators of quality (smoothness and noise) were not included in this project. The thickness of the material could not be counted on to correct any smoothness issues with the underlying pavement, and any change in noise would be considered negligible given the short nature of the project.

Quality for the HFST was gained through the use of exceptionally high-quality components. Calcined bauxite was the best material available for use as aggregate and was the only material allowed. The binder material was also considered to be of the highest quality. The combination should result in a long-lasting surface with exceptional frictional qualities. The specifications called for the surface to be tested for friction within 7 days of completion, with a minimum value of 65 considered acceptable. Initial numbers at this location indicated a FN40R of more than 86 in both directions. One year later, follow-up testing indicated that the FN40R number remained nearly 75.

User Satisfaction

Due to the short construction time and the night work involved in this project, it was assumed that there would be little or no impact to the public, so no survey was conducted.

ECONOMIC ANALYSIS

A key aspect of HfL projects is quantifying, as much as possible, the value of the innovation deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach to the more traditional methods.

The only innovation employed on the Missouri projects was the use of HFST. The comparison made here looks at only this innovation versus a traditional application of a UBAWS as described previously.

Construction Time

Missouri DOT estimated that there was no significant change in construction time between the innovation and the traditional UBAWS solution. However, compared to realignments, the HFST was constructed in a significantly shorter time and achieved the goal of reducing the construction time by 50 percent.

Construction Capital Costs

There was a significant increase in capital costs associated with the application of HFST. If it is assumed that mobilization, lighting required for nighttime construction, and pavement marking would be the same for both the innovative and traditional solutions, the only difference would be the material itself and the placement of the materials.

Missouri DOT estimates that the cost of traditional UBAWS would be $4.12 per square yard, in place. The HFST used here was bid at $77,435 for 4,555 square yards, or $17 per square yard in place. This indicates an increased cost of $58,668 for application of the HFST as compared to the UBAWS. However, the additional costs were significantly less compared to costs associated with realigning the section of the roadway to address ROR crashes. The friction numbers obtained with this innovation far exceeded those that would be expected with the traditional alternative, which translates to fewer post-construction accident rates.

User Cost

Generally there are three categories of user costs used in an economic/life cycle analysis: vehicle operating costs, delay cost, and safety-related costs.

In the case of US 54, there was no detour, and the work zone speed reduction of 10 mph applied to less than one-half mile of total travel. In addition, most work was completed at night, where substantially less traffic volume was affected. With no change of estimated construction time between the two alternatives, it is concluded that there were no differences in user costs between the traditional and innovative solutions.

Safety

It was estimated that the total time to construct this project was the same with HFST as would have been the case with traditional construction methods. Given this assumption and the fact that there were no crashes reported within the project limits during construction, it can be assumed that the safety cost differential for the innovation compared to traditional construction was zero for the actual construction period.

However, as discussed previously, initial data indicate that there was a significant decrease in crashes during the year after construction. During that year, there were only 5 crashes in this location, compared to an average of 32 per year prior to construction—a reduction of about 84 percent.

PROJECT DETAILS – I-44, PHELPS COUNTY

BACKGROUND

The second project to be constructed under the HfL program was located in Phelps County. This project included two locations. The first section was located west of Rolla near the Pulaski County line, and the second section was located just east of Rolla. Figure 11 is a map identifying the project locations. Figure 12 is an aerial photo showing the limits of the westernmost section.

The westernmost section (MO J) is a four-lane divided facility. The HFST was placed only on the eastbound lanes, where traffic averages about 12,900 vehlcles per day. The project spans a distance of only about 0.56 miles and is concentrated at a curve with a history of road departure crashes. The application started just past the exit ramp from I-44 to MO J.

The easternmost segment, near MO V, is also a four-lane divided facility carrying approximately 14,500 vehicles per day in the eastbound direction. The project length is 0.84 miles, starting just before the exit ramp to MO V, as shown in figure 13.

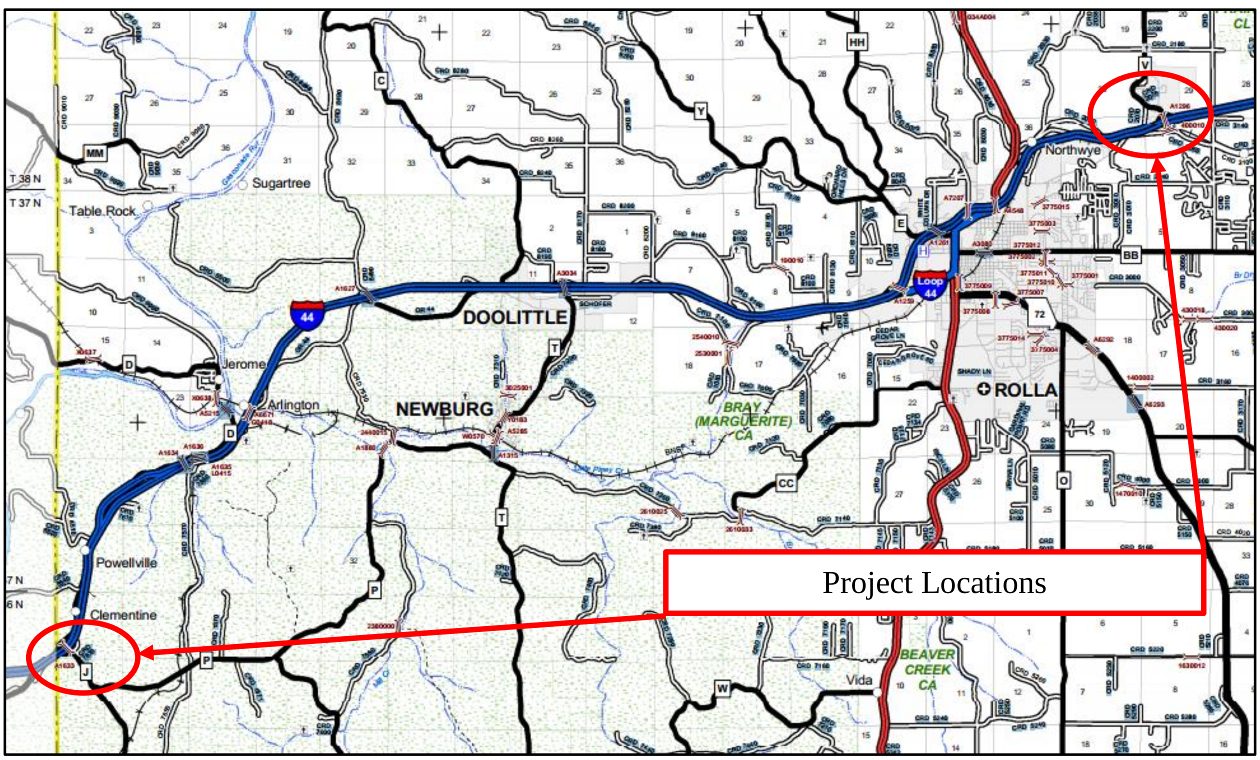


Figure 11. Map. I-44, Phelps County Missouri, general project locations (courtesy: Google Maps).

Figure 12. Photo. I-44 project location near MO J (courtesy: Google Earth).

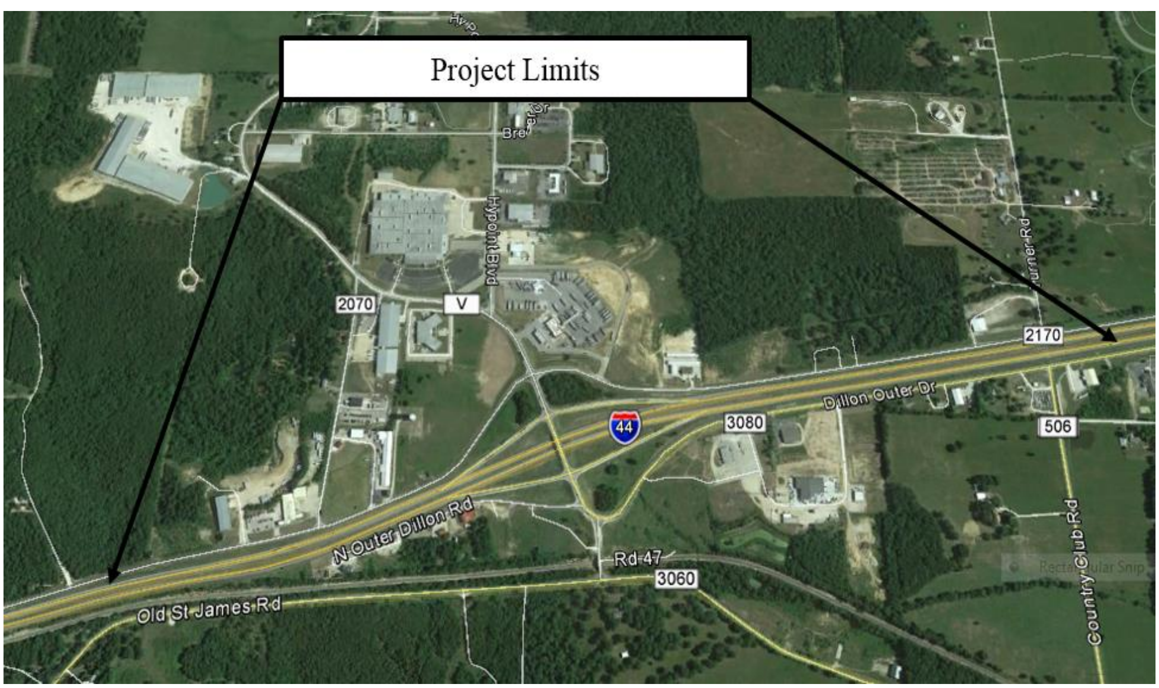


Figure 13. Photo. I-44 project location at MO V (courtesy: Google Earth).

PROJECT DESCRIPTION

The improvements were limited to the application of the HFST on the driving and passing lanes, in the eastbound directions of travel. The HFST was composed of an epoxy binder followed by the application of a very hard, durable aggregate, calcined bauxite.

Figure 14 and 15 shows the cross section for the innovation at the MO J and MO V locations, respectively.

The project was awarded in March 2014 at a cost of $568,777. The HFST component of the bid was $465,840, with the remainder used for mobilization, traffic control, striping removal, and lighting for nighttime operations.

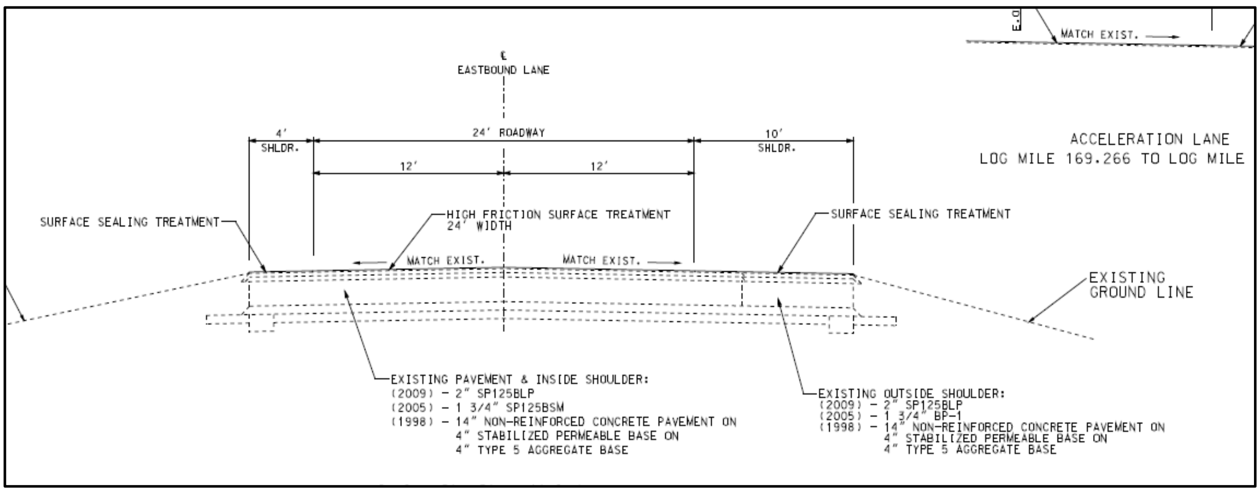


Figure 14. Diagram. Typical section for I-44 HFST placement at MO J.

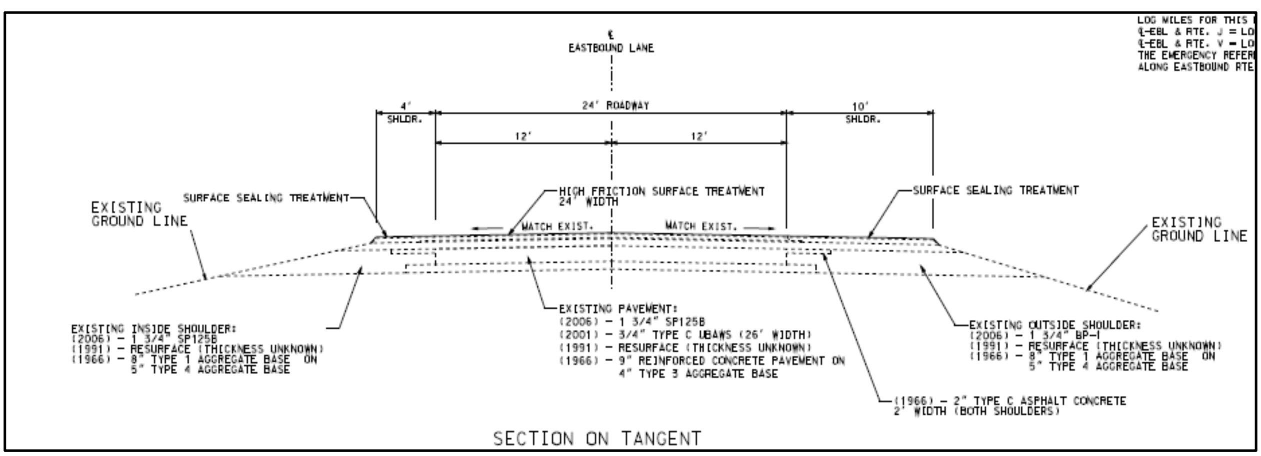


Figure 15. Diagram. Typical section for I-44 HFST placement at MO V.

PROJECT CONSTRUCTION

The duration of the project ran from May 17, 2014, until May 30, 2014. Construction on the west section near MO J started on May 17 and was completed by May 27. However, actual construction work only occurred on 6 of the 11 days at this location. Construction of the eastern section started on May 20, 2014, and ended on May 27, 2014, with actual construction work occurring on only 3 of those days.

Before the HFST was applied, the roadway was broomed to remove any loose material that might affect the bond of the HFST. The surface at the MO J location had been longitudinally grooved in the past to try and improve friction and provide drainage. The surface of the roadway prior to application of the HFST at this location is shown in figure 16. The surface at the MO V location had not been grooved.

Any wide cracks, small potholes, or distressed areas were air blasted and filled with epoxy material prior to application of the surface (see figure 17).

Application of the HFST on the Phelps County locations differed significantly from the US 54 location. In this case, a single vehicle carried both the epoxy material and the chips (see figure 18). The epoxy material was sprayed onto the surface by means of a distribution head under the vehicle, with chips dropped onto the wet surface immediately behind the distributer bar (see figure 19).

Figure 16. Photo. Grooved pavement surface prior to application (near MO J).

Figure 17. Photo. Workers fill distressed area with epoxy material prior to HFST application.

Figure 18. Photo. Machine used to place HFST.

Figure 19. Photo. Bauxite chips dropped onto surface following application of epoxy resin.

The rate of application was not critical, as any material that did not sink into the epoxy was recovered for later use. The critical factor was making sure that the entire surface was covered. If necessary, hand application supplemented the initial application. The HFST was allowed to cure overnight to ensure stability before brooming and opening to traffic.

Data Acquisition and Analysis

As appropriate, safety, construction congestion, and quality data were collected before and during the project construction to determine if this project met the HfL performance goals. The primary objective of this data acquisition and analysis was to quantify the project performance, to provide an objective basis to determine the feasibility of the project innovations, and to demonstrate that the innovations can be used to do the following:

- Achieve a safer work environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Produce a high-quality project and gain user satisfaction.

This section discusses how well the Missouri DOT project met the specific HfL performance goals related to these areas.

Safety

The HfL performance goals for safety include satisfying the following criteria:

- Meeting worker and motorist safety goals during construction.

- Reduction in fatalities and injuries after construction.

Table 4 shows the crash history for the eastbound locations for a 3-year period prior to construction.

For these locations, the analysis was done by setting a starting point one-half mile before and after the center of the projects to avoid the issue observed with the US 54 location of possibly artificially increasing the rates due to a very short section length. This allows a more fair comparison to statewide crash rates.

Table 4. Pre-construction crash rates on I-44 eastbound.

Route	Reference	Length (miles)	No. of crashes 10/13/2010 to 10/13/2013			Total	Crash Rate (crashes/ 100 million vehicle miles traveled)	
			Fatal	Injury	PDO		3-Year Rate	Statewide Average (Interstate)
I-44 E at MO J	Log mile 168.767 to Log mile 169.767	1.0	0	9	37	46	325.7	80.5
I-44 E at MO V	Log mile 189.017 to Log mile 190.017	1.0	0	6	30	36	226.7	80.5

Given these data, the crash rates in these areas prior to construction was three to four times the statewide average for interstate routes in Missouri.

There were no crashes reported within the project limits during the construction of the HFST, meeting the HfL goal of a crash rate during construction of less than or equal to the preconstruction crash rates.

Construction Congestion

The standard HfL goals for construction congestion relate to three main objectives: a reduction in total construction time of 50 percent, average trip time increased by no more than 10 percent, and no queue length greater than 0.5 miles.

Construction Time

The normal solution for a horizontal curve exhibiting greater than expected crashes would be the application of a UBAWS to increase friction. It was assumed by Missouri DOT staff that the time to construct the HFST compared to the UBAWS was approximately the same. Much of the time to construct a project using either the traditional or the innovative methods is used in the process of moving the paving operation from one lane to another or from one direction to another. This process is considered to be the same for each solution, and the overall time is considered to be equal. No significant reduction in construction time was realized relative to

UBAWS. However, compared to realignments, the HFST was constructed in a significantly shorter time and achieved the goal of reducing the construction time by 50 percent.

Travel Time

The westernmost and easternmost segments of this HfL project spanned only about 0.56 and 0.82 miles, respectively. Work was mostly done at night, during periods of lower traffic volume. The length of the work zone was such that no significant change in travel time was observed.

Queue Length

With construction activities taking place almost entirely at night, the reduced traffic volume precluded any significant queue length during paving operations, thus meeting the HfL goal of no queue greater than one-half mile.

Quality

The normal HfL indicators of quality (smoothness and noise) were not included in this project. The thickness of the material could not be counted on to correct any smoothness issues with the underlying pavement, and any change in noise would be considered negligible given the short nature of the project.

Quality for the HFST was gained through the use of exceptionally high-quality components. Calcined bauxite was the best material available for use as aggregate and was the only material allowed. The binder material was also considered to be of the highest quality. The combination should result in a long-lasting surface with exceptional frictional qualities. The specifications called for the surface to be tested for friction within 7 days of completion, with a minimum value of 65 considered acceptable. Initial numbers at this location indicated a FN40R between 82.6 and 84.1 for both directions.

User Satisfaction

Due to the short construction time and the night work involved in this project, it was assumed that there would be little or no impact to the public, so no survey was conducted.

Economic Analysis

A key aspect of HfL projects is quantifying, as much as possible, the value of the innovation deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach to the more traditional methods.

The only innovation employed on the Missouri projects was the use of HFST. The comparison made here looks at only this innovation versus a traditional application of a UBAWS as described previously.

Construction Time

Missouri DOT estimated that there was no significant change in construction time between the innovation and the traditional solution.

Construction Capital Costs

There was a significant increase in capital costs associated with the application of HFST. If it is assumed that mobilization, lighting required for nighttime construction, and pavement marking would be the same for both the innovative and the traditional solutions, the only difference would be the material itself and the placement of the materials.

Missouri DOT estimates that the cost of traditional UBAWS would be $4.12 per square yard, in place. The HFST used here was bid at $465,840 for 21,667 square yards, or $21.5 per square yard in place. This indicates an increased cost of $376,572 for application of the HFST. However, the additional costs were significantly less compared to costs associated with realigning the section of the roadway to address ROR crashes. The friction numbers obtained with this innovation far exceeded those that would be expected with the traditional alternative, which translates to fewer post-construction accident rates.

User Cost

Generally there are three categories of user costs used in an economic/life cycle analysis: vehicle operating costs, delay cost, and safety-related costs.

In the case of I-44, there was no detour, and the work zone speed reduction of 10 mph applied to less than 1 mile of total travel. In addition, most work was completed at night, where substantially less traffic volume was affected. With no change of estimated construction time between the two alternatives, it is concluded that there were no differences in user cost between the traditional and innovative solutions.

Safety

It was estimated that the total time to construct this project was the same with HFST as would have been the case with traditional construction methods. Given this assumption and the fact that there were no crashes reported within the project limits during construction, it can be assumed that the safety cost differential for the innovation compared to traditional construction was zero for the actual construction period.

While only limited time has passed since the application of the HFST, there have been no crashes reported within the project limits at the time of this report.

PROJECT DETAILS – MO 179, COLE COUNTY

BACKGROUND

The final project to be constructed under the HfL program was located on MO 179 at the intersection with US 54 in Cole County (see figure 20).

At this location, MO 179 is a four-lane divided facility carying about 15,850 vehicles per day. The HFST was added to an existing resurfacing project on MO 179 that stretched from US 50 to just south of US 54. The original plans called for cold milling and the application of a Superpave surface for a length of about 4.7 miles. There had been a history of crashes near the south end of this project, especially on ramps from eastbound US 54 to MO 179 and at southbound stop bar locations on MO 179 (see figure 21). For this reason, it was decided to add the HFST at these specific locations after completion of the overlay.

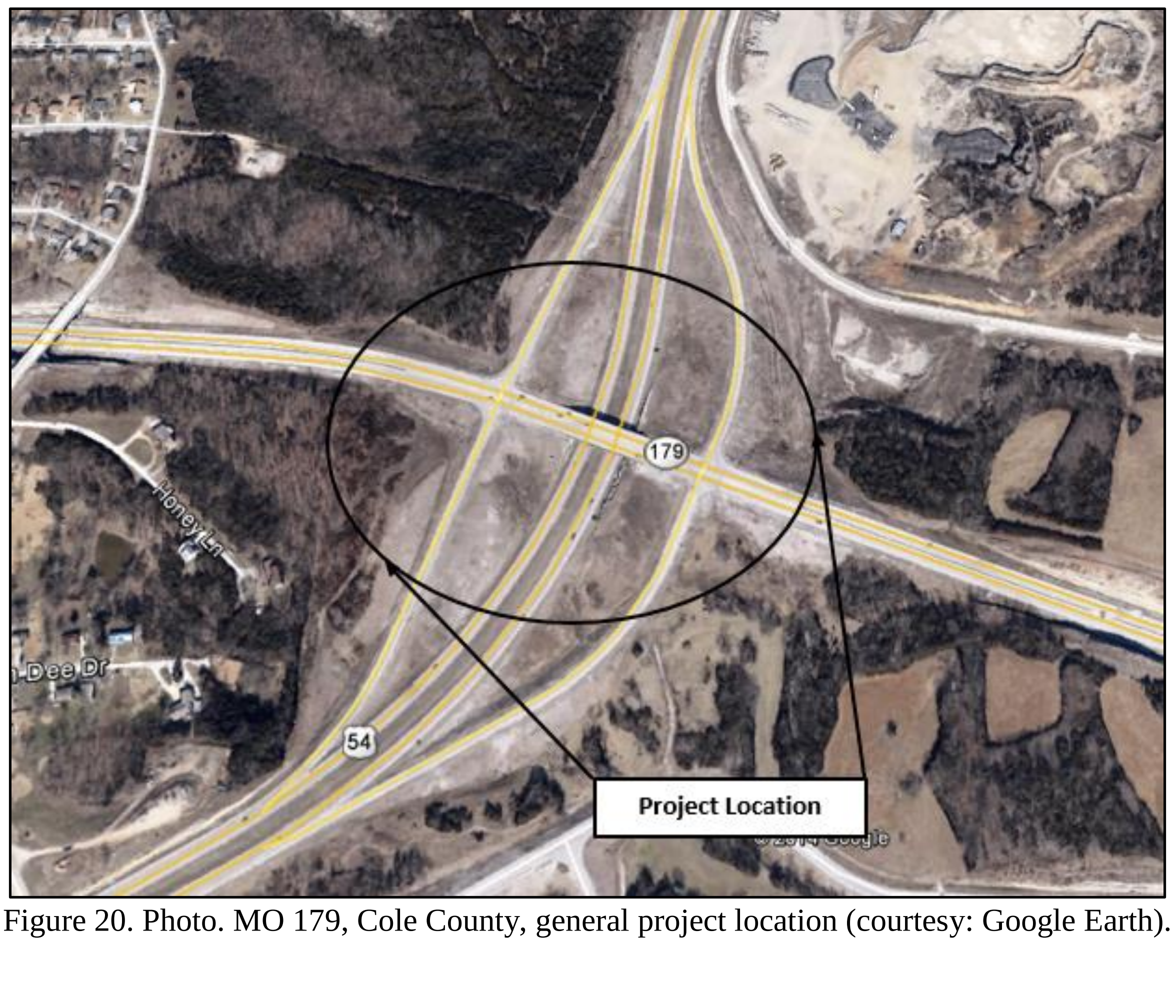


Figure 20. Photo. MO 179, Cole County, general project location (courtesy: Google Earth).

Figure 21. Photo. Specific locations of HFST application.

PROJECT DESCRIPTION

The improvements were limited to the application of the HFST on the driving and passing lanes, in the southbound direction of travel just prior to stop bar locations and at the ramp from eastbound US 54 to MO 179. A downhill grade at the two mainline locations also contributed to the need for improved friction, while travelers stopped at the top of the exit ramp experienced traction issues when making the turn onto MO 179, especially northbound.

The HFST was composed of an epoxy binder followed by the application of a very hard, durable aggregate, calcined bauxite.

The project was awarded in November 2014 at a cost of $880,908. The HFST component of the bid was $111,078, with the remainder used for traditional resurfacing of the remaining 4+ miles of the project and the associated mobilization, traffic control, striping removal, and lighting for nighttime operations.

PROJECT CONSTRUCTION

The duration of the entire project ran from August 21, 2014, until October 27, 2014. However, construction work for the HFST only occurred between October 7 and October 21. Within this time period, only 6 days were used for actual placement of the HFST.

Most work was completed at night; however, the contractor was allowed to perform some hand work during the day, when other construction activities were already being conducted.

Whereas on the previous HFST projects the underlying pavement had been in service for years, in this case, the HFST was applied to a new pavement. Specifications called for a waiting period of 30 days before the HFST could be applied. While the contractor suggested waiving or reducing this waiting period (due to the early advent of cold weather), discussions with FHWA staff and other technology experts recommended that the 30-day period be maintained. This was mainly required to allow any surface oil to be tracked off the surface to ensure proper bond.

Before the HFST was applied, the roadway was broomed to remove any loose material that might affect the bond of the HFST.

The process used at this location was the same as used at the Cole County location: application of the epoxy through a wand, spreading the epoxy with a notched squeegee, and then applying the aggregate through an air driven blower system (see figures 22 and 23).

Pavement markings (stop bars, turn arrows, etc.) that had been previously installed were taped off to avoid contact with the epoxy before application of the aggregate (see figure 24). The rate of application was not critical, as any aggregate that did not sink into the epoxy was recovered for later use. The critical factor was making sure that the entire surface was covered. If necessary, hand application supplemented the initial application. The HFST was allowed to cure overnight to ensure aggregate adhesion before brooming and opening to traffic.

Figure 22. Photo. Epoxy material spread using notched squeegee.

Figure 23. Photo. Bauxite material blown onto surface of previously installed epoxy binder.

Figure 24. Photo. Workers apply epoxy material near previously installed pavement markings.

DATA ACQUISITION AND ANALYSIS

As appropriate, safety, construction congestion, and quality data were collected before and during the project construction to determine if this project met the HfL performance goals. The primary objective of this data acquisition and analysis was to quantify the project performance, to provide an objective basis to determine the feasibility of the project innovations, and to demonstrate that the innovations can be used to do the following:

- Achieve a safer work environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Produce a high-quality project and gain user satisfaction.

This section discusses how well the Missouri DOT project met the specific HfL performance goals related to these areas.

Safety

The HfL performance goals for safety include satisfying the following criteria:

- Meeting worker and motorist safety goals during construction.
- Reduction in fatalities and injuries after construction.

In the case of MO 179, the HFST was applied at spot locations within the footprint of the MO 179/US 54 interchange. Stop/start and turning movement locations where crash history indicated improved friction may be required were the primary targets. Because of the spot nature of the improvements, the crash analysis for this HfL location was treated slightly differently than a normal range analysis. Data were drawn from crash records 0.5 miles each side of the center of the project along MO 179. Any crashes associated with any of the interchange ramps were also included. Turning movements to or from MO 179 were considered part of the MO 179 traffic volume, so ramp volumes were not considered in this analysis. Table 5 shows the crash history and rates at this location for a 3-year period prior to construction.

Table 5. Pre-construction crash rates on MO 179.

Route	Reference	Length (miles)	No. of crashes 10/13/2010 to 10/13/2013			Total	Crash Rate (crashes/ 100 million vehicle miles traveled)	
			Fatal	Injury	PDO		3-Year Rate	Statewide Average (Interstate)
MO 179/US 54 Interchange	Log mile 2.92 to Log mile 3.92	1.0	0	16	22	38	218.9	N/A

There were no crashes reported within the project limits during the construction of the HFST, meeting the HfL goal of a crash rate during construction of less than or equal to the preconstruction crash rates.

Construction Congestion

The standard HfL goals for construction congestion relate to three main objectives: a reduction in total construction time of 50 percent, average trip time increased by no more than 10 percent, and no queue length greater than 0.5 miles.

Construction Time

The traditional solution for a location exhibiting more crashes than expected due to reduced friction would be the application of a UBAWS. Missouri DOT staff assumed that the time to construct the HFST was approximately the same as would be required to apply a UBAWS. Much of the time to construct either scenario is used in the process of moving the paving operation from one lane to another or from one direction to another. This process is considered to be the same for each solution, so the overall time is considered to be equal. No significant reduction in construction time was realized.

Travel Time

Construction of the HFST spanned only a few hundred feet at a time. Work was mostly conducted at night, during periods of lower traffic volume. The length of the work zone was such that no significant change in travel time was observed.

Queue Length

With construction activities taking place almost entirely at night, the reduced traffic volume precluded any significant queue length during paving operations, thus meeting the HfL goal of no queue greater than one-half mile.

Quality

The normal HfL indicators of quality (smoothness and noise) were not included in this project. The thickness of the material could not be counted on to correct any smoothness issues with the underlying pavement, and any change in noise would be considered negligible given the short nature of the project.

Quality for the HFST was gained through the use of exceptionally high-quality components. Calcined bauxite was the best material available for use as aggregate and was the only material allowed. The binder material was also considered to be of the highest quality. The combination should result in a long-lasting surface with exceptional frictional qualities. The specifications called for the surface to be tested for friction within 7 days of completion, with a minimum value of 65 considered acceptable. Initial numbers at this location indicated a FN40R of about 86.7.

USER SATISFACTION

Due to the short construction time and the night work involved in this project, it was assumed that there would be little or no impact to the public, so no survey was conducted.

ECONOMIC ANALYSIS

A key aspect of HfL projects is quantifying, as much as possible, the value of the innovation deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach to the more traditional methods. The only innovation employed on the Missouri projects was the use of HFST. The comparison made here looks at only this innovation versus a traditional application of a UBAWS as described previously.

Construction Time

Missouri DOT estimated that there was no significant change in construction time between the innovation and the traditional solution.

Construction Capital Costs

There was a significant increase in capital costs associated with the application of HFST. If it is assumed that mobilization, lighting required for nighttime construction, and pavement marking would be the same for both the traditional and the innovative solutions, the only difference would be the material itself and the placement of the materials.

Missouri DOT estimates that the cost of traditional UBAWS would be $4.12 per square yard, in place. The HFST used here was bid at $111,078 for 6,171 square yards, or $18 per square yard in place. This indicates an increased cost of $85,653 for application of the HFST. However, the additional costs were significantly less compared to costs associated with realigning the section of the roadway to address ROR crashes. The friction numbers obtained with this innovation far exceeded those that would be expected with the traditional alternative, which translates to fewer post-construction accident rates.

User Cost

Generally there are three categories of user costs used in an economic/life cycle analysis: vehicle operating costs, delay cost, and safety-related costs.

In the case of MO 179, there was no detour, and the work zone speed reduction of 10 mph applied to less than one-half mile of total travel. In addition, most work was completed at night, where substantially less traffic volume was affected. With no change of estimated construction time between the two alternatives, it is concluded that there were no differences in user cost between the traditional and innovative solutions.

Safety

It was estimated that the total time to construct this project was the same with HFST as would have been the case with traditional construction methods. Given this assumption and the fact that there were no crashes reported within the project limits during construction, it can be assumed that the safety cost differential for the innovation compared to traditional construction was zero for the actual construction period.

While only limited time has passed since the application of the HFST, there have been no crashes reported within the project limits at the time of this report.

ECONOMIC ANALYSIS

There was a significant increase in initial cost for use of the HFST on this project as compared to UBAWS. The use of HFST on the four locations added an estimated $520,893 above the cost of the traditional solution. While no savings were realized in construction time or safety during construction activities, it is assumed that there will be major savings with respect to future safety on these roadways. MODOT's HfL application indicates that one of the goals of HFST at these locations is to reduce fatalities and injuries at test site locations by 20 percent.

While most of the sections completed are too new to have postconstruction safety data available, the US 54 location has been in place more than a year, and some initial data are available. As discussed previously, the 3-year crash history indicated that there was an average of 32 crashes per year occurring at that location. In the year since construction of the HFST, there have been only 5 crashes. Based on this limited initial data from one of the projects, MODOT's goal of 20 percent reduction in accident rates seems achievable.

MoDOT believes that, even in times of reduced funding and limited resources, the higher initial cost of the HFST is a worthwhile investment for locations that exhibit a similar crash history. While comparison with UBAWS was used for the economic analysis, UBAWS is not directly comparable with HFST in terms of long-term safety and durability performance. A long term durable solution includes realignment of portions of the roadway to reduce ROR crashes. HFST is substantially more cost effective that the realignment options.

The National Safety Council has published the average cost of crashes by severity. Table 6 shows a breakdown of these costs.

Table 6. Average comprehensive cost of injury by severity (National Safety Council 2012).

Severity	Cost (dollars)
Fatal	4,538,000
Incapacitating Injury	230,000
Injury	58,700
Possible Injury	28,000
PDO	2,500

SAVINGS BASED ON CRASH DATA TO DATE

Using the data from the 3-year period prior to construction, the percentage of crash severity is calculated to be 0.0 percent fatal, 32.3 percent injury, and 67.7 percent PDO. This equates to an average crash cost for this location of $35,790 (assuming an equal distribution of incapacitating injury, injury, and possible injury crashes).

The reduction of 27 crashes during the first year at just this one location results in a savings of about $966,300, or nearly twice the additional cost of HFST placement all four locations combined.

SAVINGS BASED ON MODOT'S GOAL OF 20 PERCENT REDUCTION

Table 7 shows the number of crashes for the four project locations over a period of 3 years prior to construction. Assuming no substantial increase in traffic volume or change in traffic patterns, this trend can be expected to continue for the traditional scenario. Using HFST, MODOT is targeting a 20 percent reduction in crashes. Assuming a treatment life of 9 years for the HFST; in the 9 years following construction, the number of injury crashes can be expected to be reduced by at least 37 and the number of PDO crashes can be expected to be reduced by at least 92. The total reduction in crashes is expected to be at least 129 at the four locations over the 9-year period.

Table 7. Pre-construction crash history at all project locations combined.

Route	No. of crashes 10/13/2010 to 10/13/2013			
	Fatal	**Injury**	**PDO**	**Total**
All Combined	0	62	154	216

Using present worth cost of crashes as shown in table 6, this 20 percent reduction in accidents, results in a minimum savings of $4,136,000, over the 9-year life of the treatment (assuming an equal distribution of incapacitating injury, injury, and possible injury crashes).

REFERENCES

1. *EDC 2012 Initiatives. High Friction Surface Treatment*. Federal Highway Administration, Washington, DC, (accessed December 15, 2014), https://www.fhwa.dot.gov/everydaycounts/edctwo/2012/friction.cfm

2. *Frequently Asked Questions about High Friction Surface Treatments (HFST)*. FHWA-CAI-14-019. Federal Highway Administration, Washington, DC, (accessed December 15, 2014). https://www.fhwa.dot.gov/everydaycounts/edctwo/2012/pdfs/fhwa-cai-14-019_faqs_hfst_mar2014_508.pdf

3. High Friction Surface Treatments: A Road Surface Treatment for Critical Safety Spot Locations that Helps Vehicles Stay in Their Lane. Federal Highway Administration, Washington, DC, (accessed December 15, 2014). https://www.fhwa.dot.gov/everydaycounts/edctwo/2012/pdfs/hfst_brochure.pdf

ACKNOWLEDGMENTS

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway administration (FHWA) Highways for Life (HfL) Team Leader Byron Lord, Contracting Officer's Representative Julie Zirlin, and Program Managers Ewa Flom, Mary Huie, and Kathleen Bergeron, who served on the technical panel on the demonstration project.

The team also is indebted to Marc Thornsberry and Mike McGee of the FHWA Missouri Division for their effective coordination effort and to Missouri Department of Transportation Research Engineer Jen Harper, Construction and Materials Liaison Engineer John Donahue, Transportation Management Systems Administrator Myrna Tucker and Traffic Safety Engineer John Miller for their efforts and cooperation on this project. The project team was instrumental in making this project a success and provided the information that helped shape this report.