Wyoming Demonstration Project:

Wyoming Hwy 196 – Buffalo South/WMA Overlay Project

Final Report
October 2014

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.
4. Title and Subtitle Wyoming Demonstration Project: Wyoming Hwy 196 – Buffalo South/WMA Overlay Project		5. Report Date October 2014 6. Performing Organization Code
7. Author(s) Deepak Raghunathan, Suri Sadasivam, and Jagannath Mallela		8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Blvd., Suite 200 Champaign, IL 61820		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Ave., 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
The Buffalo project was both WYDOT and the contractor's first experience with additive based WMA. Prior to this project, WYDOT had undertaken a WMA project (foaming based) near College Drive, Cheyenne, WY.

On this project, WMA and HMA overlay of 4.79 miles of a secondary two-lane highway was carried out. The project, located south of Buffalo, Wyoming, involved pavement rehabilitation on Wyoming Highway 196 in Johnson County from milepost 294.63 to milepost 299.42. The last rehabilitation of this section of roadway, excluding the maintenance patching, was carried out in the late 1950s. This project received 80 percent Federal funding and 20 percent State funding.

Wyoming DOT undertook this project anticipating that the properties of WMA will allow for easier and better compaction, lower permeability, and reduced segregation, resulting in better long-term pavement performance.The innovative technologies deployed on this project were 1) warm mix asphalt (additive and foaming methods), and 2) 6:1 taper. A suite of laboratory testing was conducted by WYDOT to evaluate the concerns related to WMA's potential for increased rutting and moisture damage. The Hamburg Wheel Tracking (HWT) test results indicated that the WMA mixtures have the potential to exhibit higher initial rutting (i.e. consolidation during initial stages after construction); however, their rate of rutting accumulation stabilizes over time and is comparable to that of HMA at later years.

The HfL performance goals on quality and safety aspects of this project were met. The user satisfaction survey conducted by the WYDOT indicated that a high percentage of the local residents and traveling public were satisfied with the project. The contractor received a net bonus of $32,621.98 for mat density, aggregate gradation, asphalt content, and smoothness. Cost comparison between WMA and HMA, based on the winning bid, indicated that the unit prices (i.e. $/ton) that the actual tonnage cost of WMA was 9.4 percent higher than HMA. Since the placement of HMA and WMA would have required the same construction time, there would be no differential user costs between the traditional and as-built scenarios. Hence, the computation of user costs was deemed not necessary. WYDOT had no cost associated with the Warm Mix aspect of the project except what is reflected in the bid prices. Also, the contractor received no incentive except for those related to QA.

17. Key Words Highways for LIFE, 6:1 taper, warm-mix asphalt		18. Distribution Statement No restrictions. This document is available to the public through the Highways for Life website: www.fhwa.dot.gov/hfl/	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 50	22. Price

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
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 yard	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	milliliters	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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
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 (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AADT	annual average daily traffic
DOT	department of transportation
ESAL	equivalent single axle load
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HMA	hot mix asphalt
HWT	Hamburg wheel tracking
IRI	International Roughness Index
LMLC	lab mixed, lab compacted
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
PAV	pressure aging vessel
PDO	property damage only
PMPC	plant mixed, plant compacted
QA	quality assurance
RAP	recycled asphalt pavement
RTFO	rolling thin-film oven
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
VOC	vehicle operating cost
WMA	warm mix asphalt

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration's (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)—may provide 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 a 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 has issued open solicitations for HfL project applications annually since fiscal year 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 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 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—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

- **Construction Congestion**
  - Faster construction—Fifty percent reductions in the time highway users are impacted by an active construction zone, 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 mile 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**—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 Wyoming DOT's demonstration project, which involved 4.79 miles of pavement rehabilitation on Wyoming Highway 196 in Johnson County from milepost 294.63 to milepost 299.42. The report presents project details relevant to the HfL program, including the use of innovative technologies (warm mix asphalt and 6:1 taper), HfL performance metrics measurement, and economic analysis. The lessons learned during the course of the project are also discussed.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

The Buffalo project was both WYDOT and the contractor's first experience with additive based WMA. Prior to this project, WYDOT had undertaken a WMA project (foaming based) near College Drive, Cheyenne, WY.

On this project, WMA and HMA overlay of 4.79 miles of a secondary two-lane highway was carried out. The project, located south of Buffalo, Wyoming, involved pavement rehabilitation on Wyoming Highway 196 in Johnson County from milepost 294.63 to milepost 299.42. The last rehabilitation of this section of roadway, excluding the maintenance patching, was carried out in the late 1950s. This project received 80 percent Federal funding and 20 percent State funding.

Wyoming DOT undertook this project anticipating that the properties of WMA will allow for easier and better compaction, lower permeability, and reduced segregation, resulting in better long-term pavement performance.

The innovative technologies deployed on this project were 1) warm mix asphalt (additive and foaming methods), and 2) 6:1 taper. A suite of laboratory testing was conducted by WYDOT to evaluate the concerns related to WMA's potential for increased rutting and moisture damage. The Hamburg Wheel Tracking (HWT) test results indicated that the WMA mixtures have the potential to exhibit higher initial rutting (i.e. consolidation during initial stages after construction); however, their rate of rutting accumulation stabilizes over time and is comparable to that of HMA at later years.

The HfL performance goals on quality and safety aspects of this project were met. The user satisfaction survey conducted by the WYDOT indicated that a high percentage of the local residents and traveling public were satisfied with the project. Cost comparison between WMA and HMA, based on the winning bid, indicated that the unit prices (i.e. $/ton) that the actual tonnage cost of WMA was 9.4 percent higher than HMA. Since the placement of HMA and WMA would have required the same construction time, there would be no differential user costs between the traditional and as-built scenarios. Hence, the computation of user costs was deemed not necessary.

HfL Performance Goals

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to determine if warm mix asphalt (WMA) and the 6:1 taper met the HfL performance goals.

- **Safety**
  - Work zone safety during and at the completion of construction—No motorist crashes were reported within the project limits during construction. The HfL goal of achieving a work zone crash rate equal to or less than the preconstruction rate

was met. The presence of an open traffic lane and a smaller construction zone throughout the rehabilitation process played a major role in ensuring motorist 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—This goal will be evaluated in the future. However, the installation of 6:1 taper is expected to improve the safety performance of the facility.

- **Construction Congestion**
  - Travel Time—One of the two lanes was kept open in the work zone throughout the construction period. Although no formal records of queue length or delay time were collected during this project, Wyoming DOT roughly estimated the trip time through the construction zone to be less than 5 minutes. The contractor also maintained the construction zone to a minimum length. WYDOT estimates no significant differences in travel time before and during construction.
  - Queue length during construction—No significant queuing at the project location was reported. It should be noted that the project location typically carries less than 700 vehicles per day, which may not create significant queuing conditions. Therefore, it can be safely assumed that the project met the HfL performance goal of having a moving queue length of less than 0.5 mile in a rural area.

- **Quality**
  - Smoothness—Quality was measured in terms of smoothness and noise both before and after construction. The average IRI value in 2011 (before rehabilitation) was found to be 115 inches/mile. After the rehabilitation process in 2013, the average IRI value in 2013 was noted to be 48 inches/mile. The project thus met the HfL performance goal for smoothness/IRI. The contractor received a bonus of $18,059.00 for smoothness quality
  - Noise—No sound intensity testing was conducted at the project site before or after the rehabilitation period.
  - User satisfaction—The postconstruction user satisfaction survey results indicated that the local community was very satisfied with the project. Thus, the HfL user satisfaction criterion was met for this project.
  - Construction quality is not considered a direct goal of the HfL program. However, it can have an indirect but substantial impact on HfL goals, especially those related to functional performance, user satisfaction and safety. The contractor received a net bonus of $32,621.98 for mat density, aggregate gradation, asphalt content, and smoothness. This indicates the better quality of construction achieved on this project.

ECONOMIC ANALYSIS

WMA was delivered, placed, and compacted in the same way as HMA. The construction practices and equipment were similar for both technology categories. The placement of HMA and WMA would have required the same construction time, and therefore, no significant differences in user costs between the two scenarios are expected.

Since the WMA is relatively a new technology category, studies on long-term field performance of pavements constructed with WMA are yet to be completed. Hence, no comparison is made on the life cycle performance of WMA and HMA.

The WMA and HMA unit prices listed in the bid tabulations were evaluated to assess the expected market price of WMA. The unit prices from the winning bid indicated that the actual tonnage cost of WMA was 9.4 percent higher than HMA. The average expected market price of WMA was found to be higher than that of HMA; however, there was considerable variability in the bid prices indicating that the WMA prices were comparable to HMA prices.

LESSONS LEARNED

Through this project, the Wyoming DOT gained experience with the application of foamed and additive WMA. Wyoming DOT undertook extensive efforts in this experimental project with performance testing of WMA and detailed documentation of the construction process. According to Wyoming DOT, mix production worked well for hot mix and both types of warm mix. When transitioning between hot mix and warm mix, the foamed warm mix was easier to use than the additive. The following were some specific observations:

- The foamed warm mix provided flexibility on the laydown temperature. In other words, the contractor could pave hot mix, then turn on the foamer and continue to pave while the temperatures dropped down to the desired temperature.
- Problems arose when switching from hot mix to Evotherm-based warm mix. During the transitioning process, the contractor would have to wait for the mix temperatures to drop before placing and compacting the mix. Concerns associated with the Evotherm were that it could only be compacted in a narrow temperature range. At higher temperatures, the mix would push when rolled, and at lower temperatures, the specified densities could not be achieved.

CONCLUSIONS

This project was a good learning experience for WYDOT. No difficulties were encountered with the use of the 6:1 taper, which has been WYDOT's standard for several of the previous projects. While the placement of foamed WMA went smoothly, additive based WMA's use caused some concerns because it could only be compacted in a narrow temperature range. The HfL performance goals were met for safety, travel time and queue length during construction, and smoothness.

PROJECT DETAILS

BACKGROUND

The Buffalo project was both WYDOT and the contractor's second experience with WMA. The first WMA project undertaken by WYDOT was near College Drive, Cheyenne, WY, wherein the foaming method was adopted. The Buffalo project was WYDOT's first experience with additive based WMA. This project involved WMA and HMA overlay of 4.79 miles of a secondary two-lane highway (a major collector road not on the National Highway System) that carried traffic loading of 65 equivalent single axle loads (ESALs) per day. The last rehabilitation of this section of roadway, excluding the maintenance patching, was carried out in the late 1950s. This project received 80 percent Federal funding and 20 percent State funding. The HfL grant provided for this project was $520,000.

Through this project, Wyoming DOT intended to present a model for future WMA projects throughout the State, showing that WMA can enhance the constructability and quality of thin overlays, allowing narrow roadways to be rehabilitated while improving driver safety. Wyoming DOT undertook this project anticipating that the properties of WMA will allow for easier and better compaction, lower permeability, and reduced segregation, resulting in better long-term pavement performance.

PROJECT DESCRIPTION

The project, located south of Buffalo, Wyoming, involved pavement rehabilitation on Wyoming Highway 196 in Johnson County from milepost 294.63 to milepost 299.42. Figure 1 shows the project location.

The rehabilitation included two 12-foot travel lanes without shoulders through the project length and a third lane along the northern 1.2 miles. The project was carried out using WMA for two-thirds of the surface and HMA for the remaining one-third of the surface. The work included 1.5 inches of plant mix surface course over a 1-inch leveling course after 1 inch of milling. Additionally, reclaimed asphalt pavement (RAP) from the milling was used to maintain the existing top width and to build up the slopes at a 6:1 taper to provide a safe recovery back to the roadway.

The project consisted of one HMA section on both lanes of the highway, two Evotherm WMA sections, and two foamed WMA sections. The project test sections and their respective reference markers and lengths are summarized in table 1. Figure 2 provides a pictorial representation of the test sections and the transitions.

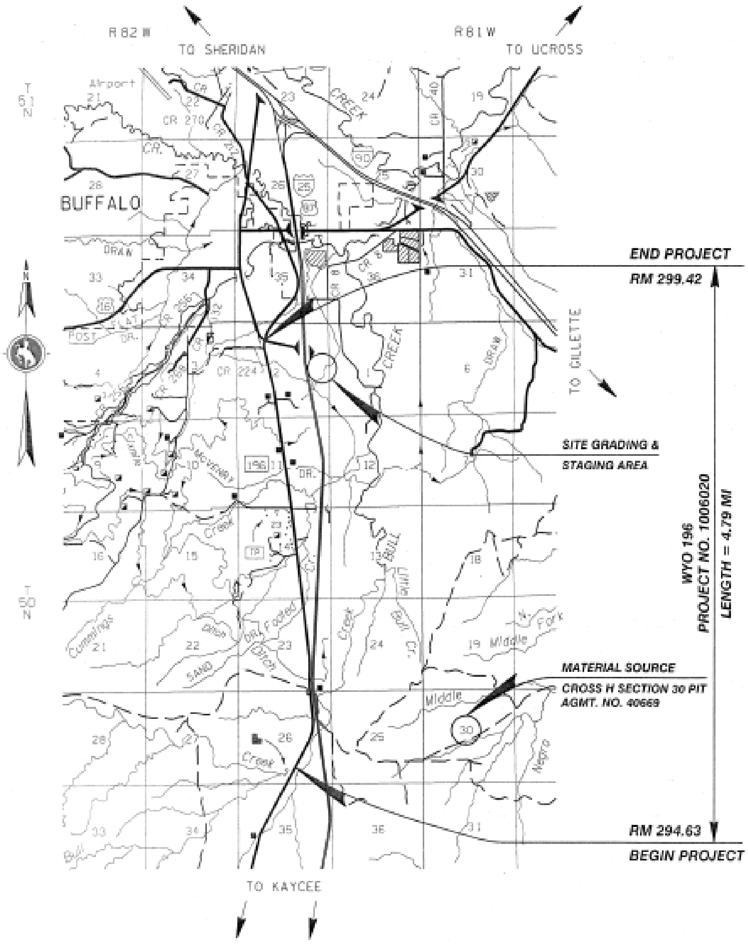


Figure 1. Map. Project location

Table 1. Test sections for Buffalo project.

Test Section	Milepost to Milepost	Length (miles)	Comments
WMA Evotherm (-50 °F)*	294.63 to 296.41 northbound	1.78	
WMA Evotherm (-40 °F)	294.63 to 296.41 southbound	1.78	
			Transition
HMA	296.53 to 298.24 northbound	1.71	
HMA	296.53 to 298.24 southbound	1.71	
			Transition
WMA Foamed (-20 °F)	298.41 to 299.42 northbound	1.01	
WMA Foamed (-40 °F)	298.57 to 299.42 southbound	0.85	

*Throughout this report, WMA temperatures are referenced according to how much lower they were than the HMA temperature.

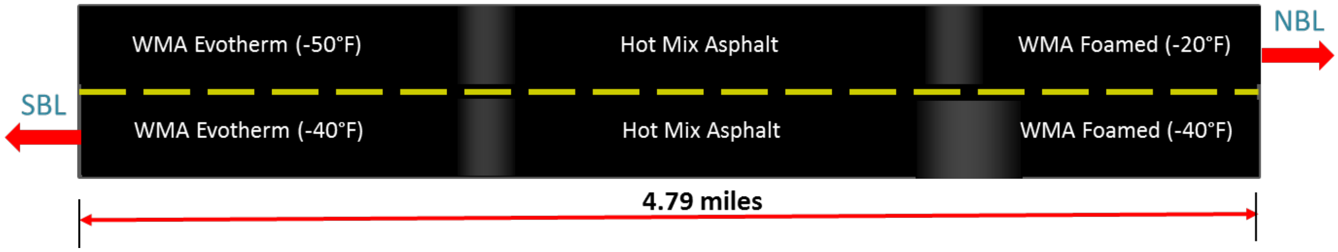


Figure 2. Drawing. Test sections and transitions.

Table 2 presents a section summary for the total length of the project.

Table 2. Length of project summary.

Milepost		
		Begin Project Section 1- Hot Plant Mix (Control Section)
		Section 2- Warm Plant Mix (Additive/Chemical Process)
		Section 3- Warm Plant Mix (Asphalt Foaming Process) End Project

Figures 3 through 6 illustrate the typical sections for this project. As shown in the typical sections, the taper slope was 1"-8" with a horizontal dimension of 20". The paving consisted of 1.5" overlay on top of 1" leveling, the total topping being of 2.5". In this case, the slope would be 20/2.5 = 8:1 which is better than the 6:1 taper that was the standard for this project.

If there had been dirt work on this project, the typical section would show a 6:1 taper extending from the top edge of the shoulder paving extending down to the bottom of the slope. Since there was no dirt work, this is not shown on the plans.

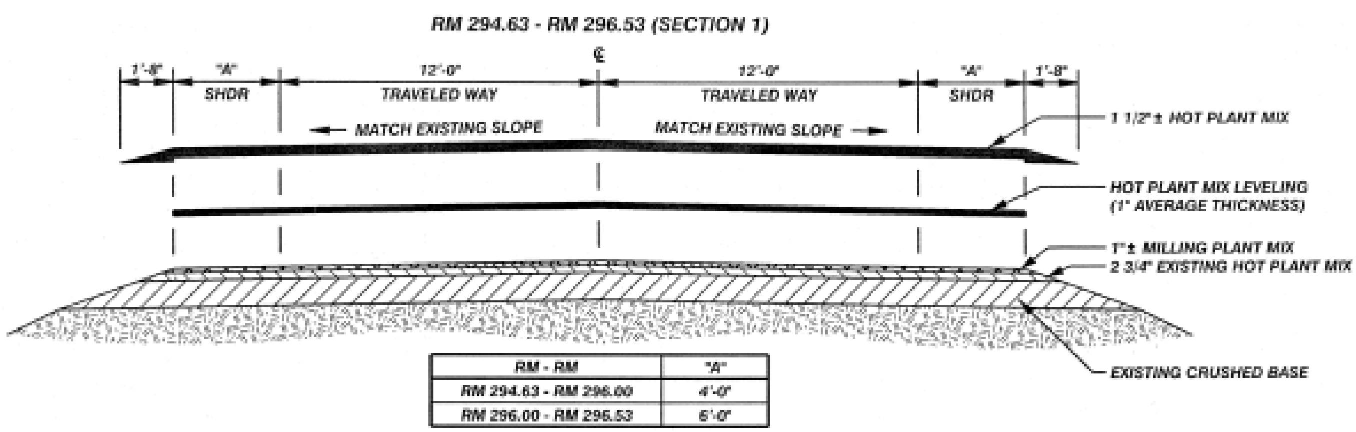
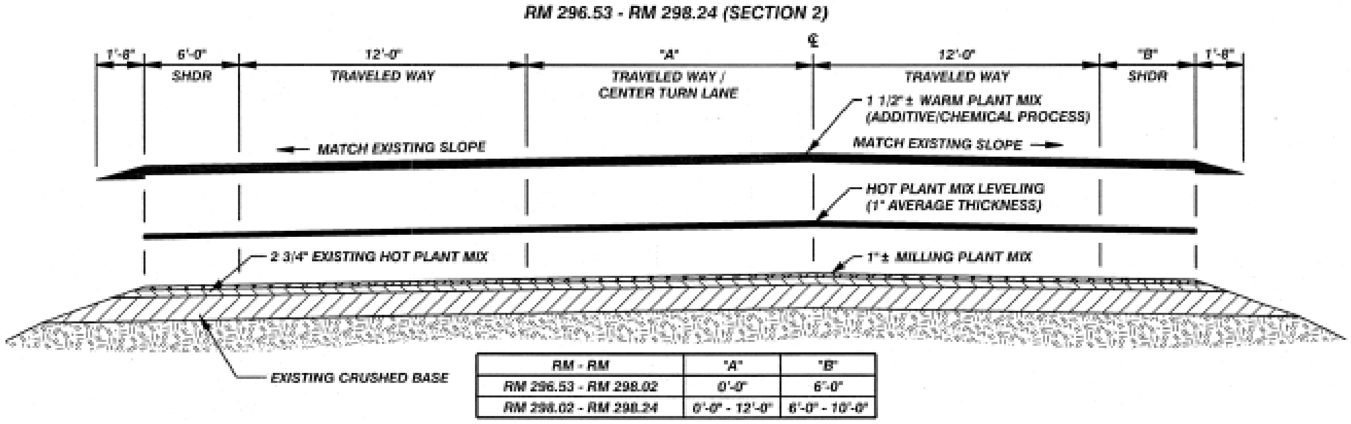
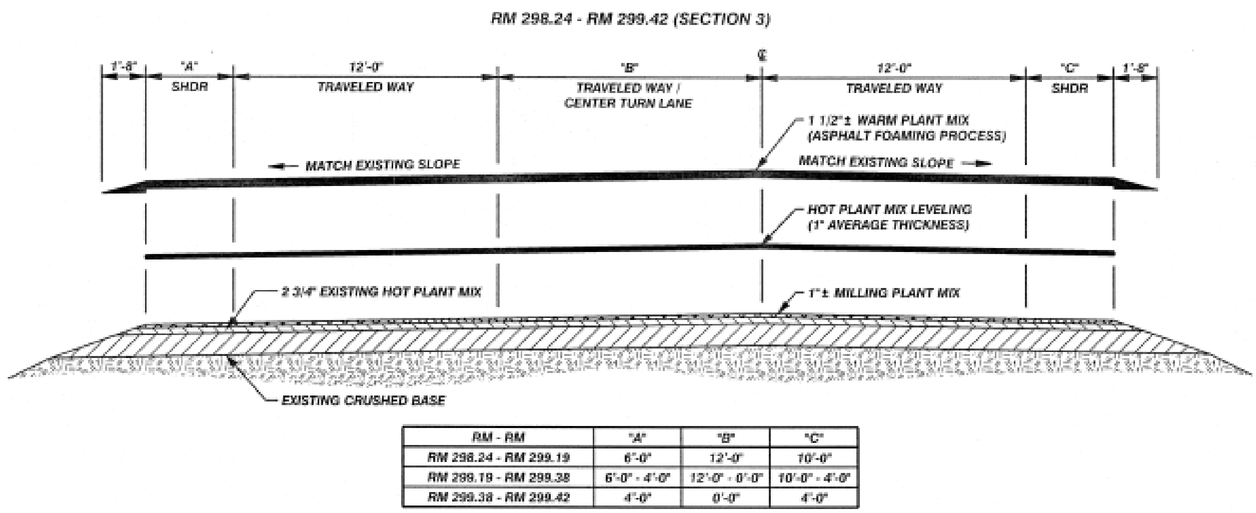


Figure 3. Diagram. Proposed typical section 1 (milepost 294.63 to milepost 296.53).



RM - RM	"A"	"B"
RM 296.53 - RM 298.02	0'-0"	6'-0"
RM 298.02 - RM 298.24	0'-0" - 12'-0"	6'-0" - 10'-0"

Figure 4. Diagram. Proposed typical section 2 (milepost 296.53 to milepost 298.24).



RM - RM	"A"	"B"	"C"
RM 298.24 - RM 299.19	6'-0"	12'-0"	10'-0"
RM 299.19 - RM 299.38	6'-0" - 4'-0"	12'-0" - 0'-0"	10'-0" - 4'-0"
RM 299.38 - RM 299.42	4'-0"	0'-0"	4'-0"

Figure 5. Diagram. Proposed typical section 3 (milepost 298.24 to milepost 299.42).

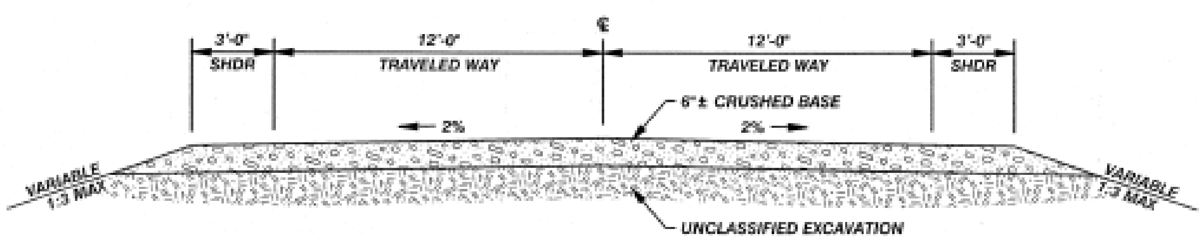


Figure 6. Diagram. Proposed typical section, staging area access road.

Existing Pavement Condition

Before rehabilitation, the pavement had an average IRI of 115 inches/mile and an average rut depth of 0.30 inches. Figures 7 through 9 presents the pavement condition before rehabilitation was carried out.

Figure 7. Photo. Beginning of pavement section (courtesy: Wyoming DOT)

Figure 8. Photo. Middle of pavement section (courtesy: Wyoming DOT)

Figure 9. Photo. End of pavement section (courtesy: Wyoming DOT)

PROJECT INNOVATIONS

The innovations on this project included the use 6:1 taper and two WMA technologies:

- 6:1 taper: The project incorporated 6:1 taper to enhance safety of the road users. As mentioned earlier, contrary to the standard 6:1 taper proposed for the project, a safer alternative of 8:1 taper was employed.
- Warm Mix Asphalt: Two WMA technologies, additive and foaming based, were used for this project. The chemical additive method and foaming method used for this project were Evotherm 3G and Gencor Ultrafoam GX2 respectively.
    a. Evotherm 3G (chemical additive): The Evotherm technology is the most commonly used WMA technology in the United States. Evotherm, a chemical WMA product designed to enhance coating, adhesion, and workability at reduced temperatures, was introduced in 2004 and is currently it is in its third generation (3G). Evotherm 3G does not contain water and may be added at the binder terminal or mix plant.
    b. Gencor Ultrafoam GX2: Ultrafoam GX2 is the second generation of the Ultrafoam GX WMA system. It uses the energy supplied by the pump or head supplying the asphalt binder to achieve the foaming process. The need for a powered mixing device is eliminated, allowing the asphalt binder to be introduced at various flow rates, temperatures, and pressures, eventually resulting in more consistent asphalt foaming at different production rates. The Ultrafoam GX2 system typically uses around 1.25 to 2 percent water by weight of total asphalt binder to achieve adequate foaming.

WMA Benefits and Concerns

There are advantages and disadvantages to using WMA. For example, although WMA may be costlier than HMA in terms of its tonnage costs, it is seen as a more sustainable alternative, primarily because of the energy savings and reduced emissions through the use of WMA. Table 3 lists some of the benefits and concerns of using WMA instead of the traditional HMA.

Table 3. WMA benefits and concerns.

WMA Benefits	WMA Concerns
• Energy savings and reduced emissions due to lower fuel consumption • Improved work environment resulting from reduced emissions • Improved compactability as a result of lubricating effect of WMA • Better workability owing to WMA compactability at lower temperatures and lubricating effect between aggregate particles by WMA additives • Longer haul distances and cold weather paving because of WMA compactability at lower temperatures • Better mat temperature uniformity leading to better long-term performance	• Incomplete aggregate drying resulting in presence of internal moisture in coarse aggregates, mixture tenderness, poor asphalt binder adhesion, and moisture damage • RAP mixing issues leading to lower effective binder contents and thereby to durability distresses • Production concerns such as reduced production rate, amperage on motors for drag slat conveyors, coaters, etc., and condensation in the baghouse • Burner tuning resulting in poor fuel efficiency fuel contamination of the mixture, stack emission problems, and potential for a baghouse fire • Potential rutting and moisture concerns because of lower aging and lower temperatures, respectively • Mix design issues due to lesser binder absorption, change in binder properties due to additive incorporation

MIXTURE DESIGN OF WARM MIX ASPHALT

A base binder of PG grade 64-28 was used for both HMA and WMA mixtures. As shown in table 4, the mixing and compaction temperatures varied for HMA and WMA mixtures.

Table 4. Target mixing and compaction temperatures for mixtures.

Mix Type	Target Mixing Temperature	Target Compaction Temperature
HMA	315 °F	290 °F
Foamed WMA (-20 °F)	275 °F	250 °F
Foamed WMA (-40 °F)	295 °F	270 °F
Evotherm WMA (-40 °F)	255 °F	230 °F
Evotherm WMA (-60 °F)	275 °F	250 °F

The job mix formula for HMA has been presented in table 5 below.

Table 5. Job Mix formula for HMA

Project #		STP 1006020CE1 & PEG 1242
Binder Grade		PG 64-28
Percent Binder by Weight	Virgin Binder	3.90
	Total Binder	5.0
Target Gradation, Percent Passing Sieve Size	3/4 in.	100
	1/2 in.	93
	3/8 in.	74
	No. 4	44
	No. 8	30
	No. 16	21
	No. 30	15
	No. 50	11
	No. 100	7
	No. 200	5.0
Voids in Mineral Aggregate		13.1
Voids Filled with Asphalt		69
Air Voids		4.1%
Mixing Temperature		315 °F
Compaction Temperature		290 °F

WYDOT undertook a suite of laboratory testing to evaluate the concerns related to WMA's potential for increased rutting and moisture damage. Only the Hamburg Wheel Tracking (HWT) test results are presented in this report. Figure 10 shows the sampling of the plant produced asphalt mixtures for laboratory testing.

Figure 10. Photo. High-production sampling. (courtesy: Wyoming DOT)

The HWT Device is used to measure the rutting and moisture susceptibility of an asphalt mixture by rolling a steel wheel across the surface of a test specimen immersed in hot water for a select number of cycles. The rutting potential of HMA and WMA mixtures was evaluated based on the viscoplastic strain derived from the average rut depth measured at select load cycles (i.e. 5,000, 10,000, 15,000 and 20,000). Higher viscoelastic strains indicate the increased potential for in-service pavement rutting. The viscoelastic strains derived from the HWT testing of HMA and WMA mixtures used in this project are presented in table 6.

Table 6. Hamburg wheel tracking test results

Mix Type	Viscoelastic Strain (%)		
	Core at Construction	PMPC	LMLC 2h@275F+5d@185F
HMA	9.28	6.87	1.39
WMA Evotherm^H	22.04	9.64	1.83
WMA Evotherm^L	16.89	5.46	-
WMA Foaming^H	10.48	7.25	1.23
WMA Foaming^L	13.63	11.4	1.54

The HWT results indicated that the WMA mixtures have the potential to exhibit higher initial rutting (i.e. consolidation during initial stages after construction); however, their rate of rutting accumulation stabilizes over time and is comparable to that of HMA at later years.

Bid Information

Wyoming DOT received seven bids for the Buffalo rehabilitation project; the winning bid was $2,561,731.26. The engineer's estimate for this project was $2,991,328.20, around 14 percent higher than the winning bid. The contractor was responsible for grading, draining, placing crushed base and bituminous pavement leveling and surfacing, stockpiling, and miscellaneous work. Table 7 presents the bid results for the Buffalo project.

Table 7. Bid results.

Company	Bid	% of Low Bid
Engineer's Estimate	$2,991,328.20	
McGarvin-Moberly Construction Co., Worland, WY	$2,561,731.26	100.00%
Mountain Construction Company, Lovell, WY	$2,977,566.75	116.23%
Intermountain Construction & Materials, Gillette, WY	$2,994,601.83	116.90%
Simon Contractors and Subsidiaries, Cheyenne, WY	$3,051,465.10	119.12%
McMurry Ready-Mix Co., Casper, WY	$3,384,449.50	132.12%
Riverside Contracting, Inc., Missoula, MT	$3,755,994.00	146.62%

Project Schedule

Wyoming DOT Project No. STP 294.63 1006020 was started on May 7, 2012, and completed on October 8, 2012. The construction work on this project was carried out during day time. The major project milestones are listed in table 8.

Table 8. Major project milestones.

Project Milestone	Period
Traffic Control	5/7/2012 to 8/3/2012
Grading	5/1/2012 to 7/6/2012
Milling	7/16/2012 to 7/20/2012
Guardrail	8/1/2012 to 8/1/2012
Reclamation	9/24/2012 to 10/8/2012
Fencing	5/8/2012 to 7/27/2012
Hot Plant Mix	4/16/2012 to 8/3/2012
Maintenance Type B 3/8" Sand	8/1/2012 to 8/3/2012

The contractor used the following equipment for paving and rolling purposes:

- Belly dump trucks.
- Two breakdown rollers.
- One pneumatic roller.
- One steel roller.

The hauling distance was 2.5 miles, and the hauling time was 10 minutes. The mat thickness was 2 inches.

INNOVATIVE STRATEGIES

As noted previously, this project employed two innovative strategies: WMA and the 6:1 taper.

6:1 Taper

Wyoming DOT has promoted the use of 6:1 taper in place of safety edge on several of its prior projects. The primary purpose of using a tapered edge is to help mitigate vertical drop-offs, thereby helping road users to get back to the pavement safely without drifting off from the highway.

While the safety edge is typically sloped at around 30 degrees, the 6:1 taper is sloped at 9.5 degrees. The 6:1 taper is constructed with the use of a fabricated shoe attached to the paver (see figure 11).

The function of the fabricated shoe is to strike off the edge and pull the excess mixture material back into the screed. The tapered edge construction for a paved and an unpaved shoulder are shown in figures 12 and 13, respectively.

No slope measurements were available from the contractor.

Figure 11. Photo. Fabricated shoe attached to the paver. (courtesy: Wyoming DOT)

Figure 12. Photo. 6:1 taper for a paved shoulder. (courtesy: Wyoming DOT)

Figure 13. Photo. 6:1 taper for an unpaved shoulder. (courtesy: Wyoming DOT)

Warm Mix Asphalt

Plant Information

The plant was located roughly 28 miles from the project location. Figure 14 presents an image of the Gencor portable mobile plant used for this project.

A counterflow drum was used for mix production purposes. The drum, although rated at 400+ tons/hr, operated at 300 to 325 tons/hr (see figure 15).

The aggregates for the mix were obtained from Cross H Section 30 Pit facility located in Johnson County. The binder grade PG 64-28 was used for both HMA and WMA mixtures on this project. Belly dump trucks were used to transport mix material to the site. Plant modifications were carried out to facilitate the production of WMA. The modifications included the use of Evotherm 3G for additive-based WMA and the use of Gencor Ultrafoam GX2 for foamed WMA. Figure 16 shows the additive system. The Evotherm M1 pump added additive, at 0.43 percent of the binder, to the mix at the site (see figure 17).

Figure 14. Photo. Gencor plant. (courtesy: Wyoming DOT)

Figure 15. Photo. Gencor Ultra Drum 400 TPH, counterflow type. (courtesy: Wyoming DOT)

Figure 16. Photo. Additive system, Evotherm 3G added at 0.43 percent of binder.
(courtesy: Wyoming DOT)

Figure 17. Photo. Additive pump. (courtesy: Wyoming DOT)

For the foaming system, water was added at1.75 percent of binder. Figure 18 shows the water being added to the binder with the help of the foaming system. Figure 19 shows a closer view of the foaming device.

Figure 18. Photo. Foaming system, water added at 1.75 percent of binder. (courtesy: Wyoming DOT)

Figure 19. Photo. Foaming device. (courtesy: Wyoming DOT)

One percent hydrated lime, primarily for anti-stripping purposes, was also added to the aggregates in the pug mill. No additional anti-stripping agents were used except with the Evotherm-based WMA. No issues were observed with regards to maintenance of baghouse temperature and drag slat amps. Additional plant details are provided in table 9.

Table 9. Plant details.

Plant Model	Gencor Ultra Drum
Year of Manufacture	1997
Drum Type	Counter Flow
Drum Dimensions	9 feet by 46 feet
Number of Silo	1
Silo Capacity	70 ton
Length of Mixing Zone	13 feet
Type of Tank	Horizontal
Number of Tanks	2
Emission Control System	Baghouse
Condition of Flights	Good

The stockpile was not sheltered, and its moisture content was maintained at 2 percent.

WMA Placement

Four rollers were used on this project—two breakdown rollers, one pneumatic roller, and one steel roller. The breakdown rollers were vibratory, and the intermediate roller was static in nature, with a tire pressure of 100 psi. The average hauling distance was about 3 miles. Belly dump trucks (see figure 20) were used for transporting the mixes to the project location, and an elevator and paver (see figure 21) were used for paving purposes.

Figures 22 and 23 show the use of steel and pneumatic rollers on the project.

Figure 20. Photo. Belly dump truck. (courtesy: Wyoming DOT)

Figure 21. Photo. Elevator and paver. (courtesy: Wyoming DOT)

Figure 22. Photo. Steel rollers. (courtesy: Wyoming DOT)

Figure 23. Photo. Pneumatic roller. (courtesy: Wyoming DOT)

Figures 24 and 25 show the HMA and WMA paving activity. Figure 26 shows the truck loading activity.

Figure 24. Photo. HMA paving. (courtesy: Wyoming DOT)

Figure 25. Photo. WMA paving. (courtesy: Wyoming DOT)


Figure 26. Photo. Truck Loading (courtesy: Wyoming DOT)

Table 10 summarizes the rehabilitation sequence followed for the laydown of the HMA and WMA.

Table 10. Mix laydown activity.

Date	Activity
8/16/2012	Hot plant mix (test strip)
8/20/2012	Hot plant mix & warm plant mix (foamed at -20 °F), northbound lane
8/21/2012	Hot plant mix & warm plant mix (foamed at -40 °F), southbound lane
8/22/2012	Hot plant mix & warm plant mix (Evotherm at -40 °F), southbound lane
8/23/2012	Hot plant mix & warm plant mix (Evotherm at -50 °F), northbound lane

The weather was generally mild to warm throughout the duration of paving, with temperatures ranging from 65 to 85 °F, as shown in table 11.

Table 11. Weather conditions during mix placement.

Date	Mix Type	Weather	Winds
8/21/2012	HMA	Sunny, 94 °F	none
8/21/2012	Foamed WMA	78 °F	5-10 mph
8/22/2012	Evotherm WMA	74 °F at start, rising to 85 °F	25 mph at start, dying off by afternoon
8/23/2012	Evotherm WMA	Sunny, 72 °F at start, rising to 90°F	5 mph

On an average, around 1,000 tons of HMA, 1,700 tons of foam, and 1,700 tons of Evotherm were produced each day. HMA was placed on August 21, 2012. Foamed WMA was placed at -20 °F and -40 °F less than the HMA temperature, on two sections on consecutive days. This was followed by the placement of Evotherm WMA at a temperature of -40 °F and -60 °F less than the HMA temperature on the remaining two sections.

As shown in table 12, the temperatures behind the screed also varied based on the type of mixture used.

Table 12. Temperature behind screed for all mixtures.

Mix Type	Temperature behind Screed
HMA	295 to 300 °F
Foamed WMA (-20 °F)	275 to 280 °F
Foamed WMA (-40 °F)	260 to 270 °F
Evotherm WMA (-40 °F)	240 to 260 °F
Evotherm WMA (-60 °F)	240 to 250 °F

The pavement lift thickness was 1.5 inches, and the laydown speed was 30 feet/minute. Table 13 shows the percent compaction obtained for the HMA and WMA mixtures. No percent compaction data were available for the foamed WMA mix.

Table 13. Percent compaction for HMA and WMA mixtures.

Mix	Date	Vibratory Roller	Static Roller	Pneumatic Tired Roller	Finish Roller	Finish Roller (Static)	Cumulative Passes	Percent Compaction
HMA	8/21/2012	2	0	4	1	0	7	90.9%
HMA	8/21/2012	2	1	4	1	0	8	92.4%
HMA	8/21/2012	3	0	7	1	0	11	95.0%
Evotherm (-40 °F)	8/21/2012	2	0	4	1	1	8	94.4%
Evotherm (-40 °F)	8/22/2012	4	0	3	1	1	9	94.0%
Evotherm (-40 °F)	8/22/2012	3	0	3	1	1	8	93.7%
Evotherm (-60 °F)	8/23/2012	2	0	3	1	0	6	93.0%

Figure 27 illustrates the relationship between the percent compaction achieved for different mixtures and the number of roller passes.

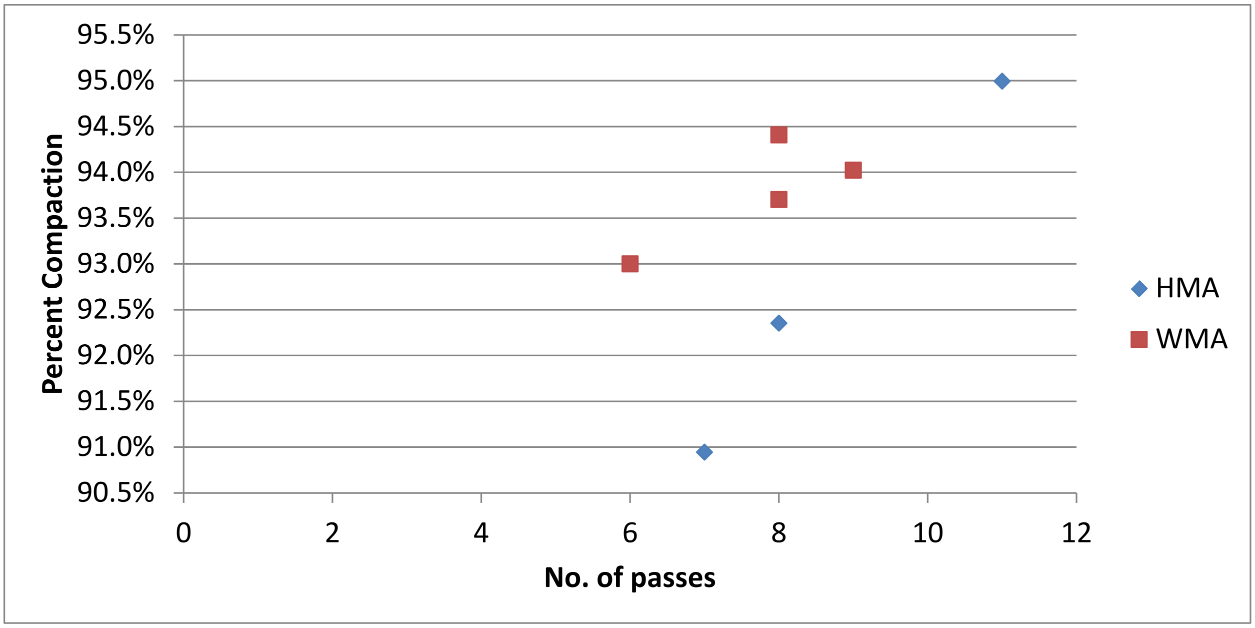


Figure 27. Graph. Percent compaction vs. roller passes.

Table 14 summarizes the constructability for the different test sections.

Table 14. Constructability for different test sections.

Section Type	Constructability
HMA control section	Good at 315 °F
Foamed WMA test sections	Good at 295°F and 275 °F
Additive WMA test sections (Evotherm)	Shoved at 295 °F, good at 275 °F

At 255 °F, poor densities were observed for the Evotherm test sections, possibly due to the lack of adequate communication between the plant and the field crews. The density values were found to be good for these sections when the temperature was raised to a range of 265 to 275 °F. For the foamed WMA test sections, at -20 °F, the paving operation went well, while at -40 °F, the mat did not look well sealed and the coating of aggregate was poor.

DATA ACQUISITION AND ANALYSIS

Wyoming DOT collected project-related data on safety, quality, and user satisfaction before, during, and after construction to determine if this project met the HfL performance goals. Pavement mat and joint densities were also collected because these values affect the service life and future maintenance of the asphalt concrete overlay.

The primary objective of this data acquisition and analysis was to evaluate how the innovations were used to achieve the following:

- Produce a high-quality project and gain user satisfaction.
- Provide smoother pavements with better ride quality.
- Reduce motorist impacts by improving the facility safety.
- Achieve a safer work environment for the traveling public and workers.

This section discusses how well the Wyoming DOT project met the specific HfL performance goals in these areas.

QUALITY

To evaluate the HfL goal on the quality of the project, three parameters were considered: smoothness, noise or sound intensity level, and user satisfaction. On this project, the quality of the WMA and HMA was evaluated based on mat densities, asphalt content, and aggregate gradation. The quality of asphalt mixtures affects the functional performance of the roadway, its service life, and future maintenance and rehabilitation costs.

Mat density, asphalt content, and aggregate gradation

WYDOT conducted quality assurance (QA) testing on mat density, asphalt content, and aggregate gradations of HMA and WMA. Table 15 and Table 16 provide a summary of QA results and associated pay adjustment factors for densities and aggregate gradation of HMA and WMA. The results indicate that but for one lot, the overall WMA were acceptable. The contractor received a bonus pay factor of 10 percent for lot #2 (that used a foaming process) and a deduction pay factor of 17 percent for lot #7 (that used Evotherm process). The densities of HMA lots were acceptable and no adjustments had to be made. On aggregate for both HMA and WMA, the contractor received a 5 percent bonus pay factor for maintaining tight tolerances.

Table 17 provides the QA related pay adjustment summary for mat density, aggregate gradation asphalt content, and smoothness. The contractor also received a bonus of $7,544.65 and $18,059.00 for asphalt content and smoothness, respectively. The contractor received a net bonus of $32,621.98 for construction quality. Also, the contractor received no incentive except for those related to QA.

Table 15. Pay adjustment for HMA and WMA density.

Mix Type	Lot Number	Date of Placement		Sample Size	Percent of Maximum Density			Pay Factor
		Begin	End		Average	Maximum	Minimum	
HMA	4	8/20/2012	8/21/2012	7	94.18	95.63	92.22	1
	6	8/21/2012	8/23/2012	7	95.23	97.11	93.38	1
WMA	2	8/20/2012	8/20/2012	7	94.62	96.08	93.89	1.10
	3	8/22/2012	8/22/2012	7	94.55	96.27	93.06	1
	5	8/22/2012	8/23/2012	7	94.16	95.24	92.22	1
	7	8/23/2012	8/23/2012	7	93.36	95.12	91.07	0.83

Table 16. Pay Adjustment for HMA and WMA aggregate gradation.

Sieve Size	3/4"	1/2"	3/8"	No. 4	No.8	No. 30	No. 200	Net Pay Factor
Specs	100	90-100	70-80	39-49	26-34	12-18	03-07	
HMA - LOT 1								
Average	100	91.6	73.6	43.4	30.4	16.4	5.9	1.05
Range	0	2	3	4	3	1	0.5	
Pay Factor	1.05	1.05	1.05	1.05	1.05	1.05	1.05	
HMA - LOT 2								
Average	100	92.6	76	45.2	31.6	16.4	5.7	1.05
Range	0	2	2	2	1	1	0.5	
Pay Factor	1.05	1.05	1.05	1.05	1.05	1.05	1.05	
WMA - LOT 1								
Average	100	91.6	73.6	43.4	30.4	16.4	5.9	1.05
Range	0	2	3	4	3	1	0.5	
Pay Factor	1.05	1.05	1.05	1.05	1.05	1.05	1.05	
WMA - LOT 2								
Average	100	92.6	76	45.2	31.6	16.4	5.7	1.05
Range	0	2	2	2	1	1	0.5	
Pay Factor	1.05	1.05	1.05	1.05	1.05	1.05	1.05	

Table 17. Quality Assurance related pay adjustment summary.

Pay Adjustment Type	Mix Type	Lot Number	Pay Factor	Pay Adjustment	
				Net	Subtotal
Aggregate Gradation	HMA	1	1.05	$2,160.82	$5,311.38
		2	1.05	$3,150.56	
	WMA	1	1.05	$3,314.35	$10,600.63
		2	1.05	$7,286.28	

Table 17. Quality Assurance related pay adjustment summary.

Pay Adjustment Type	Mix Type	Lot Number	Pay Factor	Pay Adjustment	
				Net	Subtotal
Density	HMA	4	1.00	$0.00	$0.00
		6	1.00	$0.00	
	WMA	2	1.10	$10,068.77	-$8,893.68
		3	1.00	$0.00	
		5	1.00	$0.00	
		7	0.83	-$18,962.45	
Asphalt Content	HMA	1	1.00	$0.00	$1,420.74
		2	1.05	$1,295.56	
		3	1.00	$0.00	
		4	1.00	$0.00	
		5	1.05	$125.18	
		6	1.00	$0.00	
	WMA	1	1.05	$3,314.35	$6,123.91
		2	1.00	$0.00	
		3	1.00	$0.00	
		4	1.05	$2,809.56	
Smoothness	N.A.	N.A.		$18,059.00	$18,059.00
Net Total (Bonus)					$32,621.98

Smoothness

Wyoming DOT collected smoothness data on the project location before and after construction. The average IRI value in 2011 (before construction) was 115 inches/mile. After construction in 2013, the average IRI value was approximately 48 inches/mile. The project thus met the HfL performance goal of 48 inches/mile for smoothness.

Sound Intensity Testing

No sound intensity testing was conducted for this project.

CONSTRUCTION CONGESTION

Travel Time and Queue Length

One of the two lanes was kept open throughout the construction period. Although no formal records of queue length or delay time were collected during this project, Wyoming DOT roughly estimated the trip time through the construction zone to be less than 5 minutes. During this period, the traffic was controlled by flaggers. The contractor also maintained the construction zone to a minimum length. WYDOT estimates no significant differences in travel time before and during construction.

No significant queuing at the project location was reported. It should be noted that the project location typically carries less than 700 vehicles per day, which may not create significant queuing conditions. Therefore, it can be safely assumed that the project met the HfL performance goal of having a moving queue length of less than 0.5 mile in a rural area.

SAFETY

Relevant safety-related information includes the crashes in the project area before, during, and after construction. The preconstruction crash statistics are provided in table 18.

Table 18. Preconstruction crash statistics.

Year	PDO Crashes	Injury Crashes	Fatal Crashes	Total Crashes
2008	1	0	0	1
2009	1	1	0	2
2010	2	1	0	3
2011	2	1	0	3
Total	6	3	0	9
Crash Period	2008 to 8/12/2012			
Crash Limits	milepost 294.60 to milepost 299.45 in Johnson County			

PDO = property damage only

During the construction period from August 13, 2012, to September 14, 2012, no crashes occurred at the project location. Thus, the HfL goal of achieving a work zone crash rate equal to or less than the preconstruction crash rate was satisfied. The presence of an open traffic lane and a smaller work zone throughout the construction period played a major role in ensuring motorist safety.

During construction, no worker injuries were reported, which means the WYDOT exceeded the HfL goal for worker safety (incident rate of less than 4.0 based on the OSHA Form 300 rate).

6:1 taper, which was installed during construction, is expected to improve the safety performance of the facility after construction. The postconstruction crash statistics of this facility was available for 17 months and are presented in table 19. The HfL performance goal for facility safety will be evaluated in the future by comparing the 3-year average crash statistics of this facility with its preconstruction crash rate.

Table 19. Postconstruction crash statistics.

Year	PDO Crashes	Injury Crashes	Fatal Crashes	Total Crashes
2013	2	1	0	3
Total	2	1	0	3
Crash Period	9/15/2012 to 2/14/2014			
Crash Limits	milepost 294.60 to milepost 299.45 in Johnson County			

USER SATISFACTION

The HfL performance goal for user satisfaction is to achieve a 4-plus rating on a Likert scale of 1 to 7. Wyoming DOT conducted a stakeholder survey with a different set of questions based on the following criteria:

- Whether the user was a resident in the Wyoming Buffalo area.
- Whether the user was notified of the project prior to the commencement of the project work.
- Whether the user was informed of the purpose of the project and some of its innovative features.
- Whether the user was satisfied with the way the construction work zone was managed to minimize disruptions.
- Whether the user noticed fewer asphalt fumes on this project compared to other paving projects.
- Whether the user was satisfied with the overall improvement in the pavement compared to its previous condition.

Unlike the Likert's 7-point scale, WYDOT's scale was adjectival. The survey questions allowed the stakeholders to choose from the following options:

- Strongly Agree.
- Agree.
- Neutral.
- Disagree.
- Strongly Disagree.
- N/A.
- Don't Know.

Fifteen responses were received. Complete survey results are provided in appendix A. The following conclusions were drawn from the survey results:

- Residency—87 percent of respondents were residents of the Buffalo area, and 13 percent were nonresidents.
- Prior Notification—Around 87 percent of users (residents of the Buffalo area) either agreed or strongly agreed that they had been notified of the project in advance. The nonresidents disagreed on the same.
- Informed of the purpose and innovative features of the project—60 percent of the responses were either in agreement or strong agreement to this statement. Some 20 percent of the responders were neutral, while the remaining 20 percent either disagreed or strongly disagreed with the statement.
- Work Zone Satisfaction—73 percent of the responders were satisfied, 13 percent were neutral, and 7 percent were dissatisfied with the management of the construction work zone.

- Fewer Fumes—80 percent responders felt that they noticed fewer asphalt fumes on this project compared to other paving projects. Thirteen percent of responders were neutral, and 7 percent were in strong disagreement with this notion.
- Quality Improvement—73 percent pf responders strongly agreed that there was an overall improvement in the pavement compared to its previous condition. While 13 percent of responders were neutral, the remaining 13 percent expressed strong disagreement with regards to the quality improvement.

To sum up, the results from the survey suggested that a high percentage of the local residents and traveling public were satisfied with the project.

ECONOMIC ANALYSIS

A key aspect of HfL demonstration projects is quantifying, as much as possible, the value of the innovations deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach adopted on an HfL project with those from a more traditional delivery approach on a project of similar size and scope. The latter type of project is referred to as a baseline case and is an important component of the economic analysis.

For this economic analysis, the tonnage costs for HMA and WMA mixtures were obtained from the project bid tabs provided by the Wyoming DOT. It was assumed that the DOT would have used the 6:1 taper innovation in any case, so this innovation is not factored into the economic analysis.

CONSTRUCTION TIME

According to Wyoming DOT estimates, there would be no significant difference in the construction duration for the as-built scenario (use of WMA) and the traditional scenario (use of HMA) because the WMA mix is delivered, placed, and compacted in the same way as HMA. For both technologies, the same construction practices and equipment are used.

CONSTRUCTION COSTS

The cost of WMA was expected to be more than HMA because of the use of additives or foaming in WMA, as well as the risks associated with the use of any newer technology. To evaluate the cost differences between the HMA and WMA technologies, the tonnage costs for HMA and WMA obtained from bid tabulations for this project were compared; see table 20. The unit prices (i.e. $/ton) from the winning bid indicate that the actual tonnage cost of WMA was 9.4 percent higher than HMA.

Table 20. Comparison of HMA and WMA tonnage costs.

	HMA ($/ton)	WMA ($/ton)	% Difference
Engineer's estimate	37	45	21.6
Bidder 1	37.1	40.5	9.2
Bidder 2	48	48	0.0
Bidder 3	46.6	62.4	33.9
Bidder 4	35	37	5.7
Bidder 5 (winning bid)	46.12	50.47	9.4
Bidder 6	30.45	36.85	21.0

Figure 28 shows a box plot of unit prices of WMA and HMA bid items obtained from bid tabulations. As the figure indicates, the average expected market price of WMA was higher than that of HMA; however, there was considerable variability to indicate that the WMA prices were comparable to HMA prices. It should also be noted that WYDOT had no cost associated with the Warm Mix aspect of the project except what is reflected in the bid prices.

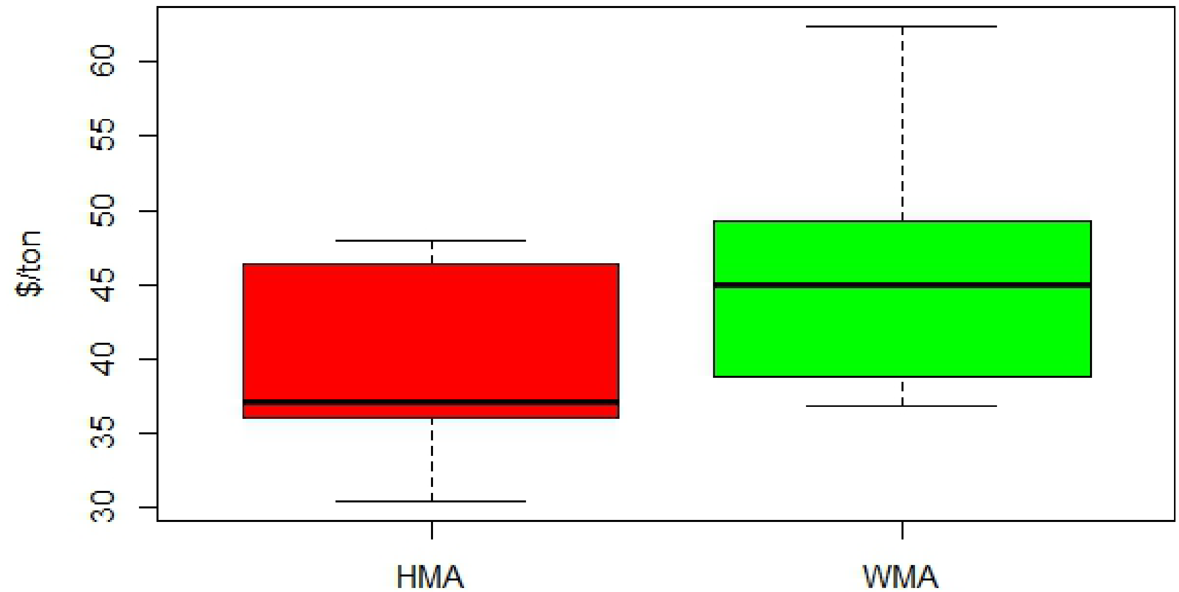


Figure 28. Graph. Box-plot showing HMA and WMA tonnage costs.

USER COSTS

Generally, three categories of user costs are considered in an economic analysis: vehicle operating costs (VOC), delay costs, and crash and safety-related costs.

Since the placement of HMA and WMA would have required the same construction time, there would be no differential user costs between the traditional and as-built scenarios. Hence, the computation of user costs was deemed not necessary.

APPENDIX A: USER SATISFACTION SURVEY

This appendix includes a summary of the user satisfaction survey results obtained between August 24, 2012, and October 1, 2012. Wyoming DOT received 15 completed responses during the 39-day survey period.

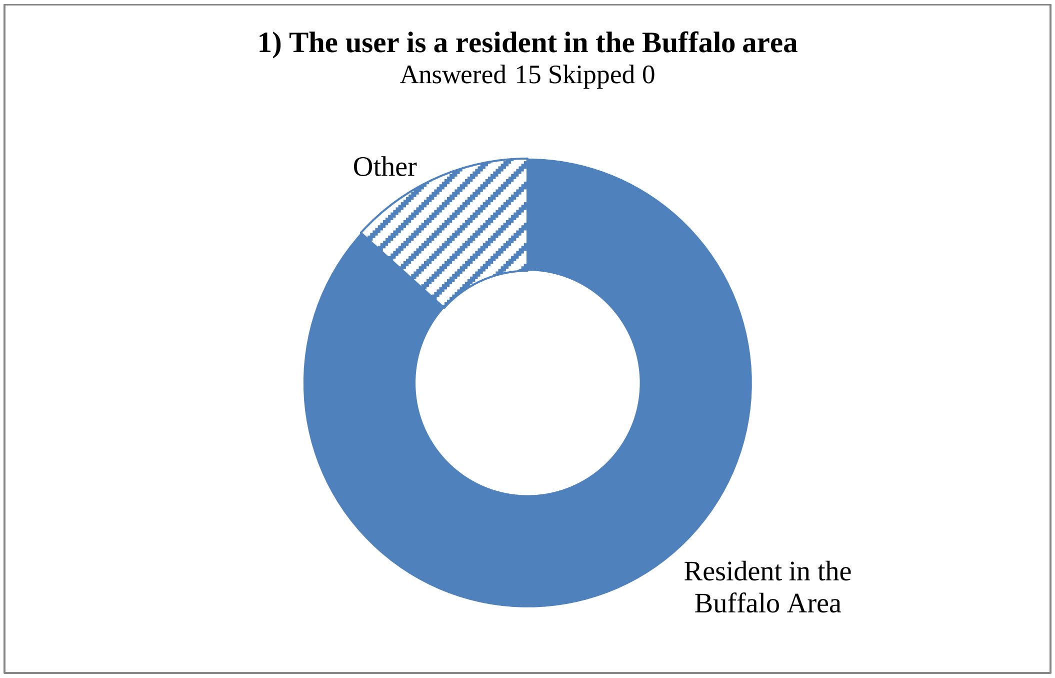


Figure 29. Chart. Residency information

Table 21. Responses on residency

Answer Choices	**Responses**	
	Number	**Percent**
Resident in the Buffalo Area	13	86.67%
Other	2	13.33%
Total	15	100%

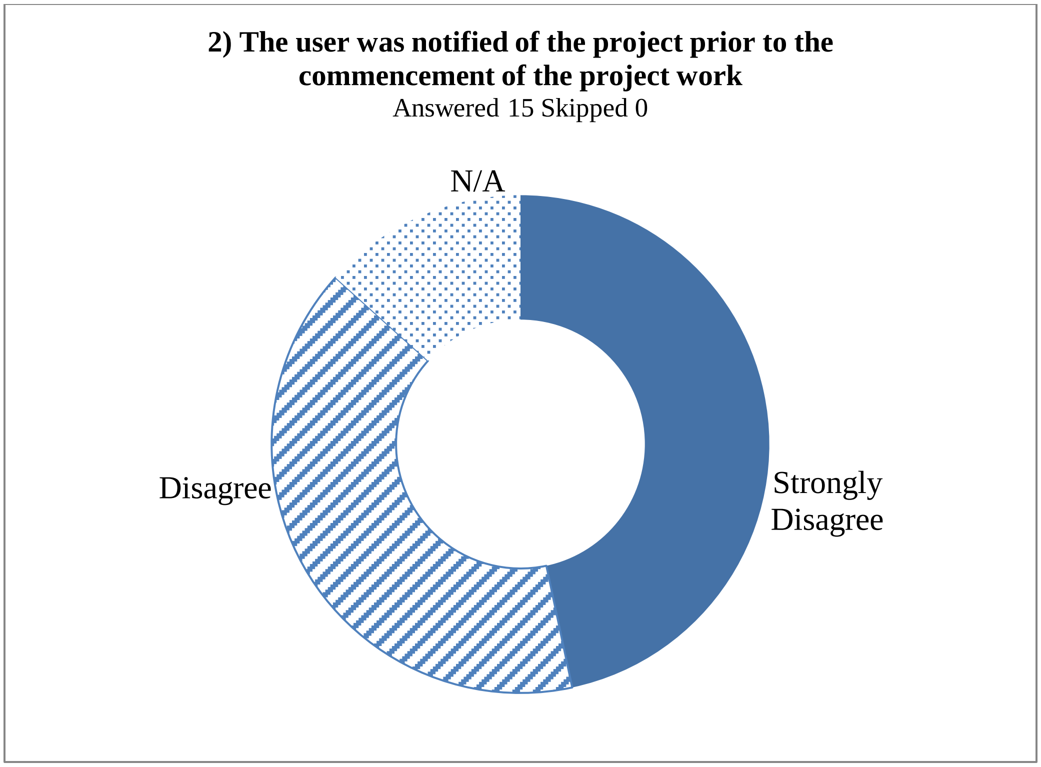


Figure 30. Chart. Prior notification on project commencement

Table 22. Responses on prior notification

Answer Choices	Responses	
	Number	Percent
Strongly Agree	7	46.67%
Agree	6	40.00%
Neutral	0	0.00%
Disagree	2	13.33%
Strongly Disagree	0	0.00%
N/A	0	0.00%
Total	15	100%

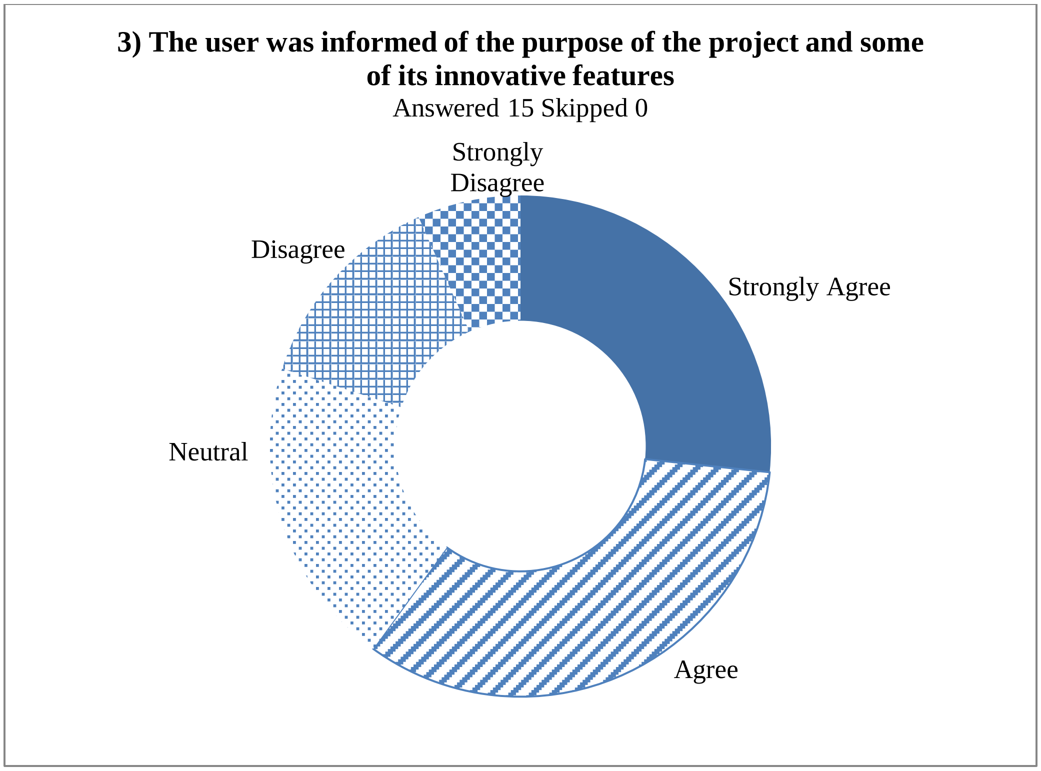


Figure 31. Chart. Project purposes and innovative features

Table 23. Responses on project purposes and innovative features

Answer Choices	Responses	
	Number	Percent
Strongly Agree	4	26.67%
Agree	5	33.33%
Neutral	3	20.00%
Disagree	2	13.33%
Strongly Disagree	1	6.67%
N/A	0	0.00%
Total	15	100%

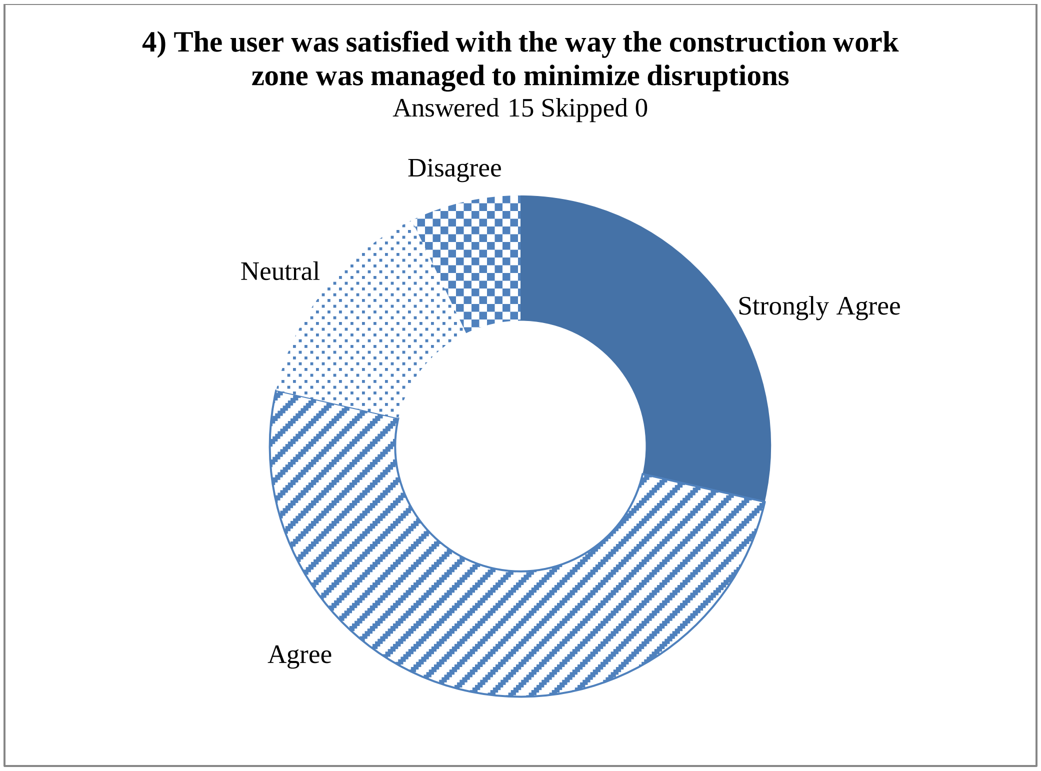


Figure 32. Chart. Work zone related satisfaction

Table 24. Responses on work zone related satisfaction

Answer Choices	Responses	
	Number	Percent
Strongly Agree	4	26.67%
Agree	7	46.67%
Neutral	2	13.33%
Disagree	1	6.67%
Strongly Disagree	0	0.00%
Don't Know	0	0.00%
Total	15	100%

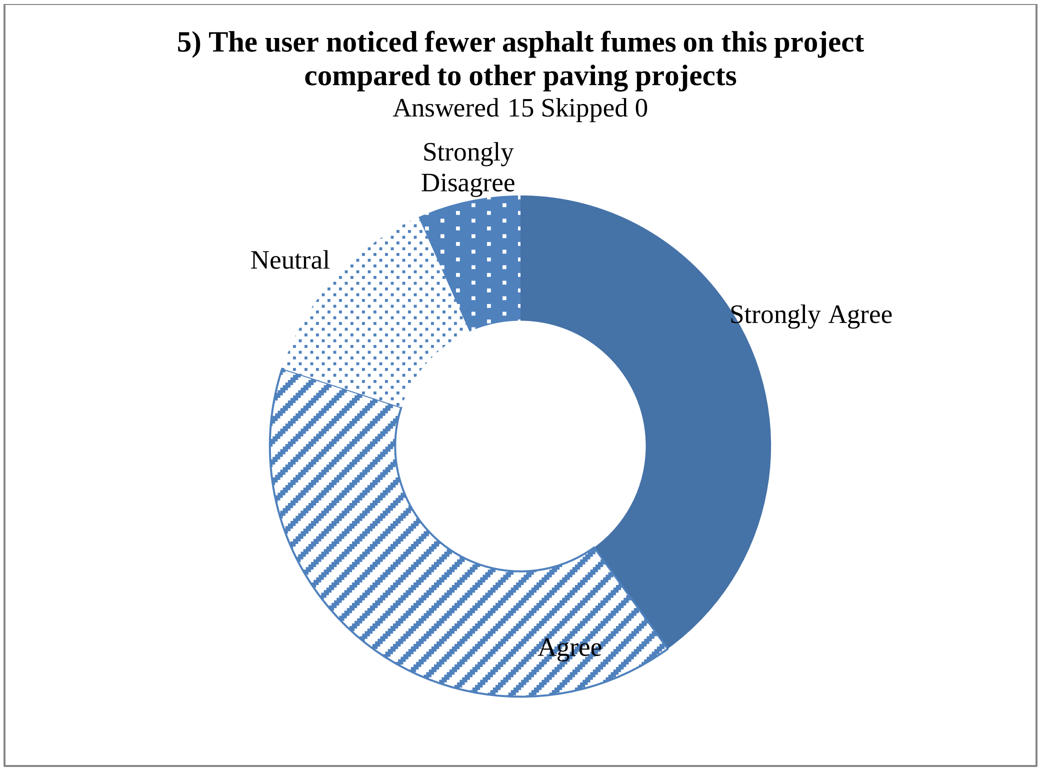


Figure 33. Chart. Fewer asphalt fumes on the project

Table 25. Responses on fewer asphalt fumes on the project

Answer Choices	Responses	
	Number	Percent
Strongly Agree	6	40.00%
Agree	6	40.00%
Neutral	2	13.33%
Disagree	0	0.00%
Strongly Disagree	1	6.67%
Don't Know	0	0.00%
Total	15	100%

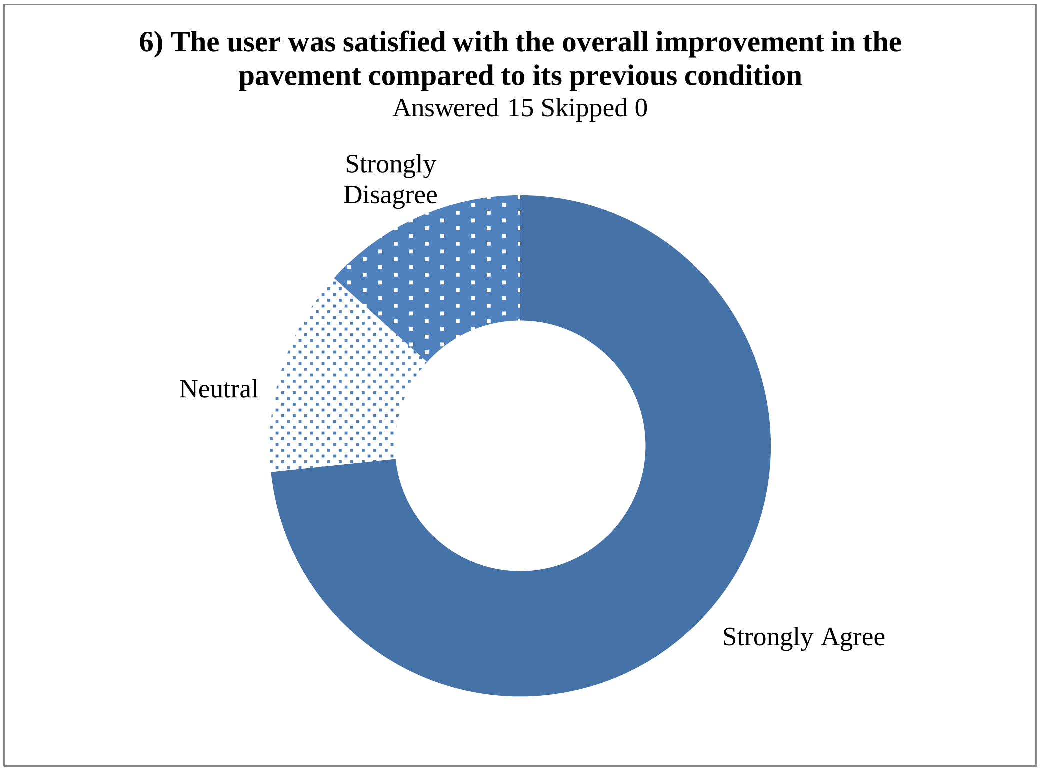


Figure 34. Chart. Improvement in pavement condition

Table 26. Responses on improvement in pavement condition

Answer Choices	Responses	
	Number	Percent
Strongly Agree	11	73.33%
Agree	0	0.00%
Neutral	2	13.33%
Disagree	0	0.00%
Strongly Disagree	2	13.33%
Don't Know	0	0.00%
Total	15	100%

ACKNOWLEDGMENTS

The project team acknowledges the invaluable insights and guidance of Highways for LIFE Team Leader Byron Lord and Program Coordinator Ewa Flom, who served as the technical panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team is also indebted to Wyoming DOT Project Manager Louis Maillet and FHWA Wyoming Division Office Engineer Mark Boushele for their assistance and coordination during the project.